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Air conditioners and comfort fans, Review of Regulation 206/2012 and 626/2011 Final report

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European Commission

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Final report

Date: May 2018

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European Commission

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 1 report

Final version

Date: May 2018

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Abbreviations

Cdc, Cdh	The cycling degradation coefficient for air conditioners in cooling (heating) mode
COP	Coefficient of Performance for air conditioners in heating mode
CDD	Cooling Degree Day
EER	Energy Efficiency Ratio for air conditioners in cooling mode
EPS	External Static Pressure for air conditioners
GNI	Gross national income
GWP	Global warming potential
H_{TO}	The number of hours the unit is considered to work in thermostat off mode for air conditioners
H_{SB}	The number of hours the unit is considered to work in standby mode for air conditioners
H_{CK}	The number of hours the unit is considered to work in crankcase heater mode for air conditioners
H_{OFF}	The number of hours the unit is considered to work in off mode for air conditioners
P_{TO}	The electricity consumption during thermostat off mode for air conditioners
P_{SB}	The electricity consumption during standby mode for air conditioners
P_{CK}	The electricity consumption during crankcase heater mode for air conditioners
P_{OFF}	The electricity consumption during off mode.
Q_{CE}	The reference annual cooling demand for air conditioners in cooling mode
Q_{HE}	The reference annual heating demand for air conditioners in heating mode
SHR	Sensible Heat Ratio for air conditioners
SEER	Seasonal Energy Efficiency Ratio for air conditioners, cooling mode
SCOP	Seasonal Coefficient of Performance for air conditioners, heating mode
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.

1 Task 1

Task 1 follows the MEErP methodology and includes the following:

- Product scope: Identification and assessment of relevant categories based on the existing ecodesign regulation, standardisation and measurement method activities and other relevant schemes and activities outside EU. Defining preliminary product scope, definitions and categorisations.
- Test standards: EU, Member State and third country level.
- Legislation: EU, Member State and third country level.

1.1 Product scope

The current scope of Commission Regulation (EU) No 206/2012 covers electric mains-operated air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating if the product has no cooling function, and comfort fans with an electric fan power input ≤ 125W.

The current scope of Commission Delegated Regulation (EU) No 626/2011 covers electric mains-operated air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating if the product has no cooling function.

The definition of air conditioners is presented and discussed in the next sub-section.

1.1.1 Existing definitions and categories

1.1.1.1 Existing definitions and categories in Ecodesign Regulation (EU) No 206/2012

Commission Regulation (EU) No 206/2012 establishes ecodesign requirements for air conditioners and comfort fans. The product definitions employed in the regulation are listed below.

Products and components that are within the scope of the Regulation are defined as:

Air conditioner means a device capable of cooling or heating, or both, indoor air, using a vapour compression cycle driven by an electric compressor, including air conditioners that provide additional functionalities such as dehumidification, air-purification, ventilation or supplemental air-heating by means of electric resistance heating, as well as appliances that may use water (either condensate water that is formed on the evaporator side or externally added water) for evaporation on the condenser, provided that the device is also able to function without the use of additional water, using air only.

Double duct air conditioner means an air conditioner in which, during cooling or heating, the condenser (or evaporator) intake air is introduced from the outdoor environment to the unit by a duct and rejected to the outdoor environment by a second duct, and which is placed wholly inside the space to be conditioned, near a wall.

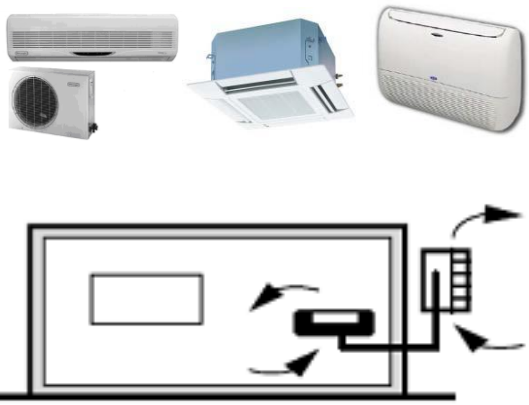
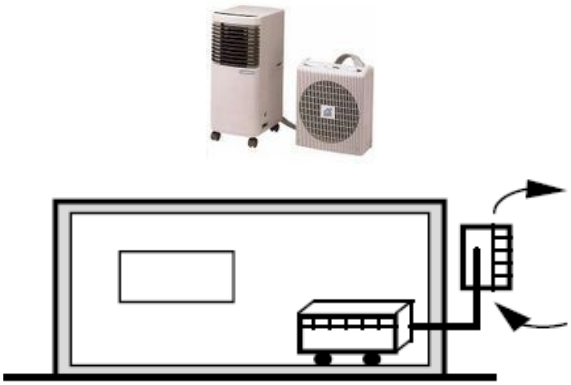
Single duct air conditioner means an air conditioner in which, during cooling or heating, the condenser (or evaporator) intake air is introduced from the space containing the unit and discharged outside this space.

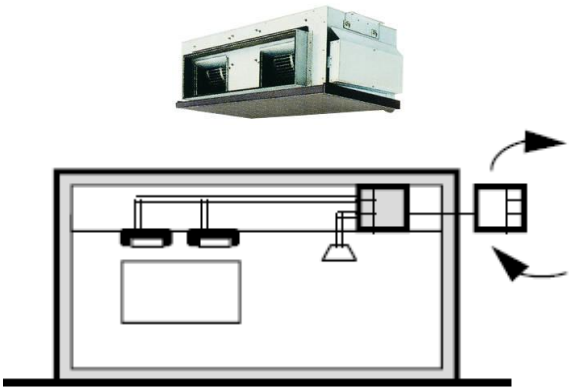
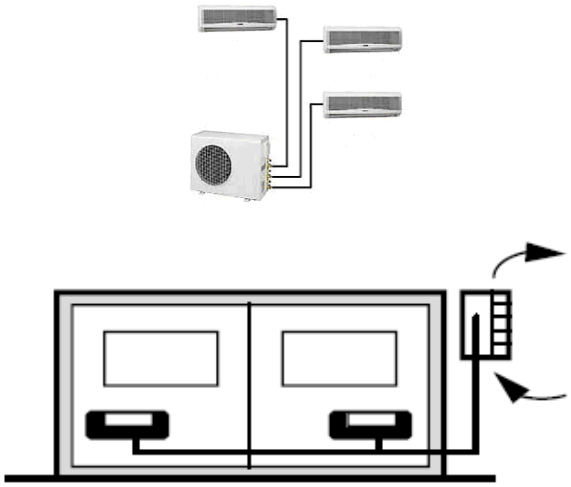
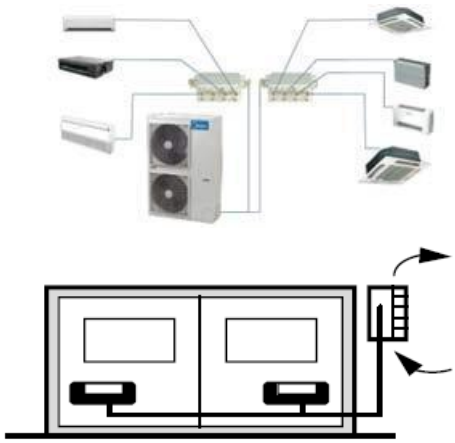
Comfort fan means an appliance primarily designed for creating air movement around or on part of a human body for personal cooling comfort, including comfort fans that can perform additional functionalities such as lighting.

Capacity limitation: the scope for air conditioners is limited to "air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating if the product has no cooling function".

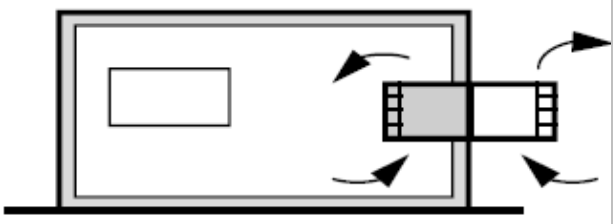
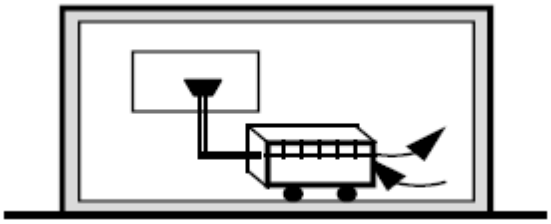
Table 1 below describes what are the common products within the scope of regulation 206/2012 as interpreted by the study team.

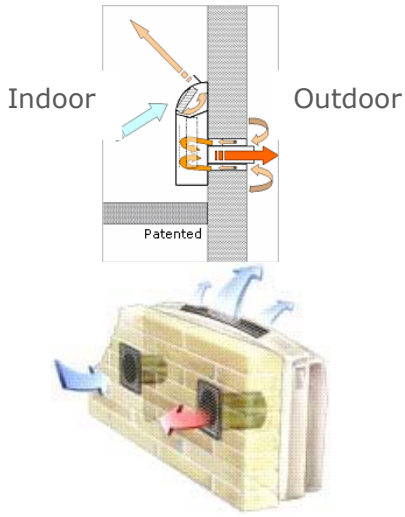
Table 1. Products in scope, categorisation and definitions.

Product group	Product category	Definition
Air conditioners - cooling only and reversible	Split (Non-ducted fixed split-packaged unit) 	A split-packaged unit is defined as a factory assembly of components of a refrigeration system fixed on two or more mountings to form a matched unit. This type of appliance comprises two packages (one indoor and one outdoor unit) connected only by the pipe that transfers the refrigerant. The indoor unit includes the evaporator (respectively condenser in heating mode) and a fan, while the outdoor unit has a fan, compressor and a condenser (respectively evaporator in heating mode). Fixed non-ducted indoor units can be mounted high on a wall, floor-mounted or as 'cassette', ceiling-suspended, built-in horizontal or built-in vertical.
	Mobile Split (Non-ducted split packaged unit with mobile indoor unit) 	Indoor unit(s) can be also be non-ducted and mobile. Mobile split units are often categorised at points of sales as mobile or portable air conditioners. Opposed to fixed split, the compressor is located in the indoor unit, while the outdoor unit only contains the condenser heat exchanger and fan. The outdoor unit for a mobile split can be either fixed or mobile.

Product group	Product category	Definition
	Ducted split packaged unit 	Indoor unit(s) for split can also be ducted. Ducted indoor units can deliver cool air to several rooms or to several spots within a single room.
	Multi-split packaged units 	Multi-split packaged units comprise several interior units (up to 4) connected to one exterior unit. These units are similar to split interior and exterior units. Indoor units can be ducted or non-ducted.
	Multi Variable Refrigerant Flow (VRF) units[1] 	This type of product is similar to multi-split packaged units, except instead of having one refrigerant connection between each indoor unit and the outdoor unit, the refrigerant is distributed in the building via a single connection to the outdoor unit. This product may allow to have heating and cooling in different zones of the building and heat recovery between zones, these options are not available for multi-split package air conditioners. These have been mostly non-residential products, but recently some manufacturers offer smaller systems ≤ 12 kW.

[1] Images source: http://york-vrf.com/

Product group	Product category	Definition
	Single-packaged unit, through the wall 	Single-packaged units, commonly known as 'window' or 'through-the-wall' air conditioners (respectively they are called "room air conditioners" and "package terminal air conditioners" in the USA), are strictly defined as a factory assembly of components of a refrigeration system fixed on a common mounting to form a single unit. This type of equipment comprises a single package, one side of which is in contact with the outside air heat release outside, while the other side provides direct cooling to the air inside. The two sides of the appliance are separated by a dividing wall, which is insulated to reduce heat transfer between the two sides. This type of air conditioners has relatively low sales in the EU but is more common in the USA.
	Single duct mobile air conditioner 	Single-packaged mobile units, commonly known as 'mobile' or 'portable' air conditioners comprise a single package, one side of which extracts indoor air to cool the condenser and releases it outdoor, while the other side provides direct cooling to the air indoor. The two sides of the appliance are separated by a dividing wall, which is insulated to reduce heat transfer between the two sides.

Product group	Product category	Definition
	Double duct air conditioner (through the wall installation)  	A double duct air conditioner is an evolution of the single duct. There are two main types. The first type is exactly similar to a single duct but a second hole at the condenser enables to take the condenser air from outside thus reducing outside air infiltration inside the room to be cooled. The second type is similar, but of a more permanent installation through the wall and in that case, the two ducts may be concentric.
Comfort fans	Comfort fans 	Comfort fans primary function is to increase air speed in such a manner the end user may feel more comfortable. Since air speed must not be increased too much to get acceptable comfort conditions and that comfort is likely to be increased if the air stream attains a larger part of the body, the function of the unit would then be "to move air inside a room" and the performance parameter to be kept is the air flow rate supplied by the fan. Comforts fans can be e.g. desk fans, floor standing fans, wall mounted fans, ceiling fans, tower fans, box fans, etc. The floor units typically have a high fan velocity and they are moving on the vertical axe, while the ceiling mounted unit has a lower fan velocity.

Comments on the definitions: Air conditioners can reject heat to different outdoor fluids (outdoor air, ventilation exhaust air, water/brine). Cooling can also be supplied to recycled air or to outdoor air (case of ventilation exhaust heat pumps / air conditioners). This is not clearly defined in the present regulation.

The definitions and scope of different ecodesign regulations should make sure all air conditioner / air to air heat pump types are covered. This is discussed in more details in part 1.1.3.

1.1.1.2 Existing definitions and categories in Ecodesign Regulation(EU) No 2016/2281

Commission Regulation (EU) No 2016/2281 is not under the current review, however the Regulation establishes definitions of various heat pumps, air conditioners and comfort chillers. These definitions are useful for understanding the differences between air conditioners and heat pumps covered by the different EU regulations, especially in relation to part 1.1.2 and 1.1.3, where the scope alignment and possible extension for the different types of air conditioners and heat pumps are discussed.

Heat pump means an air heating product:

A. of which the outdoor side heat exchanger (evaporator) extracts heat from ambient air, ventilation exhaust air, water, or ground heat sources;
B. which has a heat generator that uses a vapour compression cycle or a sorption cycle;
C. of which the indoor side heat exchanger (condenser) releases this heat to an air-based heating system;
D. which may be equipped with a supplementary heater;
E. which may operate in reverse in which case it functions as an **air conditioner**;

And the following types of heat pumps are defined as:

Air-to-air heat pump means a heat pump which has a heat generator that uses a vapour compression cycle driven by an electric motor or internal combustion engine and whereby the outdoor side heat exchanger (evaporator) allows heat transfer from ambient air and the indoor side condenser delivers the heat to the indoor air.

Water/brine-to-air heat pump means a heat pump which has a heat generator that uses a vapour compression cycle driven by an electric motor or internal combustion engine and whereby the outdoor side heat exchanger (evaporator) allows heat transfer from water or brine

Rooftop heat pump means an air-to-air heat pump, driven by an electric compressor, of which the evaporator, compressor and condenser are integrated into a single package.

Sorption cycle heat pump means a heat pump which has a heat generator that uses a sorption cycle relying on external combustion of fuels and/or other type of supply of heat.

Multi-split heat pump means a heat pump incorporating more than one indoor units, one or more refrigerating circuit, one or more compressors and one or more outdoor units, where the indoor units may or may not be individually controlled.

Air conditioner is defined differently by Regulation (EU) No 2016/2281 than from Regulation (EU) No 206/2012:

Air conditioner means a cooling product that provides space cooling and:

A. of which the indoor side heat exchanger (evaporator) extracts heat from an air-based cooling system (heat source)
B. which has a cold generator that uses a vapour compression cycle or a sorption cycle.
C. of which the outdoor side heat exchanger (condenser) releases this heat to ambient air, water or ground heat sink(s) and which may or may not include heat transfer that is based on evaporation of externally added water.
D. may operate in reverse in which case it functions as a **heat pump**;

Air-to-air air conditioner means an air conditioner which has a cold generator that uses a vapour compression cycle driven by an electric motor or internal combustion engine and whereby the outdoor side heat exchanger (condenser) allows heat transfer to air.

Water/brine-to-air air conditioner means an air conditioner which has a cold generator that uses a vapour compression cycle driven by an electric motor or internal combustion engine and whereby the outdoor side heat exchanger (condenser) allows heat transfer to water or brine.

Rooftop air conditioner means an air-to-air air conditioner, driven by an electric compressor, of which the evaporator, compressor and condenser are integrated into a single package.

Multi-split air conditioner means an air conditioner incorporating more than one indoor units, one or more refrigeration circuits, one or more compressors and one or more outdoor units, where the indoor units may or may not be individually controlled.

Sorption cycle air conditioner means an air conditioner which has a cold generator that uses a sorption cycle relying on external combustion of fuels and/or supply of heat.

Air-to-water comfort chiller means a comfort chiller that has a cold generator that uses a vapour compression cycle driven by an electric motor or internal combustion engine and whereby the outdoor side heat exchanger (condenser) allows heat transfer to air, including heat transfer that is based on evaporation into this air of externally added water, provided that the device is also able to function without the use of additional water, using air only.

Water/brine-to-water comfort chiller means a comfort chiller that has a cold generator that uses a vapour compression cycle driven by an electric motor or internal combustion engine and whereby the outdoor side heat exchanger (condenser) allows heat transfer to water or brine, excluding heat transfer that is based on evaporation of externally added water.

Sorption cycle comfort chiller means a comfort chiller which has a cold generator that uses a sorption cycle relying on external combustion of fuels and/or supply of heat.

Fan coil unit means a device that provides forced circulation of indoor air, for the purpose of one or more of heating, cooling, dehumidification and filtering of indoor air, for the thermal comfort of human beings, but which does not include the source of heating or cooling nor an outdoor side heat exchanger. The device may be equipped with minimal ductwork to guide the intake and exit of air, including conditioned air. The product may be designed to be built in or may have an enclosure allowing it be placed in the space to be conditioned. It may include a Joule effect heat generator designed to be used as back-up heater only.

Air heating product means a device that:

A. incorporates or provides heat to an air-based heating system;
B. is equipped with one or more heat generators; and
C. may include an air-based heating system for supplying heated air directly into the heated space by means of an air-moving device.

A heat generator designed for an air heating product and an air heating product housing designed to be equipped with such a heat generator shall, together, be considered as an air heating product.

Cooling product means a device that:

A. incorporates, or provides chilled air or water to, an air-based cooling system or water-based cooling system; and
B. is equipped with one or more cold generator(s).

A cold generator designed for use in a cooling product and a cooling product housing designed to be equipped with such a cold generator shall, together, be considered as a cooling product.

1.1.1.3 Prodcom (Eurostat) categories

There are a number of PRODCOM codes that relate to air conditioners and associated products that may be within scope of any potential future update to the ecodesign Regulation on air conditioners. The PRODCOM categories which are covering products relevant for this study are listed in the table below.

Table 2. Prodcom categories covering products relevant for this study.

	PRODCOM code	PRODCOM Nomenclature
Air conditioners	28.25.12.20	Window or wall air conditioning systems, self-contained or split-systems
	28.25.12.50	Air conditioning machines with refrigeration unit (excluding those used in motor vehicles, self-contained or split-systems machines)
	28.25.30.10	Parts for air conditioning machines (including condensers, absorbers, evaporators and generators)
Comfort fans	27.51.15.30	Table, floor, wall, window, ceiling or roof fans, with a self-contained electric motor of an output <= 125 W

1.1.1.4 Labelling categories (EU Energy Label and Eco-label)

EU Energy Label – The definitions used in the Energy Labelling Regulation 626/2011 are identical to the definitions in the ecodesign regulation. The definitions are listed in 1.1.1.1 Existing definitions

Eco-label – The EU Eco-label[2] for heat pumps has no specific definition of an air conditioner. The Eco-label specification describes the product category as heat pumps which also includes e.g. brine to water heat pumps and includes heat pumps driven by electricity, gas and gas absorption. The product group is defined as:

- The product group 'electrically driven, gas driven or gas absorption heat pumps' shall comprise heat pumps, which can concentrate energy present in the air, ground or water into useful heat for the supply of space heating or the opposite process for space cooling. A 'heat pump' is the device or set of devices as delivered by the manufacturer or importer to the distributor, retailer or installer. This delivery may or may not include the delivery of circulating pumps at the sink or source side, however for calculation of coefficient of performance (COP) values the methodology of EN14511:2004 is refered to (which includes part of circulator consumption). For gas absorption heat pumps the methodology shall be according to EN12309-2:2000.

1.1.2 Product scope alignment

There are several types of equipment available on the market which all are categorised as products for "space heating". These space heating products and corresponding regulations are presented in Figure 1. For simplicity, the figure categorises the different products into:

[2] http://ec.europa.eu/environment/ecolabel/eu-ecolabel-products-and-services.html

central heating or local (non-central) heating products, hydronic systems or dry systems products and cooling and ventilation. Local space heaters have the heat generator in the same room as the room that needs heating such as single duct air conditioners. Split/multisplit, double duct and multi variable refrigerant flow units are examples of central space heating units.

As the illustration below shows are multiple products somehow related to the products within the scope of EU 206/2012.

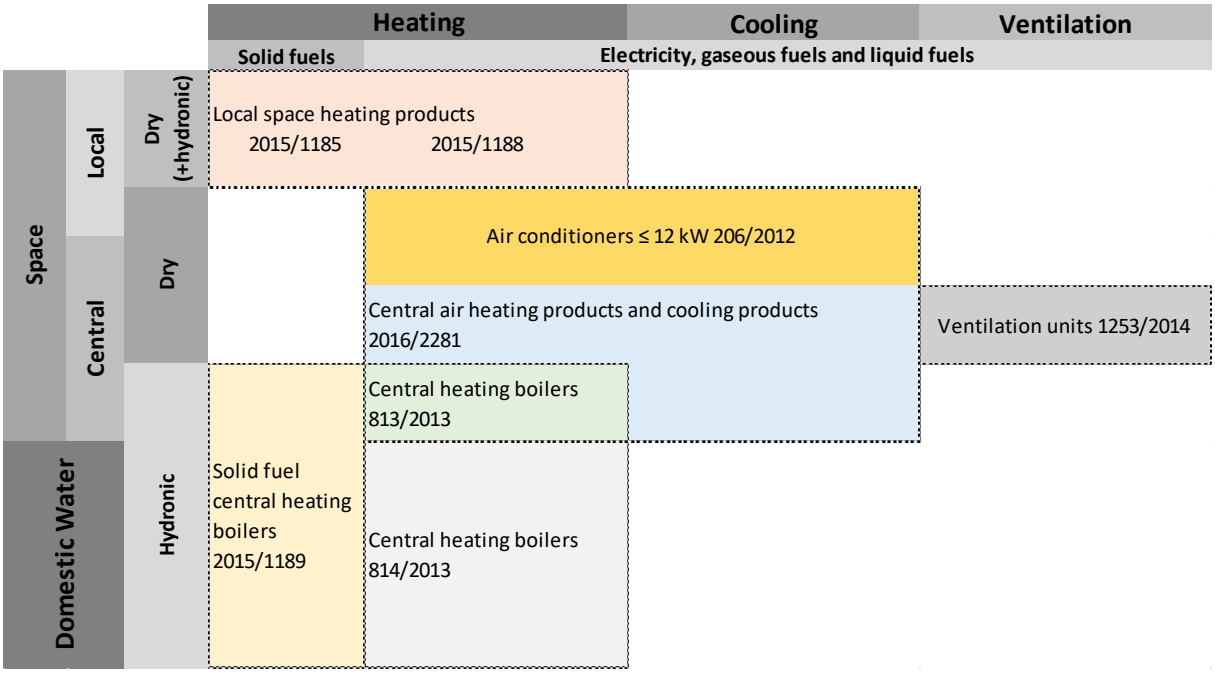


Figure 1: Division of the different products for space heating into sub-categories.[3]

The following regulations are closely connected to the EU regulation No 206/2012 (in the borders of the scope): Regulation (EU) No 2015/1188, Regulation (EU) No 2015/1185, Regulation (EU) No 2016/2281 and Regulation (EU) No 1253/2014. Their scope is described below and in general aligns well with the scope of Regulation No 206/2012:

Commission Regulation (EU) No 2015/1188 with regard to ecodesign requirements for local space heaters. Local space heaters are products that emit heat by direct heat transfer possibly in combination with heat transfer to a fluid. They are situated within the indoor space (rooms of houses or buildings, workshops, offices, warehouses, garages, hospitals, etc.) which they heat and in some cases they can in addition deliver heat to other spaces. The local space heaters under this Regulation are electric, gaseous or liquid fuel local space heaters. Outdoor heating products (e.g. terrace) are not within the scope. Air conditioners are also provided with heating functions but are though not within the scope due to scope exemption a) in the regulation.
This Regulation includes domestic local space heaters with a nominal heat output of 50 kW or less and commercial local space heaters with a nominal heat output of the product or of a single segment of 120 kW or less.

[3] http://www.eceee.org/static/media/uploads/site-2/ecodesign/products/lot-20-local-room-heating-products/bio-eup-lot20-task-1-final-report.pdf

The regulation does not apply to:

a) local space heaters using a vapour compression cycle or sorption cycle for the generation of heat driven by electric compressors or fuel;
b) local space heaters specified for purposes other than indoor space heating to reach and maintain a certain thermal comfort of human beings by means of heat convection or heat radiation;
c) local space heaters that are specified for outdoor use only;
d) local space heaters of which the direct heat output is less than 6 % of the combined direct and indirect heat output at nominal heat output;
e) air heating products;
f) sauna stoves;
g) slave heaters.

Commission Regulation (EU) No 2015/1185 with regard to ecodesign requirements for solid fuel local space heaters. Solid fuel space heaters are also local space heaters but are fired by solid fuels with a nominal heat output of 50 kW or less. Products within this scope are e.g. stoves and fireplaces and will not further be described here.

Commission Regulation (EU) No 2016/2281 with regard to ecodesign requirements for air heating products, cooling products, high temperature process chillers and fan coil units. See definitions of the products covered by this Regulation in Section 1.1.1.2. This regulation exempts the products that are already covered by an ecodesign regulation, air conditioners and comfort fans within the scope of Regulation (EU) No 206/2012 are clearly out of the scope by the exemption item b), see below.
The regulation of air heating products includes:

a) air heating products with a rated heating capacity not exceeding 1 MW;
b) cooling products and high temperature process chillers with a rated cooling capacity not exceeding 2 MW;
c) fan coil units.

The regulation has the following exemptions:

a) products covered by Commission Regulation (EU) 2015/1188 with regard to ecodesign requirements for local space heaters;
b) products covered by Commission Regulation (EU) No 206/2012 with regard to ecodesign requirements for air conditioners and comfort fans;
c) products covered by Commission Regulation (EU) No 813/2013 with regard to ecodesign requirements for space heaters and combination heaters;
d) products covered by Commission Regulation (EU) 2015/1095 with regard to ecodesign requirements for professional refrigerated storage cabinets, blast cabinets, condensing units and process chillers;
e) comfort chillers with leaving chilled water temperatures of less than + 2 °C and high temperature process chillers with leaving chilled water temperatures of less than + 2 °C or more than + 12 °C;
f) products designed for using predominantly biomass fuels;
g) products using solid fuels;
h) products that supply heat or cold in combination with electric power (‘cogeneration’) by means of a fuel combustion or conversion process;

i) products included in installations covered by Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions;
j) high temperature process chillers exclusively using evaporative condensing;
k) custom-made products assembled on site, made on a one-off basis;
l) high temperature process chillers in which refrigeration is effected by an absorption process that uses heat as the energy source; and
m) air heating and/or cooling products of which the primary function is the purpose of producing or storing perishable materials at specified temperatures by commercial, institutional or industrial facilities and of which space heating and/or space cooling is a secondary function and for which the energy efficiency of the space heating and/ or space cooling function is dependent on that of the primary function.

Commission Regulation (EU) 1253/2014 with regard to ecodesign requirements for ventilation units. This Regulation applies to ventilation units and establishes ecodesign requirements for their placing on the market or putting into service. Some ventilation units are equipped with a regenerative heat exchanger which means that a rotary heat exchanger incorporating a rotating wheel for transferring thermal energy from one air stream to another air stream. These types of products have a different function/purpose and are therefore not further described.
In this regulation, reference is made to ventilation exhaust heat pumps for air heating purpose because of possible additional pressure losses, but ventilation exhaust air heating heat pumps and air cooling air conditioners are not in the scope of this regulation.

Commission Regulation (EU) 327/2011 with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW. The products that falls under the scope of this regulation are not considered as a local space heater, though it is assessed in relation to comfort fans. The scope includes fans between 125 W and 500 kW, which aligns well with the scope of No 206/2012 for comfort fans ≤125 W. Regarding fans included in air conditioners with cooling power below 12 kW, there is a limited overlap with Regulation (EU) No 206/2012; it regards parts of the fans in ducted outdoor and indoor units, for larger static pressure difference and cooling capacity ranges (and thus air flows).

Commission Regulation (EC) No 640/2009 with regard to ecodesign requirements for electric motors. and its amendment Commission Regulation (EU) No 4/2014. The current scope includes electric three-phase AC motors with output in the range 0.75-375 kW. With the current scope, there is no overlapping of motors used for comfort fans ≤125 W. All fan motors covered by Regulation (EU) 206/2012 have unitary power well below 0.75 kW and motors of compressors are not included in Commission Regulation (EC) No 640/2009 because they are hermetic motors incorporated in the compressor shell (hermetic non accessible).

1.1.3 Assessment of extending product scope

This assessment focuses on products that are not included in any regulation and whether they should be included in the scope of this study. This assessment is made to assure alignment of the different regulations and to avoid any loopholes.

<u>Air Conditioners</u>
Air conditioners – Air conditioners are covered by Regulation (EU) No 206/2012 and 626/2011 if their cooling capacity is lower than or equal to 12 kW. Table 3 proposes a

synthesis of the different air conditioner and cooling generator types and of their inclusion in existing Ecodesign and labelling regulations.

Table 3: Synthesis of the different air conditioner and cooling generator types and of their inclusion in existing Ecodesign and labelling regulations

Product in scope					
Outdoor side	Indoor side	Capacity threshold	Usual product names	Ecodesign Regulation	Labelling regulation
Outdoor air	Recycled air	≤ 12 kW	Split, multi-split, window, through-the-wall, double duct air conditioners	206/2012	626/2011
Exhaust air	Recycled air	≤ 12 kW	Single duct air conditioners	206/2012	626/2011
Other relevant products					
Outdoor side	Indoor side	Capacity threshold	Usual product names	Ecodesign Regulation	Labelling regulation
Outdoor air	Recycled air	> 12 kW	Split, multi-split, VRF, Rooftop air conditioners	2281/2016	None
Water/ brine	Recycled air	None	Water cooled air conditioners / heat pumps	2281/2016	None
Exhaust air	Outdoor air	≤ 12 kW	Ventilation exhaust air-to-air heat pumps and air conditioners (possibly reversible)	None or 206/2012?	None
Exhaust air	Outdoor air	> 12 kW	Ventilation exhaust air-to-air heat pumps and air conditioners (possibly reversible)	2281/2016	None
Air	Water	None	Air cooled chillers (cooling only)	2281/2016	None
Water/ Brine	Water	None	Water cooled chillers (cooling only)	2281/2016	None
Air	Water	≤ 400 kW (Ecodesign) / ≤ 70 kW (Label)	Air-to-water reversible chillers (heating function only)	813/2013	811/ 2013
Water/ Brine	Water	≤ 400 kW (Ecodesign) / ≤ 70 kW (Label)	Water/brine-to-water reversible chillers (heating function only)	813/2013	811/ 2013
Outdoor air	Recycled air	None	Cooling/heating electric vapor compression cycle generators in air handling units (except rooftops)	None	None

There are several product groups considered for scope extension of the regulation of air conditioners:

Air conditioners > 12 kW are not within the scope of regulation No 206/2012. This was a potential loophole until the adoption of regulation (EU) No 2016/2281 with regard to ecodesign requirements for air heating products, cooling products, high temperature process chillers and fan coil units. This regulation covers all air conditioners above 12 kW and up to a rated heating capacity not exceeding 1 MW.

Water/brine-to-air air conditioners and heat pumps, which were not covered in Regulation (EU) No 206/2012, are now covered by Regulation (EU) No 2016/2281: 'heat generator' definition includes 'ambient air, ventilation exhaust air, water or ground heat source(s)';'cold generator' definition specifies that heat extracted can be 'transferred to a heat sink, such as ambient air, water or ground'. Ecodesign requirements regarding water/brine-to-air air conditioners are information requirements defined in Annex II / 5 / a / 4 of the Regulation (EU) No 2016/2281. Ecodesign requirements regarding water/brine-to-air heat pumps are covered by information requirement in Annex II / 5 / a / 6 of Regulation (EU) No 2016/2281.

Ventilation exhaust air-to-air heat pumps and air conditioners ≤ 12 kW are not explicitly in the scope of regulation No 206/2012, nor are they clearly excluded, as the type of indoor air used in the definition of air conditioners is unspecified ("a device capable of cooling or heating, or both, indoor air"). These products with rated capacity of 12 kW and above are quoted in regulation No 2016/2281 in the definition of 'heat pump' Information requirements in regulation No 2016/2281 apply to them, although there is not yet any part load conditions for these products to rate SEER and SCOP performances; residential exhaust air-to-air heat pumps often have cooling / heating capacity ≤ 12 kW, these are not currently included other regulations. It is advised to include these products in the scope of Regulation (EU) No 206/2012 and 626/2011 when their thermal power is below or equal to12 kW and to specify SEER and SCOP rating conditions. This also implies better specification of which air is used indoor and outdoor for air conditioners and heat pumps in Regulation (EU) No 206/2012. Test conditions for temperature and load to enable calculation of SEER / SCOP are proposed in Annex 1 to this report.

Ventilation exhaust air-to-air heat pump and air conditioners > 12 kW appears to be covered in Regulation (EU) No 2016/2281, 'ventilation exhaust air' is included in the 'heat generator' definition as a possible heat source; 'cold generator' definition specifies that heat extracted can be 'transferred to a heat sink, such as ambient air, water or ground', although it does not target explicitly 'ventilation exhaust air', it does not exclude it. Standard rating conditions are given for these products in Regulation Annex III table 16. Information requirements table for both air-to-air air conditioners (Annex II table 11) and air-to-air heat pumps (Annex II table 14) could be used. However, it should be noticed that there is not yet any specific part load conditions defined for exhaust-air-to-outdoor-air heat pump and air conditioners in EN14825:2016 nor in Regulation (EU) No 2016/2281.

Air or water cooled chillers (cooling only) are a possible air conditioner competitor in residential or service premises. However, these are covered by regulation (EU) No 2016/2281.

Air-to-water reversible chillers are a possible air conditioner competitor in residential or service premises. Regulation (EU) No 2016/2281 covers in general chillers, however it should be noted that Commission Regulation (EU) No 813/2013 only covers the chiller heating function. Thus, it is recommended also to include the cooling as the secondary function of air-to-water reversible chillers when revising the Regulation (EU) No813/2013.

Water/brine-to-water reversible chillers are a possible air conditioner competitor in residential or service premises. Regulation (EU) No 2016/2281 covers in general chillers, however it should be noted that Commission Regulation (EU) No 813/2013 only cover the chiller heating function only. Thus, it is recommended to include the cooling as the

secondary function of water / brine-to-water reversible chillers when revising the Regulation (EU) No 813/2013.

Cooling generators in air handling units (except rooftops) are not sold separately (as rooftop) but sold as a component of a specific air handling unit to pre-cool / pre-heat fresh air. According information available to the study team, these are not included in any EU Ecodesign or Labelling regulation. As a component of air handling units, these products were considered in ENTR Lot 6 study for air-conditioning and ventilation systems, but they were excluded from product scope because of low sales volumes. If cooling generators in air handling units should be included in any regulation, it should then be in regulations (EU) No 2016/2281 or in (EU) No 2014/1253.

Secondary functions of air conditioners

Air conditioners now commonly propose several functions in addition to heating and cooling. This includes air purifying, dehumidification and air movement (only the indoor fan is on). These additional functions are mentioned in Regulation (EU) No 206/2012 definition for air conditioners.

However, room air conditioning products with other primary functions than space cooling/heating and air movement creation were excluded from the scope of preparatory study for air conditioners based on their low market sales and consequent low EU energy consumption. This regards in particular dehumidifiers and air purifiers. There was no reliable data showing these markets became significant enough to justify ecodesign measures, however it should be noted that these are growing markets. The preparatory study to establish the Ecodesign Working Plan 2015-2017[4] reported a lack of data for EU-27, and an estimated annual primary energy consumption of dehumidifiers of 0.25 TWh, much greater consumption found for humidifiers of 23.6 TWh, especially steam humidifiers.

The dehumidification capability, measured by the sensible- heat ratio (SHR), is drastically reduced when operating in cooling mode, according to EU test laboratories. It means that to dehumidify, end-users would need to use the separate dehumidification mode of air conditioners or to buy an additional equipment for dehumidifying in the cooling season. However, there is presently no standardized operating conditions to establish the performance of the dehumidification function of air conditioners.

Comfort fans

Comfort fans are covered by Regulation (EU) No 206/2012 and 626/2011 if their fan power input is lower than 125 W.

Table 4 proposes a synthesis of the different fan types and of their inclusion in existing Ecodesign and labelling regulations.

Table 4: Synthesis of the different fan types and of their inclusion in existing Ecodesign and labelling regulations

Capacity threshold	Usual product names	Ecodesign Regulation	Labelling regulation
< 125 W	Comfort fans	206/2012	626/2011
Capacity threshold	Usual product names	Ecodesign Regulation	Labelling regulation
> 125 W	Fans, ventilation units	327/2011	None
nominal heat output of < 50 kW	Residential fan heaters	2015/1188	None

[4] https://www.vdma.org/documents/266687/344832/Ecodesign+WP3_Draft_Task_3_report_20140616_1500.pdf/d7f57d0c-3158-4194-aa89-d376894d7307

There are several product groups considered for scope extension of comfort fans however the following assessment shows that none of the product groups requires modification of the scope of the Regulation (EU) No 206/2012 and 626/2011. The product groups considered are:

Comfort fans with ≥ 125 W input power are not within the scope of the regulation No 206/2012. Instead these products are included in the regulation (EU) No 327/2011 with regard to ecodesign requirements for fans driven by motors with an electric input power between 125 W and 500 kW. The current assessment shows that there is no loophole for comfort fans with an input power of 125 W or above, and not necessary to extend the scope of No 206/2012.

Residential fan heaters are not within the scope of the regulation No 206/2012 though part of them are able to provide the same service as comfort fans when heating is turned off; comfort fans are defined in Regulation No 206/2012 as ' appliance[s] primarily designed for creating air movement around or on part of a human body for personal cooling comfort', whereas the primary function of fan heaters is likely to be heating. Residential fan heaters are included in the regulation (EU) No 2015/1188 for local space heaters and are specified as a portable local room heater in the explanatory notes[5].Hence their primary function is already covered in Regulation (EU) No 2015/1188. With much higher energy consumption for heating as compared to the comfort fan function only, ecodesign should stay focused on the primary function. However, as they are able to compete with comfort fans, it would have an added value for end-users to have comparable information for the secondary function as is required for comfort fans. Thus, it is recommended to include information requirement on the "air movement" function of residential fan heaters in Regulation (EU) No 2015/1188 (similar to the information requirement for comfort fans in Regulation 206/2012).

Evaporative coolers such as "misting fans" are not within the scope of Regulation No 206/2012, as the main principle for cooling is the evaporation of water, not air movement created by a fan.

1.1.4 Recommended product scope

In conclusion, the scope of ecodesign regulations of different air cooling and heating product are well aligned, however there are two concerns.

First of all, there is a possibility that ventilation exhaust air-to-air heat pumps and air conditioners ≤ 12 kW are not clearly covered by any regulation. They are not especially excluded from Regulation No 206/2012, hence it is recommended to include ventilation exhaust air-to-air heat pumps and air conditioners with heating or cooling capacity ≤ 12 kW in the revised scope. The draft definitions of exhaust air-to-air heat pumps and air conditioners are:

- 'Ventilation exhaust air to outdoor air heat pump" means a heat pump that extracts heat from the exhaust air of a building to supply it to the ventilation supply air for the thermal comfort of human beings by a compression cycle or a sorption cycle. The ventilation outdoor air passes through the condenser of the heat pump before entering the building. The exhaust air passes through the evaporator of the heat

[5] http://edit.eceee.org/ecodesign/products/solid_fuel_small_combustion_installations/LRHS-20120716ExplanatoryNotesFINAL.PDF

pump before being rejected outdoors. The unit can also be equipped with a heat recovery heat exchanger.

- 'Ventilation exhaust air to outdoor air conditioner" means an air conditioner that extracts heat from the ventilation inlet air of a building to supply it to the ventilation exhaust air for the thermal comfort of human beings by a compression cycle or a sorption cycle. The ventilation outdoor air passes through the evaporator of the air conditioner before entering the building. The exhaust air passes through the condenser of the air conditioner before being rejected outdoors. The unit can also be equipped with a heat recovery heat exchanger.

The definition of a heat pump and air-to-air heat pump will also be added to the regulation. The definitions will be adapted from Regulation (EU) No 2016/2281 and are described above in section 1.1.1.2. Secondly, an additional function of residential fan heaters, currently covered by Regulation (EU) No 2015/1188, could be "creating air movement around or on part of a human body for personal cooling comfort". This means it could be a competitor for comfort fans, information requirements on the "air movement" function of residential fan heaters could give end-users valuable comparable information. It is recommended that during the revision of Regulation (EU) No 2015/1188, similar information requirements for comfort fans are proposed for residential fan heaters targeting this secondary function. However, these are not proposed to be included in Regulation No 206/2012.

Regarding cooling and heating, the regulation (EU) No 2012/206 did not include non-electric energy sources. In fact, there is presently no product using gas or other energy sources besides electricity for air conditioners. Extending the scope of Regulation (EU) No 206/2012 to non-electric energy sources would make it difficult for manufacturers to design products using non-electric energy sources, as they may not be able to reach the efficiency limit, at the same time it may also hinder innovation for air conditioners using renewable energy sources, such as biogas. Consequently, it is advised to keep non-electric energy sources outside of the scope.

The exemptions to the product scope are still as follows:

a. appliances that use non-electric energy sources;
b. air conditioners of which the condenser side or evaporator side, or both, do not use air for heat transfer medium.

The proposed product scope for Regulation 206/2012 is summarised in Table 5.

Table 5: Recommended product scope.

Categories	Products included	Scope limits
Outdoor air / recycled air	Split, multi-split, window, through-the-wall, double duct, multi-split mini VRF	Cooling (heating) power ≤12 kW
Exhaust air / recycled air	Single duct	
Exhaust air / outdoor air	Heat recovery ventilation heat pump / air conditioner	Cooling (heating) power ≤12 kW
Comfort fans	Desk fans, floor standing fans, wall mounted fans, ceiling fans, tower fans, box fans, etc. Portable fan heater with comfort fan mode.	Electric fan power ≤ 125W

1.2 Test standards (EU, Member State and third country level)

There is a significant number of EN standards either published, or under development, to support European Union environmental legislation. To a certain extent, they cover air conditioners. This relevant EU environmental legislation includes:

- Ecodesign Directive[6]
- Machinery Directive[7]
- Waste Electrical and Electronic Equipment Directive (WEEE)[8]
- Restriction of Hazardous Substances Directive (RoHS)[9]
- Electromagnetic Compatibility Directive (EMC)[10]
- Low Voltage Directive (LVD)[11]
- Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH) Regulation[12]
- Regulation EU 517/2014 regarding fluorinated greenhouse gases

We focus hereafter on main standards as regards air conditioners and comfort fans, which are described by main domain:

- Energy performance for primary function
- Energy performance for secondary functions of air conditioners
- Noise
- Safety (including refrigerant and electricity)
- WEEE and RoHS standards

1.2.1 Energy performance for primary functions

According to the preparatory study[13], the main environmental impact of products in the scope of Regulation 206/2012 and 626/2011 is due to energy consumption in the use phase. Standards related to rating the energy performance of air conditioning and comfort fans are described below.

1.2.1.1 European standards

Standards regarding energy performance of EU Regulation 206/2012/EU and EU Regulation – 626/2011 are:

- **EN14511** which defines the rated performance and measurement methods to be used for all air conditioners in cooling and in heating mode, with the exception of air conditioners with evaporatively-cooled condensers whose ratings are defined in **EN15218** standard.
- For other than single duct, double duct and evaporatively cooled air conditioners, the standard **EN14825** defines the calculation and testing points to calculate the seasonal energy efficiency (SEER) and seasonal coefficient of performance (SCOP) and completes where required measurement methods defined in standard EN14511.

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[6] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0125
[7] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32006L0042&from=FR
[8] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32012L0019
[9] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32011L0065
[10] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32004L0108
[11] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0035
[12] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006R1907
[13] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Contract TREN/D1/40-2005/LOT10/S07.56606. CO-ORDINATOR: Philippe RIVIERE, ARMINES, France. Air conditioners, final report. December 2008. This report can be downloaded from DG ENERGY website: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products.

- **Standby and off** mode power consumption measurement method is specified in EN14511-3 for single duct and double duct air conditioners, in EN15218 for evaporatively cooled single duct or double duct air conditioners and in the EN14825 standard for other air conditioners. For comfort fans, the horizontal standard for measurement of standby and off mode consumption indicated in the transitional methods[14] is EN60321:2005, now replaced with EN50564:2011.
- Regarding the energy efficiency of comfort fan, measured through their service value (SV) ($m^3.min^{-1}.W^{-1}$), there is no harmonized standard and transitional methods refer to standard **IEC 60879**:1986/COR1:1992, which is described in the International standards section.

EN 14511:2013 Air conditioners, liquid chilling packages and heat pumps with electrically driven compressors for space heating and cooling. The standard is divided in 4 parts which are: scope, terms and definitions, test conditions, test methods and requirements. This standard defines test conditions for rating the performances of the units at their maximum available capacity for these operating conditions; only the tests in the standard conditions are mandatory, application conditions are facultative. The test conditions are defined in cooling mode and the heating mode following the classification by outdoor side and indoor side fluids. Rating conditions in heating and cooling mode are given in Table 6 and Table 7.

Table 6: Air to air, testing conditions in the heating mode (EN14511-2:2013)

		Outdoor heat exchanger		Indoor heat exchanger	
		Inlet dry bulb temperature °C	**Inlet wet bulb temperature °C**	**Inlet dry bulb temperature °C**	**Inlet wet bulb temperature °C**
Standard rating Conditions	Outdoor air / recycled air (e.g. window, double duct, split units)	7	6	20	15 max
	Exhaust air / recycled air (e.g. single duct heat pump)	20	12	20	12
	Exhaust air / outdoor air	20	12	7	6
Application rating conditions	Outdoor air / recycled air (e.g. window, double duct, split units)	2	1	20	15 max.
	Outdoor air / recycled air (e.g. window, double duct, split units)	- 7	- 8	20	15 max.
	Outdoor air / recycled air (e.g. window, double duct, split units)	- 15	-	20	15 max.
	Exhaust air / outdoor air	20	12	2	1
	Exhaust air / outdoor air	20	12	-7	-8

[14] http://eur-lex.europa.eu/legal-content/FR/TXT/?uri=uriserv:OJ.C_.2012.172.01.0001.01.FRA&toc=OJ:C:2012:172:TOC

Table 7: Air to air, testing conditions in the cooling mode (EN14511-2:2013)

		Outdoor heat exchanger		Indoor heat exchanger	
		Inlet dry bulb temperature °C	**Inlet wet bulb temperature °C**	**Inlet dry bulb temperature °C**	**Inlet wet bulb temperature °C**
Standard rating Conditions	Comfort (outdoor air / recycled air) (e.g. window, double duct, split units)	35	24 [a]	27	19
	Comfort (exhaust air / recycled air)	27	19	27	19
	Comfort (exhaust air / outdoor air)	27	19	35	24
	Single duct[b,c]	35	24	35	24
	Control cabinet	35	24	35	24
	Close control	35	24	24	17
Application rating conditions	Comfort (outdoor air / recycled air) (e.g. window, double duct, split units)	27	19 [a]	21	15
	Single duct [b,c]	27	19	27	19
	Comfort (outdoor air / recycled air)	46	24 [a]	29	19
	Control cabinet	50	30	35	24
	Close control	27	19	21	15

[a] The wet bulb temperature condition is not required when testing units which do not evaporate condensate.
[b] When using the calorimeter room method, pressure equilibrium between indoor and outdoor compartments shall be obtained by introducing into indoor compartment, air at the same rating temperature conditions.
[c] The pressure difference between the two compartments of the calorimeter room shall not be greater than 1,25 Pa. This pressure equilibrium can be achieved by using an equalizing device or by creating an open space area in the separation partition wall, which dimensions shall be calculated for the maximum airflow of the unit to be tested. If an open space is created in the partition wall, an air sampling device or several temperature sensors shall be used to measure the temperature of the air from the outdoor compartment to the indoor compartment.

Rated capacity conditions for inverter air conditioners (except single duct)

The rated cooling capacity of the unit is determined at standard rating conditions (outdoor air 35 °C / indoor air 27 °C / chosen compressor frequency). For units with single speed compressors, this used to be the maximum capacity of the unit in cooling mode. However, for inverter drive compressor units, this is a design choice made by the manufacturer. This is the rated capacity that appears in product information and, as such, this value is used to determine if the unit is included or excluded in Regulation (EU) No 206/2012 (included if the cooling capacity lies below 12 kW). The rated cooling capacity and performance at standard rating conditions is an input to the SEER according to EN14825:2016 standard (see below). This means that the compressor frequency chosen to declare the cooling capacity has an influence on the energy performance, in cooling mode.

However, in heating mode, if the capacity standard rating conditions (outdoor air 7 °C / indoor air 20 °C / chosen frequency) is still used for heating only air-to-air heat pumps to classify the unit in the scope of Regulation (EU) No 206/2012 (if heating capacity is lower than 12 kW), this capacity and related COP are not used in SCOP calculation. It means that the manufacturers freely can adjust the frequency of this point to optimize the declared rated heating capacity and/or sound power value. Consequently, the reference to standard rated conditions in heating mode is to be modified in Regulation (EU) No 206/2012 to take this point into account.

Testing method, measurement uncertainty

Two testing methods are defined, namely the enthalpy method, which consists in the direct measurement of the thermal (heating or cooling) capacity by measurement of air flow rates and inlet and outlet enthalpies. The other method is the indirect "calorimeter room" method that measures the heat (and water for the cooling mode) that have been removed from the ambiance by the indoor heat exchanger. This latter method is reputed less uncertain than the direct measurement method. It is explicitly mentioned that "the cooling capacity of air conditioners and of air-to-air heat pumps having a cooling capacity below or equal to 12 kW shall be determined by measurements in a calorimeter room". There is a problem to test multisplit units with too many indoor units for all EU test laboratories (the precise number varies depending on the indoor unit type and the test cell size, but for instance it is not possible to test more than 4 indoor wall units).

The same test method is to be used at standard rating conditions and at part load as EN14825 standard refers to EN14511-3 as regards steady state test methods.

Maximum values regarding uncertainty of measurement are defined:

- 5 %, for steady state heating or cooling capacities, using the calorimeter room, except for single duct because of the air exchange between the indoor and outdoor compartments for which 10% is required,
- 10 % for transient tests (defrost cycles) and when using the direct measurement on the air side.

For single duct air conditioners and double duct air conditioners, the cooling capacity delivered to the indoor side heat exchanger is decreased in real life conditions because of unbalanced air flows at condenser side. For single duct air conditioners, the air flow entering the condenser and leaving the building must be balanced by hot air entering the building. If the outdoor air temperature is higher than the indoor air set point (27 °C), hot air is introduced into the building and this decreases the real-life capacity of the unit. This infiltration effect is not taken into account for single duct air conditioners because both indoor and outdoor air set points are 27 °C so that the effect of infiltration of outdoor air is null. For double duct units, infiltration occurs in case of condenser air flow leakage into the building. This is however already considered in the present EN14511-3 test standard.

A second effect is that with hot air circulating in ducts inside the building there are heat leaks to the conditioned space (in the case of double duct to be installed directly on the wall, this is probably minimal). This heat is considered in the calorimeter room method but the conditions of tests consider a shorter duct connection(s) for testing constraints than supplied by manufacturers. This effect is then minimized. In addition, the effect is not quantified.

Fan correction

For ducted units, with available static pressure, a correction is made to account only for a portion of the fan electric consumption. For indoor units, the cooling / heating capacity is also corrected.

The standard specifies that: "If a fan is an integral part of the unit (this is the normal situation for products in scope of this study and mainly regards ducted split and multi-split air conditioners), only a fraction of the input of the fan motor shall be included in the effective power absorbed by the unit. The fraction that is to be excluded from the total power absorbed by the unit shall be calculated using the following formula":

$$\frac{q.(\Delta p_e - ESP_{min})}{\eta}$$

- η is equal to η_{target}; as declared by the fan manufacturer according to the ecodesign regulation n°327/2011 for fans driven by motors between 125 W and 500 kW. η is 0.3 by convention, for fans driven by motors below 125 W.
- Δp_e is the measured available external static pressure difference, expressed in Pascal, (positive pressure difference measured between the air outlet section and the air inlet section of the unit, which is available for overcoming the pressure drop of any additional ducted air)
- ESP_{min} is the minimum external static pressure difference specified in Table 8 below, as applicable for an indoor unit, or 30 Pa for an outdoor unit.
- q is the nominal air flow rate, expressed in cubic meters per second.

Table 8: Air to air, testing conditions in cooling mode (EN14511-3:2013)

Standard capacity ratings kW	Minimum external static pressure (ESPmin) a b Pa
0 < Q < 8	25
8 ≤ Q < 12	37
12 ≤ Q < 20	50
20 ≤ Q < 30	62
30 ≤ Q < 45	75
45 ≤ Q < 82	100
82 ≤ Q < 117	125
117 ≤ Q < 147	150
Q 147	175
a: For equipment tested without an air filter installed, the minimum external static pressure shall be increased by 10 Pa. b: If the manufacturer's installation instructions state that the maximum allowable discharge duct length is less than 1m, then the unit can be considered as a free delivery unit and be tested as a non ducted indoor unit with an ESP of 0 Pa.	

It is important to note the formula has changed between EN14511:3 (2010) and EN14511:3 (2013).

The correction formula in 2010 was:

$$\frac{q.(\Delta p_e)}{\eta}$$

The 2010 correction formula was the one in use when the regulation (EU) No 206/2012 was voted. This correction allowed the ratings of non-ducted and ducted split air conditioners to be comparable.

However, in the latest available version of EN14511:3(2013), the correction for ducted units is much lower than in the 2010 version and could have justified differentiating the performance requirements for ducted and non-ducted units in Regulation (EU) No 206/2012.

It can also be noted that this updated fan correction tends to standardise the available static pressure per capacity range, as for ESP larger than ESP_{min}, the impact on performance is non-negligible, particularly under part load conditions, hence on the seasonal performance metrics.

There is a revision of EN14511:3 standard in progress (prEN14511-3:2017), which reinstates the 2010 formula in the future. This is a point to be followed for setting specific requirements of future regulations. Indeed, present published values for ducted fix air conditioners and heat pumps have lower performances that after this standard is enforced.

Standby and off for single duct and double duct air conditioners
After the cooling (heating) rating test, in cooling (heating) mode for cooling only and reversible units (for heating only units), the unit is switched in standby mode with the control device if available. After 10 minutes, the residual energy consumption is measured and assumed to be the standby consumption. It is not stated if network standby consumption is included in the value measured.

Rating of multisplit air conditioners and heat pumps
An informative annex (I), indicates that to rate multisplit units, the power of the indoor unit is to be included in the ratings. The capacity ratio (ratio of the capacity for outdoor unit to the sum of the capacities of indoor units) is set to 100 % +/- 5 %. The Regulation (EU) No 206/2012 specifies a ratio of 1 should be used. Note the ratio in EN14511:3 is supposed to apply to thermal capacities before potential fan corrections (for ducted units).

Operating requirements, marking and instructions
Supplementary requirements are defined in this part:

- a starting test,
- a test at maximum operating conditions (cooling mode),
- a freeze-up test,
- a test outside the operating range,
- a safety test consisting in shutting off the heat transfer medium flows,
- a complete power supply failure test,
- a condensate draining and enclosure sweat test,
- ability to defrost for air-to-air and air-to-water heat pumps.

Instruction is given for the information that should be marked on the plate of the unit (manufacturer and model designation and rated performances).

The information that should be published in the technical documentation of the unit is also described. This information is available to installers or design engineers. It entails:

- a general description (trademark, model designation; power supply (voltage, frequency); denomination of the unit (e.g.: air-to-water); intended use of the unit (e.g.: control cabinet air conditioner); number of separate component units; type and mass of refrigerant charge; overall dimensions and weight of each separate component unit;
- Rating characteristics: the cooling capacity, the effective power input, the EER (EER: Energy Efficiency Ratio) and the SHR (where applicable - the SHR stands for Sensible Heat Ratio); the heating capacity, the effective power input and the COP (Coefficient of Performance) (where applicable); the heat recovery capacity and the type of liquid (where applicable);
- Additional characteristics: flow rates, the rotational speed of fans and external static pressure for ducted units.
- The sound power level and the corresponding test method according to EN 12102.
- Electrical characteristics according to with EN 60335-2-40 (domestic air conditioners and heat pumps) or EN 60204-1 (non domestic)

- The operating range
- A physical description of the unit (fluids including oil type, additional heating devices, control and safety information)
- Instructions for installation
- Instructions for maintenance
- instruction for test house (how to set the required frequencies to reach specified ratings).

As SHR is not commonly communicated in general product documentation (only in the technical documentation), there is no information on the capacity of the unit to dehumidify when working in cooling mode.

Also, despite most air conditioners now propose a dehumidification mode, there is no information required on these alternate modes.

Hence, information to the end-users on dehumidification is absent. This may be a problem in hot and humid parts of Europe (mainly the Mediterranean area), especially since the dehumidification capacity of modern inverter air conditioning units in cooling mode is low. It prevents the end-user to compare the dehumidification capability of the unit with alternatives (dedicated dehumidifiers).

The same is true for ventilation mode, also the impact for the end-user is probably much lower.

EN 15218:2013 Air conditioners and liquid chilling packages with evaporatively cooled condenser and with electrically driven compressors for space cooling — Terms, definitions, test conditions, test methods and requirements

This standard is dedicated to evaporatively cooled air conditioners for space cooling having their condenser cooled by air and by the evaporation of external additional water. Air conditioners evaporating the indoor condensates at their condenser are excluded (included in the EN 14511 standard) since the water must be "external", except if they have a water tank that can be filled in also with external water. Inside dry and humid bulb temperatures of rating conditions are compatible with the EN14511 standard.

This standard defines the water temperature to be used for those tests:

- for evaporatively cooled condenser air conditioner with continuous water supply circuit, a single water temperature of 15 °C is used,
- for evaporatively cooled condenser air conditioner with a water tank, water temperature is set to 35 °C for air-to-air air conditioners.

As compared to 2006 version, the standard has been complemented to satisfy information requirement and standby and off mode measurement for evaporatively cooled single duct and double duct air conditioners, as requested by European regulations 206/2012 and 626/2011. For standby and off mode measurement, it is not stated if network standby consumption is included in the value measured.

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

"This European Standard provides part load conditions and calculation methods for calculating the Seasonal Energy Efficiency Ratio (SEERon) and Seasonal Coefficient of Performance (SCOPon and SCOPnet) of such units when they are used to fulfil the cooling and heating demands". This the harmonised standard for air conditioner regulation EC/206/2012 and space heater EU regulations No 813/2013 and No 811/2013. The methods and numerical value used are defined in the regulations above. However, the test methods are defined in this specific standard.

This standard has the same scope as defined in EN14511-1 but does not apply to single duct and double duct air conditioners, for which no seasonal performance rating is defined. There is a revision project of EN14825 (prEN14825:2017) to satisfy the requirements of EU regulations 1095/2015 and 2281/2016.

Note that also ventilation exhaust heat pump/air conditioners (exhaust air/outdoor air) are in the scope of EN14511-1, but there is not yet any seasonal performance condition defined to compute SEER and SCOP values.

Cooling mode

A bin method is used to compute a seasonal efficiency ratio in cooling mode noted SEERon which only accounts for hours with non-zero cooling load. A second SEER figure is defined to take into account parasitic electricity power consumption in low power modes: thermostat off mode, standby mode, off mode and crankcase heater consumption.

The reference climate is an average climate for Europe. The load curve is a straight line as a function of outdoor air temperature with no load at 16 °C and 100 % load (matching the full load capacity of the unit) at 35 °C.

The Reference design conditions for cooling (Tdesignc)

Temperature conditions at 35 °C dry bulb (24 °C wet bulb) outdoor temperature and 27 °C dry bulb (19 °C wet bulb) indoor temperature. Part load ratio is defined as:

$$Part\ load\ ratio\ \% = (Tj - 16) / (35 - 16)$$

The hours of operation in each temperature bin are defined below.

Table 9: bin number j, outdoor temperature Tj in oC and number of hours per bin hj corresponding to the reference cooling season

j #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Tj °C	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
hj h	205	227	225	225	216	215	218	197	178	158	137	109	88	63	39	31	24	17	13	9	4	3	1	0

The EER values at each bin are determined via interpolation of the EER values at part load conditions A, B, C, D as mentioned in the tables below with methods as described in Table 10 below. For part load conditions with outdoor temperature superior to temperature of condition A, the same EER values as for condition A are used. For part load conditions with outdoor temperature lower than temperature below part load condition D, the same EER values as for condition D are used.

To compute SEERon and SEER, the formulas to be applied are:

$$SEER_{on} = \frac{\sum_{j=1}^{n} hj \times Pc(Tj)}{\sum_{j=1}^{n} hj \times \left(\frac{Pc(Tj)}{EER(Tj)}\right)}$$

Where:

- *Tj = the bin temperature*
- *j = the bin number*
- *n = the amount of bins*
- *Pc(Tj) = the cooling demand of the building for the corresponding temperature Tj.*
- *hj = the number of bin hours occurring at the corresponding temperature Tj*
- *EER(Tj) = the EER values of the unit for the corresponding temperature Tj.*

$$SEER = \frac{Q_C}{\frac{Q_C}{SEER_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB} + H_{CK} \times P_{CK} + H_{OFF} \times P_{OFF}}$$

Where:

- *Q_C = The reference annual cooling demand, expressed in kWh*
- *H_{TO}, H_{SB}, H_{CK}, H_{OFF} = the number of hours the unit is considered to work in respectively thermostat off mode, standby mode, crankcase heater mode and off mode. NOTE the number of hours to be used for several types of units is indicated in Annex C*
- *P_{TO}, P_{SB}, P_{CK}, P_{OFF} = the electricity consumption during respectively thermostat off mode, standby mode, crankcase heater mode and off mode, expressed in kW*

$$Q_c = P_{designc} \times H_{ce}$$

For air-to-air air conditioners, up to 12 kW cooling capacity, the number of equivalent cooling hours equals 350.

The 4 testing conditions A, B, C and D are defined for each type of sink-source combination. The conditions for air-to-air units (outdoor air / recycled air) are given in Table 10 below. Note that there is no reference testing conditions for ventilation exhaust air conditioners (that would be exhaust air / outdoor air).

Table 10: Part load conditions for reference SEER and reference SEERon: air to air units

	Part load ratio	Part load ratio %	Outdoor air dry bulb temperature °C	Indoor air dry bulb (wet bulb) temperatures °C
A	(35–16)/(Tdesignc –16)	100	35	27(19)
B	(30–16)/(Tdesignc –16)	74	30	27(19)
C	(25–16)/(Tdesignc –16)	47	25	27(19)
D	(20–16)/(Tdesignc –16)	21	20	27(19)

At full load (= part load condition A), the declared capacity of a unit is considered equal to the cooling load (Pdesignc). There is no oversizing factor considered. In part load conditions B,C,D, the declared capacity of a unit may or may not match the cooling load, if the declared capacity of a unit is matching with the required cooling load, the corresponding EER value of the unit is to be used. This may occur with staged capacity or variable capacity units.

If the declared capacity of a unit is higher than the required cooling load, the unit has to cycle on/off. This may occur with fixed capacity, staged capacity or variable capacity units. In such cases, a degradation factor (Cdc for air-to-air units) has to be used to calculate the corresponding EER value. Such calculation is explained below. For staged capacity units and variable capacity units with capacity steps not matching the required part load

conditions (+/- 10 % of DC for capacity staged and variable capacity units), EERx (with x=B, C or D) should be computed by linear interpolation of the cooling capacity and of the power input between the capacity stages the closest to the part load required for the same temperature conditions or alternatively using the cycling formula below.

Cdc correction for air to air air conditioners

$$EER_{bin} = EER_d \times \left(1 - Cdc \times (1 - CR)\right)$$

Where:

- *EERd = the EER corresponding to the declared capacity (DC) of the unit at the same temperature conditions as for part load conditions B, C, D*
- *Cdc = the degradation coefficient*
- *CR = is the capacity ratio, the ratio of the cooling demand (Pc) over the declared capacity (DC) of the unit at the same temperature conditions*

The Cdc value can be determined or by default be 0.25. It takes into account both the power consumption of the unit when the compressor is off and the pressure equalisation that reduces the cooling/heating capacity when the unit is restarted. Test is made at 20 % load over a cycle of 30 min. In practice however, this test is not used for air-to-air air conditioners and the default coefficient of 0.25 is used.

Heating mode

The same procedure is applied in heating mode as in cooling mode. For the purpose of reference SCOP and reference SCOPon, there are 3 reference conditions: average (A), warmer (W) and colder (C). A supplementary SCOPnet, without backup nor consumption of the low power modes, is defined in view of the renewable energy directive (Commission decision 2013/114/EU)[15].

For air-to-water heat pumps, the seasonal space heating efficiency in primary energy η_s [%], defined in regulations (EU) No 811/2013 and (EU) 813/2013 is also included, but does not apply for air-to-air heat pumps as it was not defined in Regulation (EU) 206/2012.

The Reference design conditions for heating (Tdesignh)

- Temperature conditions for average, colder and warmer climates.
- Average: -10 °C dry bulb outdoor temperature and 20 °C dry bulb indoor temperature
- Cold: -22 °C dry bulb outdoor temperature and 20 °C dry bulb indoor temperature
- Warm: +2 °C dry bulb outdoor temperature and 20 °C dry bulb indoor temperature

Bivalent temperature (Tbivalent)

It is the lowest outdoor temperature point at which the heat pump is declared to be able to meet 100% of the heating demand without additional backup.

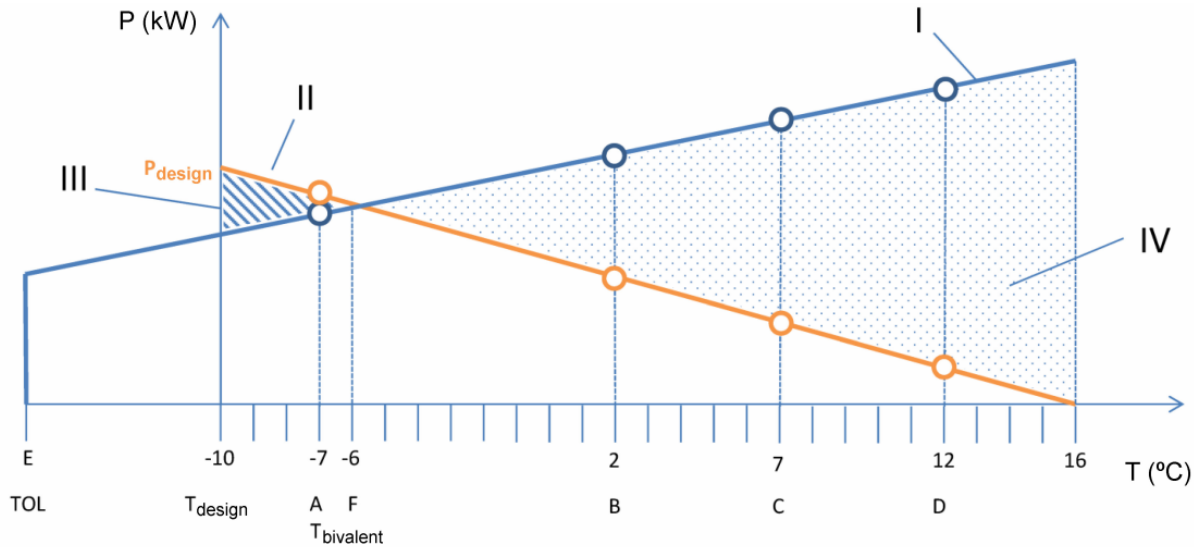
NOTE: Below this point, the unit may still deliver capacity, but additional back up heating is necessary to fulfill the heating demand.

The declared bivalent temperature can be any outdoor temperature within following limits (this is defined in Regulation (EU) 206/2012:

- for the average heating season, the bivalent temperature is +2°CDB or lower

[15] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013D0114

- for the colder heating season, the bivalent temperature is -7°CDB or lower
- for the warmer heating season, the bivalent temperature is +7°CDB or lower



Key

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

Figure 2: Schematic overview of the SCOPon calculation points (for a on-off cycling air to water unit, in EN14825:2016, Annex E, p 74)

The heating bins are given hereunder. The load curve in heating mode is also computed with 16 °C as the balance point temperature (ie outdoor dry bulb temperature with no heating load).

The heating demand Ph(Tj) can be determined by multiplying the full load value (Pdesignh) with the part load ratio % for each corresponding bin. This part load ratio % is calculated as follows:

- For the average climate: Part load ratio % = (Tj-16) / (-10-16) %
- For the warmer climate: Part load ratio % = (Tj-16) / (+2-16) %
- For the colder climate: Part load ratio % = (Tj-16) / (-22-16) %

Table 11: bin number j, outdoor temperature Tj in °C and number of hours per bin hj corresponding to the reference heating seasons —warmer, —average, —colder

j # 	Tj °C	Warmer (W) hjW h	Average (A) hjA h	Colder (C) hjC h
1 to 8	−30 to −23	0	0	0
9	−22	0	0	1
10	−21	0	0	6
11	−20	0	0	13
12	−19	0	0	17
13	−18	0	0	19
14	−17	0	0	26
15	−16	0	0	39
16	−15	0	0	41
17	−14	0	0	35
18	−13	0	0	52
19	−12	0	0	37
20	−11	0	0	41
21	−10	0	1	43
22	−9	0	25	54
23	−8	0	23	90
24	−7	0	24	125
25	−6	0	27	169
26	−5	0	68	195
27	−4	0	91	278
28	−3	0	89	306
29	−2	0	165	454
30	−1	0	173	385
31	0	0	240	490
32	1	0	280	533
33	2	3	320	380
34	3	22	357	228
35	4	63	356	261
36	5	63	303	279
37	6	175	330	229
38	7	162	326	269
39	8	259	348	233
40	9	360	335	230
41	10	428	315	243
42	11	430	215	191
43	12	503	169	146
44	13	444	151	150
45	14	384	105	97
46	15	294	74	61
Total		**3590**	**4910**	**6446**

The SCOP and SCOPon are computed as in the cooling mode but considering the electric heating required to cover the heating load below the bivalent point. Default equivalent full load hours are given for air to air reversible units with cooling capacity lower than 12 kW as well as hours for low power mode consumption to compute reference SCOP and SCOPon values. These values are the ones of Regulation (EU) 206/2012). There are differences between values used for air-to-air air conditioners and air-to-water heat pumps that should be further analysed (see part 1.3.1 regarding EU legislation).

Testing methods for active modes

Test methods at reduced capacity of variable speed and staged capacity units are the same as specified in EN14511:3, except when the unit cannot reach a specific rating point B, C or D or when it has to cycle to supply the required cooling load (two points already discussed in the cooling mode section of this standard above). Also, uncertainties of measurement are specified and reported below (only the part useful for air-to-air conditioners). Note that in EN14511:3, air-to-air conditioners have to be rated using the calorimeter method, which allows a better precision of part load performances, as shown below.

"The steady-state heating and cooling capacities determined using the calorimeter method shall be determined with a maximum uncertainty of:

- 5 % when the capacity measured is greater than 2,0 kW;
- 10 % when the capacity measured is between 1,0 kW and 2,0 kW;
- 15 % if it is lower than 1,0 kW.

The heating capacities determined during transient operation (defrost cycles) using the calorimeter method shall be determined with a maximum uncertainty of 10 %. The heating and cooling capacities measured on the air side using the air enthalpy method shall be determined with a maximum uncertainty of (4 + 6/part load ratio) %.

All uncertainties of measurement are independent of the individual uncertainties of measurement including the uncertainties on the properties of fluids. The maximum uncertainty of the measurement of the power input for off, thermostat off, standby and crankcase heater modes shall be ± 0,1 W up to 10 W; ± 1 % for powers greater than 10 W."

Regarding cycling tests, test laboratories are reluctant to use the test method proposed:

- this test was developed for on/off units; for inverter driven units, there is a delay after startup which means that to make such a test, the laboratory should require the manufacturer to modify the software of the unit to enable a 6min on and 24 min off cycle;
- it is a highly consuming test;
- it is a test of unknown precision (probably low) because of very load to be measured (1 kW cooling capacity when on, so only 200 W in average).

Thus, it is advisable at the moment, to use the default Cdc and Cdh values, which anyway has limited impact on the seasonal indices of inverter driven units. It means Regulation (EU) No 206/2012 should be amended not to allow a cycling test until the EN14825 standard be developed to allow these tests to be done.

Standby mode: For cooling only and reversible air conditioners, the standby mode power is measured after the unit has been running for 30 min in "A" test condition (outdoor temperature 35 °C, indoor temperature 27°C). The unit is stopped with the control device and after 10 min, the residual energy consumption is measured. For heating only units, the "D" test is used (outdoor temperature 12 °C, part load ratio 25 %, indoor temperature 20 °C).

Off mode: This test is measured 10 min after the standby mode test.

Thermostat-off: This is measured 30 min after the unit has been running for 30 min in "D" test condition in cooling mode for cooling only and reversible units and in heating mode for heating only units (Cooling mode: outdoor temperature 20 °C, part load ratio 25 %, indoor temperature 27 °C // Heating mode: outdoor temperature 12 °C, part load ratio 25 %, indoor temperature 20 °C). The thermostat set point related to the indoor temperature sensor is increased (decreased in heating mode) until the compressor stops. The time period for measurement is of 60 min.
In cooling mode, standby power consumption is deducted from consumption measured to calculate thermostat-off, but not in heating mode. This deduction in cooling mode is not logical (thermostat-off hours and standby hours are two distinct types of hours with no overlap) and should be corrected.
In EN14825:2016, it is written: " After the unit has been running for 30 min in "D" test condition in cooling mode (for cooling only or reversible units) [...]". Hence, for reversible units, thermostat-off power is measured in cooling mode test condition D.

Crankcase heater: It is included in standby power consumption if the crankcase is activated during the standby test. If not, the following test is performed: after the unit has been operating 30 min in "D" test condition in heating mode, the unit is stopped with the control device, and the consumption is measured for 8 hours starting 10 min after.

Regarding this method, it should be commented that power measurements are made at a certain temperature in each mode and then weighted by a number of hours to represent when the consumption is likely to occur. The impact of outdoor temperature variation is not taken into account here, and this probably makes a difference at least for crankcase heater consumption. Also, there may be for the same unit two distinct thermostat off values, which is not foreseen in Regulation (EU) No 206/2012 (adaptation to be done).

In addition, it is not stated if network standby consumption is included in the value measured, although many units already include network communication capability.

<u>Case of multisplit</u>
For multisplit appliances, the only indication in EN14825:2016 is that data in the test report shall be provided at a capacity ratio of 1 (same capacity for outdoor unit and the sum of the capacity of indoor units), as requested in Regulation (EU) 206/2012.

In prEN14825:2017 however, there is a dedicated annex (planned annex N, normative) for multisplit larger than 12 kW (for the purpose of Regulation (EU) No 2281/2016). This annex defines the SEER and SCOP of the outdoor unit only (not in line with present Regulation 206/2012 and 626/2011, which, in the ratings of multisplit air conditioners, also includes the fan power consumption). This annex specifies the number of indoor units to be connected depending on the standard-rated capacity of the multisplit unit. Currently, this is not defined for air conditioners with a capacity less than 12 kW, because all combinations (regardless the indoor unit type) must comply with requirements of Regulation 206/2012.

In annex N, are also given practical indications regarding the number of units to be considered for tests and tolerance on the capacity ratio (100 % more or less 5 %).

EN50564:2011 - Household electrical appliances - Measurement of standby power
This standard defines low power modes (standby and off mode) and measurement methods to be used. Network standby is not explicitly defined in the standard (see mandate M/544

which aims to include network standby), which does not preclude the same measurement methods also could be used for networked standby measurements.

1.2.1.2 Performance difference due to test methods

It is important to keep in mind that for variable speed units, the test requires the manufacturer to supply information on how to fix (or lock-in) the frequency of the compressor (and probably of fans) according to European standards EN14825 and EN14511-3. This is the general method used in performance test standards of air conditioners worldwide.

In Regulation 206/2012 the following is written 'The manufacturer of air conditioners and comfort fans shall provide laboratories performing market surveillance checks, upon request, the necessary information on the setting of the unit as applied for the establishment of declared capacities, SEER/EER, SCOP/COP values and service values and provide contact information for obtaining such information.' This does not mean that the manufacturer is allowed to use a specific software or other means to activate a mode dedicated to standard tests, in which the control of the unit is bypassed (or partially bypassed e.g. in case of the need to defrost).

However, it does mean that the performance of units in real life may differ from the performances measured in standard test conditions.

An alternative is to use a compensation method; in that method, the unit has to maintain the required set point temperature to compensate a given heat load (when working in cooling mode). Figure 3 below shows the comparison of tests realised in locked (lock-in) and unlocked (compensation method) modes for an inverter unit following test conditions of the AS/NZS 3823.4[16] test standard. The efficiency difference may be significant.

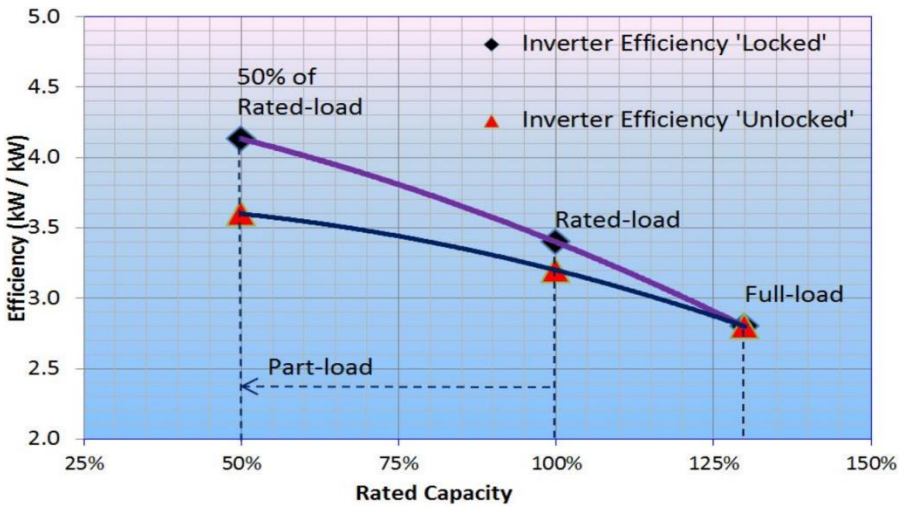


Figure 3: Impact of using lock-in mode versus compensation method on the energy efficiency of an inverter air conditioning unit[17]

[16] Australian Standards: AS/NZS 3823, Performance of electrical appliances – Airconditioners and heat pumps.
[17] Dr Satya Prasad Mavuri , " Field Behaviour of Inverter Air Conditioners Effect on Seasonal Performance" , International Journal of Application or Innovation in Engineering & Management (IJAIEM) , Volume 4, Issue 8, August 2015 , pp. 018-025 , ISSN 2319 - 4847.

Although test laboratories in Europe are aware of this method and the potential differences in results, there are issues for practical application that remain to be solved:

- there is no such method for ducted units,
- there are repeatability issues because the results obtained are dependent on the control of the unit and then in turn on the air inertia of the cell (and then on its size) and possibly on the control used to maintain the heat load (in cooling mode),
- test results are dependent on the temperature sensor of the unit being tested and on the setting of the indoor temperature (in general with 1 K precision), which may make it difficult to respect the deviation tolerances of the standard or/and may require ad-hoc corrections.
- time for testing increases significantly

Nevertheless, it is important to continue the development of compensation method as it could ultimately lead to seasonal figures closer to real life performances. Such a method is reintroduced for air-to-air air conditioners and heat pumps in case it is not possible to obtain information on how to set lock-in mode from manufacturers in prEN14825:2017. This method is not ready to be considered for this revision, but it might be included in the next revision.

1.2.1.3 International standards

Air conditioners

The main ISO standards relating to **air conditioners** (ISO 5151:2010 - 'Non-ducted air conditioners and heat pumps – Testing and rating for performance', ISO 13253:2011 – 'Ducted air conditioners and heat pumps – Testing and rating for performance', and ISO 15042:2011 Multiple split-system air-conditioners and air-to-air heat pumps – Testing and rating for performance) are not described here as main information is thought to be similar to EN14511 standard content (see description above) and that if there are differences, the EN14511 standard prevails.

Two ISO standards of specific interest for this study are being prepared; they are briefly described and discussed hereafter.

ISO/FDIS 16358-1:2013 Air-cooled air conditioners and air-to-air heat pumps — Testing and calculating methods for seasonal performance factors

This standard is made of 3 parts:

- Part 1: Cooling seasonal performance factor
- Part 2: Heating seasonal performance factor
- Part 3: Annual performance factor

Part 1 specifies the testing and calculating methods for seasonal performance factor of equipment covered by ISO 5151, ISO 13253 and ISO 15042 standards (split and multisplit non ducted and ducted units).

The general outline of the testing and calculating method is similar to standards being used in Asia (in Japan, China and South Korea specifically)[18]. The method was also completed to account for low power modes, as in the EN14825 standard.

[18] Sustainable Industrial Policy – Building on the Ecodesign Directive – Energy-Using Product Group Analysis/2, Lot 6: Air-conditioning and ventilation systems, Contract No. ENTR/B1/35-2009/LOT6/ SI2.549494, CO-ORDINATOR: Philippe RIVIERE, ARMINES, France, Final report - Air-conditioning products, July 2012

The equivalent to the $SEER_{on}$ is noted CSPF (Cooling seasonal performance factor), while the equivalent SEER is noted TCSPF (Total CSPF) and includes inactive energy consumption (which accounts in a single value for the impact of standby, off mode and crankcase heater contributions).

The mandatory minimum number of test points is lower than in the EN14825:2016 standard because modelling is used to assess performances of missing points, although manufacturers may choose to make more tests if they do not want to use default values. In addition, the calculation method is based upon only 3 load levels instead of 4 for the EN14825 standard. Only two points are mandatory (recycled air indoor conditions are fixed at 27/19 (dry bulb / wet bulb) as in the ISO 5151 and EN14511-2 standards):

- Fix capacity units: two tests at maximum capacity for outdoor conditions 35/24 (dry bulb / wet bulb) and 29/19 (dry bulb / wet bulb);
- Capacity staged units: three tests, one at maximum capacity for outdoor conditions 35/24 (dry bulb / wet bulb), the second one at 29/19 (dry bulb / wet bulb) and maximum capacity, and the third one in the same temperature conditions and half capacity;
- Variable capacity units: two tests, one at maximum capacity for outdoor conditions 35/24 (dry bulb / wet bulb), and the second one at 29/19 (dry bulb / wet bulb) and half capacity.

Regarding interpolation procedure, EER is interpolated linearly between operating points along the load curve as in EN14825 for variable capacity units. However, for capacity staged units, interpolation is made by weighting the time required for operation of each stage to satisfy the cooling load which is more realistic than linear interpolation in EN14825 for this type of unit. This has no impact however for air-to-air air conditioners in Europe as there is no capacity staged unit below 12 kW.

A reference climate is given. The weighting coefficients by temperature bins are given in the table below:

Table 12: The weighting coefficients by temperature bins

Bin number j	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Outdoor temperature tj °C	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	—
Fractional bin hours	0.055	0.076	0.091	0.108	0.116	0.118	0.116	0.1	0.083	0.066	0.041	0.019	0.006	0.003	0.002	
Bin hours nj	n1	n2	n3	n4	n5	n6	n7	n8	n9	n10	n11	n12	n13	n14	n15	—
Reference bin hours (nj) h	100	139	165	196	210	215	210	181	150	120	75	35	11	6	4	1 817

It can be commented that the zero load corresponds to an outdoor temperature of 20 °C instead of 16 °C in the EN14825 standard, and the weight of higher temperatures is more important. In addition, a guideline to define regional load curves is given in Annex D.

The hours to be used to compute the TCSPF are given in the table below:

Table 13: Hours to be used to compute the TCSPF

Unit	Active mode h	Inactive mode, Hia h	Disconnected mode h
Cooling only unit	1817	4077	2866
Cooling unit with supplemental heat	1817 (Heating operation: 2 866)	4077	0
Reversible unit	1817 (Heating operation: 2866)	4077	0

The hours in active mode are much higher than in the EN14825 standard. Disconnected mode is a mode where the unit is disconnected from the mains, not present in EN14825 standard. Inactive mode hours are hours without a cooling demand in the building.

For the measurement of the electric power consumption during inactive modes, the following test procedure is used:

- "The unit shall be electrically connected to the main power source after shut-down for 6 h. Indoor and outdoor temperature of 20 °C condition shall be reached. The power consumption shall be measured for one hour after the temperature conditions are stabilized. The same test is repeated with the temperature condition of 5 °C, 10 °C and then 15 °C with the stabilization period of 2 h between each test."
- Power consumption should then be weighted using coefficients that are given for the reference climate (representing number of inactive hours by temperature bins in the reference climate.

Although there is only one mode considered in this standard for low power mode consumption (inactive consumption), instead of four in EN14825, outdoor temperature variation is taken into account (and weighted as a function of temperature occurrence), which may result in a more precise estimate of crankcase power consumption and standby. However, it seems that supplementary thermostat off power consumption due to indoor fan is not considered (although thermostat off hours are clearly included in the inactive mode period according to definition).

According to EU test laboratories, including the impact of temperature on low power mode consumption would represent a certain supplementary burden, which may not be justified: the main interest of low power mode tests is to avoid very high energy consumption in these modes (especially unjustified all year-round use of crankcase heater), which seems have been solved by present test procedure.

Part 2 is dedicated to the HSPF (Heating Seasonal Performance Factor). The method applied is similar as the one for the cooling mode. Again, the number of test points required for the method is reduced as compared to EN14825, with only 2 testing points for on-off units and 3 for other heat pumps including variable capacity heat pumps.

In this standard, manufacturers cannot choose Pdesignc: the heat load is inferred from the heating capacity (P_H (7°C/100%) test at standard rating conditions 7 °C outdoor / 20 °C indoor / maximum capacity as follows:

$$\text{Heating load (equivalent to Pdesignc)} = 0.82 \times P_H \ (7°C/100\%)$$

The reason behind this value is: the ratio of the heating operational capacity at 0 °C in non-frosting condition to the standard heating capacity at 7 °C is assumed to be 0.82. So,

sizing is supposed to be made for 0 °C outdoor, which is in line with the distribution of temperature occurrences over the season shown in the table below:

Table 14: Distribution of temperature occurrences over the season

Bin number j	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Outdoor temperature tj °C	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3
Fractional bin hours	0	0	0	0	0	0	0	0	0	0.001	0.005	0.012	0.024	0.042
Bin hours nj	n1	n2	n3	n4	n5	n6	n7	n8	n9	n10	n11	n12	n13	n14
Reference bin hours (nj) h	0	0	0	0	0	0	0	0	0	4	15	33	68	119

Bin number j		16	17	18	19	20	21	22	23	24	25	26	27	Total
Outdoor temperature tj °C	4	5	6	7	8	9	10	11	12	13	14	15	16	
Fractional bin hours	0.059	0.07	0.082	0.087	0.091	0.092	0.091	0.085	0.075	0.067	0.053	0.038	0.027	
Bin hours nj	n15	n16	n17	n18	n19	n20	n21	n22	n23	n24	n25	n26	n27	
Reference bin hours (nj) h	169	200	234	250	260	265	260	245	215	192	151	110	76	2866

The climate chosen is definitely hotter than the average EU climate in regulation (EU) 206/2012.

Part 3 defines the calculation of the APF (Annual Performance Factor: ratio of the total thermal energy to the total electricity consumption for cooling and heating) and of the TAPF (including inactive mode consumption).

ISO/WD 18326:2016 - Non-ducted portable air-cooled air conditioners and air-to-air heat pumps having a single exhaust duct —Testing and rating for performance

"This Standard specifies the standard conditions for capacity and efficiency ratings of non-ducted portable air-cooled air conditioners having a single exhaust duct and non-ducted portable air-cooled heat pumps having a single exhaust duct. Such air conditioners and heat pumps may include an evaporatively cooled condenser cooled by air and the evaporation of:

a. condensate collected from the evaporator;
b. external supplementary water stored in a supplementary water tank; or
c. both (a) and (b).

This standard also specifies the test methods for determining the capacity and efficiency ratings.

The scope is thus broader that in the EN14511 standard and also encompasses single duct products evaporating water from a water tank at their condenser (in cooling mode), that are covered by standard EN15218 in Europe.

It is to be noted that the standard rating conditions for both heating and cooling mode are different from the ones in EN14511-2(2013):

- Cooling rating conditions: both exhaust and recycled air conditions are 35/24 (dry bulb / wet bulb), as in EN14511-2 standard;

- Heating rating conditions: both exhaust and recycled air conditions are 20/15, instead of 20/12 in EN14511-2 standard.

The test method is similar to the one in EN14511-3 standard and enables to take into account the impact of duct heat losses on the unit performance (although the duct length is only of 50 cm, while it may be much longer in real life). However, it does not include the impact of outdoor air infiltration on cooling capacity.

Comfort fans
Regarding comfort fans, the reference used in the transitional method for Regulation (EU) 206/2012 is IEC 60879 (Commission communication 2012/C 172/01).

IEC 60879: 1986 (corr. 1992) - Performance and construction of electric circulating fans and regulators
The following information has not changed since the preparatory study.

This standard applies to the following types of electric motor directly driven fans and their associated regulators intended for use on single-phase a.c. and d.c. circuits not exceeding 250 V:

a) Fans for household and similar purposes:
   - ceiling type fans;
   - table type fans;
   - pedestal fans;

b) Fans for use in ships:
   - Deck-head type fans;
   - Cabin type fans.

Note: Wherever applicable the term "fan" used in this standard includes its associated regulator, if any."

This standard does not apply to the following types of fans which are covered in separate standards:

- Jet fans (see IEC Publication 535: Jet Fans and Regulators);
- Ventilating fans (see IEC Publication 665: A.C. Electric Ventilating Fans and Regulators for Household and Similar Purposes).

This standard does not enable a priori to test tower fans but all other types.

The IEC 60879 standard defines an Energy Efficiency Index, called "service value" in English and "indice de qualité" in French, which is of the same nature as an SFP in ventilation: a ratio of the flow generated to the electrical power absorbed. It is an index suitable for the purpose, since there is no pressure difference to be maintained between upstream and downstream, as opposed to ventilation systems where pressure levels matter. It's measured at full speed. The standard does include the energy needed for the oscillating mechanism in the total electricity demand. The flow is measured without the oscillations.

The air delivery in cubic meters per minute divided by electrical power input to the fan in watts at the voltage and frequency specified for the test is named the service value.

In the event of the fan comprising an oscillating mechanism, the electrical input in watts is measured with the fan under normal full-speed conditions, that is with the oscillating

mechanism in action, whereas the air delivery is determined with the oscillating mechanism out of action.

This service value (SV) and the "rated air delivery" (flow rate) "shall be supplied on request".

One aspect of the IEC 879 standard is that there are functional requirements and even design values recommended: preferred sizes for ceiling fans, other for table fans, other for pedestal fans, a fact that generates this uniformity of declared characteristics that can be observed on the market.

Another interesting aspect of IEC 879 is that it includes a set of tolerances to apply when only one piece of equipment is tested to check the declarations of a manufacturer: 10% on air flow, which, since electrical power is very certain, means about 10% on "service value".

Even the oscillations are harmonized: "The number of oscillations per minute at full speed shall not be less than four. Whether the angular movement of the mechanism is variable, an angular movement of not less than 60° shall be available […]. A device shall be provided to render the oscillating mechanism inoperative when desired. The method of operating the device shall be indicated. "

It is the same for the speeds: "Regulators shall be capable of reducing the speed of the fan by at least 50 % of the full speed at the voltage and frequency specified for the test, except in the case of fans of the shaded pole type where the speed reduction shall be not less than 20 %. Fans shall be capable of running continuously on any of the contacts of the regulator at the rated voltage or voltages or within the whole rated voltage range, whichever is applicable."

The prescription about noise is not that clear: "The noise level of fans and regulators at all speeds shall be within reasonable limits".

Finally, tolerance is fixed on the rated air flow rate at full speed at 10 %. There is no explicit tolerance on the service vale (SFP) of the product, but it can be estimated.

There is no specific test standard in Europe for testing energy use of comfort fans (that could be easily written on the basis of IEC 879 with extension to tower fans).

1.2.1.4 Third country standards

Comfort fans: No new information on regional performance test standard of comfort fans was identified since last EuP Lot 10 study[19].

Air-to-air air conditioners but single duct / double duct and evaporatively- cooled air conditioners

Most countries in the world still use full capacity ratings based upon ISO 5151, 13253, 15041 standards[20]. However, the development of the ISO/FDIS 16358-1:2013 standard

[19] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Contract TREN/D1/40-2005/LOT10/S07.56606. CO-ORDINATOR: Philippe RIVIERE, ARMINES, France. Comfort fans, final report. December 2008. This report can be downloaded from DG ENERGY website: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products.

[20] www.claspinfo.org

accelerated the adoption of seasonal performance indicators. The first countries to have adopted the ISO standard are Australia and New Zealand, in standard AS/NZS 3823.4.1:2014 - Performance of electrical appliances — Air conditioners and heat pumps. Regional temperature distribution and associated hours for active, inactive and disconnected modes have been developed, with different zones to cover the different climates of the two countries. At least India[21] has followed, in 2015, and Thailand is planning to do so by 2020[22].

Before that, only a few countries had adopted seasonal performance standards or standards including low power modes (although air conditioner standby power consumption may be constrained in some countries, included in horizontal regulations). The description of these standards, which are for the USA, Japan, South Korea and China can be found in the EuP Lot 10 Study on air conditioners[23].

US DOE 10 CFR Parts 429 and 430. Energy Conservation Program: Test Procedures for Portable Air Conditioners; Final Rule[24]

On April 18, 2016, DOE classified portable ACs as covered consumer products under EPCA (Energy Policy and Conservation Act of 1975). DOE proposed a final rulemaking regarding test procedures (published in the Federal Register in June 2016) and associated energy conservation standards for portable ACs (proposed rulemaking published in December 2016, detailed information can be found in part 1.3 of this report).

The final test standard is based on the existing industry procedures[25] (direct air enthalpy method, i.e. measurement of the cooling capacity as the product of the indoor side air flow and enthalpy differences) and modified to account for:

- infiltration of hot air due to unbalanced flows (condenser air flow of single duct air conditioners is compensated by hot air infiltration; difference of air flow between condenser inlet and outlet for double duct air conditioners),
- heat losses of duct connections in the air-conditioned space.

The cooling capacity measured via the enthalpy difference and corrected of these two effects is named ACC for adjusted cooling capacity. The standard industry test is only slightly modified and the corrections are made via calculations.

In addition, a procedure has been designed to rate the seasonal efficiency of these units (Combined Energy Efficiency Ratio - CEER), which account for active cooling mode, thermostat off mode, standby or off mode operation in a single metrics.

Although the methodology used in cooling mode could be applied in heating mode (and was proposed in the first version of the test standard), heating mode was removed from the test procedure as it was considered that heating was not common nor commonly used for this type of units in the USA.

[21] https://www.bijlibachao.com/air-conditioners/iseer-star-labeling-inverter-air-conditioners-india.html
[22] http://www.aseanshine.org/asean-shine-task-force/d/asean-regional-policy-roadmap-for-harmonization-of-energy-performance-standards-for-air-conditioners
[23] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Contract TREN/D1/40-2005/LOT10/S07.56606. CO-ORDINATOR: Philippe RIVIERE, ARMINES, France. Air conditioners, final report. December 2008. This report can be downloaded from DG ENERGY website: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products.
[24] USA Federal Register, Vol 81, No. 105, Wednesday June 1, 2016.
[25] ANSI/AHAM PAC-1-2016: Portable Air Conditioners and ASHRAE standard 128:2011 - Method of Rating Portable Air Conditioners

Impact of infiltration and of duct heat losses on single duct and double duct performances. In May 2014, the USDOE released the results of tests conducted on several products including single duct, double duct and spot coolers air conditioners (the latter is similar to other products except it has no duct - it is not presently included in EU regulations 206/2012 and 626/2011).

The USDOE performed standard tests of these appliances according to USA industry standards (air enthalpy method) and completed it with investigations on the impact of infiltration of hot air. To do so, the calorimeter test method was used with temperature and humidity of the outdoor side maintained at 35°C/24°C (Dry bulb / Wet bulb) conditions and indoor conditions maintained at 26,7°C/19,4 (Dry bulb / Wet bulb).

About the standard rated capacity and efficiency, significant differences were identified with declared values by manufacturers. These results are given below in W for cooling capacity and in W/W for EER. On average, there is an approximate 20 % difference in capacity and EER between DOE tests and declarations, which can only be partly explained by the difference in methodology used by US DOE to rate standard capacity and EER.

Table 15: Baseline test results[26]

Test unit	Cooling capacity (W)			EER (W/W)		
	Rated	Baseline	Reduction (%)	Rated	Baseline	Reduction (%)
SD1	2344.57	1712.33	27.0	2.05	2.00	2.3
SD2	2784.18	1934.21	30.5	2.81	2.17	22.8
SD3	3516.9	3208.42	8.8	2.55	2.19	14.1
SD4	3809.9	2785.82	26.9	2.84	1.93	32
DD1	2784.18	2519.59	9.5	2.75	2.17	21.2
DD2	3809.9	2113.39	44.5	2.61	1.61	38.2
SC1	2930.7	2996.86	- 2.3	2.96	2.82	4.7
SC2	3956.46	3157.75	20.19	3.28	1.97	39.9

In a second step, the impact of air infiltration and of duct losses was established by using the calorimeter method with different temperatures on both sides of the units. These results are given below in W for cooling capacity and in W/W for EER and are compared to the baseline calorimeter approach.

It appears that the impact of the infiltration of hot air may lead to negative capacities (using a single duct unit may lead to heat the room instead of cooling it in hottest days of the Summer). There may also be a strong impact for double duct air conditioners whenever condenser inlet and outlet air flows are unbalanced.

Table 16: Investigation test results[27], impact of air infiltration on unit performance

Test unit	Cooling capacity (W)			EER (W/W)		
	Baseline	Calorimeter	Reduction (%)	Baseline	Calorimeter	Reduction (%)
SD1	1712.33	-137.98	108.1	2.00	-0.16	107.9
SD2	1934.21	-187.98	109.7	2.17	-0.21	109.4
SD3	3208.42	1018.57	68.3	2.19	0.67	69.2
SD4	2785.82	539.66	80.6	1.93	0.39	79.7
DD1	2519.59	990.55	60.7	2.17	0.85	60.9
DD2	2113.39	1008.87	52.3	1.61	0.76	52.7

The dependency of the impact of infiltrations and duct losses was investigated against varying outdoor air conditions to simulate the impact of these effects over the cooling

[26] USDOE, Notice of Data Availability (NODA), May 2014, rulemaking docket EERE-2013-BT-STD-0033.
[27] USDOE, Notice of Data Availability (NODA), May 2014, rulemaking docket EERE-2013-BT-STD-0033.

season. As expected, the closer is the outdoor climate to indoor conditions, the lower the impact. These results are given below in W for cooling capacity and in W/W for EER.

Table 17: Investigation test results[28], impact of varying outdoor conditions of air infiltration on unit performance

Test unit	Cooling capacity (W)				EER (W/W)			
	Test 1 (95/75 °F)	Test 2 (87/69 °F)	Test 3 (82/65 °F)	Test 4 (78/62 °F)	Test 1 (95/75 °F)	Test 2 (87/69 °F)	Test 3 (82/65 °F)	Test 4 (78/62 °F)
SD2	-180.06	1186.44	2063.07	2808.79	-0.21	1.32	2.31	3.12
SD4	539.66	2288.36	3068.13	3589.36	0.39	1.60	2.20	2.64
DD1	990.55	1837.20	2286.25	N/A	0.85	1.62	2.07	N/A
DD2	1008.87	1874.51	2387.74	N/A	0.76	1.46	1.88	N/A

The impact of duct heat losses was also separated by supposing ducts are insulated (correcting the magnitude of heat losses at the indoor side with better duct insulation). These results are given below in W for cooling capacity and in W/W for EER.

Table 18: Investigation test results[29], impact of insulating ducts on unit performance (comparison with calorimeter test results, outdoor conditions temperatures 35/24 (dry bulb/wet bulb)

	Cooling capacity (W)			EER (W/W)		
Test unit	Uninsulated	Insulated	Change	Uninsulated	Insulated	Change
SD1	-137.98	-1.47	136.51	-0.16	0.00	0.16
SD2	-187.98	-9.47	178.48	-0.21	-0.01	0.19
SD3	1018.57	1199.19	180.62	0.67	0.80	0.12
SD4	539.66	886.48	346.82	0.39	0.64	0.24
DD1	990.55	1372.16	381.61	0.85	1.15	0.30
DD2	1008.87	1233.65	224.79	0.76	0.92	0.16

This shows this effect has a lower impact than infiltration at high outdoor temperature conditions but should not be neglected. It can be noted that in the EN14511-3 test standard, the impact of these heat losses is normally included.

Adjusting cooling capacity for the impact of air infiltration and of duct heat losses

Consequently, DOE proposed to modify the cooling capacity measurement in US industry standards (direct air enthalpy method) by computing the impact of duct heat losses and infiltrations. The following corrections are described in detail in the final rule test procedure for portable air conditioners published in the USA Federal Register[30]. The method proposed was checked against calorimeter tests and enabled to reach a satisfying agreement.

Standard test conditions

This standard test conditions are adapted from existing US industry standards.

Table 19: USA portable air conditioners final test method: standard test conditions

Test Configuration	Evaporator Inlet Air, °F (°C)		Condenser Inlet Air, °F (°C)	
	Dry Bulb	Wet Bulb	Dry Bulb	Wet Bulb
3 (Dual-Duct, Condition A)	80 (26.7)	67 (19.4)	95 (35)	75 (23.9)
3 (Dual-Duct, Condition B)	80 (26.7)	67 (19.4)	83 (28.3)	67.5 (19.7)
5 (Single-Duct)	80 (26.7)	67 (19.4)	80 (26.7)	67 (19.4)

[28] USDOE, Notice of Data Availability (NODA), May 2014, rulemaking docket EERE-2013-BT-STD-0033.
[29] USDOE, Notice of Data Availability (NODA), May 2014, rulemaking docket EERE-2013-BT-STD-0033.
[30] USA Federal Register, Vol 81, No. 105, Wednesday June 1, 2016 (with correction published in October 2016)

Adjusted cooling capacities

Cooling capacities obtained by the air enthalpy method are adjusted from air infiltration and duct heat losses, which are calculated according to variables measured during the tests as shown below. Adjusted cooling capacity is computed as follows:

For single-duct portable air conditioners:

$$ACC_{95} = Capacity_{SD} - Q_{duct_SD} - Q_{infiltration_95}$$

For dual-duct portable air conditioners:

$$ACC_{95} = Capacity_{95} - Q_{duct_95} - Q_{infiltration_95}$$

$$ACC_{83} = Capacity_{83} - Q_{duct_83} - Q_{infiltration_83}$$

Where:

- $Capacity_{SD}$, $Capacity_{95}$, and $Capacity_{83}$ = cooling capacity measured in standard test conditions.
- Q_{duct_SD}, Q_{duct_95}, and Q_{duct_83} = duct heat transfer while operating in cooling mode, see calculation below.
- $Q_{infiltration_95}$ and $Q_{infiltration_83}$ = total infiltration air heat transfer in cooling mode, see calculation below.

Duct heat losses

For single duct air conditioners:

$$Q_{duct_{SD}} = h \times A_{duct_j} \times (T_{duct_SD_j} - T_{ei})$$

with:

- Q_{duct_SD} = for single-duct portable air conditioners, the total heat transferred from the duct to the indoor conditioned space in cooling mode when tested according to the standard test conditions, in Btu/h
- h = convection coefficient, 3 Btu/h per square foot per °F (17 $W.m^{-2}.K^{-1}$)
- $T_{duct_SD_j}$= average surface temperature for the condenser exhaust duct of single-duct portable air conditioners, as measured during testing according to the standard test conditions, in °F
- T_{ei}= average evaporator inlet air dry-bulb temperature, in °F.
- A_{duct_j} = π x d_j x L_j (with d_j the outer diameter of duct "j", including any manufacturer-supplied insulation and L_j its length)

For double duct units, the same calculation is applied, taking into account the two ducts and the different duct temperatures for the two outdoor conditions as follows:

$$Q_{duct_95} = \sum_j \{h \times A_{duct_j} \times (T_{duct_95_j} - T_{ei})\}$$

$$Q_{duct_83} = \sum_j \{h \times A_{duct_j} \times (T_{duct_83_j} - T_{ei})\}$$

With Q_{duct_95} and Q_{duct_83} = for dual-duct portable air conditioners, the total heat transferred from the ducts to the indoor conditioned space in cooling mode, in Btu/h, when tested

according to the 95 °F dry-bulb and 83 °F dry-bulb outdoor standard test conditions, respectively.

Air infiltration

The total heat contribution of the infiltration air is the sum of the sensible and latent heat (in Btu/h):

$$Q_{infiltration_95} = Q_{s_95} + Q_{l_95}$$

$$Q_{infiltration_83} = Q_{s_83} + Q_{l_83}$$

The sensible component of infiltration air heat contribution is computed as (in Btu/h):

$$Q_{S_95} = \dot{m} \times 60 \times \left[\left(c_{p_{da}} \times \left(T_{ia_95} - T_{indoor}\right)\right) + c_{p_wv} \times \left(w_{ia_95} \times T_{ia_95} - w_{indoor} \times T_{indoor}\right)\right]$$

$$Q_{S_83} = \dot{m} \times 60 \times \left[\left(c_{p_{da}} \times \left(T_{ia_83} - T_{indoor}\right)\right) + c_{p_wv} \times \left(w_{ia_83} \times T_{ia_83} - w_{indoor} \times T_{indoor}\right)\right]$$

The latent component of infiltration air heat contribution is computed as (in Btu/h):

$$Q_{l_95} = \dot{m} \times 60 \times H_{fg} \times \left(w_{ia_95} - w_{indoor}\right)$$

$$Q_{l_83} = \dot{m} \times 60 \times H_{83} \times \left(w_{ia_95} - w_{indoor}\right)$$

The notations are as follows:

- $\dot{m}$= dry air mass flow rate of infiltration air in lb/m. It is the measured condenser mass flow for single duct air conditioners and the difference between condenser inlet and outlet air flows for double duct air conditioners.
- c_{p_da}= specific heat of dry air, 0.24 Btu/lb $_m$ − °F.
- C_{p_wv}= specific heat of water vapor, 0.444 Btu/lb $_m$ − °F.
- T_{ai_95}, T_{ai_83}= infiltration air dry-bulb temperatures, 95 °F and 83 °F, respectively.
- T_{indoor}= indoor chamber dry-bulb temperature, 80 °F.
- w_{indoor}= humidity ratio of the indoor chamber air, 0.0112 lb $_w$/lb $_{da}$.
- H_{fg}= latent heat of vaporization for water vapor, 1061 Btu/lb $_m$.
- w_{ia_95}, w_{ia_83}= humidity ratios of the 95 °F and 83 °F dry-bulb infiltration air, 0.0141 and 0.01086 lb $_w$/lb $_{da}$, respectively.
- *60* = conversion factor from minutes to hours.

Seasonal calculation metrics

SACC - Seasonally Adjusted Cooling Capacity.

$$SACC = ACC_{95} \times 0.2 + ACC_{83} \times 0.8$$

Where:

- ACC_{95} *and* ACC_{83} = adjusted cooling capacity, in Btu/h, calculated above.
- *0.2* = weighting factor for ACC_{95}.
- *0.8* = weighting factor for ACC_{83}.

Calculation of annual energy consumption

$$AEC_m = P_m \times t_m \times k$$

$$AEC_T = \sum_m AEC_m$$

Where:

- AEC_m= Annual energy consumption in each operating mode (except active mode, i.e. cooling) expressed in kilowatt-hours per year (kWh/year).
- AEC_T= Total annual energy consumption in all modes except cooling (i.e. active mode),
- P_m= Average power in each mode, in watts.
- *m*= Represents the operating mode ("95" and "83" cooling mode at the 95 °F and 83 °F dry-bulb outdoor conditions, respectively for dual-duct portable air conditioners, "SD" cooling mode for single-duct portable air conditioners, "oc" off-cycle, and "ia" inactive or "om" off mode)[31].
- *t*= number of annual operating time in each mode, in hours.
- *K*= 0.001 kWh/Wh conversion factor from watt-hours to kilowatt-hours.

The following annual hours of operation for each mode are given below:

Table 20: USA portable air conditioners: hours to compute energy consumption

Operating Mode	Annual Operating Hours
Cooling Mode, Dual-Duct 95 °F1	750
Cooling Mode, Dual-Duct 83 °F1	750
Cooling Mode, Single-Duct	750
Off-Cycle	880
Inactive or Off	1,355

[1]: these operating mode hours are for the purposes of calculating annual energy consumption under different ambient conditions for dual-duct portable air conditioners, and are not a division of the total cooling mode operating hours. The total dual-duct cooling mode operating hours are 750 hours.

Note: hours of operation are similar to the hours of operation used for room air conditioners (window air conditioners, through the wall air conditioners) in the USA. DOE explains this choice based upon the results of field measurements on the energy consumption of portable air conditioners in residential and commercial premises[32]. In this report, correlations for time of use in different modes against outdoor temperature are derived from field measurement. These correlations could be used to build an ad-hoc EU metrics, in absence of other data.

Calculation of seasonal performance metrics – CEER

$$CEER_{SD} = \left[\frac{(ACC_{95} \times 0.2 + ACC_{83} \times 0.8)}{\left(\frac{AEC_{SD} + AEC_T}{k \times t}\right)}\right]$$

[31] Note that off cycle mode corresponds to thermostat off cycle mode in EN14825:2016 standard.
[32] T. Burke, et al., "Using Field-Metered Data to Quantify Annual Energy Use of Portable Air Conditioners," Lawrence Berkeley National Laboratory, Report No. LBNL–6868E-Rev (December 2014). Available at https://publications.lbl.gov/islandora/object/ir%3A6868E-Rev.

$$CEER_{DD} = \left[\frac{ACC_{95}}{\left(\frac{AEC_{95} + AEC_T}{k \times t}\right)}\right] \times 0.2 + \left[\frac{ACC_{83}}{\left(\frac{AEC_{83} + AEC_T}{k \times t}\right)}\right] \times 0.8$$

Where:

- $CEER_{SD}$ and $CEER_{DD}$= Combined energy efficiency ratio for single-duct and dual duct portable air conditioners, respectively, in Btu/Wh.
- ACC_{95} and ACC_{83}= Adjusted cooling capacity, tested at the 95 °F and 83 °F dry-bulb outdoor conditions, in Btu/h, see calculation above.
- AEC_{SD}= annual energy consumption in cooling mode for single-duct portable air conditioners, in kWh/year, see calculation above.
- AEC_{95} and AEC_{83}= Annual energy consumption for the two cooling mode test conditions, see calculation above.
- AEC_T= Total annual energy consumption attributed to all modes except cooling, in kWh/year, see calculation above.
- *t*= Number of cooling mode hours per year, 750.
- *k*= 0.001 kWh/Wh conversion factor for watt-hours to kilowatt-hours.
- *0.2*= Weighting factor for the 95 °F dry-bulb outdoor condition test.
- *0.8*= Weighting factor for the 83 °F dry-bulb outdoor condition test.

1.2.2 Energy performance for secondary functions of air conditioners

"Air movement" functionality of air conditioners is not rated. It would not be a difficult measurement to be added to EN14511 standard, air flow measurement and associated power consumption only are required in order to establish the delivered air flow and service value as for comfort fans.

Dehumidification of air conditioners is rated in EN14511 standard in cooling standard rating conditions using the sensible to heat ratio (SHR). However, there is no standard to rate the dehumidification capability of air conditioner secondary function (when working in separate dehumidification mode). Such rating conditions and test methods could be derived from dehumidifier standard EN 810 described below.

EN810:1997 Dehumidifiers with electrically driven compressors — Rating tests, marking, operational requirements and technical data sheet

This standard only applies to dehumidification using vapor compression cycle with electric compressor; however it does not apply to variable capacity units.

Performance indicator is the dehumidification capacity, in $L.h^{-1}$. Energy efficiency is rated via the dehumidifcation efficiency, the ratio of dehumidification capacity to power consumed, in $L.h^{-1}.W^{-1}$.

Rating conditions are for outdoor air and recycled air 27/21 (dry bulb/wet bulb).

1.2.3 Noise standards

EN 12102:2013 Air conditioners, liquid chilling packages, heat pumps and dehumidifiers with electrically driven compressors for space heating and cooling — Measurement of airborne noise — Determination of the sound power level. The standard EN 12102 defines the testing methods and conditions of operation to measure the sound power level of air conditioners.

This is the harmonised standard for sound power level measurement in regulations 206/2012 and 206/2011.

'Sound power level' means the A-weighted sound power level [dB(A)] indoors and/or outdoors measured at standard rating conditions, which are standard rating conditions defined in EN14511 and EN15218 standards. The standard defines indoor and outdoor measurement, which are differentiated as follows:

L_{Wi}: sound power level radiated by the indoor side.
L_{Wo}: sound power level radiated by the outdoor side.

In addition, for ducted units, it is noted that the 'attended value' (supposedly also used for compliance with regulations 206/2012 and 206/2011) is the sound power level travelling into the duct, which is measured indirectly: 'it is assessed from the sound power level radiated by the air outlet opening of the duct, corrected by the "duct end correction" factor E (method to determine the factor depends on the installation feature and operating conditions).

Hence, the standard also defines indoor and outdoor values for ducted units, which are noted as:

- For the case of a ducted indoor side of a split unit:
  - L_{Wdi} = sound power level travelling into the (discharge or suction) duct of indoor unit.
- For the case of a ducted unit on the outdoor side:
  - L_{Wdo} = sound power travelling into the (discharge or suction) duct of outdoor unit."

It is also to be noted that there are no test conditions referred to in this standard so that, if not defined in other standards, test conditions for sound power should be clearly specified in any regulation.

A draft version of this standard (prEN12102-2016) has been submitted for approval with no major change identified. According to convenor of CEN TC 113 / WG8, this standard could include rating conditions in the future. In order to link SCOP value and sound power measurement in heating mode, it is planned to use the point C in heating mode (outdoor air 7 °C / indoor air 20 °C / capacity 50 %) in order to rate the sound power level of air conditioners in heating mode. This is to be taken into account in any future regulation.

EN 60704-2-7 Household and similar electrical appliances – Test code for the determination of airborne acoustical noise (1997). Part 2. This standard describes the determination of the noise emission of household fans in normal operation at maximum speed. This standard applies to table fans, pedestal fans, ceiling fans and partition fans.

This is the test standard indicated in transitional test methods for comfort fans in European Commission communication C172/1[33].

[33] http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52012XC0616(05)&from=FR

1.2.4 Refrigerant standards

EN 378:2016 – Refrigerating systems and heat pumps — Safety and environmental requirements. The standard EN 378 (2012 version) has been reviewed to consider particularly new regulations (such as Regulation (EU) No 517/2014) and new refrigerants now available on the European market. This standard has been released in November 2016, with implementation planned at latest on May 31, 2017.

This standard covers all the equipment of refrigeration, air-conditioning and heat pumps except vehicle air conditioning systems. It specifies the requirements for the safety of persons and property, provides guidance for the protection of the environment and establishes procedures for the operation, maintenance and repair of refrigerating systems including the recovery of refrigerants.

- Part 1 specifies the classification and selection criteria applicable to refrigerating systems. The safety of refrigerant fluids is classified based on their toxicity and flammability. Safety requirements for installations depend on the fluid used, the system type (direct vs indirect) and on the location of the system (in an occupied space or in a machine room). Annex E specifies criteria for safety and environmental considerations of different refrigerants used in refrigeration and air conditioning.
- Part 2 is applicable to the design, construction and installation of refrigerating systems including piping, components, and materials. It also specifies requirements for testing, commissioning, marking and documentation. The following annexes explain the link between the EU directives applying to these products and the EN378 standard: Annex ZA (informative) Relationship between this European Standard and the Essential Requirements of EU Directive 2014/68/EC on pressure equipment; Annex ZB (informative) Relationship between this European Standard and the Essential Requirements of EU Directive 2006/42/EC on machinery.
- Part 3 is applicable to the installation site. It specifies requirements on the site for safety, which may be needed because of, but not directly connected with, the refrigerating system and its ancillary components.
- Part 4 specifies requirements for safety and environmental aspects in relation to operation, maintenance, and repair of refrigerating systems and the recovery, reuse and disposal of all types of refrigerant, refrigerant oil, heat-transfer fluid, refrigerating system and part thereof. These requirements are intended to minimise risks of injury to persons and damage to property and the environment resulting from improper handling of the refrigerants or from contaminants leading to system breakdown and resultant emissions of refrigerant.

This standard is applicable to new refrigerating systems but also in the case of the conversion of a system to another refrigerant.

To notice:

- GWP values are given by regulation (EU) No 517/2014 which uses data from 4th Assessment report of IPCC.
- HFO are included in part 1 - annex E as well as new refrigerants referenced by ASHRAE 34 standard[34].
- A2L and B2L classes are introduced in this standard as intermediate levels between A1/B1 and A2/B2 in accordance with ISO 817 :2014 refrigerants – Designation and

[34] ANSI/ASHRAE 34, *Designation and Safety Classification of Refrigerants.* Latest version: 2016.

safety classification. Hydrocarbons such as R-290 are A3 refrigerants. Many HFC-HFO blends with GWP lower than 700 are classified A2L as well as R-1234yf and R-1234ze refrigerant fluids.

EN 16084:2011 - Refrigerating systems and heat pumps - Qualification of tightness of components and joints. "This European Standard is intended to describe the qualification procedure for type approval of the tightness of hermetically sealed and closed components, joints and parts used in refrigerating systems and heat pumps as described in EN 378. The sealed and closed components, joints and parts concerned are, in particular, fittings, bursting discs, flanged or fitted assemblies. The tightness of flexible piping made from non-metallic materials is dealt with in EN 1736. This standard cover metal flexible piping. The requirements contained in this document are applicable to joints of maximum DN 50 and components of internal volume of maximum 5 l and maximum weight of 50 kg. This document is intended to characterise their tightness stresses met during their operations, following the fitting procedure specified by the manufacturer, and to specify the minimal list of necessary information to be provided by the supplier of a component to the person in charge of carrying out this procedure. It specifies the level of tightness of the component, as a whole, and its assembly as specified by its manufacturer. It applies to the hermetically sealed and closed components, joints and parts used in the refrigerating installations, including those with seals, whatever their material and their design are. This European Standard specifies additional requirements for mechanical joints that can be recognised as hermetically sealed joints."[35]

EN 60355-2-40 - Safety of electric heat pumps - covers sanitary hot water heat pumps, air-conditioners, and dehumidifiers incorporating motor-compressors and hydronic room fan coils, their maximum rated voltages being not more than 250 V for single phase appliances and 600 V for all other appliances. This standard also applies to electric heat pumps, air conditioners and dehumidifiers containing flammable refrigerant. The standard establishes the requirements regarding safety of persons and objects. Furthermore, it provides guidance for environmental protection, and establishes procedures for the operation, maintenance and repair of refrigeration systems and the recovery of refrigerants.

This standard also sets requirements for refrigerant charge sizes which might influence the efficiency of air conditioners. Although this is only a standard (so used on a voluntary basis and not legally binding), it is seen by manufacturers as mandatory in particular regarding the safety part. According to (Schleicher et al., 2017)[36], this standard and planned next revision does not allow propane split air conditioners to reach A+++ SEER level. Delonghi reports that this also limits the production of A++ single duct using propane with higher than 2.5 kW. In these conditions, the development of propane and other A3 refrigerants is not ready to start in Europe in the coming years.

EN 14624:2012 - Performance of portable leak detectors and of room monitors for halogenated refrigerants "The purpose of this European Standard is to qualify the performance of portable sniffing leak detectors and room monitors for halogenated refrigerants. These leak detectors are designed for the detection of CFC, HCFC, HFC and

[35] https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT:34680&cs=13FA5F7AB092D02583186A3C19D691C58

[36] Tobias Schleicher, Jonathan Heubes, Ran Liu, Pascal Radermacher, Jens Gröger. The Blue Angel for Stationary Room Air Conditioners – a national eco-label with international impact, Final Draft of the technical Background Report for German Federal Environment Agency. Freiburg, June 2017.

PFC halogenated gases, and their detection limit is checked with a calibration leak or calibration gas."[37]

The lowest sensitivity threshold of these detectors should be of 5000 ppm (threshold when the leak detector is moving), which corresponds to about 3 g/y leakage for R134a, 2.1 g/y for R410A and 1.5 g/y for R32. It gives an indirect evaluation of the best precision that can be achieved during leakage tests performed on installed units (at installation or maintenance time).

1.2.5 WEEE and RoHS standards

ISO 11469:2016 - Plastics - Generic identification and marking of plastics products
The EN ISO 11469 standard identifies specifies a system of uniform plastic material marking system. The standard does not cover every aspect of marking (e.g. the marking process, the minimum size of the item to be marked, the size of the lettering or the appropriate location of the marking) but the marking system described is intended to help identify plastics products for subsequent decisions concerning handling, waste recovery or disposal. The standard refers to ISO 1043-1 for generic identification of the plastics.

EN ISO 1043-2:2011 - Plastics. Symbols and abbreviated terms. Fillers and reinforcing materials. The EN ISO 1043 standard defines abbreviated terms for the basic polymers used in plastics, symbols for components of these terms, and symbols for special characteristics of plastics.

IEC TR 62635:2012 - Guidelines for end-of-life information provided by manufacturers and recyclers and for recyclability rate calculation of electrical and electronic equipment
IEC/TR 62635:2012(E) provides a methodology for information exchange involving electronic and electrical equipment manufacturers and recyclers. The standard also provides a methodology enabling calculation of the recyclability and recoverability rates of to facilitate optimized end of life treatment operations.

EN 50419:2006 - Marking of electrical and electronic equipment in accordance with Article 11(2) of Directive 2002/96/EC (WEEE)
EN 50419 contains the product marking requirements needed to ensure compliance with the WEEE Directive. EN 50419 also contains additional information relating to the marking requirements, including positioning, visibility, dimensions, location and referenced documents. The marking requirements are applicable to all manufacturers and producers of electrical and electronic equipment placing products on the EU market.

EN 50625-1:2014 Collection, logistics & treatment requirements for WEEE - Part 1: General treatment requirements
EN 50625 was prepared as part of a series of standards requested in Commission mandate 518 (detailed in section 3.2) which aim to support implementation and effectiveness of Directive 2012/19/EU (WEEE). The standard contains requirements applicable to the treatment of all types of WEEE and addresses all operators involved in the treatment (including related handling, sorting, and storage) of WEEE. In particular, the standard addresses the following issue areas:

- Management principles

[37] https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT:28179&cs=1A51FA1204B81FECC2DB08458FA65628A

    - Technical and infrastructural pre-conditions
    - Training
    - Monitoring
    - Shipments
- Technical requirements
    - General
    - Receiving of WEEE at treatment facility
    - Handling of WEEE
    - Storage of WEEE prior to treatment
    - De-pollution (including Annex A normative requirements)
    - De-pollution monitoring (including Annex B normative requirements)
    - Treatment of non de-polluted WEEE and fractions
    - Storage of fractions
    - Recycling and recovery targets (including Annex C & D normative requirements)
    - Recovery and disposal of fractions
- Documentation

The standard applies to the treatment of WEEE until end-of-waste status is fulfilled, or until the WEEE is prepared for re-use, recycled, recovered, or final disposal.

EN 50574 - on the collection, logistics & treatment requirements for end-of-life household appliances containing volatile fluorocarbons or volatile hydrocarbons.

EN 62321 series - Determination of certain substances in electrotechnical products
The purpose of the harmonized EN 62321/IEC 62321 series of standards is to provide test methods that will allow determination of the levels of certain substances of concern in electrotechnical products on a consistent global basis.

EN 50581:2012 - Technical documentation for the evaluation of electrical and electronic products with respect to restriction of hazardous substances
The EN 50581 standard specifies the technical documentation a producer of EEE has to collect for applicable substance restrictions in order to demonstrate compliance with Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS). The technical documentation required to meet the standard includes:

- A general product description
- Documentation of materials, parts and/or sub-assemblies
- Information showing the relationship between the technical documents and respective materials, parts and/or sub-assemblies
- A list of harmonized standards and/or technical specifications used to prepare the technical documents.

1.2.6 Mandates issued by the EC to the European Standardization Organizations

M488 - Mandate to CEN, CENELEC and ETSI for standardisation in the field of air conditioners and comfort fans
This mandate supported the development of harmonised standards regarding regulation 626/2011 and 206/2012 for air conditioners and fans.

M544 – Standardisation mandate to the European standardisation organisations as regards ecodesign requirements for networked standby in support of Regulation (EC) No 1275/2008 and Regulation (EC) No 642/2009

This mandate should allow the introduction of network standby in a future revision of the standard EN50564:2011. Networked air conditioners are common today and if standby and off mode are still defined, in the future, in air conditioner standards EN14511, EN15218 and EN14825, these should be adapted to include corresponding evolutions. Today, it is not clear whether network standby is taken into account or not in the standby measurement tests for air conditioners.

If networked standby is to be taken into account then air conditioners fits the definition of edge equipment in the draft version prEN 50643 which is: **Edge equipment** is networked equipment that can be connected to a network and interact with that network or other equipment and that does not have, as its primary function, the passing of network traffic to provide a network.

Regarding networked standby there are some useful definitions from the regulation (EU) No 801/2013 amending regulation (EC) No 1275/2008[38]:

Network means a communication infrastructure with a topology of links, an architecture, including the physical components, organisational principles, communication procedures and formats (protocols).

Networked equipment means equipment that can connect to a network and has one or more network ports

Networked standby means a condition in which the equipment is able to resume a function by way of a remotely initiated trigger from a network connection;

M543 – Material Efficiency

In December 2015, the EC published a standardisation request to the European standardisation organisations (ESO's) covering ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC.[39] It was noted in the mandate, that the absence of adequate metrics is one of the reasons for the relative lack of ecodesign requirements related to material efficiency in previous ecodesign implementing measures. The mandate therefore requests that the ESOs draft new European standards and European standardisation deliverables on material efficiency aspects for energy-related products in support of the ecodesign Directive 2009/125/EC. This standardisation request clarifies that the following material efficiency aspects should be covered:

- Extending product lifetime.
- Ability to re-use components or recycle materials from products at end-of-life.
- Use of re-used components and/or recycled materials in products

[38] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R1275-20170109&from=EN
[39] European Commission Mandate 543 on Material Efficiency, available from http://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=564

1.3 Legislation

Air conditioners and comfort fans are currently covered by a number of pieces of legislation, both within the EU and third party countries, which attempt to address the environmental impacts of these products through mandatory measures.

1.3.1 EU legislation

There are several pieces of environmental legislation which either directly or indirectly address products within the scope of this review project.

EU Directive 2009/125/EC - Ecodesign for Energy-Related Products [40]

The Ecodesign Directive provides consistent EU-wide rules for improving the environmental performance of products placed on the EU market. This EU wide approach ensures that Member States' national regulations are aligned so that potential barriers to intra-EU trade are removed.

The Directive's main aim is to provide a framework for reducing the environmental impacts of products throughout their entire life cycle. As many of the environmental impacts associated with products are determined during the design phase, the ecodesign Directive aims to bring about improvements in environmental performance through mandating changes at the product design stage.

The Ecodesign Directive is a framework directive, meaning that it does not directly set minimum requirements rather the aims of the Directive are implemented through product-specific Regulations, which are directly applicable in all EU member states. For a product to be covered by under the Ecodesign Directive it needs to meet the following criteria:

- have a volume of sales that exceeds 200,000 units per year throughout the internal European market
- have a significant environmental impact within the internal market
- present significant potential for improvement in environmental impact without incurring excessive costs

EU Regulation 206/2012/EU - Ecodesign Requirements for air conditioners and comfort fans[41]

The European Commission published Commission Regulation (EU) No 206/2012 implementing ecodesign requirement measures for air conditioners and comfort fans. The Regulation includes:

- Requirements on the energy efficiency for all air conditioners in scope
- Requirements on maximum energy consumption in off mode and standby mode including power management demand for single duct, double duct and comfort fans
- Requirements for maximum sound power level for all air conditioner types in scope
- Information requirements for both air conditioners and comfort fans

The Regulation applies to:

- electric mains-operated air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating if the product has no cooling function, and comfort fans with an electric fan power input ≤ 125W.

[40] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0125&from=EN
[41] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:072:0007:0027:en:PDF

The minimum efficiency requirements are:

Table 21: Regulation 206/2012 - minimum efficiency requirements

	Air conditioners, except double and single duct air conditioners		**Double duct airconditioners**		**Single duct air conditioners**	
	SEER	SCOP (heating season: Average)	EER rated	COP rated	EER rated	COP rated
If GWP of refrigerant > 150 for < 6 kW	4.60	3.80	2.60	2.60	2.60	2.04
If GWP of refrigerant ≤ 150 for < 6 kW	4.14	3.42	2.34	2.34	2.34	1.84
If GWP of refrigerant > 150 for 6-12 kW	4.30	3.80	2.60	2.60	2.60	2.04
If GWP of refrigerant ≤ 150 for 6-12 kW	3.87	3.42	2.34	2.34	2.34	1.84

The requirements for maximum power consumption in off-mode and standby mode for single duct air conditioners, double duct air conditioners and comfort fans are:

Table 22: Regulation 206/2012- The requirements for maximum power consumption in off-mode and standby

Mode	Description
Off mode	Power consumption of equipment in any off-mode condition shall not exceed 0.50 W.
Standby mode	The power consumption of equipment in any condition providing only a reactivation function, or providing only a reactivation function and a mere indication of enabled reactivation function, shall not exceed 0.50 W.
	The power consumption of equipment in any condition providing only information or status display, or providing only a combination of reactivation function and information or status display shall not exceed 1.00 W.
Availability of standby and/or off mode	Equipment shall, except where this is inappropriate for the intended use, provide off mode and/or standby mode, and/or another condition which does not exceed the applicable power consumption requirements for off mode and/or standby mode when the equipment is connected to the mains power source.
Power management	When equipment is not providing the main function, or when other energy- using product(s) are not dependent on its functions, equipment shall, unless inappropriate for the intended use, offer a power management function, or a similar function, that switches equipment after the shortest possible period of time appropriate for the intended use of the equipment, automatically into: • standby mode, or • off mode, or • another condition which does not exceed the applicable power consumption requirements for off mode and/or standby mode when the equipment is connected to the mains power source. The power management function shall be activated before delivery.

The maximum requirements for sound power level of air conditioners are dependent on the rated capacity. The requirements are shown in Table 23. It is to be noted that for ducted air conditioners, the sound power should be measured in-duct. In addition, these values are dependent on the rating conditions which refer to standard rating conditions in the Regulation. Requirements should be adapted if the sound power rating conditions vary in the future.

Table 23: Requirements for maximum sound power level of air conditioners

Rated capacity ≤ 6 kW		6 < Rated capacity ≤12 kW	
Indoor sound power level in dB(A)	Outdoor sound power level in dB(A)	Indoor sound power level in dB(A)	Outdoor sound power level in dB(A)
60	65	65	70

Besides the above-mentioned requirements also requirements concerning product information are set out in the regulation. The information requirements for air conditioners, except double duct and single duct air conditioners are shown in Table 24.

Table 24: Information requirements for air conditioners, except double duct and single duct air conditioners

Function (indicate if present)				**If function includes heating: Indicate the heating season the information relates to. Indicated values should relate to one heating season at a time. Include at least the heating season 'Average'.**			
cooling	Y/N			Average (mandatory)	Y/N		
heating	Y/N			Warmer (if designated)	Y/N		
				Colder (if designated)	Y/N		
Item	symbol	value	unit	Item	symbol	value	unit
Design load				Seasonal efficiency			
cooling	Pdesignc	x.x	kW	cooling	SEER	x.x	—
heating/Average	Pdesignh	x.x	kW	heating/Average	SCOP/A	x.x	—
heating/Warmer	Pdesignh	x.x	kW	heating/Warmer	SCOP/W	x.x	—
heating/Colder	Pdesignh	x.x	kW	heating/Colder	SCOP/C	x.x	—
Declared capacity (*) for cooling, at indoor temperature 27(19) °C and outdoor temperature Tj				Declared energy efficiency ratio (*), at indoor temperature 27(19) °C and outdoor temperature Tj			
Tj = 35 °C	Pdc	x.x	kW	Tj = 35 °C	EERd	x.x	—
Tj = 30 °C	Pdc	x.x	kW	Tj = 30 °C	EERd	x.x	—
Tj = 25 °C	Pdc	x.x	kW	Tj = 25 °C	EERd	x.x	—
Tj = 20 °C	Pdc	x.x	kW	Tj = 20 °C	EERd	x.x	—
Declared capacity (*) for heating/Average season, at indoor temperature 20 °C and outdoor temperature Tj				Declared coefficient of performance (*)/Average season, at indoor temperature 20 °C and outdoor temperature Tj			
Tj = – 7 °C	Pdh	x.x	kW	Tj = – 7 °C	COPd	x.x	—
Tj = 2 °C	Pdh	x.x	kW	Tj = 2 °C	COPd	x.x	—
Tj = 7 °C	Pdh	x.x	kW	Tj = 7 °C	COPd	x.x	—
Tj = 12 °C	Pdh	x.x	kW	Tj = 12 °C	COPd	x.x	—
Tj = bivalent temperature	Pdh	x.x	kW	Tj = bivalent temperature	COPd	x.x	—
Tj = operating limit	Pdh	x.x	kW	Tj = operating limit	COPd	x.x	—
Declared capacity (*) for heating/Warmer season, at indoor temperature 20 °C and outdoor temperature Tj				Declared coefficient of performance (*)/Warmer season, at indoor temperature 20 °C and outdoor temperature Tj			
Tj = 2 °C	Pdh	x.x	kW	Tj = 2 °C	COPd	x.x	—
Tj = 7 °C	Pdh	x.x	kW	Tj = 7 °C	COPd	x.x	—
Tj = 12 °C	Pdh	x.x	kW	Tj = 12 °C	COPd	x.x	—
Tj = bivalent temperature	Pdh	x.x	kW	Tj = bivalent temperature	COPd	x.x	—

Tj = operating limit	Pdh	x.x	kW	Tj = operating limit	COPd	x.x	—
Declared capacity (*) for heating/Colder season, at indoor temperature 20 °C and outdoor temperature Tj				Declared coefficient of performance (*)/Colder season, at indoor temperature 20 °C and outdoor temperature Tj			
Tj = – 7 °C	Pdh	x.x	kW	Tj = – 7 °C	COPd	x.x	—
Tj = 2 °C	Pdh	x.x	kW	Tj = 2 °C	COPd	x.x	—
Tj = 7 °C	Pdh	x.x	kW	Tj = 7 °C	COPd	x.x	—
Tj = 12 °C	Pdh	x.x	kW	Tj = 12 °C	COPd	x.x	—
Tj = bivalent temperature	Pdh	x.x	kW	Tj = bivalent temperature	COPd	x.x	—
Tj = operating limit	Pdh	x.x	kW	Tj = operating limit	COPd	x.x	—
Tj = – 15 °C	Pdh	x.x	kW	Tj = – 15 °C	COPd	x.x	—
Bivalent temperature				Operating limit temperature			
heating/Average	Tbiv	x	°C	heating/Average	Tol	x	°C
heating/Warmer	Tbiv	x	°C	heating/Warmer	Tol	x	°C
heating/Colder	Tbiv	x	°C	heating/Colder	Tol	x	°C
Cycling interval capacity				Cycling interval efficiency			
for cooling	Pcycc	x.x	kW	for cooling	EERcyc	x.x	—
for heating	Pcych	x.x	kW	for heating	COPcyc	x.x	—
Degradation co-efficient cooling (**)	Cdc	x.x	—	Degradation co-efficient heating (**)	Cdh	x.x	—
Electric power input in power modes other than 'active mode'				Annual electricity consumption			
off mode	POFF	x.x	kW	cooling	QCE	x	kWh/a
standby mode	PSB	x.x	kW	heating/Average	QHE	x	kWh/a
thermostat-off mode	PTO[42]	x.x	kW	heating/Warmer	QHE	x	kWh/a
crankcase heater mode	PCK	x.x	kW	heating/Colder	QHE	x	kWh/a

[42] There are in fact two values for PTO, one in cooling mode and the other one in heating mode. It means that there could be 4 different set of values for power input in non active modes.

Capacity control (indicate one of three options)		Other items			
fixed	Y/N	Sound power level (indoor/outdoor)	LWA	x.x/x.x	dB(A)
staged	Y/N	Global warming potential	GWP	x	kgCO2 eq.
variable	Y/N	Rated air flow (indoor/outdoor)	—	x/x	m3/h
Contact details for obtaining more information	Name and address of the manufacturer or of its authorised representative.				

The information requirements for single duct and double duct air conditioners are shown in Table 25.

Table 25: Information requirements for single duct and double duct air conditioners.

Description	Symbol	Value	Unit
Rated capacity for cooling	Prated for cooling	[x.x]	kW
Rated capacity for heating	Prated for heating	[x.x]	kW
Rated power input for cooling	PEER	[x.x]	kW
Rated power input for heating	PCOP	[x.x]	kW
Rated Energy efficiency ratio	EERd	[x.x]	—
Rated Coefficient of performance	COPd	[x.x]	—
Power consumption in thermostat-off mode	PTO	[x.x]	W
Power consumption in standby mode	PSB	[x.x]	W
Electricity consumption of single/double duct appliances (indicate for cooling and heating separately)	DD: QDD SD: QSD	DD: [x] SD: [x.x]	DD: kWh/a SD: kWh/h
Sound power level	LWA	[x]	dB(A)
Global warming potential	GWP	[x]	kgCO2 eq.
Contact details for obtaining more information	Name and address of the manufacturer or of its authorised representative.		

Regarding information requirements, there is no information required on backup heater capacity so that the unit plus the backup heater may supply Pdesignh capacity at the Tdesign temperature. This information is required in Regulation (EU) no 813/2013 for air-to-water heat pumps. The reason is that for air-to-water heat pumps, an electric backup heater is commonly included in the heat pump or heat pump system, while no air-to-air heat pump manufacturer supplies additional backup inside the unit. As it was not included in air-to-air unit, information on backup heater was not included. However, this seems to create confusion according to comments received from stakeholders, Pdesignh is sometimes understood as the heat pump capacity, while in fact it highly depends on the choice of the bivalent temperature.

Keeping a variable bivalent temperature may be useful for the end-user (see Task 3 part 3.1.5 for more information). However, it is necessary to indicate additional backup heater capacity required to reach Pdesignh even if it is not included in the unit. So it is proposed

to require the following additional information requirement under the heading "backup heater":

- Required additional backup heater capacity: 3 values in kW to be supplied for warm / average/cold climates; this corresponds to the difference between Pdesignh for a specific climate and unit capacity of the unit at Tdesignh;

- Backup heater included in the unit: Yes or No (3 values for the 3 different climates).

The information requirements for comfort fans are shown in Table 26.

Table 26:Information requirements for comfort fans

Description	Symbol	Value	Unit
Maximum fan flow rate	F	[x.x]	m3/min
Fan power input	P	[x.x]	W
Service value	SV	[x.x]	(m3/min)/W
Standby power consumption	PSB	[x.x]	W
Fan sound power level	LWA	[x]	dB(A)
Maximum air velocity	c	[x.x]	meters/sec
Measurement standard for service value	[state here the reference to measurement standard used]		
Contact details for obtaining more information	Name and address of the manufacturer or of its authorised representative.		

Regarding information to enable the products to be tested, this Regulation requires that "*The manufacturer of air conditioners and comfort fans shall provide laboratories performing market surveillance checks, upon request, the necessary information on the setting of the unit as applied for the establishment of declared capacities, SEER/EER, SCOP/COP values and service values and provide contact information for obtaining such information.*" For inverter units, it means that SEER/SCOP performance indicators cannot be checked independently of the manufacturer/importer and some laboratories report that in some case it is not possible to get testing information via the contact indicated in the product fiche. It is thus proposed that testing information required to set up the machine to reach claimed values be indicated in the technical documentation of the product instead of being provided upon request or to include it in the compliance part of the EU label database (where it can only be accessed by market surveillance authorities). To make it mandatory in the product information would also help the development of competitive surveillance systems where manufacturers can check the claims of their competitors.

This regulation also defines the SEER and SCOP values for air conditioners and heat pumps, as well as their calculation. Regarding the calculation method, following input from test laboratories reported in the description of standard EN14825 paragraph 1.2.2, it is advised not to allow performance tests to measure cycling performance degradation coefficients Cdc and Cdh, but to use the default value 0.25 instead as there is no proof the value can be measured satisfactorily for inverter units.
In the future, SEER and SCOP values should be replaced by primary energy efficiency ratio in cooling and in heating mode following the example of more recent regulations (e.g. Regulation (EU) No 2281/2016).
In addition, there are small differences in the number of equivalent active mode hours for heating, when compared to Regulation (EU) No 813/2013. Harmonisation is to be studied,

keeping in mind that the destination (residential / commercial) of heating products in both regulations may differ.
Regarding low power modes, in the EN 14825:2016, the crankcase heater consumption is measured in test condition D in both heating and cooling mode, it means that for the average climate, there are two values for P_{CK}, and thus potentially also for P_{TO}, P_{SB} and P_{OFF}..
Above that, the impact of outdoor temperature on crankcase heating consumption is not accounted for presently while it is in ISO/FDIS 16358-1:2013. The impact and feasibility to include this variation in the calculation of SEER and SCOP value should be investigated; in ISO/FDIS 16358-1:2013, different hours are used for low power mode calculation (including cranckase heater), and this is to be compared with values in Regulation 206/2012; any change in the crankcase heater average power or in the number of hours should be done keeping in mind the total impact of crankcase heater on the final SEER / SCOP metrics. In addition, present regulation does not specify if network connection consumption is to be included in low power modes values (which reflects in present standard EN14511, EN15218 and EN14825).
For heating only units, the 12 kW threshold should be related to other than present standard rating conditions as these conditions are not used to compute SCOP values. It is suggested that the declared heating capacity of the unit refer to point A in heating mode for the average climate in standard EN14825:2016 (outdoor air temperature - 7°C).
It is also suggested that the test conditions to measure sound power level in heating mode are specified. The planned test conditions are heating mode point C in EN14825:2016 (outdoor air temperature + 7°C / declared capacity 50 %).

Lastly, crankcase heater mode and off mode hours have been updated in the test standards in EN14825 and therefore the relevant table in the Regulation should be updated accordingly.

EU Regulation – 626/2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners

The European Commission published Commission Regulation (EU) No 626/2011 implementing labelling requirement measures for air conditioners and requirements for the execution of the label itself. The Regulation applies to:

- electric mains-operated air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating, if the product has no cooling function.

This Regulation introduces two energy efficiency scales based on the primary function and on specific aspects important to consumer. Given that air conditioners are used mainly in part load conditions, the efficiency testing was changed to a seasonal efficiency measurement method, except for single and double duct air conditioners. The seasonal measurement method takes better into account the benefits of the inverter driven technology and the conditions in which these appliances are used. The new efficiency calculation method with an Ecodesign implementing measure setting minimum energy efficiency requirements higher than the current A level, will lead to a reclassification of these appliances. Consequently, split, window and wall air conditioners should have a new A-G energy efficiency class scale with a '+' added on the top of the scale every two years until the A+++ class has been reached.

For double duct and single duct air conditioners, steady-state energy efficiency performance indicators should continue to be applied, as there are currently no inverter units on the market. As no reclassification of these appliances is appropriate, single and double duct air conditioners should have an A+++-D scale. While these, inherently less efficient than split appliances, can go only up to an A++ energy efficiency class in a scale of A+++-D, the more efficient split appliances can reach up to the A+++ energy efficiency class.

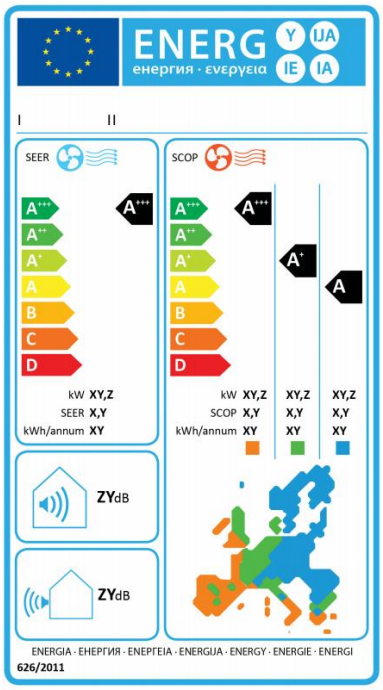


Figure 4: Example of an energy label for a reversible air conditioner

The energy efficiency classes are dependent on the type of air conditioner and the related SEER and SCOP. The Energy efficiency classes for air conditioners, except double ducts and single ducts are shown in Table 27.

Table 27: Regulation 626/2011 – Energy efficiency classes for air conditioners, except double ducts and single

Energy Efficiency Class	SEER	SCOP
A+++	SEER ≥ 8.50	SCOP ≥ 5.10
A++	6.10 ≤ SEER < 8.50	4.60 ≤ SCOP < 5.10
A+	5.60 ≤ SEER < 6.10	4.00 ≤ SCOP < 4.60
A	5.10 ≤ SEER < 5.60	3.40 ≤ SCOP < 4.00
B	4.60 ≤ SEER < 5.10	3.10 ≤ SCOP < 3.40
C	4.10 ≤ SEER < 4.60	2.80 ≤ SCOP < 3.10
D	3.60 ≤ SEER < 4.10	2.50 ≤ SCOP < 2.80
E	3.10 ≤ SEER < 3.60	2.20 ≤ SCOP < 2.50
F	2.60 ≤ SEER < 3.10	1.90 ≤ SCOP < 2.20
G	SEER < 2.60	SCOP < 1.90

The Energy efficiency classes for double ducts and single ducts are shown in Table 28.

Table 28: Regulation 626/2011 – Energy efficiency classes for double ducts and single ducts are

Class	Double ducts		Single ducts	
	EER rated	COP rated	EER rated	COP rated
A+++	≥ 4.10	≥ 4.60	≥ 4.10	≥ 3.60
A++	3.60 ≤ EER < 4.10	4.10 ≤ COP < 4.60	3.60 ≤ EER < 4.10	3.10 ≤ COP < 3.60
A+	3.10 ≤ EER < 3.60	3.60 ≤ COP < 4.10	3.10 ≤ EER < 3.60	2.60 ≤ COP < 3.10
A	2.60 ≤ EER < 3.10	3.10 ≤ COP < 3.60	2.60 ≤ EER < 3.10	2.30 ≤ COP < 2.60
B	2.40 ≤ EER < 2.60	2.60 ≤ COP < 3.10	2.40 ≤ EER < 2.60	2.00 ≤ COP < 2.30
C	2.10 ≤ EER < 2.40	2.40 ≤ COP < 2.60	2.10 ≤ EER < 2.40	1.80 ≤ COP < 2.00
D	1.80 ≤ EER < 2.10	2.00 ≤ COP < 2.40	1.80 ≤ EER < 2.10	1.60 ≤ COP < 1.80
E	1.60 ≤ EER < 1.80	1.80 ≤ COP < 2.00	1.60 ≤ EER < 1.80	1.40 ≤ COP < 1.60
F	1.40 ≤ EER < 1.60	1.60 ≤ COP < 1.80	1.40 ≤ EER < 1.60	1.20 ≤ COP < 1.40
G	< 1.40	< 1.60	< 1.40	< 1.20

In addition, to differentiate single duct air conditioners, it is specified in Article 3 (g) that: "single ducts shall be named 'local air conditioners' in packaging, product documentation and in any advertisement material, whether electronic or in paper." This distinction is supposed to advertise the end-users about the functionality of the air conditioners which is able to cool locally and also able to heat due to air infiltration. However, the "local air conditioner" term cannot be found in practice.

Hence, the only difference in information obtainable for end-users today between single duct air conditioners and standard split systems is the use of the EER versus the SEER on the label. However, the distinction between EER and SEER is not obvious to end-users and therefore it is unlikely that the end-users can differentiate the different types of air conditioners and understand that the energy efficiency scale and the principles of operations are different.

Thus, is it recommended to ensure the energy efficiency ratings of split and of single and double duct air conditioners are indeed comparable, or that the energy efficiency information is communicated to the end-user for these products (comparative label, information label, warnings, and so on) are explicitly two different product types.

Stakeholders have raised the questions about the appropriateness of the label in cold climates where they believe the label is almost unusable. Today the end user has to know the meaning of Pdesign to determine whether the air conditioner is useful. A possible solution could be:

- to publish together with the SCOP the capacity and efficiency of the heat pump and/or the capacity of the complementary heating required at Tdesign
- or capacity efficiency at Tbiv

Stakeholders of northern countries have also suggested to make it mandatory to show SCOP for cold climates on the energy label. This could be useful and possible since most manufactures have special models for cold climates.

Tolerances and uncertainties in Regulation 206/2012 and 626/2011

Ecodesign and Energy Labelling Regulations No 206/2012 and 626/2011 define tolerances regarding the measured efficiency value compared to the declared value by manufacturer as follows:

- 8 % on SEER and SCOP values for fixed air conditioners
- 10 % on EER and COP for portable air conditioners

For portable air conditioners, uncertainty of measurement in standard EN14825:2016 is of 10 %. Hence, for these products, both values are aligned, which is in agreement with Regulation (EU) 2282/2016[43] regarding tolerances: as tolerance is larger or equal than uncertainty of measurement, a value measured in a laboratory with minimum value according to uncertainty still fits in the tolerance limit fixed by the product regulation.

However, for fix air conditioners, uncertainties of measurement in EN14825:2016 have been set as follows:

- 5 % on EER and COP values for capacities measured that are higher than 2 kW
- 10 % for capacities between 1 and 2 kW
- 15 % for capacities below 1 kW
- And regarding standby/off mode, thermostat off and crankcase heater, 0.1 W for value measured up to 10 W and 1 % above

With individual EER/COP uncertainty levels, for certain products, the SEER and SCOP compound uncertainty is higher than regulation tolerances. The study team tested this hypothesis on real units of various sizes and efficiency levels. Declared values are real unit efficiency values. Capacities were decreased to the declared values minus maximum allowed uncertainty, and power consumed in standby/thermostat-off/crankcase was increased by maximum allowed uncertainty. Results are presented in Table 29 (problematic cases are highlighted in red).

[43] http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1490878675216&uri=CELEX:32016R2282

Table 29: Impact of maximum uncertainty level according to EN14825:2016 standard on SEER and SCOP declared values

	Unit	Indicator	SEER/SCOP	SEER/SCOP w uncertainties	Variation %
1.7 kW	1	SEER	5.70	5.10	-12.30%
		SCOP	4	3.5	-13.80%
2.5 kW	2	SEER	10.5	9.5	-10.30%
		SCOP	5.2	4.8	-9.00%
	3	SEER	7.8	7.1	-10.40%
		SCOP	4.6	4.2	-10.50%
3.5 kW	4	SEER	6.1	5.6	-8.20%
		SCOP	3.8	3.4	-10.80%
	5	SEER	6.5	6.1	-6.70%
		SCOP	4	3.7	-9.30%
	6	SEER	6.1	5.6	-8.70%
		SCOP	3.8	3.5	-9.40%
	7	SEER	7.8	7.2	-8.10%
		SCOP	4.6	4.2	-9.30%
	8	SEER	8.5	7.8	-9.00%
		SCOP	4.6	4.2	-11.50%
	9	SEER	10	9.2	-8.80%
		SCOP	5.9	5.4	-9.30%
5 kW	10	SEER	6.3	5.9	-6.00%
		SCOP	4	3.7	-9.20%
	11	SEER	6	5.7	-6.20%
		SCOP	4.3	3.9	-9.00%
7.1 kW	12	SEER	6.1	5.7	-6.20%
		SCOP	4	3.7	-7.80%
	13	SEER	7.4	7.1	-4.70%
		SCOP	4.4	4.1	-7.30%
	14	SEER	6.4	6.1	-5.30%
		SCOP	3.9	3.6	-7.50%
	15	SEER	5.3	5	-5.30%
		SCOP	3.9	3.6	-7.70%
	16	SEER	6	5.7	-5.20%
		SCOP	3.8	3.5	-7.70%
	17	SEER	7.1	6.7	-6.20%
		SCOP	4	3.7	-9.30%
10 kW	18	SEER	4.7	4.5	-5.70%
		SCOP	3.8	3.5	-7.70%
	19	SEER	6.1	5.8	-5.20%
		SCOP	4	3.7	-7.80%

Between 6 and 12 kW, there is no unit for which measurement uncertainties is higher than allowed tolerances. Measurement uncertainties are higher in heating mode because of the 10 % individual uncertainty on COP in frost conditions (supposed to apply for all units at +2 °C).

Problems are related to units below 6 kW. It is enough that one of the declared capacity points are below 2 kW to have uncertainty levels higher than the tolerance. For tolerances to cover the worst-case situation of provisions for measurement uncertainties in EN14825:2016, these should be increased to 14 % for SCOP for 1.7 kW unit (13 % for SEER), 12 % for SCOP for 2.5 and 3.5 units (10 % for SEER) and to 10 % for SCOP for 5 kW units (7 % for SEER).

These values are in line with APF (annual performance factor compound of the equivalent to SEER and SCOP in Japanese standards) tolerances in Japan (as reported in the Preparatory study for 2004 and 2006 JRA standards) of 10 % for commercial air conditioners (above 4 kW) and 15 % for residential units (below 4 kW). Nevertheless, these are very high values in view of setting labeling requirements.

Zero tolerance is applied in the USA, and according to discussions with EU manufacturers during this review study, this corresponds to measurements uncertainties as low as 2 to 3 % on the measurement of SEER and SCOP (HSPF in the USA). Such low uncertainty levels are thought to be the result of regular Round Robin tests and harmonization efforts between laboratories.

The ISO 16358:2013 standard uses the 5 % maximum uncertainty value as a basis (reference also used for standard rating conditions tests in ISO5151). The case when measurement uncertainty is above 5 % is not envisaged for variable capacity air conditioners / heat pumps, whereas a test at 50 % capacity at 35 °C outdoor temperature and 27 °C indoor is mandatory. This means that all laboratories using this standard should be able to maintain a 5 % uncertainty level at capacity down to 1.7/2=0.85 kW (1.7 kW is the lowest capacity unit identified on the EU market).

Base on the above assessment, it can be concluded that:

- in order for tolerances to be higher than maximum measurement uncertainties implied by individual uncertainties mentioned in EN14825, these would have to be increased to: 14 % and13% (respectively for SCOP and SEER) for below 2 kW capacities, 12 % and10% (respectively SCOP and SEER) for between 2 and 6 kW, 10 % and8% (respectively SCOP and SEER) between 6 and 12 kW.
- nevertheless, manufacturers have suggested to reduce both tolerances and measurement uncertainties; this requires investments to be done by laboratories (and thus could result in higher test costs for manufacturers and the market surveillance authorities); Round Robin tests should be made on a regular basis in order to improve repeatability; possibly, the EN14825 standard should be enriched in specifying in more details the measurement equipment required and installation conditions in order to help improving repeatability. A first objective to be met with such measures could be uncertainties of 5 % for capacities equal or above 1 kW and 10 % for capacities below 1 kW and for frost conditions. This would help decreasing maximum uncertainties, and consequently tolerances to the following levels: 10 % and8 % (respectively SCOP and SEER) for below 6 kW, 9 % and 6 % (respectively SCOP and SEER) for above 6 kW. This is a more optimal approach for revising tolerances.

EU Regulation 1275/2008/EU - Ecodesign Requirements for standby and off mode, and networked standby, electric power consumption of electrical and electronic household and office equipment[44]

EU ecodesign requirements are mandatory for all manufacturers and suppliers wishing to sell products consuming electric power in standby and off mode in the EU. A wide range of equipment – computers, TVs, audio and video equipment, dishwashers, microwave ovens, and electric toys – can have standby modes so the regulation covers a wide range of products. The complete list of products is presented in annex 1 in the regulation. The requirements for products listed in annex 1 is:

- Standby and off mode ≤ 0.5 Watts
- Standby with display ≤ 1 Watts
- Networked standby ≤ 3 Watts
- HiNA equipment ≤ 8 Watts

It should be noted that air conditioners not are included in the standby regulation but the requirements for standby in Regulation 206/2012 (with and without a display) and off mode are in line with the standby regulation. Stakeholders have raised the question whether air conditioners also should comply with the requirements of networked standby and HiNA equipment. The standby consumption is already included in the SEER calculation and leaves more room for development for manufacturers. It should though be investigated in later task whether it is feasible to include the requirements.

EU Draft Commission Regulation implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for electronic displays[45]

In principle, displays of air conditioners are in the scope of the proposed draft regulation. However, there is an exemption which potentially excludes the displays of all air conditioners today on the market. In article 1, point 5, the following exemption is stated: Displays of a surface area smaller than or equal to 1 square decimetre.

EU Directive 2012/19/EU - WEEE Directive [46]

The Waste Electrical and Electronic Equipment (WEEE) Directive implements the principle of "extended producer responsibility" where producers of EEE are expected to take responsibility for the environmental impact of their products at the end of life. As such, the WEEE Directive aims to reduce environmental impacts through setting targets for the separate collection, reuse, recovery, recycling and environmentally sound disposal of WEEE.

As EEE, air conditioners and comfort fans fall under the scope of the WEEE Directive. Ecodesign requirements for air conditioners and comfort fans could therefore be used to assist the WEEE Directive aims via the introduction of product design requirements that enhance reuse, material recovery and effective recycling.

[44] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R1275-20170109&from=EN
[45] http://ec.europa.eu/growth/tools-databases/tbt/en/search/?tbtaction=search.detail&Country_ID=EU&num=433&dspLang=en&basdatedeb=&basdatefin=&baspays=&basnotifnum=433&basnotifnum2=&bastypepays=&baskeywords
[46] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN

EU Regulation 1907/2006/EC - REACH Regulation [47]

The Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) addresses chemicals, and their safe use, and aims to improve the protection of human health and the environment through a system of Registration, Evaluation, Authorisation and Restriction of Chemicals. The REACH Regulation places greater responsibility on industry to manage the risks from the chemicals they manufacture, import and market in the EU. Companies are required to demonstrate how substances can be used safely and risk management measures must be reported to users. The REACH Regulation also establishes procedures for collecting and assessing information on the properties and hazards of substances and requires that companies register their substances in a central database. The entries in the database are then assessed to determine whether the risks of the substances can be managed. The REACH Regulation allows for some chemicals to be determined "substances of very high concern (SVHC)" due to their large potential negative impacts on human health or the environment. The European Chemicals Agency must be notified of the presence of SVHCs in certain products and the use of SVHCs may then be subject to prior authorisation. Substances can also be banned were risks are deemed to be unmanageable. As such, REACH encourages substitution of the most dangerous chemicals when suitable alternatives have been identified.

As REACH applies to all chemical substances, which implies that it also covers the chemicals that are used in air conditioners and comfort fans that are within scope of this review project.

EU Directive 2011/65/EU - RoHS Directive[48]

The Restriction of Hazardous Substances (RoHS) Directive aims to reduce hazardous substances from electrical and electronic equipment (EEE) that is placed on the EU market. A number of hazardous substances are listed in the Directive along with maximum concentration values that must be met. The RoHS Directive does contain some exemptions where it has been decided that it may not be possible to manufacture some products without the use of one or more of the banned substances.

EU Directive 2006/42/EC - Machinery Directive[49]

The Directive has the dual aim of harmonising the health and safety requirements applicable to machinery on the basis of a high level of protection of health and safety, while ensuring the free circulation of machinery on the EU market. The revised Machinery Directive does not introduce radical changes compared with the previous versions. It clarifies and consolidates the provisions of the Directive with the aim of improving its practical application. This directive applies to products which are not residential and includes some of the same safety standards as for residential air conditioners.

EU Directive 2004/108/EC - Electromagnetic Compatibility Directive [50]

The Electromagnetic Compatibility Directive (EMC) Directive has the primary aim of protecting the electromagnetic spectrum. The Directive requires that products must not emit unwanted electromagnetic interference and must be protected against a normal level of interference. The vast majority of complete electrical products must comply independent of whether they are mains or battery powered. The EMC Directive does contain exemptions

[47] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006R1907-20140410&from=EN
[48] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0065&from=EN
[49] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006L0042-20160420&from=EN
[50] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:390:0024:0037:en:PDF

for a range of components with no intrinsic function and some products that are already covered by other directives such as medical, military and communications equipment.

The new EMC directive (2014/30/EU) has been published and will come into force on the 20th April 2016.[51]

EU Directive 2006/95/EC - Low Voltage Directive [52]

The Low Voltage Directive (LVD) ensures that electrical equipment that operates within certain voltage limits, provides a high level of protection. The LVD Directive covers all health and safety risks of electrical equipment operating with a voltage of between 50 and 1000 volts for alternating current and between 75 and 1500 volts for direct current. Consumer goods with a voltage below 50 for alternating current or 75 for direct current are covered by the General Product Safety Directive (GPSD) (2001/95/EC).

The new Low Voltage Directive (2014/35/EU) will come into force on the 20th April 2016.[53]

Most air conditioners that are within scope of this review project would fall under the scope of the LVD Directive.

EU Directive 97/23/EC – Pressure directive[54]

The Pressure Equipment Directive aims to guarantee free movement of these products in the internal market while ensuring a high level of safety. The directive covers a very broad range of products such as vessels, pressurised storage containers, heat exchangers, steam generators, boilers, industrial piping, safety devices and pressure accessories. Such equipment is widely used in the process industries (oil & gas, chemical, pharmaceutical, plastics and rubber and the food and beverage industry), high temperature process industry (glass, paper and board), energy production and in the supply of utilities, heating, air conditioning and gas storage and transportation.

EU Directive 2010/31 – Energy Performance of Buildings[55]

Buildings are responsible for 40% of energy consumption and 36% of CO2 emissions in the EU. While new buildings generally need fewer than three to five litres of heating oil per square meter per year, older buildings consume about 25 litres on average. Some buildings even require up to 60 litres. The energy performance of buildings also includes inspections of air conditioners since they are important to the overall energy performance of buildings.

The EPBD defines an air-conditioning system as "a combination of all components required to provide a form of air treatment in which temperature is controlled or can be lowered, possibly in combination with the control of ventilation, humidity, and air cleanliness". Moreover, "the effective rated output (expressed in kW) is the maximum calorific output specified and guaranteed by the manufacturer as being deliverable during continuous operation while complying with the useful efficiency indicated by the manufacturer". However, even after defining those terms, article 9 remains unclear because the 12-kilowatt limit can be defined in several ways. Member States will have to define the meaning of the 12-kilowatt limit through a cost/benefit analysis[56].

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[51] http://ec.europa.eu/growth/sectors/electrical-engineering/directives/index_en.htm
[52] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:374:0010:0019:en:PDF
[53] http://ec.europa.eu/growth/sectors/electrical-engineering/directives/index_en.htm
[54] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01997L0023-20130101&from=EN
[55] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN
[56] Dupont M. and Adnot J., present by the ECEEE 2005 Summer Study, Mandelieu, Côte d'Azur,

That limit is associated on the one hand to an energy saving potential and on the other hand to a workload (number of inspections). The lower the limit (the wider the scope), the higher the workload but the higher the energy savings. One can understand the weight of consequences generated by that definition. There are 4 main ways to understand the boundary:

- 12 kW per cooling system. Only systems with an effective rated output over 12 kilowatts will be taken into account.
- 12 kW per temperature controlled zone. Every cooling system included in the same thermal zone (bound by a common control system) but with a total effective rated output of the zone over 12 kW is taken into account. (The rated output of each system can be lower than 12kW)
- 12 kW per building. Every cooling system included in the same building (bound by exterior walls) but with a total effective rated output for the building over 12 kW is taken into account. (The rated output of each system can be lower than 12kW)
- 12 kW per owner (or tenant) in a given building. Based on previous technical definitions, the scope may be extended to the real ownership in case of a share of the building.

Directive 2009/28 – renewable energy[57]

The Renewable Energy Directive establishes an overall policy for the production and promotion of energy from renewable sources in the EU. It requires the EU to fulfil at least 20% of its total energy needs with renewables by 2020 – to be achieved through the attainment of individual national targets. Air conditioners are able to obtain a considerable amount of renewable energy. Each Member State shall adopt a national renewable energy action plan. The national renewable energy action plans shall set out Member States' national targets for the share of energy from renewable sources consumed in transport, electricity and heating and cooling in 2020, taking into account the effects of other policy measures relating to energy efficiency on final consumption of energy.

- **Commission Decision of 1 March 2013** establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council

Commission Decision of 1 March 2013 – establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies pursuant to Article 5 of Directive 2009/28/EC of the European Parliament and of the Council.

The gross final consumption of energy from renewable sources in each Member State shall be calculated as the sum of:

a. gross final consumption of electricity from renewable energy sources
b. gross final consumption of energy from renewable sources for heating and cooling
c. final consumption of energy from renewable sources in transport

Aerothermal, geothermal and hydrothermal heat energy captured by heat pumps shall be taken into account for the purposes of paragraph (b) provided that the final energy output

France, 30 May-4 June 2005.

[57] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=EN

significantly exceeds the primary energy input required to drive the heat pumps. The quantity of heat to be considered as energy from renewable sources for the purposes of this Directive shall be calculated

F-gas Regulation - (EU) No 517/2014[58]

A first F-gas Regulation was adopted in 2006 and succeeded in stabilising EU F-gas emissions at 2010 levels. A new regulation, which replaces the first and applies from 1 January 2015, strengthens the existing measures and introduces a number of far-reaching changes. By 2030 it will cut the EU's F-gas emissions by two-thirds compared with 2014 levels. The F-gas regulation also covers air conditioners and there are two relevant prohibitions for air conditions which are described in Table 30.

Table 30: Prohibition of high GWP refrigerants

Placing on the market prohibitions	Date of prohibition
Movable room air-conditioning equipment (hermetically sealed equipment which is movable between rooms by the end user) that contain HFCs with GWP of 150 or more	1 January 2020
Single split air-conditioning systems containing less than 3 kg of fluorinated greenhouse gases, that contain, or whose functioning relies upon, fluorinated greenhouse gases with GWP of 750 or more	1 January 2025

Besides the prohibitions of refrigerants with a high GWP for portable air conditioners and single split air conditioners there is also a quota system that applies to all products using hydrofluorocarbons if a viable alternative to the hydrofluorocarbons exist.

The maximum quantity shall be calculated by applying the percentages shown in Table 31 of the annual average of the total quantity placed on the market into the Union during period 2009 to 2012, and subsequently subtracting the amounts for exempted uses, on the basis of available data.

The maximum quantity, reference values and quotas for placing hydrofluorocarbons on the market shall be calculated as the aggregated quantities of all types of hydrofluorocarbons, expressed in tonne(s) of CO2 equivalent.

Table 31: Quotas for hydrofluorocarbons

Years	Percentage to calculate the maximum quantity of hydrofluorocarbons to be placed on the market and corresponding quotas
2015	100 %
2016–17	93 %
2018–20	63 %
2021–23	45 %
2024–26	31 %
2027–29	24 %
2030	21 %

This quota system will cut the use of hydrofluorocarbons with more than 2/3 by 2025 for products with a viable alternative to hydrofluorocarbons.

[58] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&from=EN

EU Regulation 66/2010/EC - EU Ecolabel [59, 60]

The EU Ecolabel is a voluntary labelling scheme, enforced in EU Regulation (66/2010/EC), that includes a large number of criteria, which aim to identify products which have low environmental impacts across many impact categories. Manufacturers can apply the logo to products, which meet all of the EU Ecolabel criteria.

Some of these criteria's concern the energy efficiency of the air conditioner and are listed below in Table 32 and Table 33.

Table 32: Ecolabel minimum requirements of the coefficient of performance (COP)

Type of heat pump	Outdoor unit [°C]	Indoor unit [°C]	Min. COP
air/air	Inlet dry bulb: 2 Inlet wet bulb: 1	Inlet dry bulb: 20 Inlet wet bulb: 15 max	2.90

Table 33: Ecolabel minimum requirements of the energy efficiency ratio (EER)

Type of heat pump	Outdoor unit [°C]	Indoor unit [°C]	Min. EER
air/air	Inlet dry bulb: 35 Inlet wet bulb: 24	Inlet dry bulb: 27 Inlet wet bulb: 19	3.20

These requirements are outdated and there is a clear need to revise the Ecolabel criteria for air conditioners.

1.3.2 Member State legislation

Since Member States follow the European Directives, ecodesign and energy labelling regulations are directly imposed in the Member States, there appears to be no other particularly outstanding legislation at member state level with relevance for the scope of this study. Though some countries have previously implemented alternative Ecolabels and different taxes to limit the use of e.g. fluorinated greenhouse gasses.

F-gas (Fluorinated greenhouse gases) regulation – regarding reduction of F-gas emissions.

In Germany, the German Regulation "Chemikalien-Klimaschutzverordnung" entered into force on 1 August 2008 and includes national measures which are stricter than those of the Regulation 2006/842/EC on fluorinated greenhouse gases. The German law sets the following maximum limits for the leakage of hydrofluorocarbons from systems installed after 30 June 2008: 1% per year for systems containing more than 100 kg of refrigerant and 3% for systems with less than 10 kg of HFCs.

Regarding the situation in Austria, the responsible body, the Federal Ministry of Agriculture, Forestry, Environment and Water Management is considering an amendment, aiming at a rescission of the former position.

At least one country, France, has specific limitations for the use of refrigerating equipment that contain refrigerant in buildings intended to welcome public, in addition to existing EN 378 standard.

Furthermore, a number of countries have adopted different kinds of tax systems on hydrofluorocarbons. Among them e.g. Denmark, France and Spain. In Denmark, the tax

[59] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:027:0001:0019:en:PDF
[60] http://ec.europa.eu/environment/ecolabel/index_en.htm

was applied 2001 concerning both production and import though there is no production in Denmark. A part of the revenue from this tax system is invested back in into the refrigeration industry through the establishment of the Knowledge Centre for HFC-Free Refrigeration[61]. Norway has also a tax on import and production of HFCs. In 2017 this tax was ca 48€ (450 NOK) pr. GWP-tonnes of gas. The same amount is refunded if used gas is delivered for safe destruction.

Blue Angel RAL-UZ 204: Stationary air conditioners

The Blue Angel is a German ecolabel and is a voluntary, state-run ecolabel. The criteria are established by the German Federal Environment Agency and awarded by an independent Jury to products that are environmentally friendlier than others serving the same use. It is to assist consumers in their purchase decisions. The basic criteria for stationary air conditioners includes requirements regarding e.g. SEER, SCOP and noise. Some of the requirements are:

- SEER ≥ 7
- SCOP ≥ 4.6
- Refrigerant: The air conditioner must be free of refrigerants containing halogens. In addition, it is not permitted to use ammonia as a refrigerant.
- Air filter: The indoor units of the devices (evaporator) must be fitted with air filters that can be easily cleaned either manually or automatic. Also, requirements regarding the heat exchanger exists.
- Noise emissions: The noise emissions of the devices must comply with the following requirements:

Table 34: Blue Angel requirements for the sound power level at rated capacity

Rated capacity (P_{rated}) in cooling or heating operation	Requirements for the sound power level at rated capacity	
	Indoor units	Outdoor units
≤ 4.5 kW	≤ 50 dB(A)	≤ 58 dB(A)
4.5 kW < Prated ≤ 6 kW	≤ 55 dB(A)	≤ 62 dB(A)
6 kW < Prated ≤ 12 kW	≤ 58 dB(A)	≤ 68 dB(A)

- Material requirements: Different requirements of exclusion of hazardous and carcinogenic substances.
- Environmentally friendly product design: Unless there are compelling technical reasons to the contrary, the following principles for the recyclable design of technical products must be observed and declared in writing:
    - The avoidance of non-detachable material connections between different materials
    - The avoidance of composite materials
    - Components that are easy to dismantle, also for the purpose of repair
    - Reduction in the diversity of the materials used

  In addition, the manufacturer must provide a written declaration of compliance with the following requirements when applying for the environmental label:

[61] http://www.igsd.org/documents/NationalLegislationonHydrofluorocarbons_9.11.151.pdf

- Product components made of plastic with a weight of more than 25 g must be labelled with an abbreviated term in accordance with DIN EN ISO 1043-116 or DIN ISO 162917 (rubber) or DIN ISO 207618 (chemical fibres).

1.3.3 Third country legislation

There are a number of pieces of legislation that have already been adopted, or are in the process of being developed, which address the energy efficiency of air conditioners and comfort fans.

Australia – Greenhouse and Energy Minimum Standards (Air Conditioners and Heat Pumps) Determination 2013[62]

The Australian regulation covers the following types of air conditioners:

- single and three phase non-ducted or ducted room air conditioners of the vapour compression type of up to 65kW cooling capacity (commercial or residential)
- Units with a single or multiple refrigeration systems with a single indoor control such as single packaged units (unitary)
- packaged ducted units (unitary)

The measure of energy efficiency of air conditioners is the Energy Efficiency Ratio (EER) for cooling and the coefficient of Performance (COP) for heating. The EER and COP are defined as the capacity output divided by the power input. The Star Rating Index is calculated on the measured values for energy and capacity during a rating test, rather than the nameplate or rated values.

The MEPS are set in terms of full load performances. Starting from 2011, the full load EER T1 is replaced by an "annual EER" value computed for a typical annual operating profile including low power mode consumption (it does not account for reduced temperature and part load impact however). In the same manner, the heating mode coefficient of performance COP is replaced with a ACOP.

Table 35: MEPS: MINIMUM EER FOR AIR COOLED CONDENSER AIRCONDITIONERS (from AS/NZS 3823.2-2009)

Product Description	MEPS 2006-07	MEPS 2010	MEPS 2011(**)
Unitary (*) - all types, <10kW, all phases	2.75	2.84	2.84
Unitary (*) – all types, 10kW to <19kW, all phases	2.75	2.75	2.75
Split systems – all types, <4kW, all phases	3.05	3.33	3.33
Split systems – all types, 4kW to <10kW, all phases	2.75	2.93	2.93
Split systems – all types, 10kW to <19kW, all phases	2.75	2.75	2.75
Ducted systems – all types, <19kW, single phase	2.50	2.75	2.75
Ducted systems – all types, <10kW, three phase	2.50	2.75	2.75
Ducted systems – all types, 10kW to <19kW, three phase	2.75	2.75	2.75
All configurations, all types, 19kW to 39kW, all phases	3.05	3.05	3.05
All configurations, all types, <39kW to 65kW, all phases	2.75	2.75	2.75

(*) unitary refers here to window and package units.
(**) values based on « annual EER »

[62] https://www.legislation.gov.au/Details/F2013L01672

Labelling

The original star rating equations for air conditioners were developed in 1987. These were revised (re-graded) in 2000 and again in 2010 to take account of the substantial improvement in the energy efficiency of products over this period. Until 2010, all energy labels showed possible star ratings from a minimum of 1 star to a maximum of 6 stars. In 2010, the star rating system for refrigerators and air conditioners was expanded to show up to 10 stars for products that have exceptional energy efficiency. Products that achieve up to 6 stars continue to use a normal 6-star energy label. They were further revised in 2011.

The 2011 star rating system is based on an annual efficiency calculation which includes any non-operational energy consumption such as standby and power consumption of crank case haters (where present).

Australia has been considering the extension of the energy label and minimum performance requirements to portable air conditioners since 2009. However, there are not yet any minimum energy performance requirements or requirements of an energy label. A study was conducted in 2009 to assist for the development of labels for single duct air conditioners and spot coolers[63]. The study consisted of testing information display to customers that were planning to buy a portable air conditioner and to customers that had already bought it. It was advised by technical experts not to include a scale system (stars in the case of the Australia and New-Zealand) due to technical issues with standards and the relatively low EER dispersion. The display of cooling capacity and EER values was also tested but together with a complex message regarding the test conditions (similar indoor and outdoor temperatures as in EN14511 standard) and thus it was not helpful to the customers. Furthermore, several messages and information label designs were tested to inform the hot air infiltration during summer, but all suggestions became too complicated. The final proposal of the study is shown below. Note that this label was not adopted, although the study dates back to 2009.

Figure 5: Proposed label designs for single duct air conditioners in Australia in 2009[64]. Text on the label: "This product has a cooling function when ducted to the outside, but during hot weather hot air is drawn into the building to replace the exhausted hot air. Over time this may result in an increase in indoor temperatures in other parts of the building. Please ask your retailer about alternatives."

[63] http://www.energyrating.gov.au/sites/new.energyrating/files/documents/200917-portable-space-cond-spot-coolers_0.pdf

[64] http://www.energyrating.gov.au/sites/new.energyrating/files/documents/200917-portable-space-cond-spot-coolers_0.pdf

Japan

Japan operates with a program called the Top Runner standards program. This program aims to improve energy efficiency of appliances by setting target values based on the current highest efficiency level of each type of product instead of the current average efficiency level. Manufacturers and importers have to ensure the average (sales weighted) efficiency of all their appliances meet this standard by a specified date (the target year). The program allows a continuum for improvement over time making manufacturers constantly increase the efficiency of appliances.

The Top Runner standards are voluntary as there is no minimum level, however penalties can be evoked if the average efficiency target is not met. The Ministry of Economy Trade and Industry monitor the program and it is legislated through the Energy Conservation Law. The program so far has been quite successful with most manufacturers gearing up to meet the targets. When the target year is reached, new target levels can be established. Regarding air conditioners, 2007 is the latest fiscal year with target on the full load efficiency. The targets are COP values, i.e. for reversible units, to be understood as "(EER+COP) / 2" with ISO notations. These targets are still active and are reported below.

The EER and COP are the reference ISO 5151, as used in Europe.

Table 36: Japan full load MEPS for air conditioners

Category			Standard energy consumption efficiency (COP)
Unit form	**Cooling capacity**	**Category name**	
Non-ducted wall-mounted type (except multi-type operating indoor units individually)	Up to 2.5kW	b	5.27
	Over 2.5kW up to 3.2kW	c	4.90
	Over 3.2kW up to 4.0kW	d	3.65
	Over 4.0kW up to 7.1kW	e	3.17
	Over 7.1kW up to 28.0kW	f	3.10
Other non-ducted type (except multi-type operating indoor units individually)	Up to 2.5kW	g	3.96
	Over 2.5kW up to 3.2kW	h	3.96
	Over 3.2kW up to 4.0kW	i	3.20
	Over 4.0kW up to 7.1kW	j	3.12
	Over 7.1kW up to 28.0kW	k	3.06
Ducted type (except multi-type operating indoor units individually)	Up to 4.0kW	l	3.02
	Over 4.0kW up to 7.1kW	m	3.02
	Over 7.1kW up to 28.0kW	n	3.02
Multi-type operating indoor units individually	Up to 4.0kW	o	4.12
	Over 4.0kW up to 7.1kW	p	3.23
	Over 7.1kW up to 28.0kW	q	3.07

In addition to these full load targets, new targets are planned in terms of APF or energy consumption value E. Both consider a weighted average of a SEER for the cooling season and a HSPF (Heating Seasonal Performance Factor) for the heating season with the climate of Tokyo. It is not possible to compare directly with standard EER and COP values with APF and energy consumption because these seasonal indicators take account of part load performance and of the impact of outdoor air temperature on the performance, while EER and COP do not.

Table 37: Japan APF Top Runner efficiency target - Air conditioners for home use - Non-duct and wall-hung type: Fiscal year 2010

Category			Standard energy consumption efficiency (APF)
Cooling capacity	**Dimension type of indoor units**	**Category name**	
Up to 3.2kW	Dimension -defined type	A	5.8
	Free-dimension type	B	6.6
Over 3.2kW up to 4.0kW	Dimension -defined type	C	4.9
	Free-dimension type	D	6.0

Table 38: Japan APF Top Runner efficiency target - Air conditioners for home use - Others: Fiscal year 2012

Category			Standard energy consumption efficiency (COP)
Unit form	**Cooling capacity**	**Category name**	
Non-ducted wall-mounted type (except multi-type operating indoor units individually)	Up to 2.5kW	b	5.27
	Over 2.5kW up to 3.2kW	c	4.90
	Over 3.2kW up to 4.0kW	d	3.65
	Over 4.0kW up to 7.1kW	e	3.17
	Over 7.1kW up to 28.0kW	f	3.10
Other non-ducted type (except multi-type operating indoor units individually)	Up to 2.5kW	g	3.96
	Over 2.5kW up to 3.2kW	h	3.96
	Over 3.2kW up to 4.0kW	i	3.20
	Over 4.0kW up to 7.1kW	j	3.12
	Over 7.1kW up to 28.0kW	k	3.06
Ducted type (except multi-type operating indoor units individually)	Up to 4.0kW	l	3.02
	Over 4.0kW up to 7.1kW	m	3.02
	Over 7.1kW up to 28.0kW	n	3.02
Multi-type operating indoor units individually	Up to 4.0kW	o	4.12
	Over 4.0kW up to 7.1kW	p	3.23
	Over 7.1kW up to 28.0kW	q	3.07

Table 39: Japan APF Top Runner efficiency target - Air conditioners for business use: Fiscal year 2015

Category				Standard energy consumption efficiency or calculation formula thereof
Form & function	**Indoor unit type**	**Cooling capacity**	**Category name**	
Combination of plural types or any type other than following	4-directional cassette type	Less than 3.6 kW	aa	E = 6.0
		Not less than 3.6 kW but less than 10.0 kW	ab	E = 6.0 - 0.083×(A - 3.6)
		Not less than 10.0 kW but less than 20.0 kW	ac	E = 6.0 - 0.12×(A - 10)
		Not less than 20.0 kW and up to 28.0 kW	ad	E = 5.1 - 0.060×(A - 20)
	Other than 4-directional cassette type	Less than 3.6 kW	ae	E = 5.1
		Not less than 3.6 kW but less than 10.0 kW	af	E = 5.1 - 0.083×(A - 3.6)
		Not less than 10.0 kW but less than 20.0 kW	ag	E = 5.1 - 0.10×(A - 10)
		Not less than 20.0 kW and up to 28.0 kW	ah	E = 4.3 - 0.050×(A - 20)
Multi-type controlling operation of indoor units individually		Less than 10.0 kW	ai	E = 5.7
		Not less than 10.0 kW but less than 20.0 kW	aj	E = 5.7 - 0.11×(A - 10)
		Not less than 20.0 kW but less than 40.0 kW	ak	E = 5.7 - 0.065×(A - 20)
		Not less than 40.0 kW and up to 50.4 kW	al	E = 4.8 - 0.040×(A - 40)
Ducted type whose indoor unit is set on floor or any like type	Non-ducted type	Less than 20.0 kW	am	E = 4.9
		Not less than 20.0 kW and up to 28.0 kW	an	E = 4.9
	Ducted type	Less than 20.0 kW	ao	E = 4.7
		Not less than 20.0 kW and up to 28.0 kW	ap	E = 4.7

Remarks:
1. "Ducted type" indicates systems connected to ducts at the outlet.
2. "Multi-type" indicates a type that has two or more indoor units connected to an outdoor unit.
3. E and A represents the following values respectively. E: standard energy consumption efficiency (unit: yearly energy consumption efficiency). A: Cooling capacity (unit: kilowatts)

A study for CLASP on benchmarking main requirements and metrics suggests that Japanese minimum performance requirements for less than 3.2 kW units (Japanese Annual Performance Factor of 6.6 for residential free dimension single split wall units) roughly corresponds to an EU SEER value of 8 (close to the EU label A+++ limit of 8.5), with lower values of about 6.5 for larger single split wall units with free dimensions (APF of 4.5). Study concludes that there is still an important margin for increasing minimum performance requirements in cooling mode[65].

China

<u>China Energy Label and Minimum Energy Performance Standard (MEPS)</u>

The China Energy Label program was introduced in China in 2005. Fixed speed air conditioners were the first product group meaningful label was implemented for, but the China Energy Label can be now found for a range of household appliances and products on the Chinese market. Each product label is supported by a standard that specifies what the grades mean and the allowable limits for each grade. In the 2004 edition, there are 5 grades in the scale, and in 2010 edition, only 3 grades are left. In the 2010 edition, grade 3 is the minimum requirement and grade 1 is the best grade, due to the fast increasing efficiency of air conditioners. Consumers should use the 2010 edition as the purchasing reference. See the labels in Figure 6.

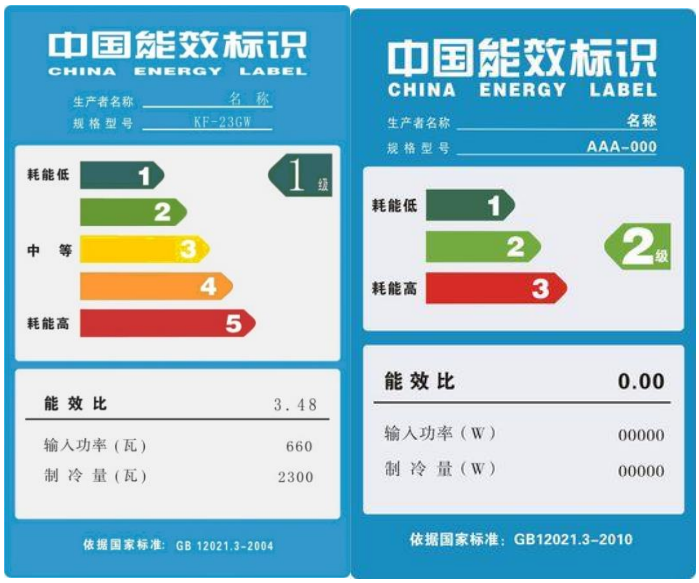

Figure 6 China Energy Label for air conditioners 2004 version that is out of use (left) and the currently in use 2010 version (right)[66]

As shown in the figure, the 2010 version refers to the Minimum Energy Performance Standard (MEPS) for fixed speed air conditioners: GB 12021.3-2010 the minimum allowable value of the energy efficiency and energy efficiency grades for room air conditioners, which replaced the GB 12021.3-2004. This standard specifies the national minimum requirements for air conditioners which is equal to the requirement for grade 3, as well as the allowable efficiency for different grades, see Table 40 for the requirements.

[66] http://www.top10.cn/English/recommendations/Recommendation-fix-speed-air-conditioner.html&fromid=

Table 40 Minimum requirement and energy label allowable limits[67]

Type	Cooling capacity	Energy Efficiency Ratio (EER) W/W		
		Grade 1	Grade 2	Grade 3
Window/through-the-wall		3.30	3.10	2.90
Split	≤ 4500W	3.60	3.40	3.20
	> 4500 W and ≤ 7100 W	3.50	3.30	3.10
	> 7100 W and ≤ 14000 W	3.40	3.20	3.00

The MEPS for variable speed (VS) air conditioners GB 21455 was implemented in 2008. New version has been released in 2013. See the label in Figure 7.

Figure 7 China Energy Label for variable speed air conditioners according to MEPS GB 21455 -2013[68]

In the standard GB 21455 -2013, requirements for Annual Performance Factor (APF) was defined (see Table 41), this is the parameter to measure energy efficiency of VS air conditioners with heating pump, whereas the seasonal energy efficiency ratio (SEER), as originally defined in GB 21455 -2008, is the parameter to measure energy efficiency of VS air conditioners without heating function. See the changes to SEER requirements in Table 42.

Table 41 APF requirement and energy label allowable limits for variable speed air conditioners according to MEPS GB 21455 -2013

Rated cooling capacity	Annual Performance Factor (APF) Wh/Wh		
	Grade 1	Grade 2	Grade 3
≤ 4500W	4.5	4.0	3.5
> 4500 W and ≤ 7100 W	4.0	3.5	3.3
> 7100 W and ≤ 14000 W	3.7	3.3	3.1

[67] GB 12021.3-2010 the minimum allowable value of the energy efficiency and energy efficiency grades for room air conditioners
[68] http://www.topten.eu/uploads/File/EEDAL15_Luting_Huang_MEPS_China.pdf

Table 42: SEER requirement and energy label allowable limits for variable speed air conditioners according to MEPS GB 21455 – 2008 and GB 21455 – 2013

Rated cooling capacity	SEER Wh/Wh							
	Grade 1		Grade 2		Grade 3		Grade 4	Grade 5
	2008	2013	2008	2013	2008	2013	2008	2008
≤ 4500W	5.2	5.4	4.5	5.0	3.9	4.3	3.4	3.0
> 4500 W and ≤ 7100 W	4.7	5.1	4.1	4.4	3.6	3.9	3.2	2.9
> 7100 W and ≤ 14000 W	4.2	4.7	3.7	4.0	3.3	3.5	3.0	2.8

Technical standard GB/T 7725 - 2004

The testing method specified in the standard GB 12021.3-2010 and GB 21455 -2008 refers to GB/T 7725 - 2004. According to the measurement standards, the SEER of variable speed air conditioners is calculated based on the testing of 100% and 50% of the rated cooling capacity. The definition of the cooling season plays an essential role in the calculation of the SEER. The technical testing standard (GB/T 7725-2004) defines the cooling season with a using time of 2399 hours, while the MEPS (GB 21455 – 2008) defines the cooling season with a using time of 1136 hours. The difference in cooling hours leads to different SEER results. Generally, the resulting SEER based on the GB/T 7725 – 2004 is higher than the SEER based on the GB 21455 – 2008. The China energy labeling program adopted GB 21455 – 2008 as the basis of the labeling scheme. However, the manufacturers also indicate SEER of GB/T 7725 – 2004 on the nameplate of the product in parallel with GB 21455 –2008[69].

The results of measurement of SEER or Heating Seasonal Performance Factor (HSPF) according to Chinese standard GB/T 7725 – 2004 and SEER or SCOP according the European standard EN 14825 cannot be directly compared, much higher value for SEER and HSFP/SCOP can be obtained when measured with European standard.

USA

Minimum standards of energy efficiency for many major appliances were established by the U.S. Congress in the National Appliance Energy Conservation Act (NAECA) of 1987, and in the National Appliance Energy Conservation Amendments of 1988. Standards for some fluorescent and incandescent reflector lamps, plumbing products, electric motors, and commercial water heaters, heating, ventilation and air conditioning (HVAC) systems were added in the Energy Policy Act of 1992 (EPACT). The US Department of Energy (DOE) is responsible for developing the standards and test procedures for the Appliance Standards Program as well as periodically issuing new standards for specific appliances.

The USA has an extensive MEPS program for air conditioners and heat pumps, that includes the following product types:

- residential room air conditioners (Window/wall)
- Portable air conditioners
- package terminal air conditioners (wall units with an air change function included)
- central air conditioners and heat pumps
- small commercial package air conditioners and heat pumps
- large commercial package air-conditioners and heat pumps

[69] TopTen, Energy efficient room air conditioners – best available technology(BAT)

Requirements for residential room air conditioners and portable air conditioners are reported hereunder.

Residential air conditioners (window/wall)

The program covers single-phase air conditioners that are not packaged terminal air conditioners. Products with and without louvered sides are defined as distinct categories. The product is required to be tested in accordance with Federal test procedures to meet mandatory efficiency standards. This test procedure can be found in the current U.S. Code of Federal Regulations (CFR, Title 10, Part 430 Appendix F). Minimum performance thresholds are based on the CEER metrics, which is a full load metrics integrating thermostat off, standby and off mode in a single figure.

Table 43: Minimum performance thresholds based on CEER (USA)

Product Class	Cooling (Heating) Power in Btu/h	CEER, effective as of June 1, 2014
Cooling Only		
with louvered sides	Less than 6000	11.0
	6000 to 7999	11.0
	8000 to 13999	10.9
	14 000 to 19999	10.7
	20000 to 27999	9.4
	20000 and over	9.0
without louvered sides	Less than 6000	10.0
	6000 to 7999	10.0
	8000 to 13999	9.6
	14000 to 19999	9.5
	20 000 or more	9.3
Cooling and Heating		
with louvered sides	less than 20000	9.8
	and 20000 or more	9.3
without louvered sides	less than 14 000 (4.10)	9.3
	and 14 000 (4.10) or more	8.7
Casement-Only		9.5
Casement-Slider		10.4

Central air conditioners (includes split and multisplit air conditioner)

Central air conditioners and heat pumps. The energy conservation standards defined in terms of the heating seasonal performance factor are based on Region IV, the minimum standardized design heating requirement, and the sampling plan stated in § 430.24(m). Central air conditioners and central air conditioning heat pumps manufactured on or after January 1, 2015, shall have a Seasonal Energy Efficiency Ratio and Heating Seasonal Performance Factor not less than the values shown in the below table.

Table 44: Seasonal Energy Efficiency Ratio and Heating Seasonal Performance minimum requirements for central air conditioners

Product class	Seasonal energy efficiency ratio (SEER)	Heating seasonal performance factor (HSPF)
(i) Split-system air conditioners	13	
(ii) Split-system heat pumps	14	8.2
(iii) Single-package air conditioners	14	
(iv) Single-package heat pumps	14	8
(v) Small-duct, high-velocity systems	13	7.7
(vi)(A) Space-constrained products—air conditioners	12	
(vi)(B) Space-constrained products—heat pumps	12	7.4

In addition to meeting the applicable requirements in Table 44, products in product classes (i) and (iii) in Table 44 (i.e., split-system air conditioners and single-package air conditioners) that are manufactured on or after January 1, 2015, and installed in the States of Arizona, California, Nevada, or New Mexico shall have a Seasonal Energy Efficiency Ratio not less than 14 and have an Energy Efficiency Ratio (at a standard rating of 95 °F dry bulb outdoor temperature) not less than the following values in the table shown below.

Table 45: Energy Efficiency Ratio for central air conditioners in selected states

Product class	Energy efficiency ratio (EER)
(i) Split-system rated cooling capacity less than 45,000 Btu/hr	12.2
(ii) Split-system rated cooling capacity equal to or greater than 45,000	11.7
(iii) Single-package systems	11

Central air conditioners and central air conditioning heat pumps manufactured on or after January 1, 2015, shall have an average off mode electrical power consumption not more than the following values in the below table.

Table 46: Minimum requirements for average off mode electrical of central air conditioners

Product class	Average off mode power consumption $P_{W,OFF}$ (watts)
(i) Split-system air conditioners	30
(ii) Split-system heat pumps	33
(iii) Single-package air conditioners	30
(iv) Single-package heat pumps	33
(v) Small-duct, high-velocity systems	30
(vi) Space-constrained air conditioners	30
(vii) Space-constrained heat pumps	33

A study for CLASP on benchmarking main requirements and metrics suggest that for split air conditioners[70], the present requirement in US of SEER 13 is comparable to EU SEER 4.4, which is the requirement for larger than 6 kW units. For reversible units, SEER 14 would be equivalent to an EU SEER value of 4.8.

[70] http://clasp.ngo/Resources/Resources/PublicationLibrary/2012/Cooling-Benchmarking-Study

Portable air conditioners

The regulation for portable air conditioners are not yet in force and still needs to be approved.

"Portable air conditioner" means a portable encased assembly, other than a "packaged terminal air conditioner," "room air conditioner," or "dehumidifier," that delivers cooled, conditioned air to an enclosed space, and is powered by single-phase electric current. It includes a source of refrigeration and may include additional means for air circulation and heating.

In the USA, portable air conditioners are supposed to be bought as other types of room air conditioners and used similarly. Consequently, the US DOE decided to use similar seasonal performance metrics as for room air conditioners, corrected for air infiltration and duct heat losses.

The suggested regulation applies a minimum allowable combined energy efficiency ratio (CEER) standards, which are expressed in British thermal units (Btu) per watt-hour (Wh), and are shown in table below.

Table 47: Energy Conservation Standards for Portable Air Conditioners

Portable Air Conditioner Product Class	Minimum CEER (Btu/Wh)	Note
Single-duct and dual-duct portable air conditioners	$1.04 \times \frac{SACC}{(3.7117 \times SACC^{0.6384})}$	SACC is the representative value of Seasonally Adjusted Cooling Capacity, in Btu/h, as determined in accordance with the DOE test procedure at title 10 Code of Federal Regulations (CFR) 430, subpart B, appendix CC and applicable sampling plans.

1.4 Conclusions and recommendations

Product scope

The scope of ecodesign regulations for different air cooling and heating products are well aligned, except for one subset of air to air heat pumps and air conditioner that uses ventilation exhaust air, these products with capacity over 12 kW are already covered by another regulation, so to avoid potential loophole, it is recommended that **ventilation exhaust air-to-air heat pumps and air conditioners with heating or cooling capacity ≤ 12 kW** to be included in the revised scope of Regulation 206/2012. The rest of the product scope remains unchanged: "electric mains-operated air conditioners with a rated capacity of ≤ 12 kW for cooling, or heating if the product has no cooling function, and comfort fans with an electric fan power input ≤ 125W".

The exemptions to the product scope are still as follows:

a. appliances that use non-electric energy sources;
b. air conditioners of which the condenser-side or evaporator side, or both, do not use air for heat transfer medium.

The proposed product scope for Regulation 206/2012 is summarised in Table 48.

Table 48: Recommended product scope.

Categories	Products included	Scope limits
Outdoor air / recycled air	Split, multi-split, window, through-the-wall, double duct	Cooling (heating) power ≤12 kW
Exhaust air / recycled air	Single duct	
Exhaust air / outdoor air	Heat recovery ventilation heat pump / air conditioner	Cooling (heating) power ≤12 kW
Comfort fans	Desk fans, floor standing fans, wall mounted fans, ceiling fans, tower fans, box fans, etc. Portable fan heater with comfort fan mode.	Electric fan power ≤ 125W

Energy labelling Regulation (EU) No 626/2011should follow the recommended scope of ecodesign Regulation, with the exception of comfort fans.

Test standards

Regarding air conditioners other than single duct and double duct, the EN14825 harmonised standard addresses the requirements of the Regulation (EU) No 206/2012. However, seasonal performance rating conditions are missing for ventilation exhaust air heat pumps and air conditioners, if these products are to be included in the scope.

It can be noted that there are possible improvements for test method in Regulation (EU) 2012/206, i.e. EN14825, EN15218 and EN14511 test standards. Improvements include network standby, (at the moment it is neither defined in regulation nor in test standards, it should be taken into account as there are already units with network capabilities), cycling test in EN14825 (it is proposed to use default values for Cdc and Cdh and not to allow to measure the value), low power modes power measurement and weighting hours and total cooling / heating hours.

Regarding single duct and double duct air conditioners, US DOE proposed a seasonal performance metrics which enables to account for air infiltration of hot air inside the zone to be cooled and for thermostat off mode and standby. This is a progress axis in Europe as it would enable to make efficiency figures of single/double duct and split air conditioners comparable.

It can be noted that outside of EU, there is ongoing improvement of test standards in different countries striving for closer testing conditions to real-life operation conditions. In this attempt, it appeared clearly that the present test methods for rating the performances of air conditioners are not fully satisfactory. This is because the control of the unit is bypassed and instead manufacturers choose the control parameters to be fixed for each different test. To avoid this, a compensation method can be used; the unit is set free to work in a room with a given heat load to compensate. Such a method is to be included in the next version of the EN14511-3 to help to test the unit when it is not possible to contact the manufacturer / its representative to set the control parameters. However, this method is not thought to be mature enough to become the standard test method yet. In the meanwhile, it is proposed to require manufacturers to include information on product set-up for performance tests if and when Regulations (EU) 206/2012 and 626/2011 are rerevised.

Legislations

The new F-gas regulation introduced a quota system that will cut the use of hydrofluorocarbons by more than 2/3 by 2025 for products with a viable alternative to hydrofluorocarbons. Though, the challenge remains in finding these alternatives for air conditioners which not are widely available today. Besides the quota system, prohibition on the use of refrigerants with a high GWP is introduced. For split air conditioners, refrigerants with a GWP higher than 750 is prohibited to use by 2025. As a result of the F-gas regulation, the industry will be required to reduce the impact of high GWP refrigerants and the need for a bonus system for air conditioners using low GWP refrigerant in the revised ecodesign regulation is reduced.

Third country legislations show that there is a trend for increasing the stringency of requirements for air conditioner efficiency, although it is often not directly comparable with the EU requirement due to the differences in testing method. A study from CLASP on benchmarking main requirements suggests that there is still an important margin for increasing minimum performance requirements in cooling mode[71] in the EU. Both the US and Japan have more ambitious requirements today than the EU.

Regarding policies for portable air conditioners, there are different approaches worldwide. In 2009, a study for national authorities of Australia and New Zealand suggested it could be counterproductive to label the energy performance of single duct air conditioners and that it could be of higher value to inform the customer on the problem linked to the outdoor air infiltration instead. Meanwhile in Europe, there is a A+++ - G energy label for portable air conditioners similar to the one for fixed air conditioners, with an indication of single duct products being "local air conditioner" in the product fiche and other marketing documentation, however this indication is rather "weak" because the difference of local air conditioner is rarely ever understood by the consumers as intended. Therefore, it should be considered that single duct and double duct products and other air conditioners could be rated on the same efficiency scale on the energy labels to enable comparison by the consumers.

As mentioned, a seasonal performance standard was developed by US DOE in 2016 for portable air conditioners based on existing metrics and including the impact of infiltration air so that portable cooling performance metrics may be comparable to the metrics of other room air conditioners in the USA. Currently in the EU, air infiltration is not measured by the standard, nor is the problem disseminated to the consumers. Since air infiltration is not included, it is not clear that a product with a better EER leads to a better field performance; false expectation would be given to the consumers, as an increased EER may mean an increased condenser air flow and hence more infiltration. Therefore, it is worth considering the infiltration issue for single duct in the current review. The US DOE experience has further shown that air infiltration was also an issue for double duct air conditioners; if it is worth considering the air infiltration issue for double duct air conditioners too in the current review, it should be reminded that the impact of infiltration is already accounted for in Europe for these products thanks to the use of the calorimeter room test method.

[71] Heating mode metrics were not compared in the frame of the study.

European Commission

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 2 report

Final version

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Abbreviations

Cdc, Cdh	The cycling degradation coefficient for air conditioners in cooling (heating) mode
COP	Coefficient of Performance for air conditioners in heating mode
CDD	Cooling Degree Day
EER	Energy Efficiency Ratio for air conditioners in cooling mode
EPS	External Static Pressure for air conditioners
GNI	Gross national income
GWP	Global warming potential
H_{TO}	The number of hours the unit is considered to work in thermostat off mode for air conditioners
H_{SB}	The number of hours the unit is considered to work in standby mode for air conditioners
H_{CK}	The number of hours the unit is considered to work in crankcase heater mode for air conditioners
H_{OFF}	The number of hours the unit is considered to work in off mode for air conditioners
P_{TO}	The electricity consumption during thermostat off mode for air conditioners
P_{SB}	The electricity consumption during standby mode for air conditioners
P_{CK}	The electricity consumption during crankcase heater mode for air conditioners
P_{OFF}	The electricity consumption during off mode.
Q_{CE}	The reference annual cooling demand for air conditioners in cooling mode
Q_{HE}	The reference annual heating demand for air conditioners in heating mode
SHR	Sensible Heat Ratio for air conditioners
SEER	Seasonal Energy Efficiency Ratio for air conditioners, cooling mode
SCOP	Seasonal Coefficient of Performance for air conditioners, heating mode
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.

2 Task 2

Task 2 follows the MEErP methodology and includes the following:

1. Generic economic data: EU sales and trade data based on production, import and export is assessed based on PRODCOM data analysis, aiming at identifying any similarities with our established stock model and/or filling data gaps.
2. Market and stock data: The establishment of the EU installed base (stock) based on EU annual total sales and growth rates and average product lives.
3. Market trends: The trends have been assessed regarding products, product features, market channels, production structures and market players.
4. Consumer expenditure base data: Identifying average EU consumer prices, repair and maintenance costs, disposal tariffs and taxes, electricity prices and regional differentiations.

2.1 Generic Economic data

The PRODCOM statistics are the official source for product data on the EU market. It is based on product definitions that are standardised across the EU thus guaranteeing comparability between Member States. Data are reported by Member States to Eurostat.

The PRODCOM statistics have some limitations given the complexities in the market and so are they not always as detailed as necessary to support decision making within ecodesign preparatory studies (e.g. data for air conditioners).

Within this study, the PRODCOM statistics are used to compare against product data sourced from other data sources and expert assumptions in order to provide a higher degree of confidence in the final product dataset. The product data sourced was used to establish annual sales for product categories in scope, and subsequently for establishing the installed base in the EU (i.e. stock).

PRODCOM EU sales and trade (i.e. the EU consumption) is derived by using the following formula based on data from PRODCOM:

$$EU\ sales\ and\ trading = production + import - export$$

For air conditioners and comfort fans, the following PRODCOM categories have been used to search for available data in the database:

Table 1: Prodcom categories covering products relevant for this study.

PRODCOM code	PRODCOM Nomenclature
28.25.12.20	Window or wall air conditioning systems, self-contained or split-systems
28.25.12.50	Air conditioning machines with refrigeration unit (excluding those used in motor vehicles, self-contained or split-systems machines)
28.25.30.10	Parts for air conditioning machines (including condensers, absorbers, evaporators and generators)
27.51.15.30	Table, floor, wall, window, ceiling or roof fans, with a self-contained electric motor of an output <= 125 W

Furthermore, data for dehumidifiers and humidifiers have been searched with no results. Sales data regarding humidifiers and dehumidifiers could have potentially shown some general tendencies e.g. if air conditioners with more functions (dehumidification and humidification) have an impact on sales of this type of equipment.

Air conditioners

The available data on PRODCOM for air conditioners are very limited and not sufficient to calculate the EU sales and trading. The limited available data is shown in Table 2 for the year of 2015. The data in Table 2 represents the available data for the following PRODCOM codes 28.25.12.20 and 28.25.12.50 in year 2009 to 2015. For PRODCOM code 28.25.30.10 no data at all is available. Though is this code of less importance since it relates to parts for air conditioners.

Table 2: Example of available data on PRODCOM for air conditioners

INDICATORS	EXPQNT	IMPQNT	PRODQNT	QNTUNIT
France	:	:	:	p/st
Netherlands	:	:	1,817	p/st
Germany	:	:	:	p/st
Italy	:	:	66,918	p/st
United Kingdom	:	:	285,067	p/st
Ireland	:	:	:	p/st
Denmark	:	:	76	p/st
Greece	:	:	:	p/st
Portugal	:	:	0	p/st
Spain	:	:	125,048	p/st
Belgium	:	:	:	p/st
Luxemburg	:	:	0	p/st
Iceland	:	:	0	p/st
Norway	:	:	:	p/st
Sweden	:	:	:	p/st
Finland	:	:	81,424	p/st
Austria	:	:	:	p/st
Malta	:	:	0	p/st
Estonia	:	:	0	p/st
Latvia	:	:	:	p/st
Lituania	:	:	0	p/st
Poland	:	:	:	p/st
Czech Republic	:	:	:	p/st
Slovakia	:	:	0	p/st
Hungary	:	:	0	p/st
Romania	:	:	0	p/st
Bulgaria	:	:	:	p/st
Slovenia	:	:	0	p/st
Croatia	:	:	0	p/st
EU25TOTALS	:	:	:	:
EU27TOTALS	:	:	3,151,669	p/st

The available production data for the PRODCOM codes 28.25.12.20 and 28.25.12.50 are shown in Figure 1.

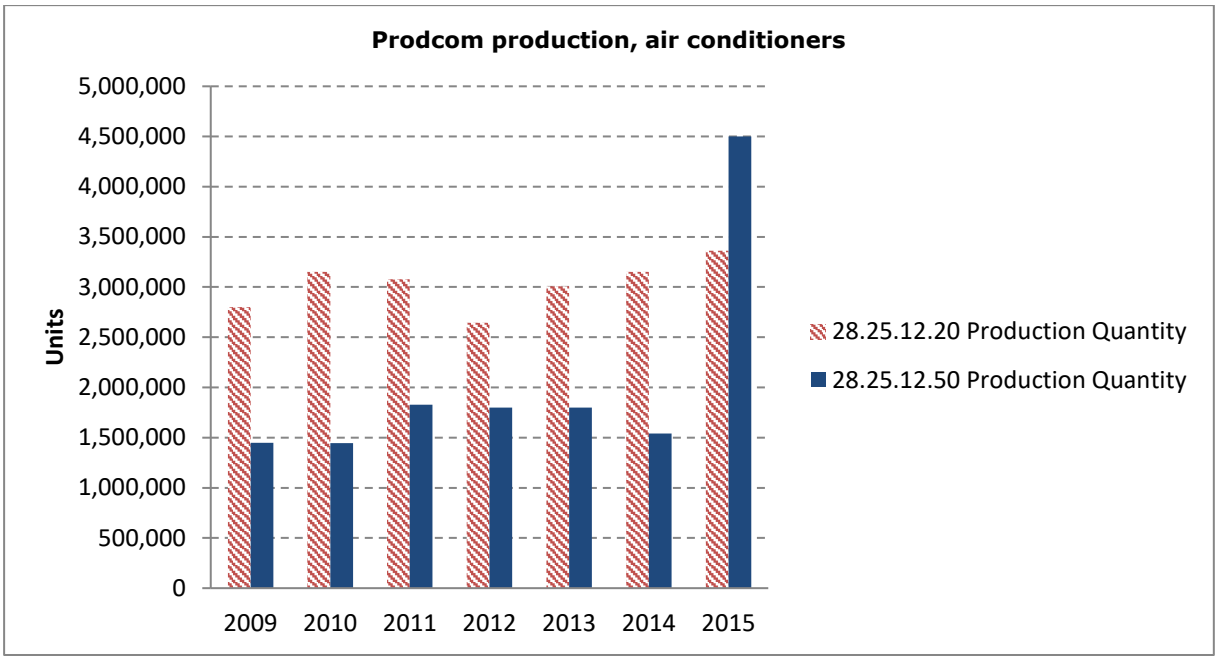


Figure 1: Total production of air conditioners (PRODCOM code 28.25.12.20 and 28.25.12.50). PRODCOM assessed April 2017.

After a minor decrease in production numbers in 2011 and 2012 are the production increasing within EU for the products covered by the PRODCOM code 28.51.12.20 (window or wall air conditioning systems, self-contained or split-systems). Since 2012 the production of air conditioners has increased steadily with an average increase of 8 % per year.

According to products covered by the PRODCOM code 28.51.12.50 (air conditioning machines with refrigeration unit (excluding those used in motor vehicles, self-contained or split-systems machines)) the production has more than doubled in 2015 compared to 2014. The data from PRODCOM is insufficient for calculating apparent sales and trade, therefore will not be used to establish sales and stock of air conditioners in this study.

Unfortunately, it was not possible to include data from 2016 due to unreliable values and missing total numbers.

Comfort fans below 125 W

Figure 2 illustrate the EU-28 production, import and export quantity according to PRODCOM data for comfort fans below 125 W and Figure 2 shows the calculated EU sales and trading for comfort fans below 125 W. The most recent data retrievable from PRODCOM at the time of writing the report (April 2017) were from 2015.

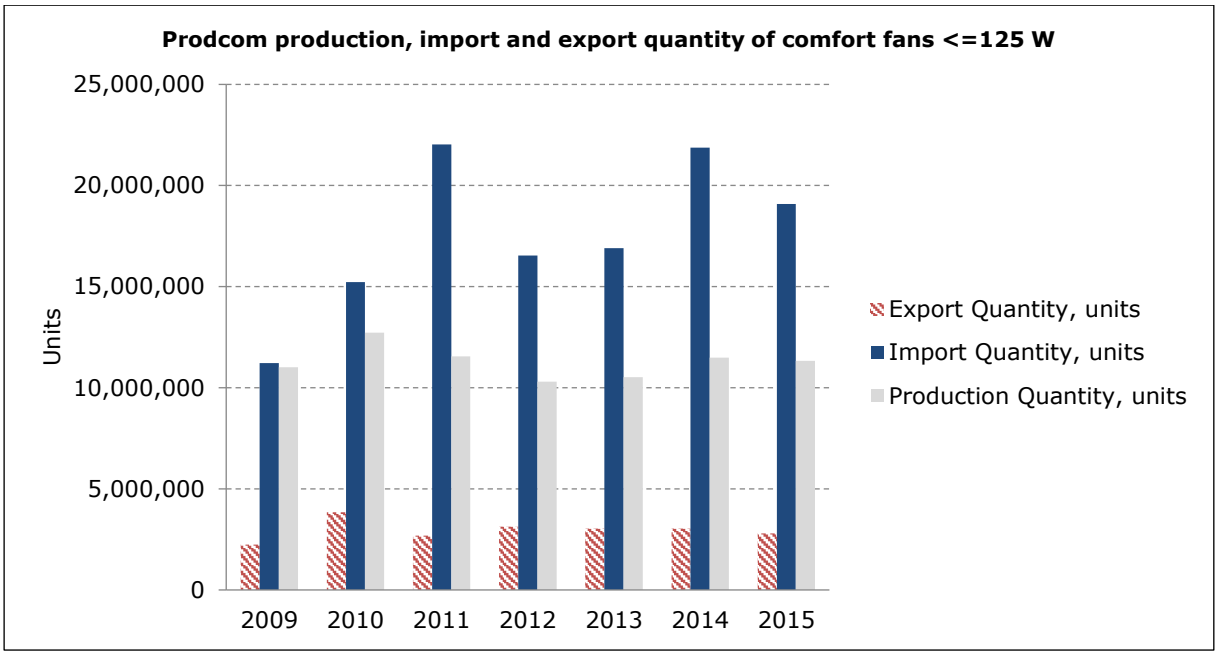


Figure 2: Total production, import and export quantity of comfort fans below 125 W 2009-2015. PRODCOM assessed April 2017.

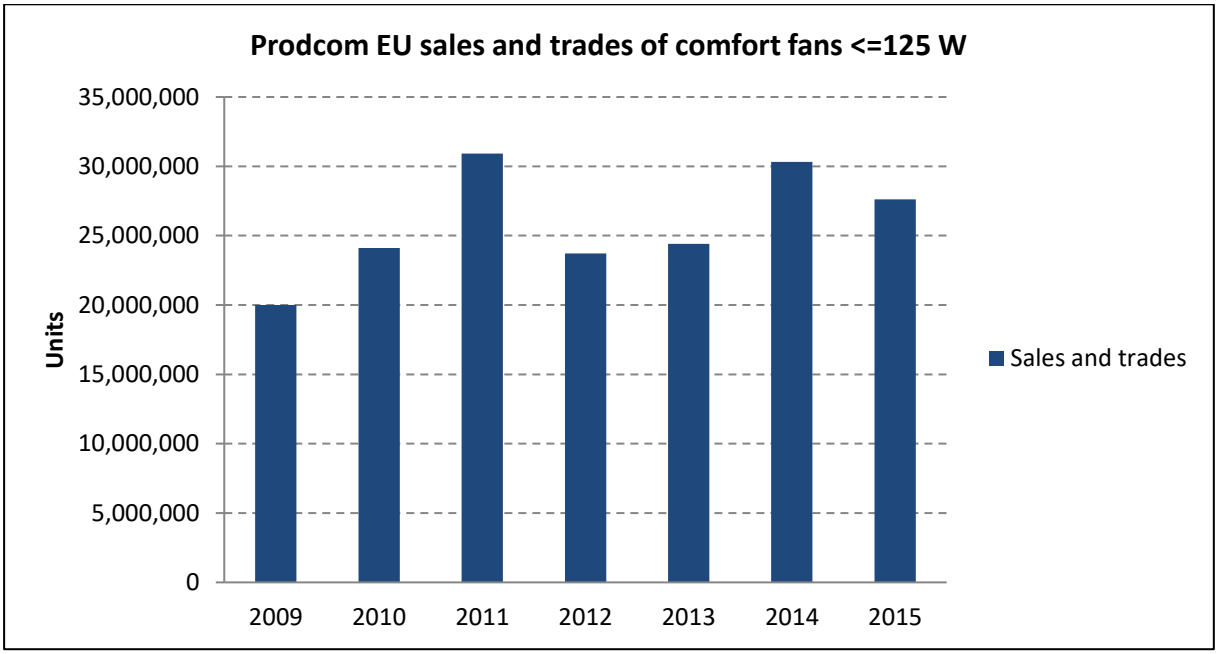


Figure 3: Total EU sales and trading of comfort fans below 125 W 2009-2015. PRODCOM assessed April 2017.

The general tendency is a slight increase in the period from 2009 to 2015. The sales and trading are expected to be highly connected with the weather in the year concerned, so over a period of time one must expect some fluctuation in the sales and trading. Since 2012 the EU sales and trading of comfort fans has increased with an average increase of 5 % per year. This increase is highly connected with the increase in import. The production and export of comfort fans only have minor fluctuation over the years with an almost flat trend.

In case of no other data available for comfort fans, PRODCOM data would be used in the later tasks. Data shows that the sales and trades of comfort fans in EU countries is in the

range of 20 to 30 million units per year. This meets the criteria set in Ecodesign Directive Article 15 that "the product shall represent a significant volume of sales and trade, indicatively more than 200 000 units a year within the Community according to the most recently available figures".

2.2 Market and Stock data

This section presents estimated market and stock data for each of the product types within scope as defined in task 1.

2.2.1 Present market

EU wide, main types of air conditioners in use are single duct (and double duct) air conditioners and split systems. Other types have very low sales:

- window / through the wall air conditioners: about 4000 units sold in 2015[1] (about 20000 in 2005 according to Lot 10 preparatory study)
- in the portable segment, mobile split air conditioners have almost disappeared with total sales below 1000 units in Europe[2];
- mini-VRF multisplit systems: this is a new product on the market; total EU sales of VRF are about 100000 units in 2015, of which maximum 30000 units have cooling power below 20 kW[3]; still, very few models are available below 12 kW but their number is growing; so sales of mini-VRF are likely to be below 10000 units[4] per year so far but are likely to increase with the consolidating offer.
- ventilation exhaust recovery heat pumps: EHPA statistics indicate figures about 10000 units in 2015 but it probably also encompasses exhaust air to water heat pumps, and not only air-to-air units.

It is thought that the sharp decrease in sales of window air conditioners and mobile split is in part due to the effects of the Regulation (EU) No 206/2012, where these products are classified with fixed split systems.

Total sales of air conditioners were about 4.2 million units in 2015, a figure about 40 % lower than the 2007 sales (Figure 4), before the economic crisis. The sales of portable air conditioners were about 0.6 million units in 2015, which is similar to 2005 sales (as modelled in EuP lot 10 preparatory study). The share of portable air conditioners in sales is similar in 2015 and in 2005 about 14 %, varying depending on the years between 10 and 15 % according available information.

[1] Source BSRIA
[2] Source GfK
[3] Source BSRIA
[4] Estimate built upon UNICLIMA statistics for France.

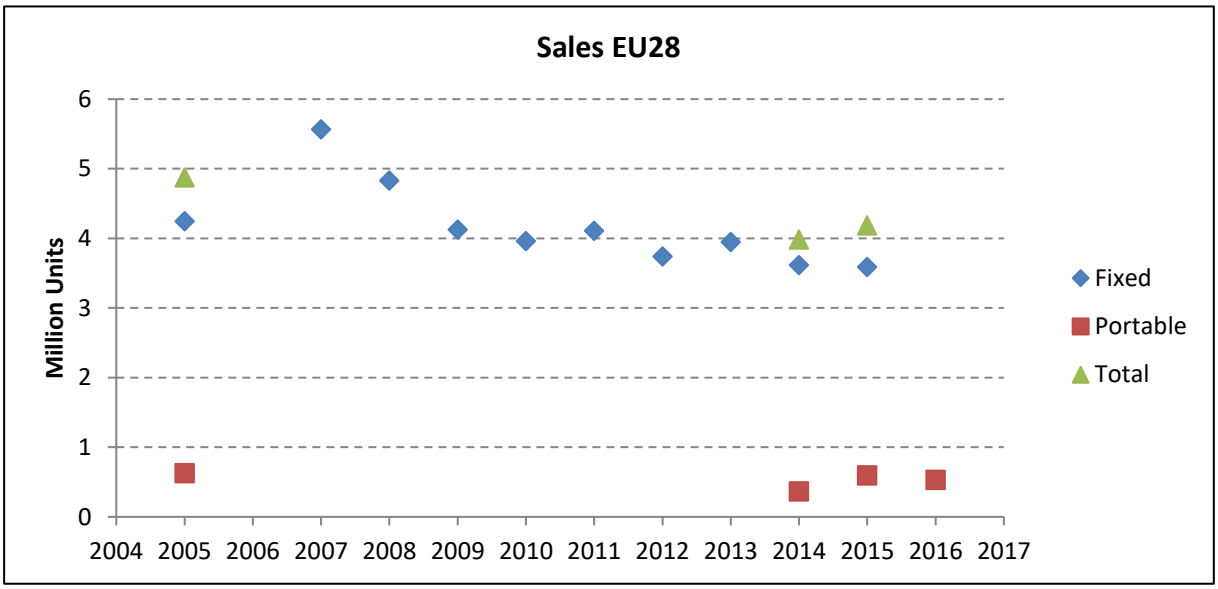


Figure 4: Total EU sales in units, 2005 data - EuP Lot 10 preparatory study (2008), other split data - BSRIA source adapted, other portable data - BSRIA and GfK source adapted.

These sales are worth 2.7 billion euros, of which about 0.2 billion euros are for the portable air conditioners and 2.5 billion euros for fixed split. Above the decreasing sales from 2007 to 2015, the average value of split unit sold decreased. The total value of split sales sank from a high at 4.7 billion euro in 2007 down to 2.5 billion euro in 2015.

According to BSRIA, more than 99% of portable air conditioners are imported with small production in the Netherlands and in Sweden. The situation is different for split air conditioners, for which a larger proportion is produced in Europe. The share of production in sales however is not known at EU scale.

It is important to have an order of magnitude of what these sales mean in terms of installed power. EU28 sales represent about 16 GW cooling capacity or around 4.5 electric GW in peak conditions. Only a small portion of the sales being replacements, there is a net electric load addition of over 3 GW per year due to these products.

The analysis by country for split air conditioners (Figure 5), shows that largest AC countries, Spain and Italy, most suffered from the crisis, as their relative share of the EU market significantly decreased, in addition to the general sales decrease. Main markets are still Spain, Italy and Greece, but they only represent 45 % of 2015 sales versus 65 % in 2007.

Regarding mobile air conditioners (Figure 5), Spain, Italy and Greece only represent about 35 % of the sales, while biggest EU countries Germany, France and the UK gather nearly 40 % of the sales.

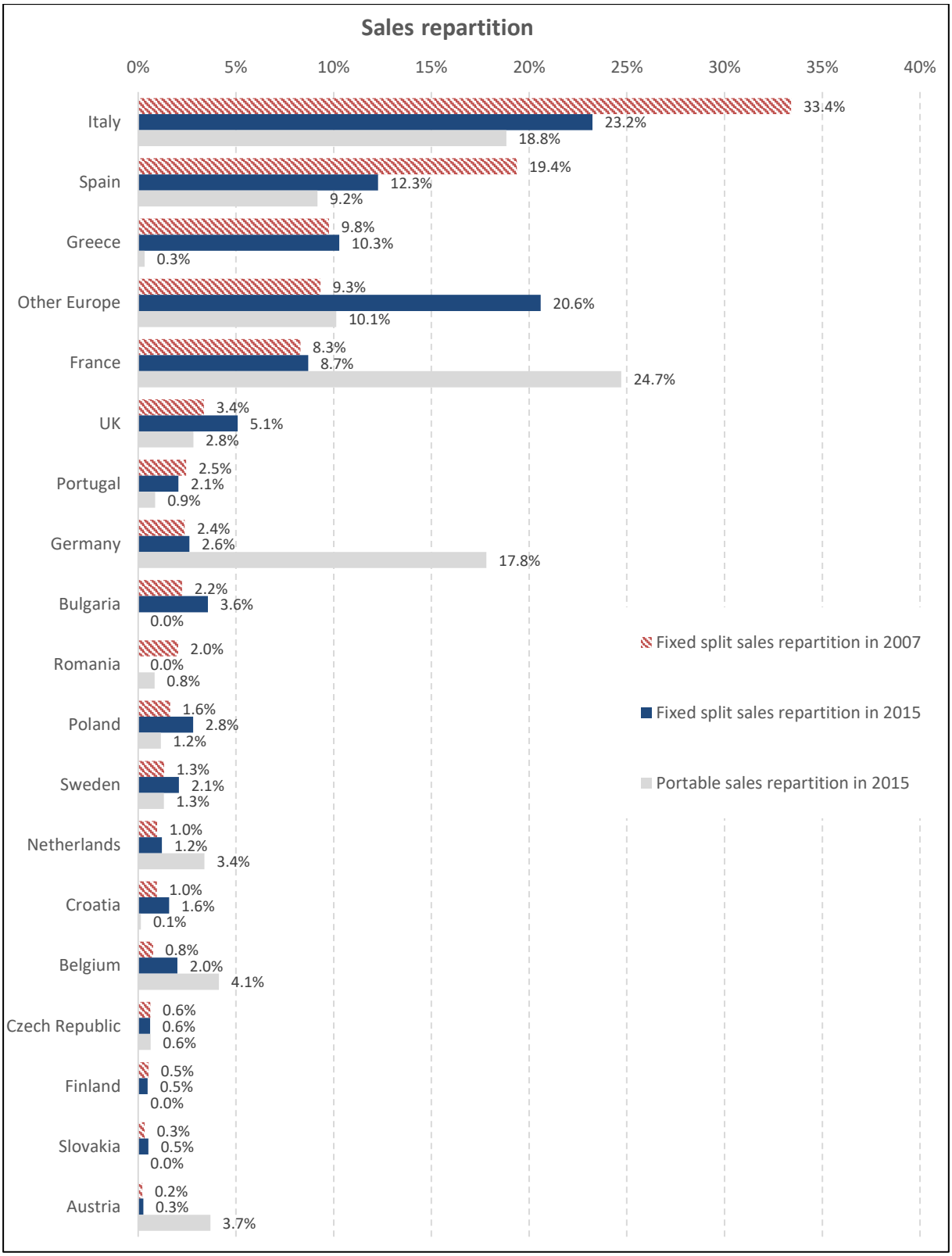


Figure 5: Portable and Split air conditioners repartition by country of EU28 sales in 2007 and in 2015, sources BSRIA and GfK adapted.

The primary driver of energy consumption is the unit size (supposing adequate sizing of the unit to the cooling needs). The analysis by size is shown Figure 6 for portable air conditioners. The weighted average size of portable is 2.6 kW.

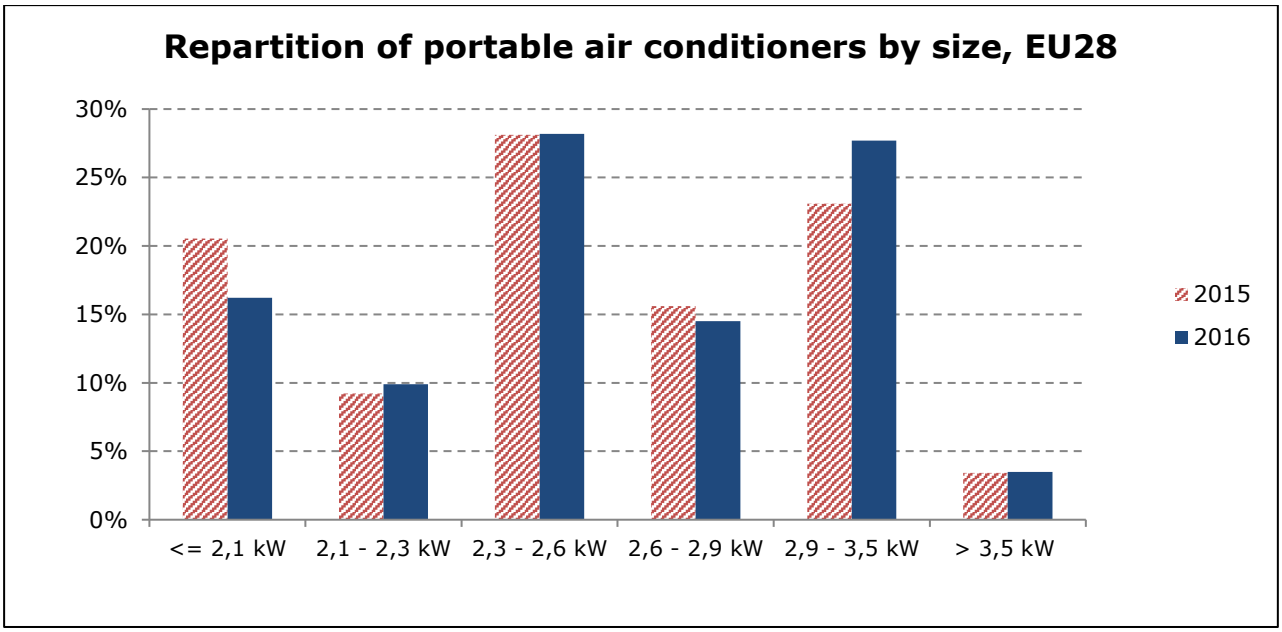


Figure 6: Portable sales distribution by size, sources BSRIA and GfK adapted.

Sales distribution for split are shown in Figure 7. The weighted average unit size is of 4.2 kW. In Regulation (EU) No 206/2012, two different capacity segments are used, 0-6 kW and 6-12 kW, they respectively represent 80% and 20% of the sales, and 2/3 and 1/3 of the sold cooling capacity. Multisplit units represent about 18% of the sales in number of units and close to 20% in terms of cooling capacity.

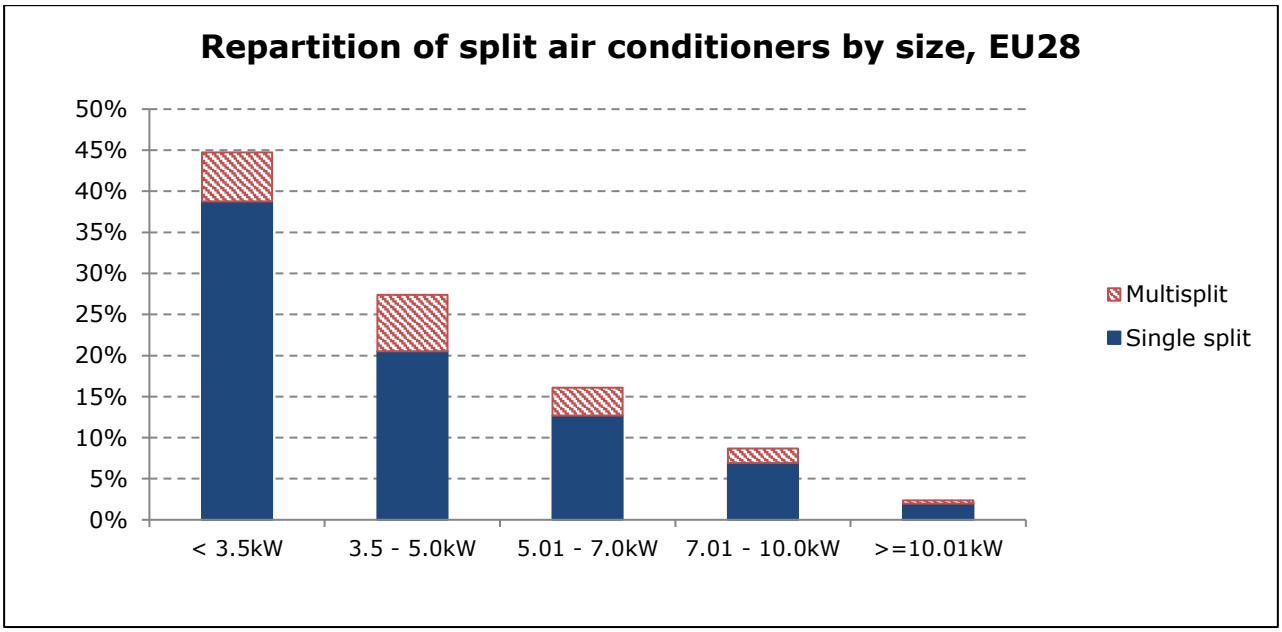


Figure 7: Split sales distribution by size, source BSRIA.

Indoor units of split systems may have different mounting types, with different typical technical characteristics, including differences in average capacity and efficiency levels. Distribution of indoor units of single split air conditioners is shown in the table below in terms of number of units and in terms of capacity.

In Table 3, indoor unit type is shown by product type, separating multisplit air conditioners, while in Table 4, the indoor unit type of split and multisplit air conditioners are added to have a single distribution of all indoor unit types.

Table 3: Distribution of split systems by type of indoor unit, BSRIA source

Distribution of split systems by type in number						
	Single split					Multi-split
Capacity range in kW	Wall	Ceiling type	Floor/vertical or consoles	Cassette	Ducted	All types
0-5	74 %	2%	2%	2%	3%	18%
5-12	39 %	6%	1%	20%	17%	17%
7-12	17 %	8%	1%	35%	24%	15%
0-12	63 %	3%	1%	8%	7%	17%
Distribution of split systems by type in capacity						
	Single split					Multi-split
Capacity range in kW	Wall	Ceiling type	Floor/vertical or consoles	Cassette	Ducted	All types
0-5	73 %	2%	2%	3%	3%	18%
5-12	35 %	6%	1%	23%	19%	16%
7-12	16 %	8%	1%	35%	25%	14%
0-12	54 %	4%	1%	13%	11%	17%

Table 4: Distribution of indoor units of split and multisplit systems by type of indoor unit, BSRIA source

Distribution of indoor units of split and multi-split systems by type in number					
Capacity range in kW	Wall	Ceiling type	Floor/vertical or consoles	Cassette	Ducted
0-5	91%	2%	2%	3%	3%
5-12	74%	4%	2%	11%	9%
7-12	20%	9%	2%	38%	30%
0-12	83%	3%	2%	6%	6%
Distribution of indoor units of split and multi-split systems by type incooling capacity					
Capacity range in kW	Wall	Ceiling type	Floor/vertical or consoles	Cassette	Ducted
0-5	90%	2%	2%	3%	3%
5-12	47%	7%	2%	23%	21%
7-12	20%	9%	2%	38%	30%
0-12	71%	4%	2%	12%	11%

Over the 0-6 kW capacity range, single split with wall indoor unit is clearly the most common product type. However, above 7 kW, the most common product type is a single split unit with cassette type indoor unit.

Air conditioners below or equal 12 kW do not only serve the residential sector. The sector of use is differentiated depending on the type of unit. This is an important matter to then evaluate the cooling needs and the energy consumption of units as internal loads and hours of use are very different depending on the sector of use. Portable are more likely to be

found in residences while larger split and multisplit air conditioners are mostly installed in the service sector. However, there are large variations on a country by country basis. Destinations are shown for 5 countries and in average for portable and split air conditioners in Figure 8 below. In average about 75 % of portable sales are in the residential sector, and only 65 % for split. However, there is marked variation with size: for larger than 5 kW units, the share of the sales in the residential sector falls down to 33% in average.

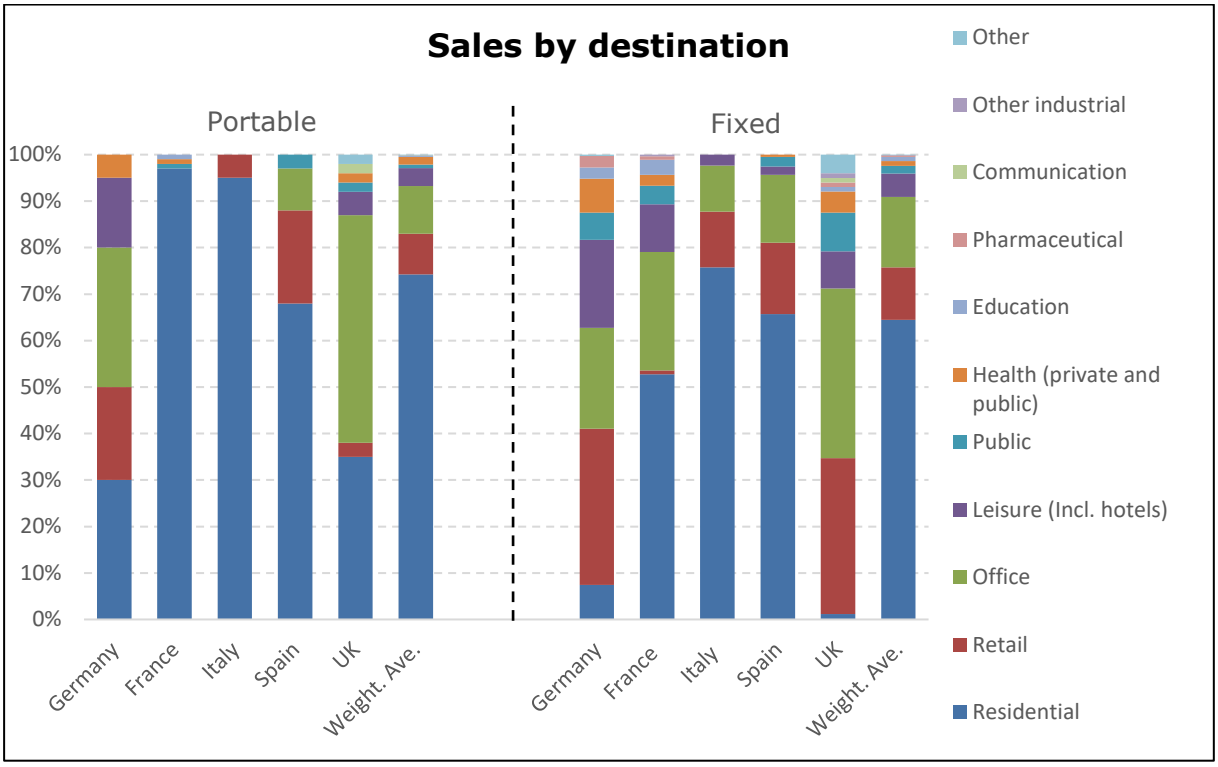


Figure 8: Repartition of portable and fixed split sales by sector of use, source BSRIA.

For the market dynamics, it is essential to know the application type, i.e. whether the sales are for replacement, first time installation in an existing building or in a new building. In a completely saturated market, the stock of products in use only grows by new building installations and there is no sale corresponding to first time installation in existing buildings. As shown in Figure 9 below, the majority of sales of both portable and split air conditioners are still largely first-time installations in existing building, 70 to 80 % in average.

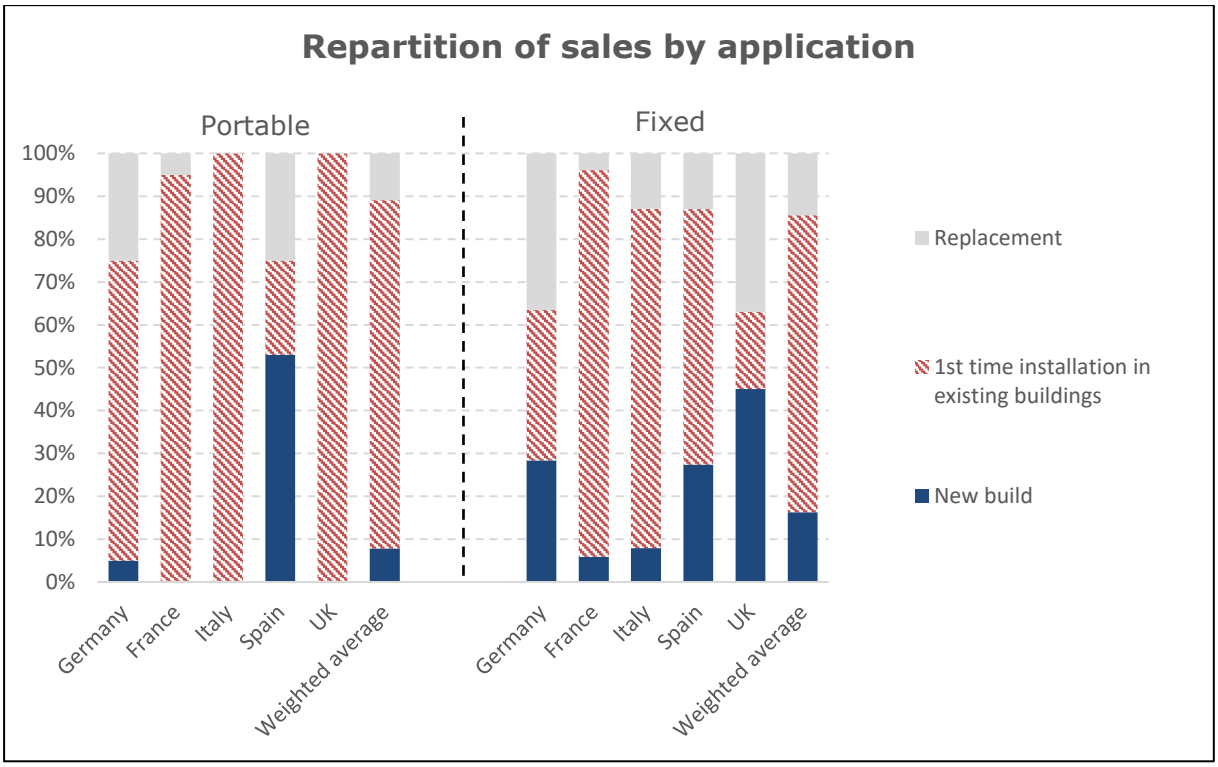


Figure 9: Repartition of portable and split sales by application, source BSRIA.

Reversibility is an essential characteristics of air conditioners as the heating function may be the main reason to buy an air conditioner in some cases.

The trend observed in EuP Lot 10 study for split air conditioners have been confirmed: cooling only units have almost completely extinguished. BSRIA sales indicate their share moved from about 10% in 2007 to roughly 3 % in 2015. In the ECC certified product database 2016 catalogue, there only remains 90 multisplit over 2200 models that are not reversible, or about 4 % of the models (note: the share of cooling only units were about 60 % in 2000 and 30 % in 2005 in the same database).

Reversibility is also present for portable air conditioners. Based on GfK information, at least 5 % of portable units sold in Europe were reversible in 2015 and 11% in 2016. These figures are for thermodynamic heating. However, some of the reversible models proposed are not using the thermodynamic cycle for heating but rather a simple electric resistance. According to BSRIA information, this is limited however to about 3 to 4 % of the sales of portable air conditioners. This to be compared with the situation in 2002-2005 described in Figure 10 below extracted from EuP Lot 10 study. It appears that the proportion of reversible portable air conditioners sold did not change but that reversible products using electric resistance have been replaced partly by thermodynamic heating.

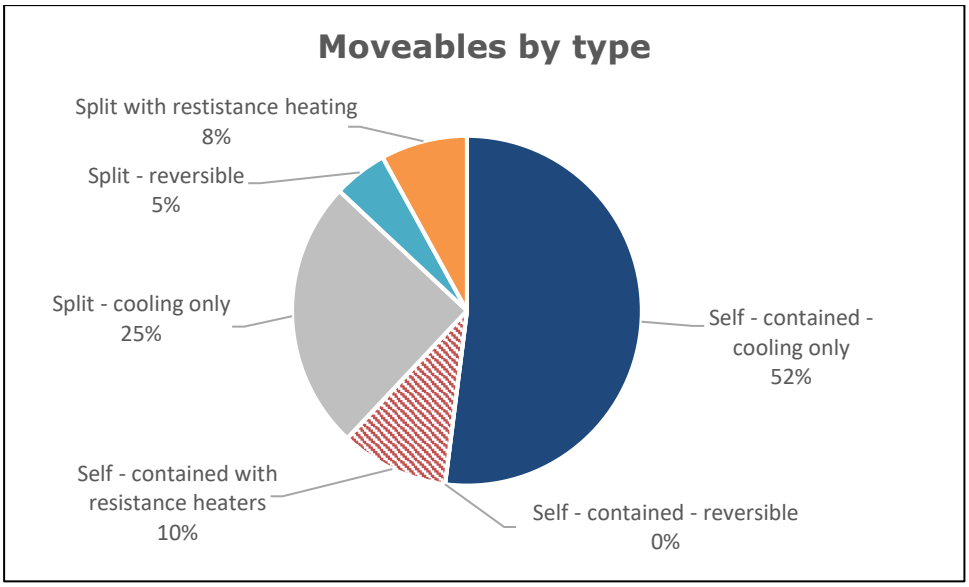


Figure 10: Portable air conditioners share by type and reversibility in Europe in years 2002-2005, source EuP Lot 10 study.

Product life time is a necessary input to compute the stock of models in use. In the Lot 10 preparatory study, 12 years was used for both splits and portable air conditioners. This value is conserved for split air conditioners, as data collection from industry stakeholders have confirmed the lifetime for split air conditioners is 12 years[5]. For portable air conditioners, more recently, US DOE[6] used a 10.5 year average lifetime with a rather large dispersion however (standard deviation close to 5 years). This average life time is close to the one in the ENEA study (referred to in the EuP Lot 10 preparatory study) of 10.5 years average life time. For ease of calculation, this value is rounded to 10 for stock calculation here after.

2.2.2 Model for estimating sales and stock

2.2.2.1 General outline of the model

A sales and stock model is necessary to estimate present values and to build scenarios in Task 7. As explained in previous EuP Lot 10 study, air conditioning sales depend on climate and economics, but also on cultural and building construction habits. The EU28 dynamics is thus best represented at country level (or at lower scale, but there finding information is nearly impossible).

A similar model to the one developed for Lot 10 study has been used. Sales are projected to reach a defined air conditioning penetration level (called saturation hereafter) at a long-term horizon depending on climate. Climate change impact on saturation levels has been included. This model is adapted to model the sales of countries for which limited information on sales is available.

In order to better represent the penetration of air conditioning in the building sector and its evolution towards saturation levels, the share of units installed in the tertiary sector

[5] Data collection from industry stakeholders, June 2017.
[6] https://www.regulations.gov/document?D=EERE-2013-BT-STD-0033-0047

have been represented and the other air conditioning systems (Package, VRF, Chillers) as well.

Note that this model has been first developed by Armines in the frame of the H2020 Heat Roadmap Europe project[7] and adapted for this review study.

More details on the methodology, equations, assumptions, and data sources used in the model are given here after and in Annex 1: Test conditions for SEER and SCOP determination of exhaust air-to-outdoor air heat pumps and air conditioners

2.2.2.2 2015 stock estimate

Stock estimate, in number of units and in kW rated cooling capacity, is based on sales data, lifetime and average product size by product type and sector for years 1992-2015 for 16 EU member states: Austria, Belgium, Czech Republic, Greece, Finland, Italy, France, Germany, Hungary, Netherlands, Poland, Portugal, Romania, Sweden, Spain and UK. This mean that the stock model is an upper estimate driven by economic and sales data.

The stock *s* at the end of year *n* for each country (16), each sector and technology is given by:

$$s_n = \sum_{i=n-L+1}^{n} v_i \qquad \text{(Eq. 1)}$$

where *L* is the average lifetime and *v* the sales.

For the other 12 EU countries for which there is not enough sales data available (Bulgaria, Croatia, Cyprus, Denmark, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Malta, Slovakia, Slovenia), the procedure presented in Annex 2: Estimating 2015 stock for countries with insufficient sales dataAnnex 1: Test conditions for SEER and SCOP determination of exhaust air-to-outdoor air heat pumps and air conditioners is used to estimate the 2015 stock. Note: these 12 countries represent about 7% of the total EU population.

2.2.2.3 Future sales and stock projection

A logistic function with three free parameters (Eq. 2) is used to model the growth of total power sold in each of the 16 countries with past sales information, separately for each sector, until 2050 which then allows to calculate the future total installed capacity as explained above for 2015.

$$power\ sold\ in\ year\ y\ = \frac{\boldsymbol{L}}{1 + exp[\,-\boldsymbol{k}\,(y-\boldsymbol{y_m})]} \qquad \text{(Eq. 2)}$$

L is the upper asymptote, k the 'steepness' and y_m the midpoint (and inflection point) about which the curve is symmetric. The three free parameters are calibrated using three points:

1) The power sold in 2015 for all unit types
2) The power sold in 2020 estimated by linear growth based on the compound (growth of the installed rated cooling capacity by country and sector) annual growth rate before the economic crisis (1994-2007) derived from the sales data.
3) A market saturation limit represented by the total cooled indoor floor area derived from the stock.

[7] http://www.heatroadmap.eu/

The capacity sold and stock are then redistributed into the different technologies based on past years' sales repartition trends (Table 26 and Table 27).

This procedure is illustrated below (Figure 11) for the residential sector in Spain. In that case, the Spanish market is estimated to reach again its highest level of 2007 around 2045.

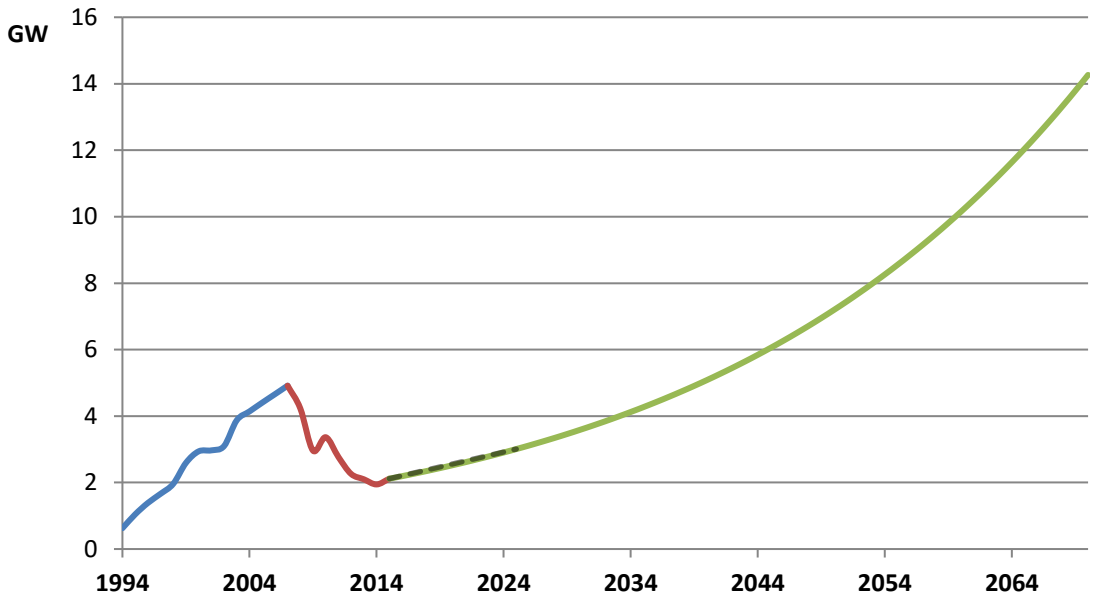


Figure 11: Air conditioning sales in the residential sector in Spain (in GW of rated cooling capacity); past sales - in blue (before crisis) and in red (post crisis); sales projection - in green ; sales growth 2015-2025 in black dash line.

Compound annual growth rates of sales of rated cooling capacity of all product types for years 1992-2015 are shown in Table 5 below.

Table 5: Compound annual sales growth rates of standard rated cooling capacity by country for 16 EU countries, 1992-2015, sum of all product types and sectors

Country	1992-2007	2007-2015	1992-2015
Austria	11%	-3%	6%
Belgium	10%	1%	7%
Czech Republic	15%	-4%	8%
Finland	8%	-8%	2%
France	10%	-4%	5%
Germany	10%	-1%	6%
Greece	10%	-5%	4%
Hungaria	15%	-6%	7%
Italy	12%	-7%	5%
Netherlands	7%	0%	4%
Poland	14%	2%	10%
Portugal	12%	-11%	3%
Romania	18%	-2%	10%
Spain	14%	-9%	5%
Sweden	11%	-1%	6%
UK	11%	-1%	7%

For the 12 EU countries with limited information, the development of the stock is modelled directly, based on a logistic curve connecting the current cooled floor areas to the supposed saturation. By reverting the logic of the stock model from the point of projected saturation sales data going back to 2015 can be deduced, following Eq. 3 below, adapted from Eq. 1 above.

$$v_n = v_{n+L} + s_{n+L-1} - s_{n+L} \qquad \text{(Eq. 3)}$$

The total EU building stock is supposed to grow annually at a constant growth rate, the same for both sectors, so that the stock of air conditioning products goes on growing slightly even after the saturation has been reached.

For the 12 EU countries with limited information, hence, sales after saturation continue growing as follows (Eq. 4):

$$v_{n+L}{}^{(sat)} = v_n{}^{(sat)}(1+r)^L \qquad \text{(Eq. 4)}$$

where r is the rate of growth of the total floor area which drives the growth at saturation and L the product lifetime. This assumption allows to deduce the sales figures by relating v_{n+L} to v_n reducing Eq. 3 to one unknown.

2.2.2.4 Saturation of air conditioners market

In the residential sector, the total cooled floor area at market saturation of the EU 28 is modelled as a function of the cooling degree days (CDD) and additionally as a function of the average household income for the residential sector. The household income is estimated by the average Gross national income (GNI) per capita at purchasing power parity in 2015 US$ multiplied by the countries average household size. The US market saturation is assumed to be limited only by climate and not by income. The values obtained this way are then corrected for income which results in the following overall equation for the residential sector:

$$share\ of\ residential\ cooled\ floor\ area\ = \frac{1-\exp(a \times CDD)}{1+b \times \exp(c \times GNI/household)} \qquad \text{(Eq. 5)}$$

where a, b and c are regression parameters; a is calibrated based on the US market (denominator assumed to tend to zero at high income) and b and c are given by a calibrated model by McNeil et Letschert (2010)[8].

Service sector penetration at saturation is supposed to depend only on climate (Eq. 6), where d is a regression parameter.

$$share\ of\ service\ floor\ area\ cooled = 1 - \exp(d \times CDD) \qquad \text{(Eq. 6)}$$

Both correlations of (Eq. 5) and (Eq. 6) as well as US zones computed from US EIA residential 2009 microdata and 2012 commercial microdata[9] are shown on Figure 12 below.

[8] http://www.sciencedirect.com/science/article/pii/S0378778809003119
[9] https://www.eia.gov/consumption/

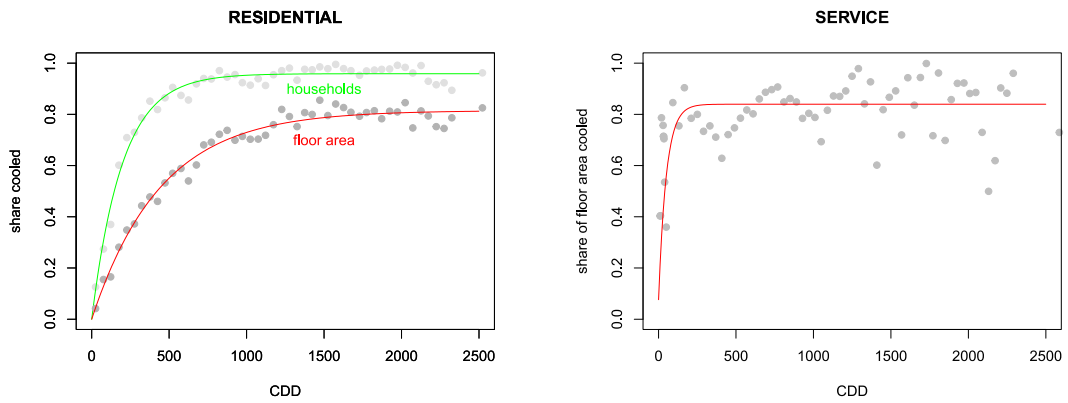


Figure 12: Saturation models and US penetration data (source EIA) of air conditioning in the residential (left) and service sector (right),

Because of global warming, cooling degree days evolve in time, increasing the market saturation level. The same is true for GNI while number of people per household rather tends to decrease in Europe.

Yearly values of cooling degree days are computed from the maximum and minimum temperatures for each day of the year, by comparing their average to a reference temperature (here 18°C).

$$CDD = \sum_{i=1}^{days\ of\ year} max\left(0 \ , \frac{(T_{max}(i)+T_{min}(i))}{2} - T_{ref} \right) \quad \text{(Eq. 7)}$$

The expected change over time up to 2050 of the CDD is modelled based on the Representative Concentration Pathway (RCP) 4.5 scenario developed for the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). CDD are calculated from daily temperature maxima and minima projections by the model of the French Centre National de la Recherche Météorologique (CNRM) based on the RCP scenario. The results are provided by the public NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset. A population weighted average of the largest urban centres (between 1 and 8 locations depending on the spacial population distribution of the country) is chosen to represent the countries' climates (this distribution is given in Annex 3: Cities by country to compute national average CDD from CNRM model).

Figure 13 shows the projection of CDD according to the CNRM model and RCP4.5 scenario for six specific countries (All the modelled countries are shown in Annex 4: CDD evolution and GNI per capita). Yearly variability has been erased to exhibit climate evolution trends.

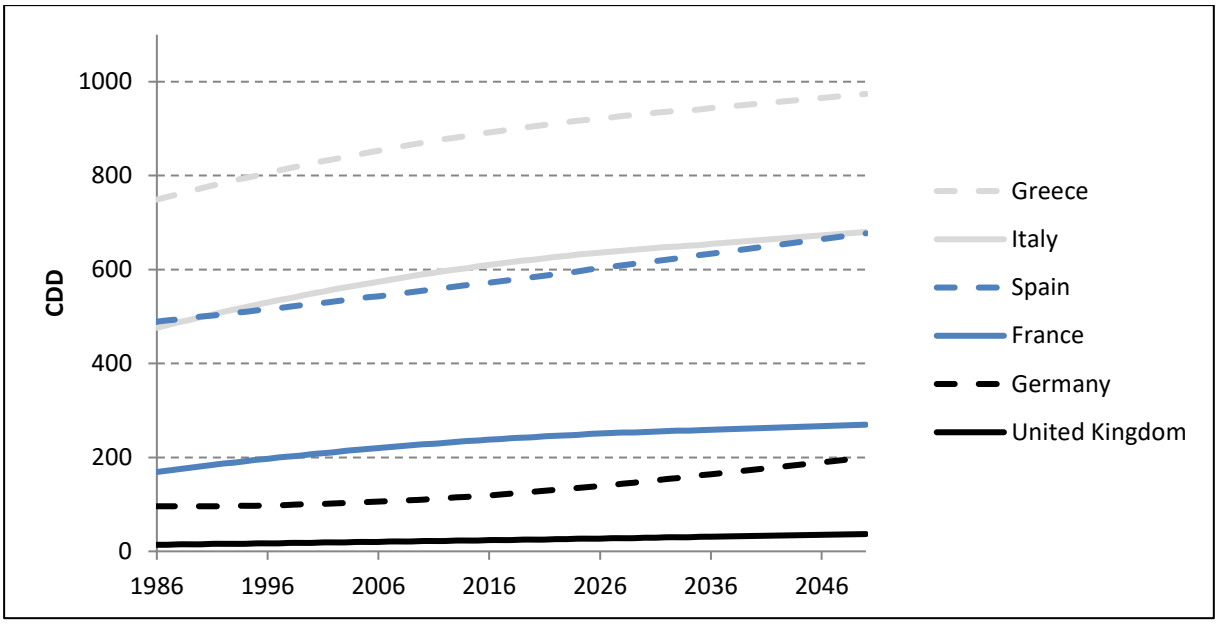


Figure 13: CDD evolution following climate change impact according to CNRM model, scenario RCP4.5, and country model according this report

GNI ppp (Purchasing Power Parity) per capita are available from the World Bank. Number of people per household are available from Eurostat. GNI ppp per capita and linear projections to 2030 are shown on Figure 14 below.

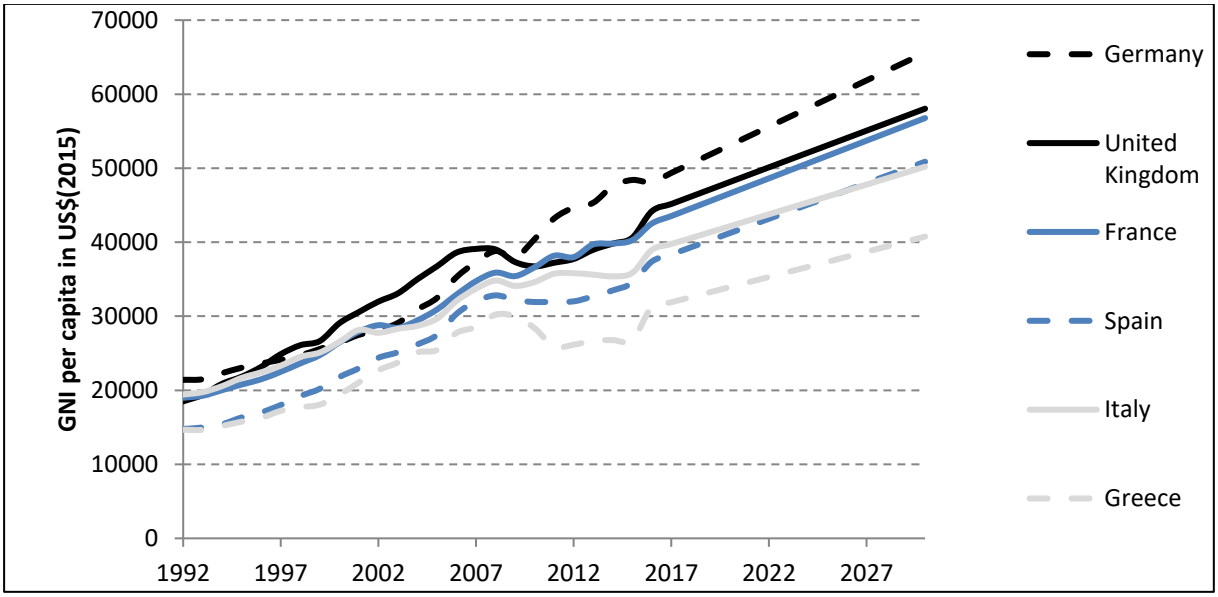


Figure 14: GNI per capita in US$(2015), source World Bank, and linear projections to 2030

The impact of CDD and GNI per household variations in time (considering constant 2015 number of people per household) is shown in Table 6 below. Looking at countries with limited change in CDD between 2015 and 2030, it appears the main impact in the saturation formula is due to the GNI evolution. Countries with lower GNI per capita levels see their saturation level increasing more strongly between 2015 and 2030. To estimate future saturation levels, supposed to be reached by 2060, 2030 saturation levels calculated have been kept avoiding hazardous projections of GNI and number people per households at a longer time horizon.

The comparison between saturation levels and penetration levels shows that the potential for growth is still very high, that it will increase significantly with climate change and that it is very sensitive to household purchasing power for EU countries with lower GNI per capita and hence to product price evolution.

Table 6: Comparison of CDD, saturation level in residential and service sectors, penetration level in residential and service sectors in 2015 and 2030

	2015 CDD	2030 CDD	Sat. res. 2015	Sat. res. 2030	Sat. ser. 2015	Sat. ser. 2030	Res. pen. 2015	Ser. pen. 2015
Austria	226	280	30%	38%	77%	80%	1.2%	13.5%
Belgium	89	95	14%	16%	53%	55%	1.7%	41.2%
Bulgaria	317	384	4%	15%	81%	83%	4.2%	26.2%
Croatia	325	377	15%	39%	82%	83%	5.8%	27.3%
Cyprus	1417	1467	56%	77%	85%	85%	35.0%	84.7%
Czech Republic	117	161	10%	22%	61%	69%	1.5%	18.1%
Denmark	43	74	6%	12%	35%	48%	0.6%	6.6%
Estonia	30	59	2%	9%	28%	42%	0.4%	6.1%
Finland	24	49	3%	8%	24%	38%	0.3%	16.8%
France	236	254	28%	35%	77%	79%	5.1%	33.1%
Germany	118	149	16%	23%	61%	67%	0.5%	15.6%
Greece	889	931	25%	60%	85%	85%	18.1%	76.3%
Hungary	259	320	10%	30%	79%	82%	2.4%	17.2%
Ireland	6	7	1%	1%	12%	13%	0.3%	4.9%
Italy	607	644	42%	60%	85%	85%	13.2%	79.1%
Latvia	42	82	2%	11%	34%	51%	0.5%	6.6%
Lithuania	76	123	4%	18%	49%	62%	0.9%	8.0%
Luxembourg	115	121	19%	19%	60%	62%	1.8%	10.1%
Malta	1258	1321	59%	74%	85%	85%	31.0%	84.7%
Netherlands	42	48	7%	8%	34%	37%	0.8%	17.1%
Poland	109	157	8%	22%	59%	69%	0.9%	19.5%
Portugal	418	491	26%	49%	84%	84%	3.2%	31.0%
Romania	437	495	14%	39%	84%	84%	6.0%	45.8%
Slovakia	168	214	17%	31%	70%	76%	2.3%	13.1%
Slovenia	243	283	17%	35%	78%	80%	3.9%	19.0%
Spain	569	615	44%	60%	84%	85%	10.8%	79.8%
Sweden	18	39	2%	7%	20%	33%	0.8%	31.0%
UK	23	29	3%	5%	24%	27%	0.9%	48.4%

2.2.3 Estimated sales and stock

Based on the data described in part 2.2.1 and the model presented in part 2.2.2, the sales and stock estimates by country have been calculated from 2010 to 2050 and are presented below. These are the sum of portable and split sales and stock. Sales are shown in Table 7 and Figure 15. Sales growth corresponds to almost a doubling of the sales by 2025. Detailed data by country and product categories, in MW and number of units are given in Annex 3. Portable sales have been set almost constant (growing with the building stock growth rate estimate)[10] although the sales history of portable air conditioners do not confirm that hypothesis. It might be however that the 2020 ban on portable air conditioners

[10] Supplementary hypothesis made after a suggestion by Delonghi, April 2017

using higher than GWP 150, by imposing a refrigerant restriction for the EU market lead to a large increase of portable unit prices and consequent sales stalling.

Table 7: EU sales estimate and prevision of less than 12 kW units (in thousands), from year 2010 to 2050

Country	2010	2015	2020	2025	2030	2035	2040	2045	2050
Austria	12	33	22	24	27	30	34	38	42
Belgium	95	100	93	103	110	118	126	135	145
Bulgaria	52	78	88	120	131	144	174	184	212
Croatia	19	51	51	91	94	100	144	149	157
Cyprus	89	91	94	97	100	103	106	109	112
Czech Republic	31	27	37	46	56	67	80	95	110
Denmark	9	20	24	48	48	52	83	89	121
Estonia	0	1	1	2	2	2	4	4	6
Finland	5	3	4	4	4	5	5	5	6
France	517	506	532	626	732	847	973	1108	1253
Germany	196	214	209	243	282	326	376	431	492
Greece	259	336	373	416	461	508	558	613	673
Hungary	66	41	59	74	94	117	146	181	222
Ireland	2	3	4	5	5	6	7	7	8
Italy	1194	970	1248	1465	1706	1979	2290	2648	3056
Latvia	1	1	2	5	4	4	8	8	12
Lituania	2	3	6	11	11	11	19	20	29
Luxembourg	1	3	3	5	5	6	9	9	12
Malta	33	34	35	37	38	39	40	41	42
Netherlands	107	68	82	95	109	124	140	157	174
Poland	121	118	150	184	221	262	306	350	396
Portugal	320	260	278	286	304	320	339	364	389
Romania	78	88	117	143	171	201	235	273	314
Slovakia	12	29	32	59	62	68	99	107	137
Slovenia	7	16	17	30	32	36	51	55	70
Spain	935	573	727	850	983	1130	1294	1484	1706
Sweden	87	84	95	99	104	109	115	121	128
United Kingdom	198	234	240	249	259	270	281	293	306
EU28	4450	3984	4622	5418	6156	6986	8041	9077	10330
Norway*	87	59	74	79	83	87	91	95	99

**Sales data provided by Norway.*

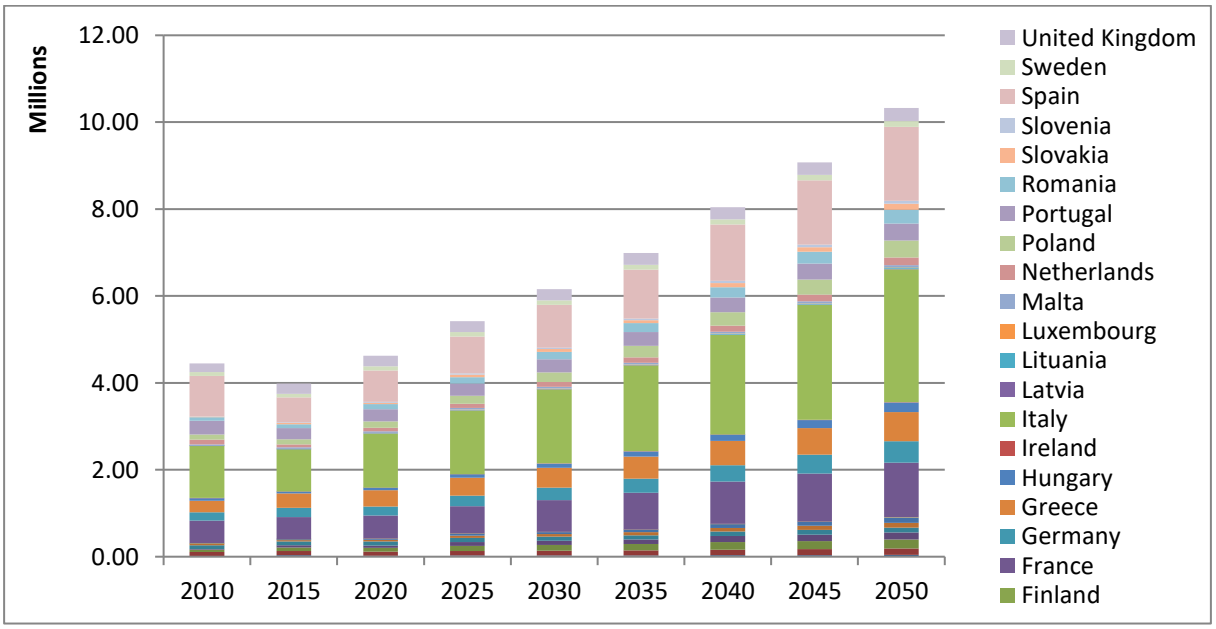


Figure 15: Sales estimates for EU28 countries of portable + split air conditioners, 2010-2050

Stock estimates for EU 28 as a total and each Member State are given below in Table 8.

Table 8: EU stock estimate and prevision of less than 12 kW units (in millions), from year 2011 to 2050

	2011	2015	2020	2025	2030	2035	2040	2045	2050
Austria	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4
Belgium	0.5	0.8	1.0	1.1	1.2	1.3	1.4	1.5	1.6
Bulgaria	0.5	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.2
Croatia	0.3	0.4	0.5	0.7	0.9	1.1	1.4	1.6	1.8
Cyprus	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3
Czech Republic	0.4	0.4	0.4	0.4	0.5	0.7	0.8	0.9	1.1
Denmark	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.9	1.1
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Finland	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1
France	4.8	5.5	5.5	6.1	7.3	8.5	9.9	11.4	13.0
Germany	1.7	1.9	2.1	2.3	2.8	3.2	3.7	4.3	5.0
Greece	4.6	4.3	3.8	4.4	4.9	5.5	6.0	6.6	7.3
Hungary	0.7	0.7	0.6	0.7	0.9	1.1	1.4	1.7	2.1
Ireland	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1
Italy	17.5	16.7	13.1	14.4	17.2	20.0	23.3	27.0	31.2
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Lituania	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Malta	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5
Netherlands	0.6	0.8	0.8	0.9	1.1	1.3	1.4	1.6	1.8
Poland	0.9	1.2	1.5	1.8	2.2	2.6	3.1	3.6	4.1
Portugal	1.0	0.9	0.7	0.7	0.8	1.0	1.2	1.4	1.7
Romania	0.8	1.1	1.1	1.4	1.7	2.0	2.4	2.8	3.2
Slovakia	0.2	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.3
Slovenia	0.1	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7
Spain	12.3	11.0	8.1	8.4	10.0	11.6	13.3	15.3	17.6
Sweden	0.6	0.8	1.0	1.1	1.2	1.2	1.3	1.4	1.4
United Kingdom	2.6	2.6	2.5	2.8	2.9	3.0	3.1	3.3	3.4
EU28	51.6	51.9	46.1	51.3	60.1	69.6	80.1	91.7	104.5
Norway*	0.5	0.7	0.8	0.8	0.9	0.9	1.0	1.1	1.1

**Stock data provided by Norway.*

The impact of the economic crisis as modelled is a stock decrease in traditional air conditioning countries, is leading to a nearly constant stock at EU28 level from 2011 to 2020. It is surprising to see the stock decrease slightly around 2015. In real life, it may mean that people have differed their decision to renew their air conditioner because of the economic crisis, with then temporary longer average lifetimes than modelled, which is not captured by the model. The stock starts again to grow by 2020 and doubles between 2045 and 2050.

2.3 Market trends

2.3.1 General market trends

The main change in the market in the recent years is the replacement of the Energy label in 2013 and the adoption of MEPS for both portable and split air conditioners in 2013 and 2014, together with the shift from full capacity ratings to seasonal performance ratings for split units.

For split air conditioners, it is not possible to directly compare SEER and SCOP values before and after regulatory changes because of the metrics change. What can be tracked

are two important efficiency drivers, which are inverter rate penetration and EER and COP at rating conditions.

Regarding penetration of inverter driven compressors in the fixed air conditioner segment, it was estimated to be about 60 % already in France in 2006 (EuP Lot 10 study). Recent BSRIA data for Germany, France, Italy, Spain and the UK confirm this rate to be 100 % for all split air conditioner sold in 2015 (lowest penetration value in 2015 was 99.7% in Spain). For portable air conditioners, only a few double duct models (concentric tubes type) could be identified so the market is almost 100% without inverter, which mainly translates the fact that EU regulation does not value it.

The ECC[11] database has been used to identify changes in split air conditioner efficiency in Europe from 2006 to 2016, for EER (Figure 16) and COP (Figure 17). The below data is also available as tables in Annex 5: Changes in split air conditioner efficiency in Europe from 2006 to 2016

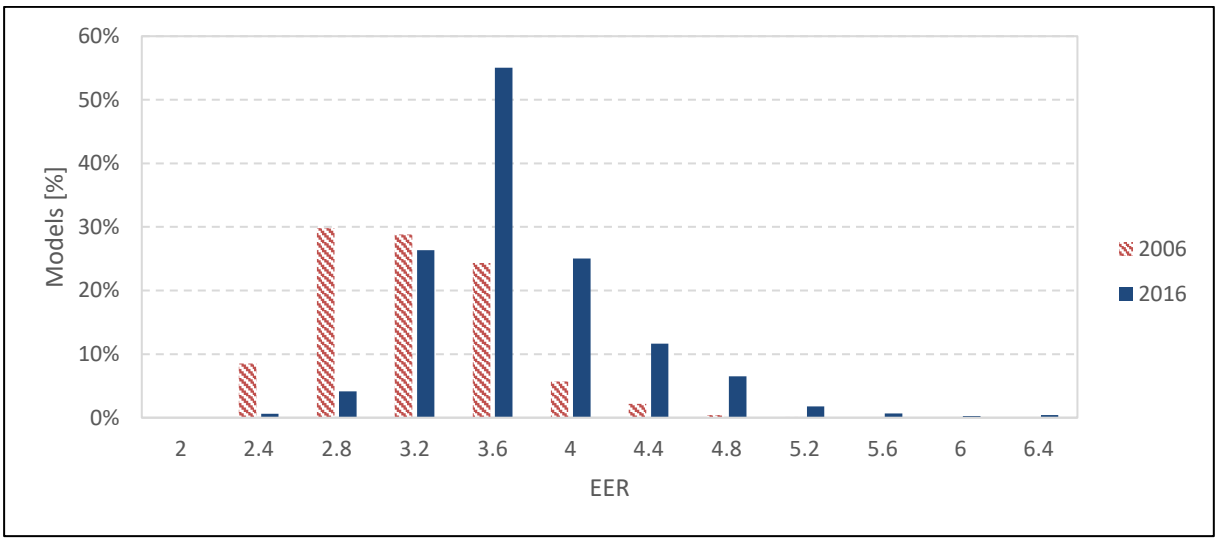


Figure 16: Eurovent Certita Certification split air conditioners below 12 kW certified products, EER evolution 2006/2016

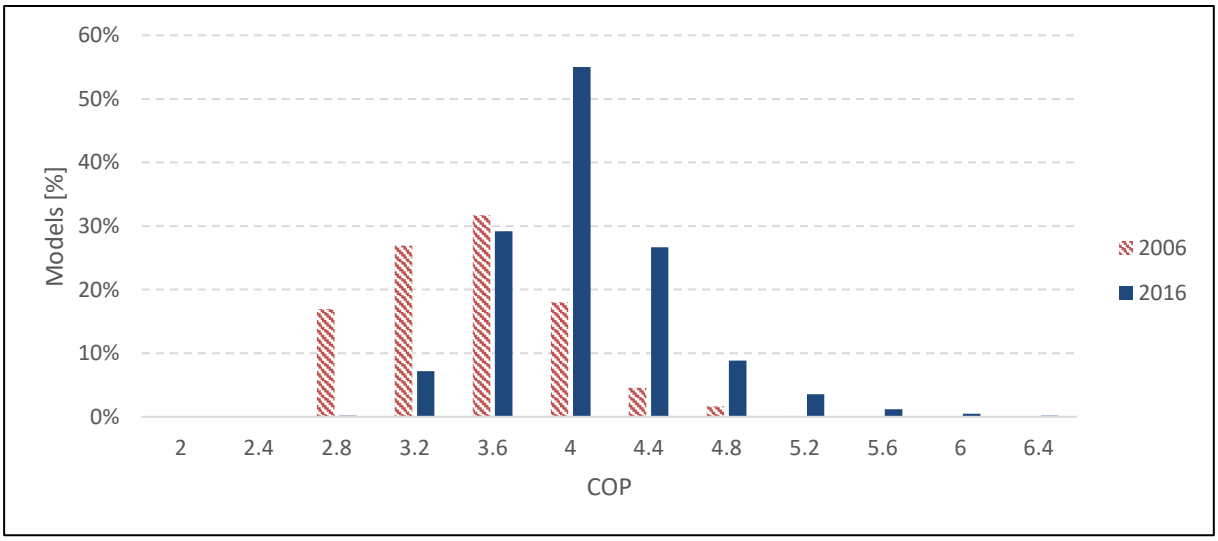


Figure 17: Eurovent Certita Certification split air conditioners below 12 kW certified products, COP evolution 2006/2016

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

Median EER increased from 2.9 to 3.4 from 2006 to 2016, which is comparable to the previous decade 1996 to 2006, where it had increased from 2.5 to 2.9. Median COP increased from 3.2 to 3.7 from 2006 to 2016, which is more than during the previous decade 1996 to 2006, where it had increased from 2.9 to 3.2.

The declared sales efficiency of split and portable air conditioners sold in Europe (GfK data for 10 EU countries) are presented in Figure 18 and Figure 19 regarding the efficiency of heating and cooling, respectively. For split air conditioners, total sales are very low as compared to total sales for these countries, so that values may not be completely representative. Not all products seem to be labelled properly, more often for portable than for split, and SCOP appear to be indicated largely below MEPS levels for a significant portion of the sales. From this data (taking only authorized declarations), it is possible to compute sales weighted efficiency values, which gives: portable EER = 2.65, portable COP = 2.53, split SEER = 5.7, split SCOP = 4.0.

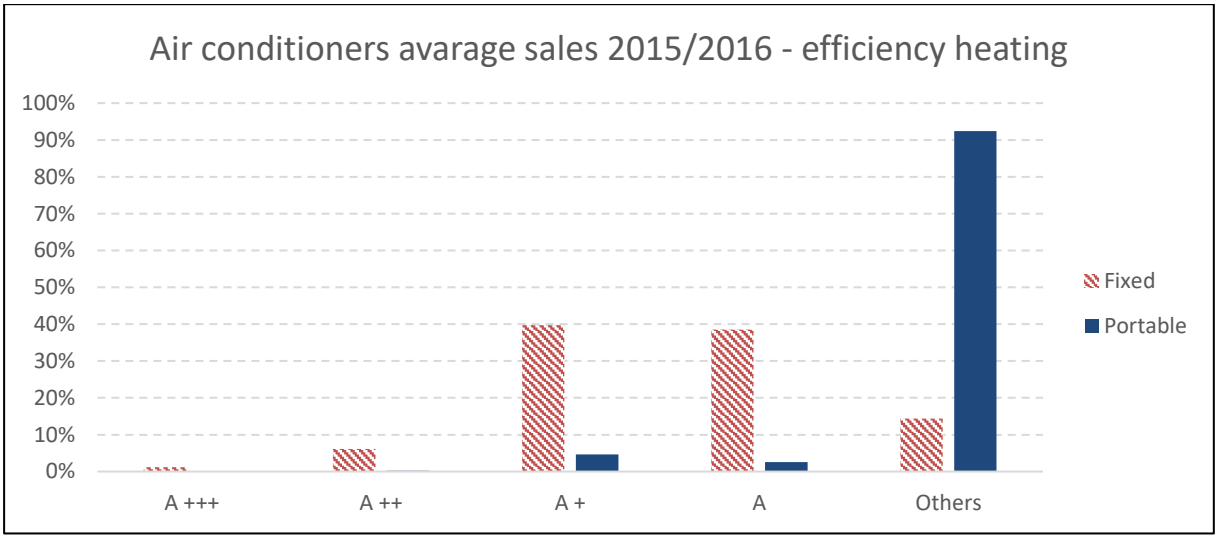


Figure 18: Air conditioners average sales 2015/2016 - efficiency heating

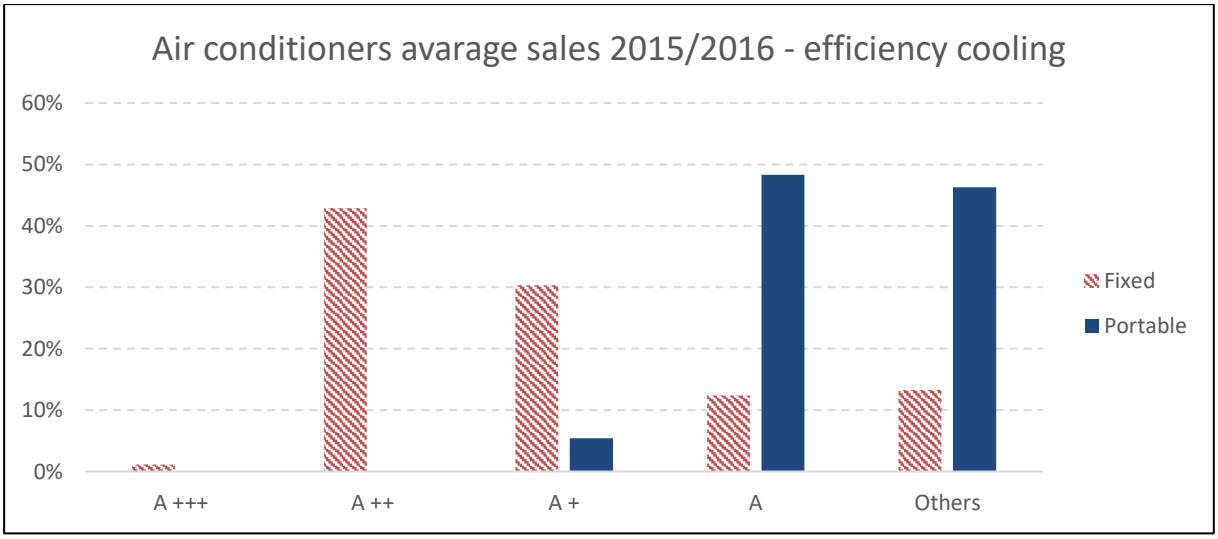


Figure 19: Air conditioners average sales 2015/2016 - efficiency cooling

For split air conditioners, these values are lower than average certified SEER and SCOP values in ECC directory: average SEER 6.2 and SCOP 4.1. It is of interest to remark that the fixed air conditioner A+++ label classes are already populated, although the label

with the A+++ indication can only be introduced in 2019 according to Energy Labelling Regulation (EU) No 626/2011 It should be emphasised that it is not lawful to use A+++ indication before 2019.

The most efficient air conditioners seem to be the air conditioners with the lowest capacity. The correlation between capacity (pdesignc) and efficiency is assessed through available data from the ECC database. In Figure 20 is the correlation between capacity and seasonal efficiency for single split air conditioners shown.

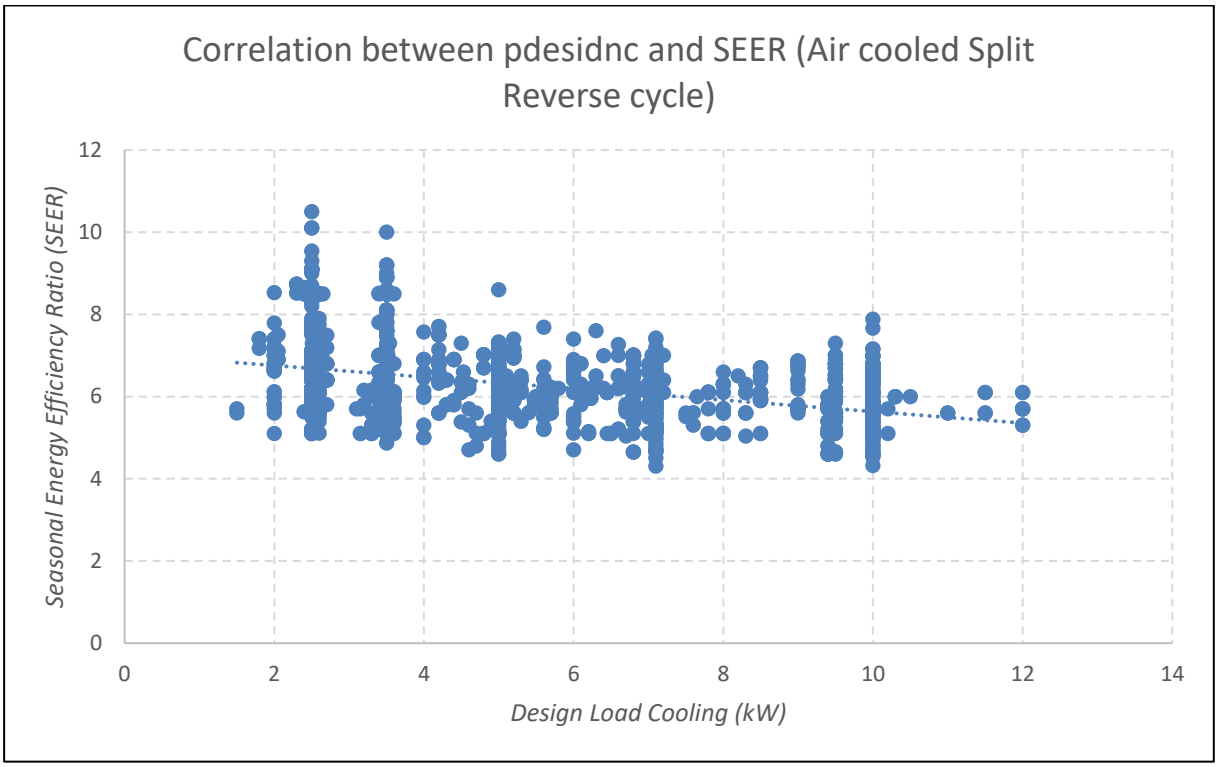


Figure 20: Correlation between Pdesignc and SEER (Air cooled Split Reverse cycle), source ECC

Regarding the change to seasonal performances for fix split conditioners, SEER versus EER and SCOP versus COP are shown respectively in Figure 21 and Figure 22 below using ECC 2016 directory. High dispersion of SEER (resp. SCOP) values for the same EER (resp. COP) shows it is a better way to compare the performances of these products to use seasonal performance indicators (if SEER and EER (resp. SCOP and COP) had been perfectly correlated, the metrics change from full capacity at rating conditions to seasonal performance metrics would have proven useless).

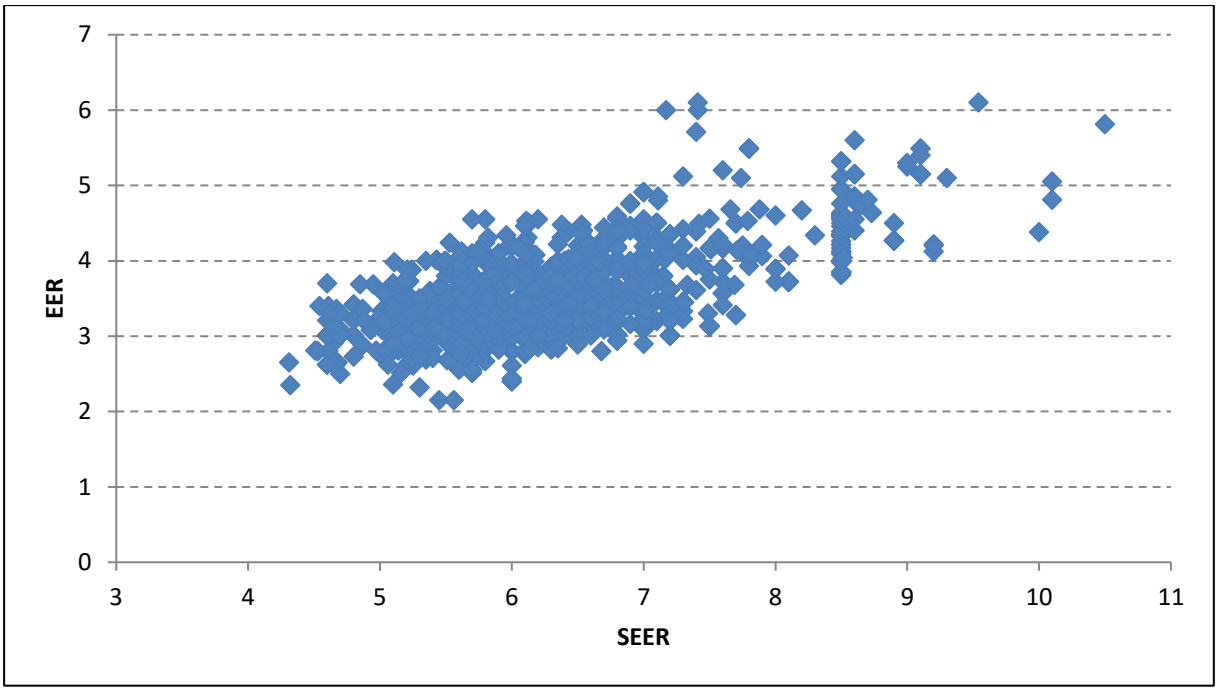


Figure 21: ECC directory 2016, EER Vs SEER

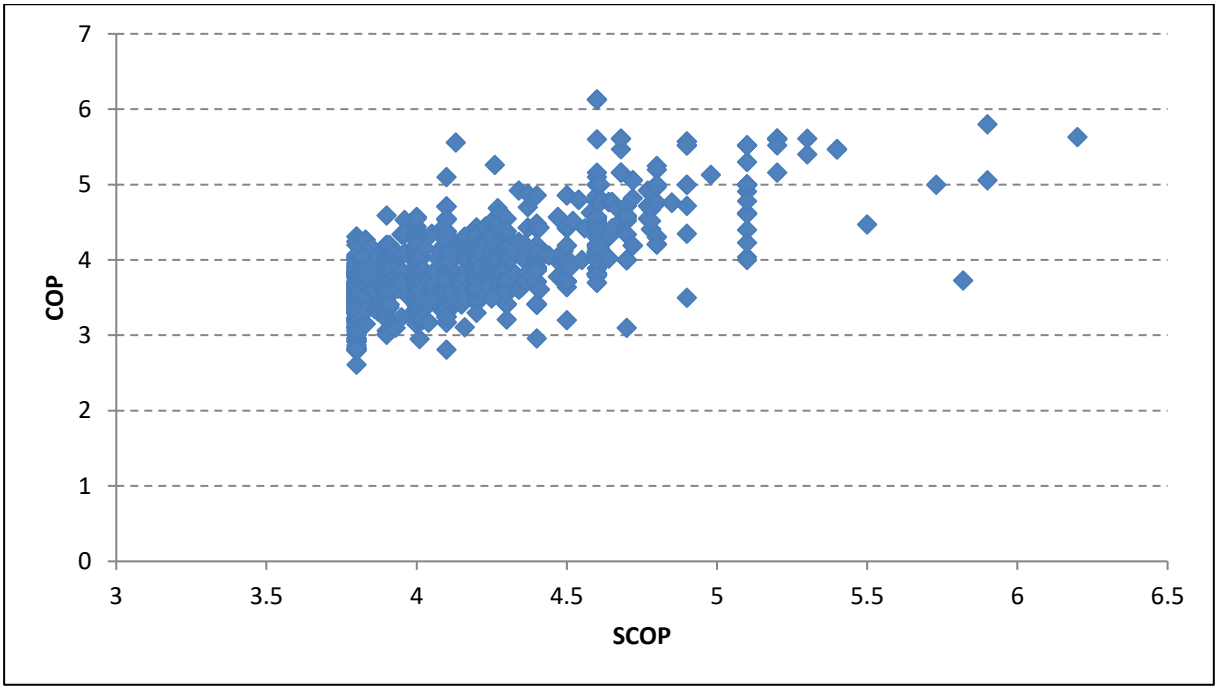


Figure 22: ECC directory 2016, COP Vs SCOP

2.3.2 Market channels and production structure

The European market for split air conditioners is only a small portion of the world market which represented about 90 million units in 2015 according to JRAIA[12], and because of its regulations (on energy efficiency and refrigerants) is also somewhat specific. A minor part

[12] *https://www.jraia.or.jp/english/World_AC_Demand.pdf*

of the production (or assembly) is made in Europe, main countries of production for these products being Czech Republic, Spain, Italy and the UK.

Most of the portable air conditioners are produced in Asia, although there is still a small share of the production made in Europe (Sweden and the Netherlands) according to BSRIA. Main split manufacturers are Japanese, Korean and Chinese brands although US and European brands seem to reinforce their position with more products and models offered. For portable air conditioners, traditional European manufacturers are challenged by retailers (and DIY and other garden or home stores) directly importing from China (and sometimes even specifying the design), direct sales through internet, and Asian new entrant brands from China and Japan mainly.

The standard distribution chain for new construction is shown in Figure 23 below. For replacement and new sales in existing buildings, there is normally no general contractor.

Figure 23: Distribution route for new construction, source US DOE[13]

Distribution routes for portable and split air conditioners in 5 EU countries and the weighted average routes are given in Figure 24 below. As expected, portable, which do not require installation, are mainly sold directly by retailers. For split air conditioners, the proportions of the different routes are more balanced. Note that this is the first point of sales distribution. Products sold to distributor/wholesaler can then be sold via general or specific retailers. When they are sold directly to the customer, most likely the wholesale margin is likely to increase.

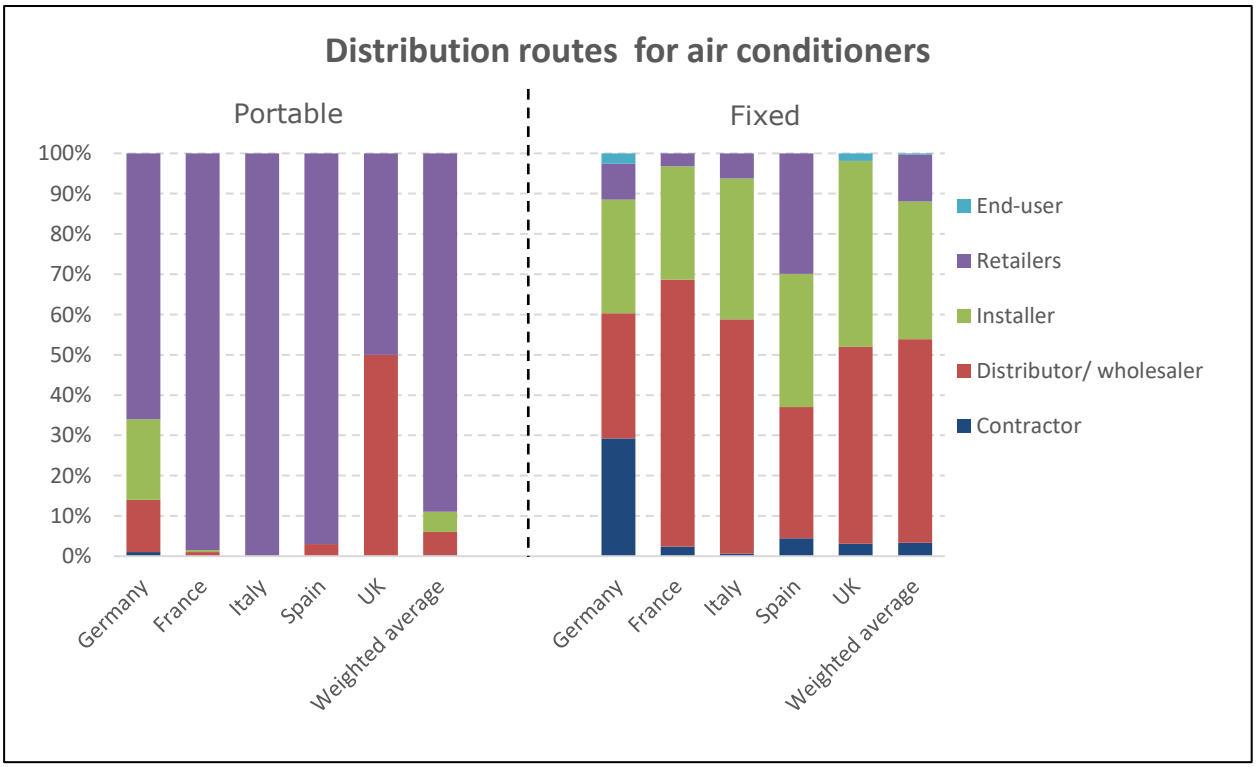


Figure 24: Distribution routes for portable and split air conditioners, source BSRIA

[13] *https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0098*

2.3.3 Trends in product design and features

Beside energy efficiency, the trends in product design identified mainly regard alternative refrigerants, sound power (driven by Regulation (EU) No 206/2012) and "smart" functions. The trend to include more air treatment functions observed in EuP Lot 10 study is more or less generalised, such as dehumidification, fan only, cooling, heating and air purification.

2.3.3.1 Low GWP refrigerant

The planned ban of certain refrigerants by F-gas Regulation (EU) No 517/2014 with higher than 750 values for split air conditioners in 2025 (resp. 150 for portable in 2020) is an important motivation to adopt compatible refrigerant fluids. However, the answer is different in both product segments.

In the split segment, there seems to be a clear trend. Daikin first, and now other Japanese manufacturers are progressively converting their R410A split product range to R32 (it can be noticed that not only single split products are proposed with R32 but also multisplit, despite the ban only regards single split products). It is still the beginning of the conversion however. In 2016, sales of R32 split are estimated to about 5 %, which is also the proportion of models declared with R32 in the ECC[14] directory. Basing on the ECC product database, it seems there is no product using the GWP bonus (allowing an 8 % lower SEER for split air conditioners) to enter the market with alternative refrigerant fluids. Instead, R32 products are put on the market at the same capacity, efficiency and price as middle efficiency or premium R410A units. It thus seems that the impact of the GWP bonus has been null or negligible.

In the portable segment, one company already proposed propane products in 2006 and still does[15]. But there does not seem to be other competitor using alternative refrigerants compatible with the 2020 ban (GWP lower than 150) yet. Information on refrigerant in portable air conditioners is surprising (Table 9) for several reasons. First, not all refrigerants are known, while a refrigerant information label is required by Regulation (EU) 517/2014 for fluorinated gases. Secondly, it is prohibited to sell R22 products in Europe. Third, there are R32 products being sold also for the portable segment although this is not a viable option for the 2020 ban; this is probably a product developed for other markets and imported (Japan for instance). Above that, the share of post ban compatible refrigerant (propane here) is also about 5 % as for split air conditioners. This market is then late for its conversion (because the ban is already in 2020 versus 2025 for split air conditioners). According to experience from a company, it may prove difficult to find reasonably expensive propane compressor manufacturers as at the moment demand volumes are very limited (when compared to global sales)[16]. Thus, the portable air conditioning is likely to adopt other than propane solutions for its conversion, most likely pure HFO or HFC/HFO mixtures with high HFO proportions.

[14] *www.eurovent-certification.com*
[15] Consultation with Delonghi, April 2017
[16] Consultation with Delonghi, April 2017

Table 9: Distribution of refrigerants in air conditioners sold, source GfK

Refrigerant	Fixed average share 2015/2016 %	Portable average share 2015/2016 %
R 407 C	-	2.8%
R 410 A	96.3%	74.8%
R 290	-	5.5%
R 22	-	0.04%
R 32	0.4%	0.4%
<Others>	3.4%	16.4%

With the implementation of the F-gas regulation and the suggested removal of the bonus systems, the only incitement to promote refrigerants with very low GWP i.e. < 150 is the phase down schedule.

It can be discussed if this is sufficient and whether the GWP of the refrigerant should be included with a different approach. A possible solution could be the Total Equivalent Warming Impact methodology (TEWI)[17]. This methodology compares the impact of the refrigerant leakage and the electricity used. In this matter, the equipment is rated according to its total environmental impact and promotes low GWP refrigerants and efficient equipment. The TEWI is calculated by the below equation (defined in Europe in Standard EN378-1):

$$TEWI = GWP \times L \times n + GWP \times m \times (1 - \alpha) + n \times E \times \beta$$

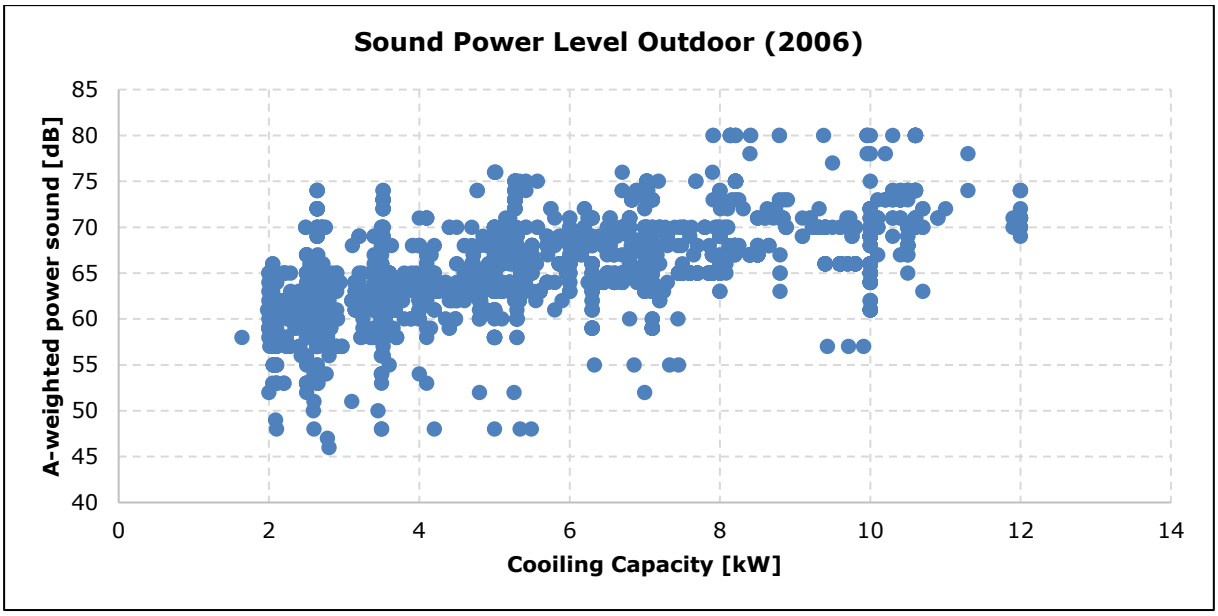
Where:

- GWP is the refrigerant Global Warming Potential (kg CO2/kg refrigerant)
- L is the annual leakage rate [kg/year]
- n is the systems operating lifetime [years]
- m is the refrigerant charge [kg]
- α is the recycling factor [%]
- E is the annual energy consumption [kWh/year]
- β is CO2 emissions on energy generation [kg CO2/kWh]

2.3.3.2 Noise

Ecodesign Regulation (EU) No 206/2012 on air conditioners also has requirement regarding maximum sound power level of indoor (60 dB(A) for ≤ 6 kW and 65 dB(A) for > 6 kW) and outdoor units (65 dB(A) for ≤ 6 kW, 70 dB(A) for >6 kW). The reduction in noise level due to ecodesign is visible when comparing 2006 and 2016 data for both outdoor (Figure 25) and indoor units (*Figure 26*).

[17] http://docs.lib.purdue.edu/cgi/viewcontent.cgi?article=1708&context=iracc



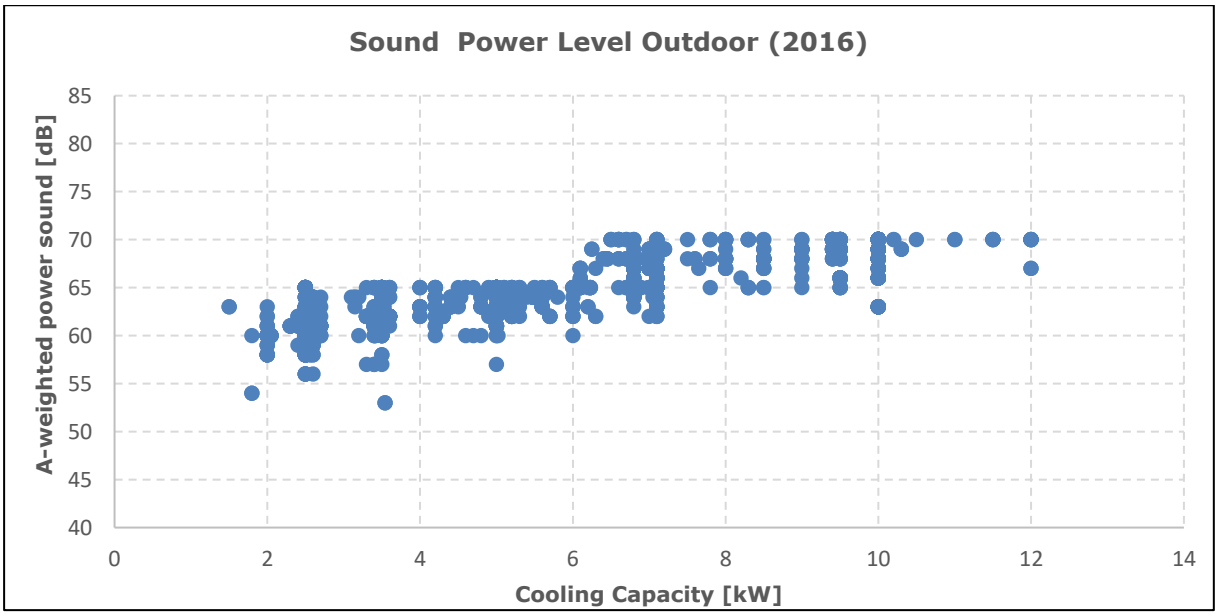


Figure 25: ECC directory 2006 and 2016, air conditioners below 12 kW, sound power level of outdoor unit in cooling mode

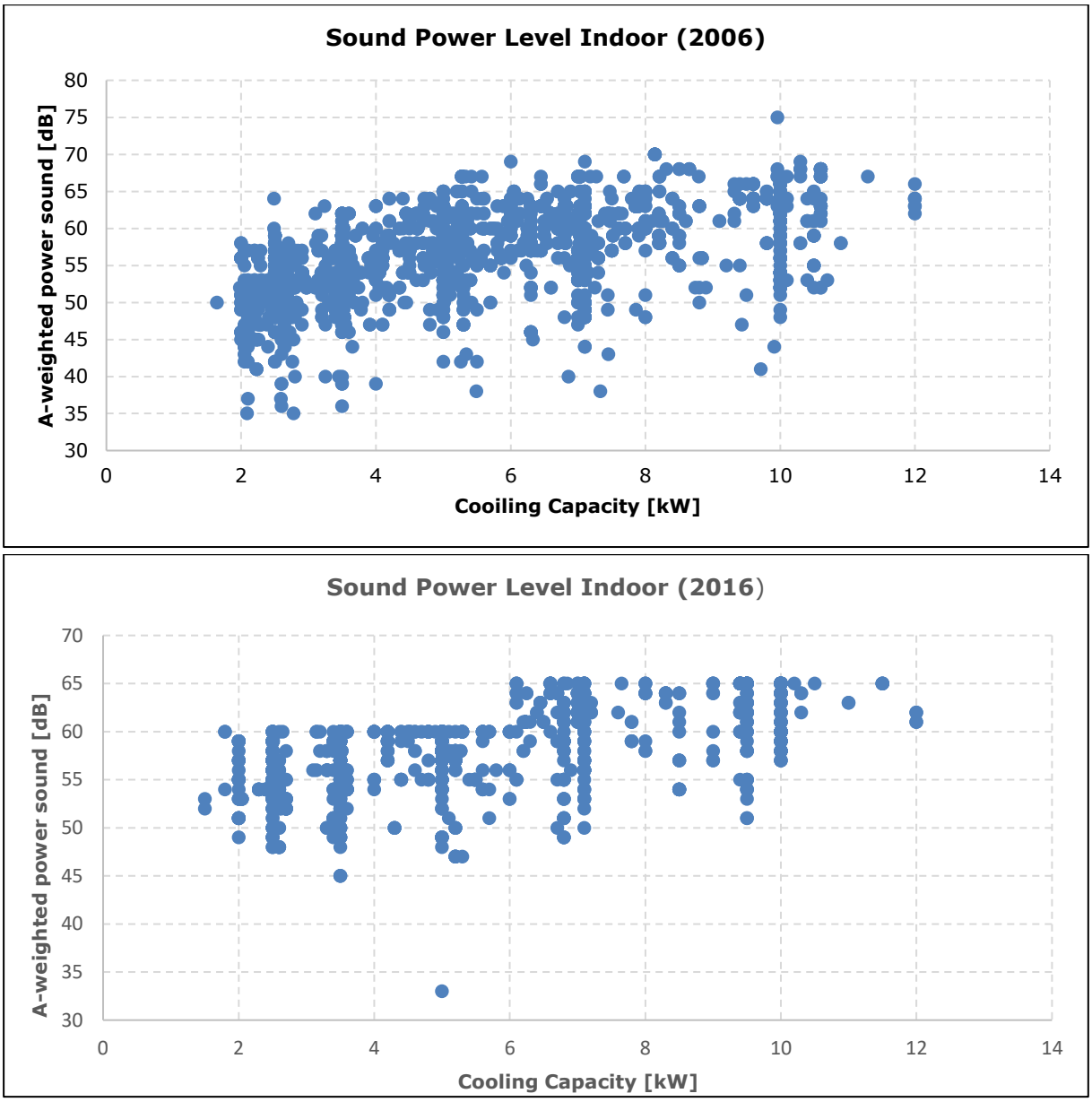


Figure 26: ECC directory 2006 and 2016, air conditioners below 12 kW, sound power level of indoor unit in cooling mode

Today the average indoor sound power level of fixed split air conditioners (≤6 kW) is 56.3 dB(A) while the average outdoor sound power level is 62.3 dB(A). For larger air conditioners (>6 kW) the average indoor sound power level is 61 dB(A) while the average outdoor sound power level is 67.6 dB(A).

From a consumer perspective, the sound power level is less relevant than the sound pressure level. The sound power level is representing the sound directly emitted by the equipment while the sound pressure level is the sound reaches a person's ear (certain measure point from the unit). However, unlike sound power level, the sound pressure level cannot be regulated for products placed on the market as it can depend on the distance of measurement and installation on site. To enable comparison, it can roughly be estimated that the sound pressure level equals the sound power level minus subtracted 8-12 (dB). This means that the average indoor sound power level of fixed split air conditioners (≤6 kW) corresponds to a sound pressure level of 44.3 to 48.3 (dB)

As a comparison, for most concentrated office work, the corresponding Standard EN ISO 11690, Acoustics: Recommended practice for the design of low-noise workplaces containing machinery recommends sound pressure levels of no more than 35-45 dB(A). It should also be noted that the sound power level is a more robust indicator for sound emitted by air conditioners, albeit more difficult to measure, because it is not room dependent nor distance dependent but reflects the total sound power emitted by the unit in all directions. It is thus preferred for rating air conditioner noise emission, even if sound pressure is an interesting reference to compare with requirements in building and other international standards and regulations.

It will be investigated in later tasks how much the requirements for sound power level can be reduced without compromising the efficiency.

2.3.3.3 Network capabilities

Functionalities such as app-controlled functions are more common today than a few years ago. It is assumed that all new air conditioners are ready to be connected to the internet but only a few of the models include this feature directly out of the box. For the majority of the air conditioners sold, these functions are supplementary equipment one has to buy. The share of air conditioners sold with the ability to connect to a network directly out-of-the-box is presented in Figure 27.

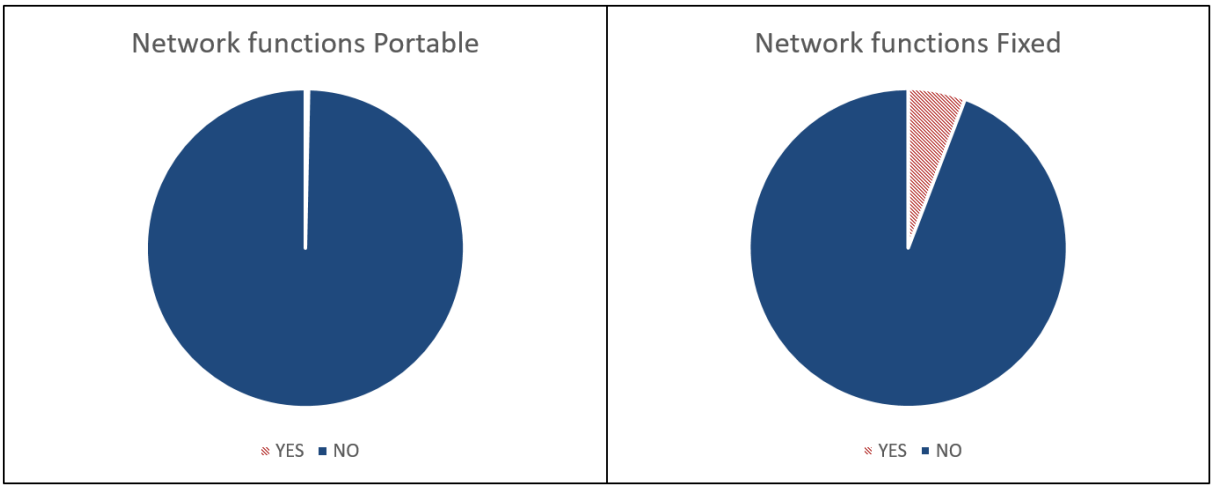


Figure 27: Share of air conditioners sold with network functions

2.4 Consumer expenditure base data

2.4.1 Average EU consumer prices

Manufacturer selling price and final product prices are described below for portable and split air conditioners.

BSRIA data consists of total sales values (manufacturer selling prices, MSP) for 18 EU countries and detailed information on 5 countries.

From GfK, there are weighted average final price of units sold in 10 EU countries (including BSRIA countries) for products sold directly to the customer through retailers.

In BSRIA data for **portable air conditioners**, there appears large variations in manufacturing selling price depending on countries, average MSP for Germany is 393 euros, France 201 euros, 276 for Italy, 338 for Spain and 490 for the UK. Similar trends have been found via online research of various online retail platforms from different countries, the UK seems to have higher prices for portable air conditioners in general. This probably reflects to a certain extent the different types of products sold in each country (whether more or less capacity or higher or lower efficiency) and brands' market shares.

The weighted average manufacturer selling price across 18 EU countries according BSRIA is 342 euros (Table 10), however, the average product size of product sold is not known for all 18 EU countries, therefore the MSP or final product price ratio per kW is not derived. It can be noticed in BSRIA data, prices are starting to increase again after a large drop from 2005 to 2014.

GfK data for average final product price including VAT and retailer margin is 355 euros; with an average size of 2.6 kW this corresponds to about 135 euros /kW (Table 10). Note that GfK values correspond to much lower values than BSRIA estimates: removing 20 % VAT and a typical 40 % retailer margin (see mark-up analysis hereafter at the end of paragraph 2.4.1), the manufacturer selling price corresponds to 210 euros, versus 342 euros for BSRIA. Online research based on various retail platform from 7 countries[18] show also deviations from GfK data, with an average of 460 euros. Datasets on portable air conditioners prices seems to deviate from each other.

BSRIA dataset contains likely more than only residential air conditioners and may be missing a part of the low-cost market available through retailers. On the other hand, GfK prices may underestimate the average price as other distribution routes apart from retails are significant in Germany and in the UK for instance. It seems however more reasonable to use the GfK estimate in the rest of the studies as residential air conditioners bought via retailers is the most current situation, and the average capacity is known for the derived prices. The final manufacturer selling price of 81 Euros per kW is coherent with the 82 Euros per kW (Price sold: 162 USD/kW, corrected for change rate USD/Euro 2014 of 1.33, US retailer margin 1.39 and sales taxes of 1.07) hypothesis of the US DOE in the technical support document of the final ruling proposal of portable air conditioners (based on 2014 price and mark-up information)[19]. It can also be noticed that according this same study, the price per kW of double duct products is similar to the one of single duct air conditioners (74 Euros/kW against 82 Euros/kW for single duct), with only slightly higher average cooling capacity (3.4 kW against 2.8 kW).

Table 10: Estimated manufacturer selling price and final product price of portable air conditioners, based on data from BSRIA and GfK

	BSRIA data	GfK data
Manufacturer selling price weighted average (Euros)	342	210 (2.6 kW)
Manufacturer selling price ratio (Euros per kW)	-	81
Average final product price (Euros)	-	355 (2.6 kW)
Final product price ratio (Euros per kW)	-	135

[18] Spain, Italy, the UK, Netherlands, France, Germany, Denmark
[19] https://www1.eere.energy.gov/buildings/appliance_standards/standards.aspx?productid=65

Regarding the prices of **fixed split air conditioners**, according to BSRIA data, there are also important price variations, with the same countries exhibiting high prices and low prices as for portable. An average fixed split air conditioner costs 1181 euros in Germany, 746 in France, 719 in Italy, 548 in Spain and 1264 in the UK. The weighted average manufacturer selling price across 18 EU countries is of 704 euros (Table 11), or 154 Euros/ kW with the average unit size of 4.6 kW (weighting sales below 5 kW with anaverage size of 3.5 kW unit and sales above 5 kW with an average size of 7.5 kW unit). This was 195 euros / kW in EuP Lot 10 study. This represents a 21 % price decrease in 10 years. However, BSRIA expects the price to increase in the coming years with the renewed growth of the construction sector. The product category has much influence on the price per kW. According BSRIA, smaller split units have lower price per kW. With an average size of split below 5 kW, e.g. a 3.5 kW unit, the manufacturer selling price is 138 euros/kW. Above 5 kW, using a 7.1 kW average product, the ratio is 165 euros/kW.

GfK data indicates final price values of about 180 euros/kW through retailer channel. When removing 20% VAT and retailer margin (36 % value used here), this results only 110 euros/ kW as manufacturer selling price (Table 11).

The difference between the prices derived from BSRIA and GfK data is likely due to the difference in product type (GfK distribution gives more weight to smaller products with higher share of single split wall units), but also due to the difference in product distribution types as manufacturer selling price varies depending on the distribution routes.

Table 11: Estimated manufacturer selling price of fix (split and multi-split) air conditioners, based on data from BSRIA and GfK

	BSRIA data	GfK data
Manufacturer selling price weighted average (Euros)	704 (4.6 kW)	375(3.5kW)
Manufacturer selling price ratio (Euros per kW)	154	110
Average final product price (Euros)	-	630 (3.5kW)
Final product price ratio (Euros per kW)	-	180

We attempted above to compare manufacturer selling price seen as a constant value above which a variable margin applied depending on destination. This is the US model developed right after. However, BSRIA statistics does not give this value, but the compound value of the product sold to its first buyer (that can be retail, wholesaler, installer, contractor or end-user). For a manufacturer, selling directly to an installer enables to increase its margin of the money given to the wholesaler in the complete value chain. We evaluated this maximum gain based on mark-up values indicated in Table 12 and the product distribution routes in Figure 24: this leads to a 20 % increase in manufacturer selling price (18 % below 5 kW and 25 % above, when specifying the different distribution channels by size). Hence, the weighted average BSRIA manufacturer selling price is now close to 128 (117 for less than 5 kW units and 132 for higher than 5 kW units) and thus closer to the estimate from GfK value.

However, there is still some differences to be explained: GfK retail final price for single split wall unit is 512 euros, however, the unit size is not known. Using again average BSRIA product size and GfK product type distribution, the average wall unit type product size in GfK data is probably about 3.4 kW, which gives when accounting for 36% retailer markup

and taxes about 92 Euros per kW. Hence using 117 euros per kW seems exaggerated. As a consequence, the study team made an estimate of the likely EU average price per size and category (trying to be coherent with BSRIA data as a whole and using GfK information price information via internet search). The estimated manufacturer selling prices by unit type are presented below in Table 12.

This representation, combined with the sales per product type given in Table 3, allows to have the same weighted average as derived from BSRIA (117 for less than 5 kW units and 132 for higher than 5 kW units) and to be compatible with the estimate for single split wall unit derived from GfK data (95 euros / kW for base unit versus estimated 92 from GfK). A few remarks should be added:

- the ratio multi-split / split has been derived from 18 countries (about 1.9), but has been corrected accounting for internet price survey for larger units (where prices are lower); multi-split indoor units are mainly of wall type and it was not possible to disaggregate by the prices per type because of the difficulty to find prices for these products.
- largest uncertainties are for non wall product types as there sales are lower (errors have less impact on the weighted average final price).

Table 12: Estimated manufacturer selling price by product type, adapted from GfK and BSRIA source

	Single split					Multisplit
	Wall	**Ceiling type**	**Floor/vertical or consoles**	**Cassette**	**Ducted**	**All (mainly wall)**
< 5 kW	95	171	190	171	171	181
>5 kW	124	137	137	137	127	153

Above manufacturer selling price, the final price paid for the unit also depends on the distribution route. Often the more players involved, the more expensive the unit.

Typical mark-ups from a recent US regulatory text on central air conditioners (which includes part of EU type split systems) is shown in Table 13.

Table 13: Example of mark-up multipliers depending on distribution routes for central air conditioners, source US DOE[20]

	Replacement		New Construction	
	Baseline Mark-up	**Incremental Mark-up**	**Baseline Mark-up**	**Incremental Mark-up**
Manufacturer	1.34		1.34	
Wholesaler	1.36	1.10	1.36	1.10
Mechanical Contractor	1.53	1.23	1.43	1.14
General Contractor	-		1.46	1.33
Sales Tax	1.07		-	
Total Mark-up	3.00	1.95	3.80	2.24

For a limited number of products, it was possible to compare manufacturer selling prices and installer + wholesale margin + VAT in Europe. For average efficiency products, the result is close to 2.2, which is in line with US values (2.2 using a 7 % VAT). However, with

[20] https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0098

the 20 % VAT in Europe, the mark-up comes to 2.5 (in Table 13, 1.36 x 1.53 x 1.2=2.5). We keep in what follows this detrimental value of 2.5.

Table 14 shows the extract of the US regulatory text regarding mark-up multipliers for portable air conditioners. Retailer mark-up in Europe for portable air conditioners, starting from manufacturer selling price and including 20 % VAT (instead of 7% in the USA) is thought to be close to 1.7 for first time installation and replacement. This is based on US values with adapted taxes (in Table 14, 1.39 x 1. 2=1.67). This is a useful input to compare manufacturer selling prices and street prices of best products in further tasks.

Note that the incremental mark-up multipliers are to be applied to the manufacturer selling price increase due to more efficient and thus more expensive product. Mark-up thus decrease for more efficient products, from 2.5 to 1.6 for fixed air conditioners, and from 1.67 to 1.36 for portable air conditioners.

Table 14: Example of mark-up multipliers depending on distribution routes for portable air conditioners, source US DOE[21]

	Replacement		New Construction	
	Baseline Mark-up	Incremental Mark-up	Baseline Mark-up	Incremental Mark-up
Manufacturer	1.42		1.42	
Retailer	1.39	1.13	1.36	1.13
Sales Tax	1.071		1.071	
Total Mark-up	2.11	1.72	2.11	1.72

Distribution routes for portable and split air conditioners in 5 EU countries and the weighted average routes are given in Figure 24 in section 2.3.2 above.

As expected, portable, which do not require installation, are mainly sold directly by retailers. Only about 5 % are surely sold via installers according to BSRIA: using the mark-up chain of split air conditioners sold via installers (2.5) and the retail mark-up of 1.67 (1.39 * 1.2), the total markup is then about 1.7 (1.72), while it could be reduced to about 1.35 for premium efficiency products.

For split air conditioners, the proportions of the different routes are more balanced, and comparing with GfK total B2C sales, it can be assessed this share is larger than just the retailer share in BSRIA statistics on first point of sales, higher than 40 %. According to BSRIA it should also be lower than about 60 % (as installers and contractors represent about 60 % of the total). Assuming a 50/50 sharing between final B2C retail and sales via installers, this leads to a total markup of 2.1 (50% * 1.36 * 1.2 + 50% * 1.36 * 1.53 * 1.2 = 2.1). The mark-up is probably higher when there is a contractor; according to BSRIA statistics, it is at least 5 % and could go up to 15 % (considering all new built need a contractor). Considering 10 % and using the USA mark-up hypothesis for the additional general contractor of 1.46, the total average mark-up for split air conditioners increases up to 2.2 (2.22), while it could be reduced to about 1.65 for premium efficiency products.

A summary of average manufacturer selling prices and of final prices is given in Table 15 below. Manufacturer selling price differences for less than 5 and more than 5 kW seem to be correctly explained by the change of the mix of product type (less wall indoor units and more cassettes and other types) so that in practice, the prices per kW are thought to be

[21] https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0098

relatively flat for the same type of unit. For multisplit air conditioners, the price ratio to wall single split would vary depending on the type of indoor unit; the price given is an average over the 0-12 kW range.

For split air conditioners, a sensitivity analysis of at least +/- 10 % is to be performed on the results of the study given the differences in prices for both datasets used to derive the prices.

Table 15: Average product price

Air conditioner type	Portable	Single split						Multisplit
	Single duct	Size / type	Wall	Suspended ceiling	Floor/vertical or consoles	Cas-sette	Ducted	all mounting types
Manufacturer selling price (Euros / kW)	81	< 5 kW	95	171	190	171	171	181
		>5 kW	124	137	137	137	127	153
Mark-up (incl. VAT)	1,7	< 5 kW	2,2	2,2	2,2	2,2	2,2	2,2
		>5 kW						
Final price to customer (Euros / kW)	138	< 5 kW	209	368	490	399	418	418
		>5 kW	272	301	301	301	278	338

Price premium indications have been supplied by several stakeholders for split air conditioners (variations of manufacturer selling prices) for different levels of efficiency. The result of the analysis is shown in Figure 28. In that figure, the 100 % price has been aligned to the product type efficiency using the ECC directory (1st quartile, see comparison of average SEER between GfK and ECC directory in section 2.3.1). This SEER value matches with the average price indicated in Table 15 for corresponding product type. The maximum SEER value drawn on the graph is also extracted from ECC directory.

For wall units, for which many price information are available via internet, efficiency cost increments (or price/cost depending on data supplied) were compared with market values from internet search. The overcost curve built compares well to the information received from stakeholders and to the internet search results. SEER values above 8.5 are prospective indications supplied by manufacturers. Note that R32 units have not been considered here because of the different manufacturer policies regarding the prices of these units; there are in some cases relatively high overcost at equal efficiency (mainly for high class products) and in other cases (mainly lower end products) lower prices, while the bulk of average products exhibit similar or slightly lower prices. Hence, there is no clear signal of a higher price for R32 units versus R410A units in general and the study team thinks these differences are not meaningful and cannot represent the mid-term evolution of R32 unit prices. For larger units, the price increase curve is similar, and the same curve can be used, although the base price per kW is higher and the maximum efficiency reached is lower.

For cassettes and ducted type units, information on 3.5 kW units were too limited so that only 7.1 units could be assessed. For these categories, the study mixed stakeholder information and its own price information research because of limited information. It can be seen that the slope of the overcost curves increases from wall to cassette and ducted units in relation to the maximum SEER value that can be reached in the specific category.

Note that these price curves are to be considered carefully. Indeed, there may be other functionalities / features added in premium products that are also included in the price (to be investigated in Task 4). It is also important to state that this is not forcedly the price signal seen by the end-user, because of the pricing policy of the different actors in the distribution routes (for instance retailers may take larger mark-ups on low efficiency ranges or adapt those in order to maximise their sales or profit or to empty the stocks), and of the different possible distribution routes.

It is interesting to notice that overall, the price relationship to efficiency for split products mainly depends on SEER values (despite a limited number of manufacturers may have different policies). If using it also systematically for heating and rationale, the customers should rather look at SCOP values, which makes most of the consumption (QHE=1400 and QCE=350).

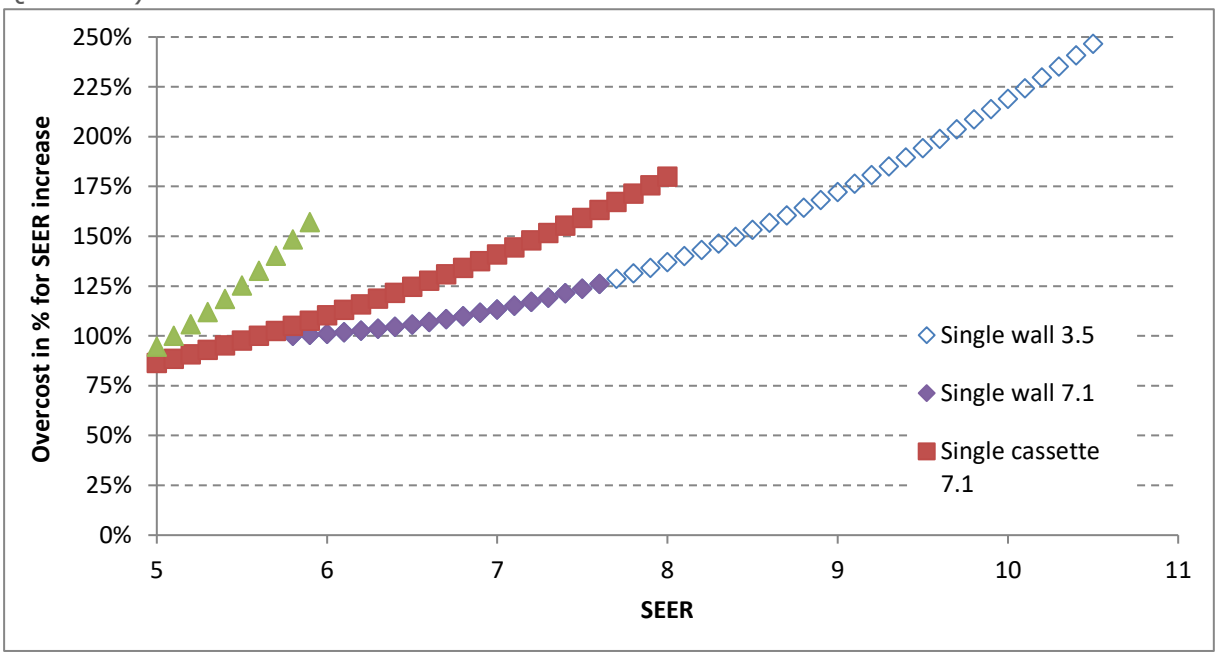


Figure 28: Price premium for some of the split air conditioners

For portable air conditioners, prices were derived based on GfK data. However, the information is averaged at EU level and price signal between classes are thus difficult to interpret. The average final product price (355€ presented in Table 10) also equals the price of an energy class A product. However, the change from class A to class A+ leads to much higher prices, 650 to 700€, resp. about 80% and 100% product price increase. This is probably because A+ models are sold only by EU manufacturers whose models are usually more expensive.

2.4.2 Installations costs

Installation costs in EuP Lot 10 study were evaluated to be of 1000 Euro (Incl. VAT) per fix single split unit, independently of the unit size. Industry stakeholders have indicated that the installation costs for split units vary a lot depending on the country and to some extent the size of the air conditioner. The price of a similar sized unit can be above 1500 in one country and as low as 350-700[22] Euro/unit in another country. Based on inputs from the stakeholders the suggested installation costs is reduced to 800 Euro/unit independently of the unit size. It should be noted that the installation costs have no impact on the efficiency of the LLCC.

[22] Data collection from industry stakeholders, June 2017.

2.4.3 Repair and maintenance costs

For split air conditioners, as in EuP Lot 10 study, repair and maintenance are based on prEN 15459:2006(E) and are estimated to be of 4 % of the initial investment (including installation costs) per year. This includes annual preventative maintenance and repair and servicing costs. Using the weighted average manufacturer selling prices of 128 euros / kW, this leads to:

$$Average\ maintenance\ annual\ cost:\ 4\% \times (800\ Euros\ + (128\ \times 2.2\ \times 4.6\ \mathrm{kW}) \approx\ 85\ euros$$

Stakeholders have indicated varying cost of repair and maintenance depending on the country and the unit size. The 85 Euro/year in this example seems reasonable based on the inputs from the stakeholders. An average repair and maintenance cost of 4 % on initial investment will be used.

There is no maintenance cost for portable air conditioners as in most cases end-users maintain themselves their units following manual instructions.

2.4.4 Disposal costs

The disposal costs are paid by the end-user buying the products under the form of the Eco tax under the WEEE directive. For an air conditioner, this corresponds nowadays to a fee of 80 to 120 euros/tonne. This fee is adjusted on a country basis and by product category depending on recycling costs. The fee is not always included in the final product price, and even if it is, it is not always allowed to be visible at the point of sale. Stakeholders have also indicated that the removal of air conditioners can cost up to 850 euro for a multi-split system including recovery of the refrigerant and removal of units, refrigerant pipe, drain pipe and electric wires. The disposal costs are estimated to 500 Euro/unit independently of the unit size.

2.4.5 Interest, inflation and discount rates

The generic interest and inflation rates in the EU-28 are presented in Table 16. The European Commission recommends a discount rate of 4%[23].

Table 16. Generic interest and inflation rates in the EU-28[24].

	Domestic	Non-domestic
Interest rate (%)	7.7	6.5
Inflation rate (%)	2.1	
Discount rate (%)	4	

2.4.6 Electricity prices

Electricity prices are presented in the MEErP methodology. Recent updated average household and industry prices were found for 2015 S1 (first half of the year) including average annual price increase based on EUROSTAT[25], and are presented in Table 17.

From the first half of 2014 to the first half of 2015 the electricity prices have increased by 2 % for household consumers. For industrial consumers, there have been a 2 % percent decrease in the same period. The electricity prices are subject to yearly fluctuations but in the long-term the electricity prices are expected to increase. The development in electricity prices from 2008 to 2016 are presented in Annex 6: Electricity prices

[23] http://ec.europa.eu/smart-regulation/guidelines/tool_54_en.htm
[24] VHK(2011), MEErP 2011 METHODOLOGY PART 1.
[25] Source: Eurostat, assessed April 2017

Table 17. Household and industry electricity costs and annual increase from 2014 S1 to 2015 S1 (first half of the year).

EU country	Household electricity price 2015 S1, €/kWh	Annual household price increase 2014 S1 to 2015 S1, %/a	Industry electricity price 2015 S1, €/kWh	Annual industry price increase 2014 S1 to 2015 S1, %/a
Belgium	0.2126	1%	0.11	1%
Bulgaria	0.0942	13%	0.0692	-7%
Czech Republic	0.1385	0%	0.0772	-7%
Denmark	0.3068	1%	0.0899	-4%
Germany	0.2951	-1%	0.1509	-5%
Estonia	0.1302	0%	0.0889	-3%
Ireland	0.2426	1%	0.1417	4%
Greece	0.1767	0%	0.1292	-3%
Spain	0.2309	7%	0.1173	-6%
France	0.1624	2%	0.1008	2%
Croatia	0.1317	0%	0.092	-4%
Italy	0.245	0%	0.1608	-7%
Cyprus	0.1957	-15%	0.1393	-20%
Latvia	0.1635	20%	0.1178	1%
Lithuania	0.1256	-6%	0.0989	-15%
Luxembourg	0.1767	2%	0.0928	-8%
Hungary	0.1127	-6%	0.0867	-5%
Malta	0.1257	-15%	0.1599	-10%
Netherlands	0.1986	8%	0.0902	-3%
Austria	0.2009	-1%	0.1039	-5%
Poland	0.1444	2%	0.0882	7%
Portugal	0.2279	5%	0.114	-2%
Romania	0.1303	1%	0.083	-5%
Slovenia	0.1589	-3%	0.0827	-5%
Slovakia	0.1506	0%	0.1126	-2%
Finland	0.1552	-1%	0.0707	-4%
Sweden	0.1851	-6%	0.0622	-12%
United Kingdom	0.2125	11%	0.1489	16%
EU (28 countries)	**0.2085**	**2%**	**0.1206**	**-2%**
Norway	0.1614	-2%	0.077	-4%

Electricity prices from EUROSTAT presents the past and current electricity prices but does not suggest any projections for the future. Standardised projections are suggested in the Ecodesign impact accounting[26] The impact accounting study use updated electricity price for 2013 (0.189) and then escalate with 4 % pa (MEERP). The suggested electricity prices are presented in the below table.

Table 18: Real rates electricity prices from 1990 to 2030. Based on the Ecodesign impact accounting

Real rates electricity prices from Ecodesign impact accounting*						
	1990	2000	2010	2015	2020	2030
Residential €/kwh elec*	0.178	0.162	0.170	0.205	0.249	0.369
Industry €/kwh elec*	0.119	0.084	0.105	0.122	0.149	0.220

** Inflation index (2010=1, inflation 2%)*

***Residential (incl. VAT); Industry (excl. VAT, tariff Ie)*

The electricity prices from the ecodesing impact accounting seems a little high and the commission have discussed how to apply more realistic projections of the electricity prices.

[26] Van Holsteijn en Kemna B.V. (VHK), ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013, available at: https://ec.europa.eu/energy/sites/ener/files/documents/2014_06_ecodesign_impact_accounting_part1.pdf

The commission have decided to use data from PRIMES[27]. The suggested electricity prices are presented in Table 19.

Table 19: Electricity priced suggested by the commission[28].

Electricity	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Average €/kwh	0.117	0.136	0.144	0.153	0.157	0.161	0.165	0.165	0.163	0.163
Industry €/kwh	0.084	0.097	0.097	0.098	0.099	0.100	0.101	0.102	0.101	0.101
Households €/kwh	0.156	0.172	0.190	0.203	0.209	0.212	0.217	0.215	0.211	0.209
Services €/kwh	0.127	0.148	0.157	0.171	0.176	0.179	0.184	0.182	0.180	0.178

In real life air conditioners are used in households and in the service sector. Hence, the electricity price to be used in EcoReport Tool (Task 5) for the average air conditioner in EU consists of both the residential and industry rate. The share of residential consumers is presented in Figure 29.

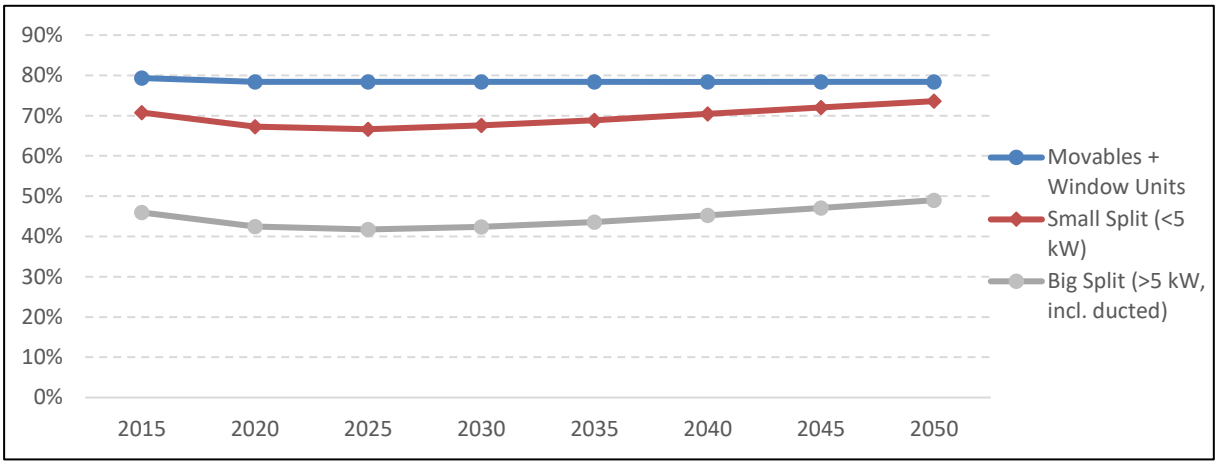


Figure 29: Share of residential users for portable air conditioners and fixed air conditioners

2.5 Conclusions and recommendations

There have been important changes in the market structure since the preparatory study completed in 2009. Mobile split and window/wall air conditioners have almost completely disappeared from the EU market. Regarding fixed air conditioners, they are now nearly all reversible (> 99%).

Since the preparatory study the development in sales of air conditioners have been almost flat (comparing 2005 and 2015 markets) which is widely due to the financial crisis (sales increased to very high levels in 2007, dropped until 2013-2014 and started to grow again in 2015-2016 depending on the country). Even though the trend has been flat it is expected that the sales will increase over the next decades. It has been shown based on US and world air conditioning development that sales and stock could be increased by fourfold from 2015 to 2050. The comfort decision to install air conditioning is influenced by climate (and global warming will increase air conditioning penetration), building regulations and affordability, the increasing gross national income (GNI) per capita will increase the consumers' willingness to buy air conditioners. In 2015 the sales were approximately 4

[27] PRIMES 2016
[28] PRIMES 2016

million units and the stock were 53.7 million units. The sales and stocks are expected to increase and reach above 10 million units in sales and 98.5 million units in stock by 2030.

The market is dominated by air conditioners with R 410A refrigerant, but this is expected to change soon to refrigerants with much lower Global Warming Potential (GWP) due to the F-gas regulation.

According to the market data of fixed air conditioners, A++ is well populated and the A+++ category is already populated before the regulation (EU) No 626/2011 introduces the A+++ class. It should be noted that it is not lawful to use A+++ class indication before 2019. For portable air conditioners, only a few of them can reach an A++ mark currently.

Based on Eurovent Certita Certification data, it is clear to see the increasing trend of air conditioners efficiency, median EER increased from 2.9 to 3.4 from 2006 to 2016, and COP increased from 3.2 to 3.7 from 2006 to 2016. Sales weighted efficiency is calculated based on available data; for portable air conditioner EER = 2.65, and COP = 2.53, for fixed split air conditioners, SEER = 5.7, split SCOP = 4.0.

Today the average sound power levels of air conditioners are well below the ecodesign requirements. For small fixed split air conditioners (≤6 kW), average indoor sound power level is 56.5 dB(A) while the average outdoor sound power level is 62.4 dB(A). For larger air conditioners (>6 kW) the average indoor sound power level is 61.1 dB(A) while the average outdoor sound power level is 67.6 dB(A).

The average price of air conditioners decreased since the preparatory study due to the financial crisis but started to increase again as observed recently. The average final product price for portable air conditioners is found approx. 135 EUR/kW, while the manufacturer selling price is approx. 80 EUR/kW. The average manufacturer selling price for fixed split air conditioners is found approx. 130 EUR/kW and while the final product price is approx. 285 EUR/kW. The mark-up factor for split systems starting from manufacturer selling price is approx. 2.2, and the mark-up for portable unit is approx. 1.7. Price increase for wall split units, large cassettes and ducted units were identified and will be used in later tasks for life cycle cost analysis.

Annex 1: Test conditions for SEER and SCOP determination of exhaust air-to-outdoor air heat pumps and air conditioners

SEER calculation: for exhaust air/outdoor air units, the part load conditions for determining the declared capacity and the declared energy efficiency ratio are given in Table 20.

Table 20: Conditions for determining $EER_{A,B,C,D}$ values in SEER calculation

Test condition	Part load ratio		Outdoor heat exchanger: exhaust air dry bulb (wet bulb) temperatures	Indoor heat exchanger: outdoor air dry bulb (wet bulb) temperatures
	%	%	°C	°C
A	(35–16)/(Tdesignc–16)	100	27(19)	35(24)
B	(30–16)/(Tdesignc –16)	74	27(19)	30(21)
C	(25–16)/(Tdesignc –16)	47	27(19)	25(18)
D	(20–16)/(Tdesignc –16)	21	27 (19)	20(15)

SCOP calculation: for exhaust air/outdoor air units, the part load conditions for determining the declared capacity and the declared coefficient of performance are given in Table 21.

Table 21: Conditions for determining $COP_{A,B,C,D,E,F,G}$ values in SCOP calculation

Test condition	Part load ratio				Outdoor heat exchanger	Indoor heat exchanger
	Formula	A	W	C	Exhaust air dry (wet) bulb temperatures	Outdoor air dry (wet) bulb temperatures
	%	%	%	%	°C	°C
A	(-7–16)/(Tdesignh –16)	88	n/a	61	20(12)	-7(-8)
B	(+2–16)/(Tdesignh –16)	54	100	37	20(12)	2(1)
C	(+7–16)/(Tdesignh –16)	35	64	24	20(12)	7(6)
D	(+12–16)/(Tdesignh –16)	15	29	11	20(12)	12(11)
E	(TOL–16)/(Tdesignh –16)				20(12)	TOL
F	(Tbiv–16)/(Tdesignh –16)				20(12)	Tbiv
G	(-15–16)/(Tdesignh –16)	n/a	n/a	82	20(12)	-15

Annex 2: Estimating 2015 stock for countries with insufficient sales data

For the 12 EU countries which there is not enough sales data available (Bulgaria, Croatia, Cyprus, Denmark, Estonia, Ireland, Latvia, Lithuania, Luxembourg, Malta, Slovakia, Slovenia), the following procedure in 6 steps is used to estimate the 2015 stock. Note: these 12 countries represent about 7% of the total EU population.

STEP 1: The total installed rated cooling power in 2015 in the first 16 EU countries is estimated using the average power of units sold (Table 22) and the lifetime (Table 23) of the technology.

Table 22: Average power of units installed per product type

Technology	Average rated capacity (kW)
Movables + Window Units	2.5
Small Split (<5 kW)	3.5
Big Split (>5 kW, incl. ducted)	7.5
VRF	25
Rooftop + Packaged	65
Chillers (A/W) < 400 kW	81
Chillers (A/W) > 400 kW	616
Chillers (W/W) < 400 kW	114
Chillers (W/W) > 400 kW	755

Regarding average rated capacities per unit type, country specific values is used when data is available. The average (Table 22) is used for the remaining countries.

Table 23: Average lifetime of units per product type

Technology	Average lifetime (years)
Movables + Window Units	10
Small Split (<5 kW)	12
Big Split (>5 kW, incl. ducted)	12
VRF	15
Rooftop + Packaged	15
Chillers (A/W) < 400 kW	15
Chillers (A/W) > 400 kW	20
Chillers (W/W) < 400 kW	15
Chillers (W/W) > 400 kW	20

STEP 2: Dividing the installed power by the average power installed per unit of indoor floor area (equipment sizing in W/m^2) gives the total cooled floor area.

Sizing values of EuP Lot 10 study for the residential and service sectors were used. These are results of dynamic building demand simulations for a number of locations in Europe which were fitted to CDDs to deduce all countries and were then corrected by a 20% oversizing estimate based on limited evidence of real life sizing.

Installation (W/m²)	RES	SER
Austria	108	134
Belgium	85	110
Bulgaria	122	151
Croatia	123	152
Cyprus	181	349
Czech Rep.	90	115
Denmark	76	101
Estonia	74	99
Finland	73	98
France	110	136
Germany	90	115
Greece	177	254
Hungary	113	140
Ireland	69	95
Italy	157	203
Latvia	76	101
Lithuania	82	107
Luxembourg	89	114
Malta	185	320
Netherlands	76	101
Poland	88	113
Portugal	135	169
Romania	138	172
Slovakia	98	124
Slovenia	111	137
Spain	153	196
Sweden	71	97
UK	72	98

STEP 3: A matrix of repartition of sales (Table 24) into the different sectors is used to separate residential and tertiary cooled floor area. Penetration levels of cooling in the building stock are then computed, for residential and tertiary sectors separately.

Table 24: Share of sales in the residential sector by country (years 2011-2015)

Country	movable	Split <5kW	Split >5kW	VRF	Chiller air <400kW	Chiller water <400kW
Austria	82%	28%	18%	6%	28%	28%
Belgium	80%	9%	6%	6%	4%	3%
Bulgaria	89%	62%	37%	5%	22%	22%
Croatia	92%	77%	55%	7%	27%	28%
Cyprus	67%	88%	80%	3%	13%	21%
Czech Rep.	84%	17%	11%	7%	29%	29%
Denmark	95%	32%	10%	0%	0%	0%
Estonia	90%	75%	11%	0%	0%	0%
Finland	73%	3%	2%	6%	2%	2%
France	97%	62%	26%	6%	47%	49%
Germany	30%	8%	7%	5%	5%	3%
Greece	98%	94%	85%	4%	48%	48%
Hungary	83%	39%	25%	6%	28%	29%
Ireland	56%	9%	0%	21%	5%	5%
Italy	95%	84%	68%	5%	28%	28%
Latvia	90%	73%	10%	0%	0%	0%
Lithuania	90%	67%	9%	0%	0%	0%
Luxembourg	95%	55%	19%	2%	21%	23%
Malta	97%	89%	76%	7%	36%	36%
Netherlands	68%	4%	2%	5%	3%	2%
Poland	75%	13%	8%	6%	3%	2%
Portugal	87%	14%	4%	1%	5%	5%
Romania	91%	68%	43%	7%	27%	28%
Slovakia	88%	32%	18%	3%	13%	14%
Slovenia	91%	62%	45%	9%	35%	35%
Spain	90%	78%	57%	9%	25%	24%
Sweden	83%	2%	1%	7%	4%	3%
UK	35%	2%	0%	10%	2%	2%

All Rooftop systems as well as all chillers>400kW are assumed to be sold in the service sector.

For country with available information, this is based on years 2011-2015 depending on the product and country. For missing countries and/or product types, neighbouring countries were used as model.

STEP 4: For each sector, a correlation between AC penetration and cooling degree days is established for year 2015 (Figure 30).

The total cooled floor area is an input from the EU buildings database[29].

[29] https://ec.europa.eu/energy/en/eu-buildings-database

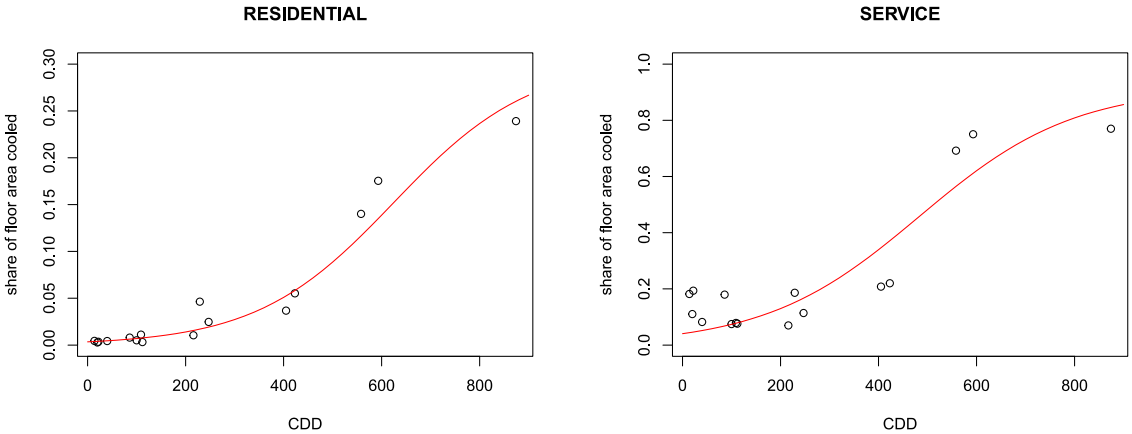


Figure 30: Cooled area penetration in % of total floor area by sector in 16 EU countries (black circles) and correlations (red circles) for other 12 EU countries; left - residential (Penres - Residential penetration); right - services (Penser - Services penetration).

STEP 5: These two correlations are finally used to estimate the penetration of air conditioning cooled floor of the remaining 12 minor countries in both countries (in addition for the residential sector, the GNI per household is used as a limiting factor as indicated in section 2.2.2.4 hereafter)

Estimated penetrations of cooled floor area for the 28 EU countries in 2015 by sector are reported in Table 25. More information on the coiling degree days' estimate is given in part 2.2.2.4.

Table 25: Estimated penetration of cooled area by sector in 28 EU countries

	Cooled floor area penetration in % of total floor area		Est. Cooling degree days in 2015
Country	**Residential**	**Services**	**base 18 °C**
Austria	1.2%	13.5%	226
Belgium	1.7%	41.2%	89
Bulgaria	4.2%	26.2%	317
Croatia	5.8%	27.3%	325
Cyprus	35.0%	84.7%	1417
Czech Republic	1.5%	18.1%	117
Denmark	0.6%	6.6%	43
Estonia	0.4%	6.1%	30
Finland	0.3%	16.8%	24
France	5.1%	33.1%	236
Germany	0.5%	15.6%	118
Greece	18.1%	76.3%	889
Hungary	2.4%	17.2%	259
Ireland	0.3%	4.9%	6
Italy	13.2%	79.1%	607
Latvia	0.5%	6.6%	42
Lithuania	0.9%	8.0%	76
Luxembourg	1.8%	10.1%	115

Malta	31.0%	84.7%	1258
Netherlands	0.8%	17.1%	42
Poland	0.9%	19.5%	109
Portugal	3.2%	31.0%	418
Romania	6.0%	45.8%	437
Slovakia	2.3%	13.1%	168
Slovenia	3.9%	19.0%	243
Spain	10.8%	79.8%	569
Sweden	0.8%	31.0%	18
United Kingdom	0.9%	48.4%	23

According to available penetration information in terms of equipped households[30], considering that in average only one room per dwelling is equipped nowadays and that these statistics do not account for portable air conditioners in general, penetration levels appear compatible, except for Bulgaria, Croatia and Slovakia, whose residential penetration appears to be underestimated by a factor 2 to 3.

STEP 6: Air conditioning product types are disaggregated by product type using the repartition of products by sectors.

For country with available information, this is based on years 2011-2015 depending on the product and country. For missing countries and/or product types, neighbouring countries were used as model. Values are given below for residential (Table 26) and service (Table 27).

Table 26: Share of the residential stock by product type and country

Country	Portable	Small Split (<5 kW)	Big Split (>5 kW, incl. ducted)	VRF	Rooftop + Packaged	Chillers (A/W) < 400 kW	Chillers (A/W) > 400 kW	Chillers (W/W) < 400 kW	Chillers (W/W) > 400 kW
AT	10%	13%	13%	7%	0%	34%	0%	23%	0%
BE	33%	23%	19%	18%	0%	3%	0%	5%	0%
BG	3%	60%	30%	4%	0%	1%	0%	2%	0%
HR	3%	60%	30%	4%	0%	1%	0%	2%	0%
CY	54%	43%	0%	0%	2%	0%	0%	0%	0%
CZ	17%	23%	21%	11%	0%	19%	0%	9%	0%
DK	58%	17%	5%	2%	0%	11%	0%	7%	0%
EE	67%	3%	3%	10%	0%	10%	0%	8%	0%
FI	67%	3%	3%	10%	0%	10%	0%	8%	0%
FR	12%	29%	25%	3%	0%	25%	0%	6%	0%
DE	27%	9%	26%	22%	0%	11%	0%	5%	0%
EL	54%	43%	0%	0%	2%	0%	0%	0%	0%
HU	9%	53%	24%	0%	0%	10%	0%	4%	0%
IE	20%	3%	1%	72%	0%	4%	0%	1%	0%
IT	5%	55%	32%	1%	0%	6%	0%	1%	0%
LV	67%	3%	3%	10%	0%	10%	0%	8%	0%
LT	67%	3%	3%	10%	0%	10%	0%	8%	0%
LU	12%	29%	25%	3%	0%	25%	0%	6%	0%

[30] https://ec.europa.eu/energy/en/eu-buildings-database

MT	5%	55%	32%	1%	0%	6%	0%	1%	0%
NL	53%	9%	8%	15%	0%	11%	0%	2%	0%
PL	6%	42%	32%	15%	0%	4%	0%	1%	0%
PT	5%	44%	37%	5%	0%	8%	0%	1%	0%
RO	3%	60%	30%	4%	0%	1%	0%	2%	0%
SK	17%	23%	21%	11%	0%	19%	0%	9%	0%
SI	9%	53%	24%	0%	0%	10%	0%	4%	0%
ES	2%	40%	51%	2%	0%	4%	0%	0%	0%
SE	58%	17%	5%	2%	0%	11%	0%	7%	0%
UK	20%	3%	1%	72%	0%	4%	0%	1%	0%

Table 27: Share of the service sector stock by product type and country

Country	Portable	Small Split (<5 kW)	Big Split (>5 kW, incl. ducted)	VRF	Rooftop + Packaged	Chillers (A/W) < 400 kW	Chillers (A/W) > 400 kW	Chillers (W/W) < 400 kW	Chillers (W/W) > 400 kW
AT	0%	4%	8%	13%	1%	12%	26%	8%	27%
BE	1%	15%	20%	17%	0%	5%	12%	11%	19%
BG	0%	17%	24%	33%	1%	2%	5%	3%	15%
HR	0%	17%	24%	33%	1%	2%	5%	3%	15%
CY	12%	18%	15%	5%	18%	21%	2%	9%	0%
CZ	0%	17%	25%	22%	1%	7%	12%	3%	12%
DK	0%	32%	15%	1%	0%	11%	16%	9%	15%
EE	1%	4%	6%	6%	0%	17%	13%	14%	39%
FI	1%	4%	6%	6%	0%	17%	13%	14%	39%
FR	0%	8%	29%	22%	7%	12%	12%	2%	8%
DE	3%	6%	18%	23%	0%	12%	14%	9%	15%
EL	6%	18%	23%	0%	12%	14%	9%	15%	0%
HU	1%	30%	26%	1%	2%	9%	17%	3%	11%
IE	2%	6%	31%	30%	1%	7%	16%	1%	6%
IT	0%	12%	18%	15%	5%	18%	21%	2%	9%
LV	1%	4%	6%	6%	0%	17%	13%	14%	39%
LT	1%	4%	6%	6%	0%	17%	13%	14%	39%
LU	0%	8%	29%	22%	7%	12%	12%	2%	8%
MT	0%	12%	18%	15%	5%	18%	21%	2%	9%
NL	1%	13%	18%	14%	1%	19%	13%	6%	16%
PL	0%	21%	26%	18%	1%	8%	13%	3%	9%
PT	0%	9%	31%	28%	6%	8%	10%	1%	6%
RO	0%	17%	24%	33%	1%	2%	5%	3%	15%
SK	0%	17%	25%	22%	1%	7%	12%	3%	12%
SI	1%	30%	26%	1%	2%	9%	17%	3%	11%
ES	0%	9%	30%	17%	15%	10%	14%	1%	4%
SE	0%	32%	15%	1%	0%	11%	16%	9%	15%
UK	2%	6%	31%	30%	1%	7%	16%	1%	6%

Annex 3: Cities by country to compute national average CDD from CNRM model

Note that population associated to a city corresponds to the population located inside the geographic coordinates of the grid cell of the meteorological model, and for that reason may only cover a share of large metropole population. It is however a useful indicator of climate weighting coefficients for large countries.

Table 28: Cities by country to compute national average CDD from CNRM model

City	Population associated	Country
Vienna	2 065 500	Austria
Brussels	1 381 011	Belgium
Sofia	1 029 913	Bulgaria
Plovdiv	319 089	Bulgaria
Zagreb	710 746	Croatia
Nicosia	212 376	Cyprus
Prague	582 043	Czech Republic
Ostrava	396 025	Czech Republic
Kobenhavn	1 085 000	Denmark
Tallinn	367 025	Estonia
Helsinki	836 728	Finland
Tampere	230 983	Finland
Paris	4 957 588	France
Marseille	1 097 405	France
Lyon	947 658	France
Toulouse	640 027	France
Lille	636 164	France
Berlin	3 250 007	Germany
Frankfurt	1 787 332	Germany
Stuttgart	1 775 644	Germany
Hamburg	1 748 058	Germany
Mannheim	1 337 587	Germany
Munich	1 267 695	Germany
Essen	1 157 801	Germany
Cologne	983 697	Germany
Athens	1 985 568	Greece
Budapest	1 679 000	Hungary
Dublin	1 013 988	Ireland
Milan	2 125 830	Italy

Rome	1 687 226	Italy
Naples	1 619 486	Italy
Turin	1 258 631	Italy
Florence	935 758	Italy
Riga	723 802	Latvia
Vilnius	524 697	Lithuania
Luxembourg	91 972	Luxembourg
Valletta	187 608	Malta
The Hague	953 862	Netherlands
Amsterdam	886 318	Netherlands
Warsaw	1 704 569	Poland
Katowice	1 527 362	Poland
Lodz	758 000	Poland
Krakow	755 525	Poland
Lisbon	1 664 901	Portugal
Bucharest	1 842 097	Romania
Iasi	325 914	Romania
Timisoara	309 575	Romania
Galati	302 621	Romania
Craiova	301 143	Romania
Cluj-Napoca	299 444	Romania
Brasov	293 566	Romania
Bratislava	398 712	Slovakia
Ljubljana	284 961	Slovenia
Barcelona	3 250 797	Spain
Madrid	2 808 718	Spain
Seville	957 533	Spain
Valencia	806 652	Spain
Bilbao	614 369	Spain
Stockholm	1 258 654	Sweden
Goteborg	520 940	Sweden
London	7 994 104	United Kingdom
Birmingham	1 634 666	United Kingdom
Manchester	1 312 757	United Kingdom
Leeds	992 061	United Kingdom

Annex 4: CDD evolution and GNI per capita

Figure 31 shows the projection of CDD according to the CNRM model and RCP4.5 scenario for six specific countries (All the modelled countries are shown in Annex 4: CDD evolution and GNI per capita). Yearly variability has been erased to exhibit climate evolution trends.

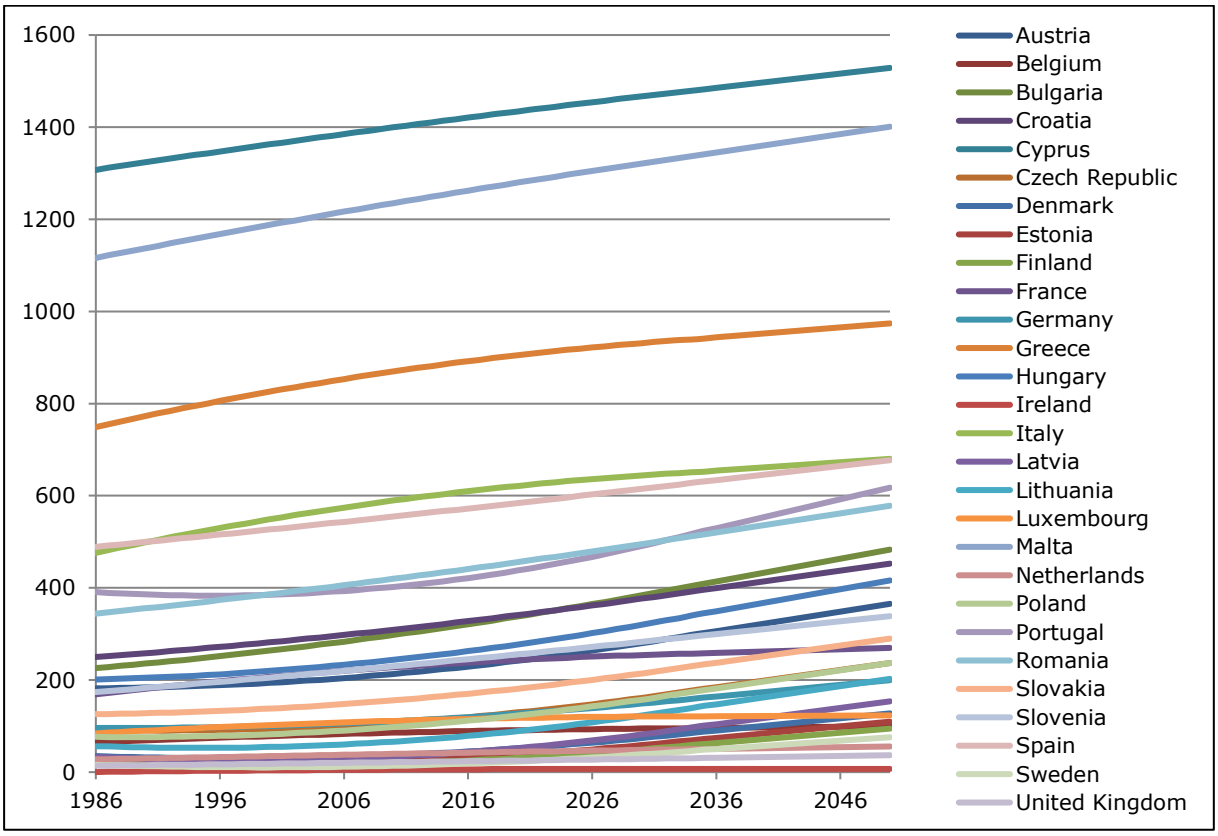


Figure 31: CDD evolution following climate change impact according to CNRM model, scenario RCP4.5, and country model according this report

GNI ppp (Purchasing Power Parity) per capita are available from the World Bank. Number of people per household are available from Eurostat. GNI ppp per capita and linear projections to 2030 are shown on Figure 32 below.

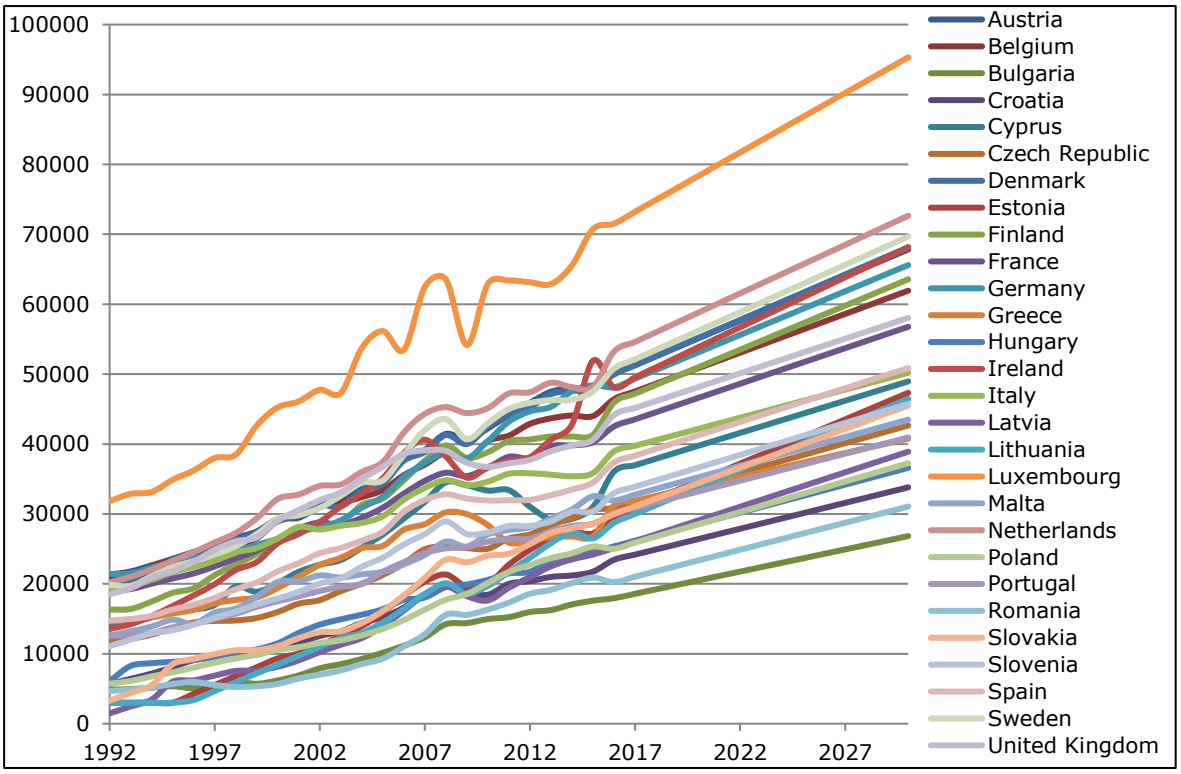


Figure 32: GNI per capita in US$(2015), source World Bank, and linear projections to 2030

Annex 5: Changes in split air conditioner efficiency in Europe from 2006 to 2016

The ECC[31] database has been used to identify changes in split air conditioner efficiency in Europe from 2006 to 2016, for EER and COP

Table 29:Eurovent Certita Certification split air conditioners below 12 kW certified products, EER evolution 2006/2016

EER	2006	2016
2	0.03%	0.00%
2.4	8.52%	0.63%
2.8	29.83%	4.13%
3.2	28.82%	26.35%
3.6	24.31%	55.07%
4	5.71%	25.03%
4.4	2.16%	11.64%
4.8	0.44%	6.51%
5.2	0.14%	1.75%
5.6	0.05%	0.69%
6	0.00%	0.25%
6.4	0.00%	0.44%

Table 30:Eurovent Certita Certification split air conditioners below 12 kW certified products, COP evolution 2006/2016

COP	2006	2016
2	0.00%	0.00%
2.4	0.03%	0.00%
2.8	16.93%	0.19%
3.2	26.93%	7.20%
3.6	31.72%	29.16%
4	17.98%	55.01%
4.4	4.57%	26.66%
4.8	1.65%	8.82%
5.2	0.11%	3.57%
5.6	0.06%	1.19%
6	0.03%	0.50%
6.4	0.00%	0.19%

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

Annex 6: Electricity prices

The development of electricity prices for household consumers and industrial consumers are shown in the below figures.

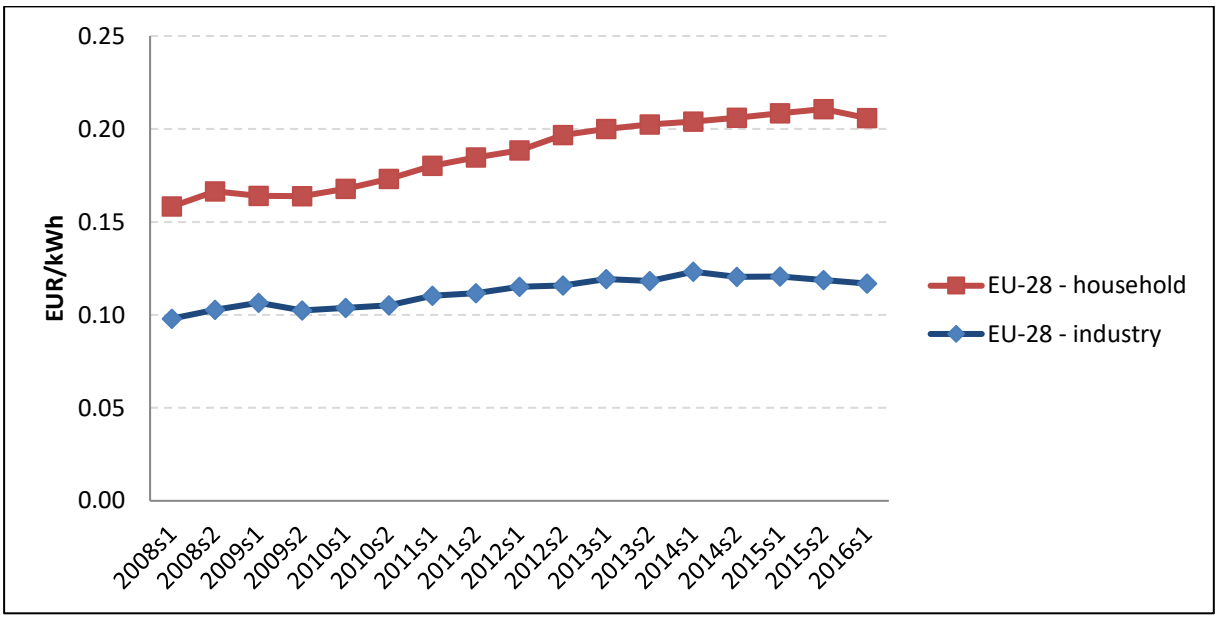


Figure 33: Development of electricity prices from first half of 2008 to first half of 2016 (based on EUROSTAT)

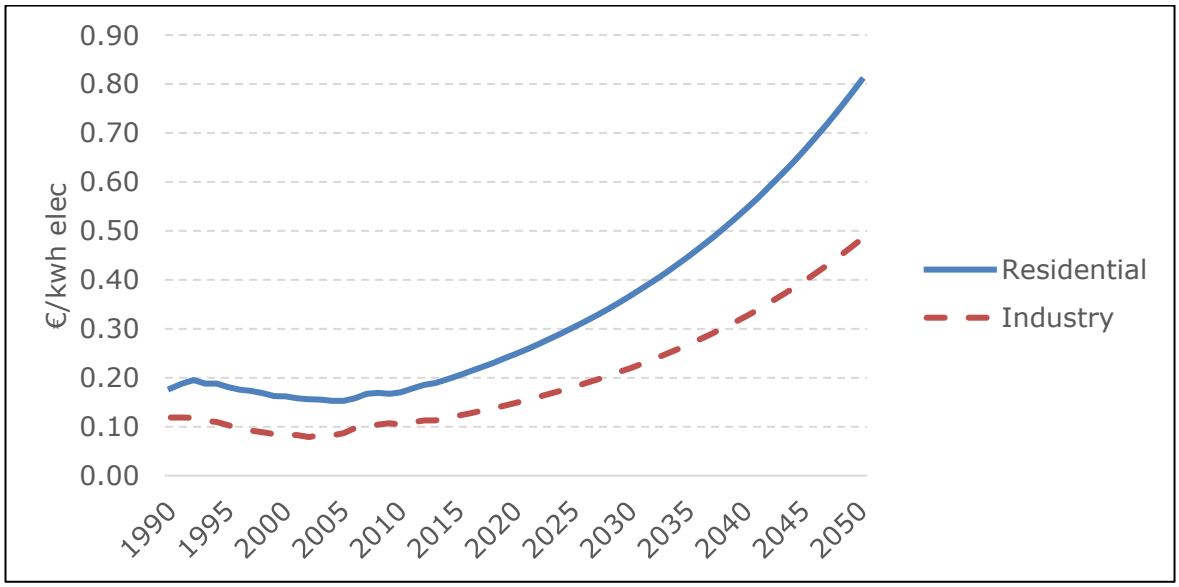


Figure 34:Development of electricity prices from 1990 to 2050 (based on Ecodesign impact accounting[32])

[32] Van Holsteijn en Kemna B.V. (VHK), ECODESIGN IMPACT ACCOUNTING Part 1 – Status Nov. 2013, available at: https://ec.europa.eu/energy/sites/ener/files/documents/2014_06_ecodesign_impact_accounting_part1.pdf

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 3 report

Users

Final version

Date: May 2018

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As agreed with Policy Officer Veerle Beelaerts, some of the budget for data purchase was reallocated for project work.

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Abbreviations

COP	Coefficient of Performance for air conditioners in heating mode
BLc	Annual cooling load per square meter of room area (kWh/m2/year/)
CDD	Cooling Degree Day
EER	Energy Efficiency Ratio for air conditioners in cooling mode
GWP	Global warming potential
HCK	The number of hours the unit is considered to work in crankcase heater mode for air conditioners
HOFF	The number of hours the unit is considered to work in off mode for air conditioners
HSB	The number of hours the unit is considered to work in standby mode for air conditioners
HTO	The number of hours the unit is considered to work in thermostat off mode for air conditioners
INF	Infiltration in kW (cooling capacity lost - negative capacity value - because of infiltration)
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
QCE	The reference annual cooling demand for air conditioners in cooling mode
QHE	The reference annual heating demand for air conditioners in heating mode
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
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.

3 Task 3

Task 3 follows the MEErP methodology and aims to identify consumer behaviour likely to influence the assessment of the environmental impact and the life cycle cost of the product, and it should also identify barriers and restrictions to possible ecodesign measures, due to social or infrastructural factors. At last, it should quantify relevant user-parameters that influence the environmental impact during product-life and that are different from the standard test conditions. It includes the following sections:

1. Systems aspect: Use phase
2. End-of-life behaviour: Discussion of the current state of play in terms of end of life options and practices.
3. Local infrastructure: Description and identification of barriers and opportunities relating to the local infrastructure.

3.1 System aspects use phase

Use phase often accounts for the largest energy consumption in a product's lifetime. It is therefore important to investigate what influences the use phase consumption.

At the time of the preparatory study, a seasonal performance standard has been developed to account for main variables influencing air conditioner energy consumption, which are the variations of the cooling energy supplied and of outdoor temperature along the year. This is in line with the "extended product approach" defined by MEErP, that as the energy-related products (ErP) are subject to various load/user demands, the product scope should extend to controllability i.e. the flexibility and efficiency to react to different load situations. In the following subsections, the foundations of this extended product approach are briefly described, and main parameters are reviewed to see whether they have to be adapted or not.

Regarding portable air conditioners, a seasonal performance standard is not yet available and an additional parameter is to be considered under the extended scope approach, which is the infiltration of outdoor air due to the operation of the product. The impact of infiltration is studied in heating and in cooling mode. Possible seasonal performance metrics are discussed.

These points are discussed in the following sections:

- **The basics of energy consumption**: understanding in general what the consumption consists of, and in particular the implications of modifying the main parameters of the present seasonal performance metrics;
- **Cooling loads and SEER metrics parameters:** investigating if it is necessary to update the parameters of the metrics. Important factors are the cooling loads, sizing, standard equivalent full load hours, SEER temperature profile, hours of operation per mode.
- **Heating loads and SCOP metrics parameters:** investigating if it is necessary to update the parameters of the metrics in heating mode. Important factors are the use of heating (reversible units) and the heating load.
- **Crankcase heater in SEER and SCOP metrics:** investigating the need to update the measurements.

- **Case of portable air conditioners:** investigating the infiltration of air and whether seasonal performance cooling metrics should be adopted.
- **Real life versus standard performance** and the impact of proper maintenance.
- In the case of comfort fans, the **use patterns of comfort fans**.

3.1.1 Basics of energy consumption of air conditioners

The energy consumption used for cooling/heating by air conditioners (reversible air conditioner) depends on the cooling load (respectively cooling and heating load), product efficiency for hours with cooling SEERon (or heating SCOPon) and consumption of the unit in auxiliary modes (thermostat-off, standby, crankcase heater).

Cooling energy consumption is calculated via the following equation:

$$Q_{CE}\ (kWh) = \frac{Q_C}{SEER_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB} + H_{CK} \times P_{CK} + H_{OFF} \times P_{OFF}$$

Where:

- *Q_{CE} = Annual electricity consumption for cooling, expressed in kWh/a*
- *Q_C = The reference annual cooling demand, expressed in kWh/a*
- *H_{TO}, H_{SB}, H_{CK}, H_{OFF} = the number of hours the unit is considered to work in respectively thermostat off mode, standby mode, crankcase heater mode and off mode.*
- *P_{TO}, P_{SB}, P_{CK}, P_{OFF} = the electricity consumption during respectively thermostat off mode, standby mode, crankcase heater mode and off mode, expressed in kW*

The cooling load is the sum of the transmission heat losses, air change due to ventilation and infiltration, internal loads (heat loads due to people and equipment releasing heat inside the building) and solar heat gains to maintain a desired room temperature. Transmission and air change losses mainly depend on temperature difference indoor/outdoor, hence on climate and indoor set point temperature and the building envelope. In addition, there may be dehumidification loads due to moisture condensation on cold coils of cooling equipment.

The cooling load of a cooled area/building is in general given in annual kWh of cooling load per square meter of room area (noted as *BLc*). This is the useful unit for the building but has no meaning for the product itself. What matters for a product consumption is the cooling energy it supplies, or kWh cooling load per product noted below as *Q_{ce} (product)*. In Regulation 206/2012, it is supposed what is called a "perfect sizing" condition, which means the capacity of the unit at design conditions is exactly matching the maximum cooling load in these same conditions.

The link between the product and building loads is then derived as follows:

$$Q_C(product) = P_{designc}\ (in\ kW) \times\ H_{CE}\ (in\ hours)$$

$$and\ H_{CE} = \frac{BLc\ (kWh/m^2/y)}{Sc\ (W/m^2)}$$

With:

- Sc: the sizing coefficient for cooling (Sc), which is the ratio linking the maximal cooling load at design conditions and the cooled area,

- H_{CE}: the equivalent number of full load cooling hours,
- Pdesignc: the maximum building cooling needs in kW, which is equal to the maximum cooling capacity of the unit.

It is important to notice that the higher the sizing coefficient Sc, the lower the number of equivalent hours H_{CE}, the lower the reference annual cooling demand Q_C and the lower is the energy consumption

Regarding the seasonal cooling efficiency of a given unit over a season, it depends on:

- the indoor and outdoor temperatures of operation,
- the indoor humidity,
- the load ratio of the unit (ratio of building cooling load to unit capacity), which in turn depends on the sizing of the unit and on the unit's capability to modulate its capacity,
- the indoor air flow set by the end-user (in general the outdoor air flow is fixed by the unit controller),
- its power consumption when it is not cooling,
- and the maintenance of the unit.

Oversizing here may lead to decrease in efficiency and then to an increase in energy consumption; this depends on efficiency variation with loads and also whether consumption of the unit when compressor is not working is proportional or not to the size of the unit. It is also important to notice that reducing the equivalent number of full load cooling hours (Hce) tends to increase the weight of low power mode consumption and then to reduce efficiency (increasing the gap between SEERon and SEER).

Regarding heating, what has been discussed above for cooling load is also valid for heating load, with two main differences:

- there is no latent load for heating,
- in heating mode, products may not be designed to supply by themselves the whole heating capacity of the building at design conditions due to e.g. the sizing was done according to the cooling load (for reversible units), therefore part of the heat may be supplied by a back-up heater[1] (result of an economic optimization) so that Pdesignh is a declaration of the manufacturer.

Using the same notations but replacing c for cooling by h for heating:

$$Q_H(building) = P_{designh}\ (in\ kW) \times\ H_{HE}\ (in\ hours)$$

$$and\ H_{HE} = \frac{BLh\ (kWh/m^2/y)}{Sh\ (W/m^2)}$$

Still it is supposed that the declared maximum capacity of the unit plus the back-up heater capacity at Tdesignh equals the maximum building load in the same condition to derive the heating load of the unit. In present Regulation (EU) 206/2012, the SCOPon calculation includes the impact of an electric back-up heater with a coefficient of performance of 1.

[1] An electric back-up heater is defined in Regulation (EU) N° 206/2012, but other types might be used.

3.1.2 Cooling loads and SEER metrics parameters

In this part, the hypothesis of the SEER metrics in Regulation (EU) 206/2012 and 626/2011 are assessed if they need to be updated. This regards the following parameters:

- the specific cooling loads BLc in kWh/m^2/year,
- the sizing coefficient Sc in W/m^2/year,
- the equivalent full load hours,
- The outdoor temperature profile.

3.1.2.1 Specific cooling loads

As it cannot be measured easily, there is no statistics available on real life building cooling loads or the cooling capacity supplied by air conditioners (note that building cooling load equals the air conditioner cooling capacity, except in case of under-sizing); the same is true for cooling efficiency (which requires the measurement of cooling load).

Information on energy consumption for space cooling in Europe is also scarce and information on measured values generally insufficient to identify separately product efficiency and load (consumption being the ratio of load to efficiency). The preparatory study used simulations to derive cooling loads of air-conditioned buildings. Three different simple buildings were simulated, one house, one office and one shop (in Figure 1, respectively noted as "Res", "Off" and "Shop"), varying envelope insulation characteristics and air change properties for existing buildings and for new buildings built after 2006. The main characteristics of these buildings are given in the ANNEX.

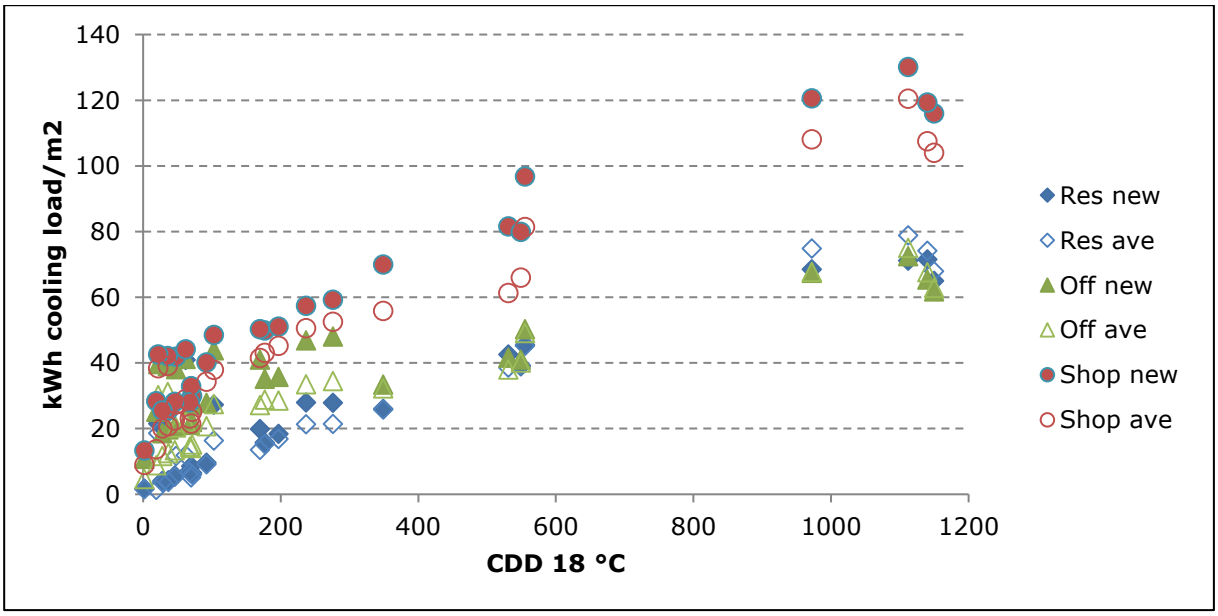

Figure 1: Yearly cooling load versus cooling degree days (CDD)[2] with base temperature 18 °C, source preparatory study.

As it can be seen on Figure 1, the total cooling load is in general proportional to the cooling degree day indicator of the specific climate simulated. Offices and shops, with larger internal loads and with larger operating hours have higher requirements in total.

One of the specifics of these simulations is that, as it can be seen in table below in red, cooling loads appear very high as compared to the cooling degree day (CDD) indicator in

[2] CDD: cooling degree days have been defined in Task 2 paragraph 3.2.2.4

Nordic countries and other central Europe countries with simulated high U values. This is supposedly a heat trapping effect of internal loads because of high insulation levels, but in some buildings where people can open doors and windows (for instance residential buildings in quiet environment), this most likely overestimates the real air conditioner cooling loads. The insulation levels were based on an Ecofys report of 2006 and represented indicative insulation values for average existing and new buildings (respectively noted average and new in Figure 1 and Table 1). Note this is still the source used in (Kemna, 2014)[3] to estimate average EU heating load in Europe.

More insulated new buildings also have lower cooling loads for higher cooling degree day CDD values.

*Table 1: Cooling load versus cooling degree days, source preparatory study. * indicates CDD values not given in Preparatory study, these are issued from ASHRAE IWEC data. Below in red shows that cooling loads appear very high as compared to the cooling degree day (CDD) indicator in Nordic countries and other central Europe countries with simulated low U values.*

	CDD18	Cooling load in kWh/m2/year					
		Res new	Res ave	Off new	Off ave	Shop new	Shop ave
Ireland	2	1.7	1.5	10.8	4.6	13.4	8.9
Lithuania	19	28.2	1.3	25.1	8.9	28.3	13.7
Sweden	22	21.6	18.6	39.6	30.2	42.5	38.3
UK	28	4.1	3.6	18.6	11.7	25.5	20.1
Finland	36	24.7	22.3	39.0	31.2	42.0	39.1
Denmark	37	4.2	3.8	19.7	12.5	25.6	20.7
Netherlands	46	5.7	5.3	20.8	13.4	28.1	22.5
Estonia	48	39.7	11.7	38.1	20.3	41.9	27.4
Latvia	62	41.0	11.8	41.2	22.0	44.1	29.0
Germany	68	7.2	6.7	21.1	14.5	28.1	23.1
Czech Republic	70	8.5	5.2	27.2	14.1	32.9	21.5
Belgium	71	6.5	6.0	22.0	15.2	29.9	25.2
Luxembourg	92	9.6	9.1	27.9	20.8	40.1	34.3
Poland	103	27.2	16.4	43.9	27.5	48.5	37.9
Slovenia	170	19.8	13.5	41.0	27.2	50.2	41.5
Austria	177	15.7	15.3	35.1	28.8	49.8	43.1
France (Mâcon)	197*	18.4	16.9	35.8	28.5	51.1	45.2
Slovakia	237	27.9	21.3	46.9	33.5	57.3	50.5
Hungary	276	27.8	21.4	48.0	34.5	59.3	52.5
Italy (Milano)	349	26.0	25.8	33.4	32.2	69.9	55.8
Portugal	531	42.6	38.5	41.6	38.0	81.6	61.3
Spain (Madrid)	549	38.9	39.3	41.0	40.2	79.9	66.0
Italy (Roma)	555*	45.5	45.2	50.2	49.1	96.7	81.3
Malta	972	68.5	74.8	67.4	67.7	120.5	108.0
Cyprus	1112	71.2	78.8	72.5	75.0	130.1	120.4
Spain (Seville)	1140*	71.5	74.2	65.4	67.6	119.3	107.5
Greece	1150	65.0	67.9	61.8	62.9	116.0	104.0

[3] René Kemna (VHK), 2014. Final report on Average EU building heat load for HVAC equipment. Specific contract No. ENER/C3/412-2010/15/FV2014-558/SI2.680138 with reference to Framework Contract ENER/C3/412-2010. Prepared for the European Commission DG ENER C.3. Delft, 2014.

As mentioned, the above presented cooling loads were simulated. Although annual average real cooling loads of air conditioners < 12 kW are not known in Europe, we can compare the simulations of the Preparatory study with other sources.

Values of average real cooling loads monitored at substations of district cooling in different cities in Europe are given in the literature[4]; cooling loads are shown against cooling degree days of the cities in Figure 2; CDD values used are ASHRAE IWEC data[5]. This gives relatively high values, in line with buildings connected to district cooling (e.g. tall office buildings and data centres), which are likely to have higher cooling loads than residences or small shops and offices.

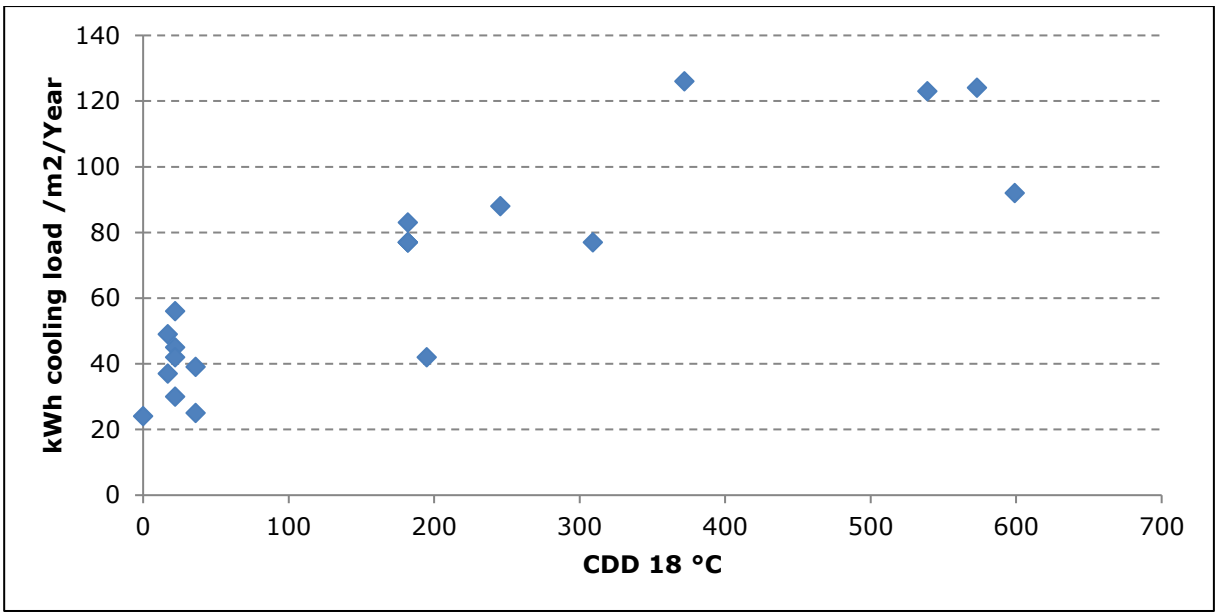

Figure 2: Average building cooling loads of some district cooling networks in Europe[6].

The JRC used US EIA estimate of cooling electricity consumption in the USA to derive an estimate of residential cooling load for air-conditioned buildings by dividing it by the SEER of the specific unit in house (using minimum mandatory US MEPS of the installation year in the house) and correlated this against CDD; both cooling electricity consumption and load are shown in Figure 3. There is a clear dependency of consumption and loads with cooling degree days (base 18 °C). Note that the JRC estimate has to be corrected to get the cooling load per m^2 of cooled area, as m^2 in JRC regression are total house m^2 and that in mild climate only a portion of the dwelling might be cooled. This is done in Figure 4 using input from Task 2 (Ratio of surface to penetration as a function of CDD computed on the same base data).

[4] Sven Werner, European space cooling demands, In Energy, Volume 110, 2016, Pages 148-156, https://doi.org/10.1016/j.energy.2015.11.028.
[5] https://energyplus.net/weather
[6] Sven Werner, European space cooling demands, In Energy, Volume 110, 2016, Pages 148-156, https://doi.org/10.1016/j.energy.2015.11.028.

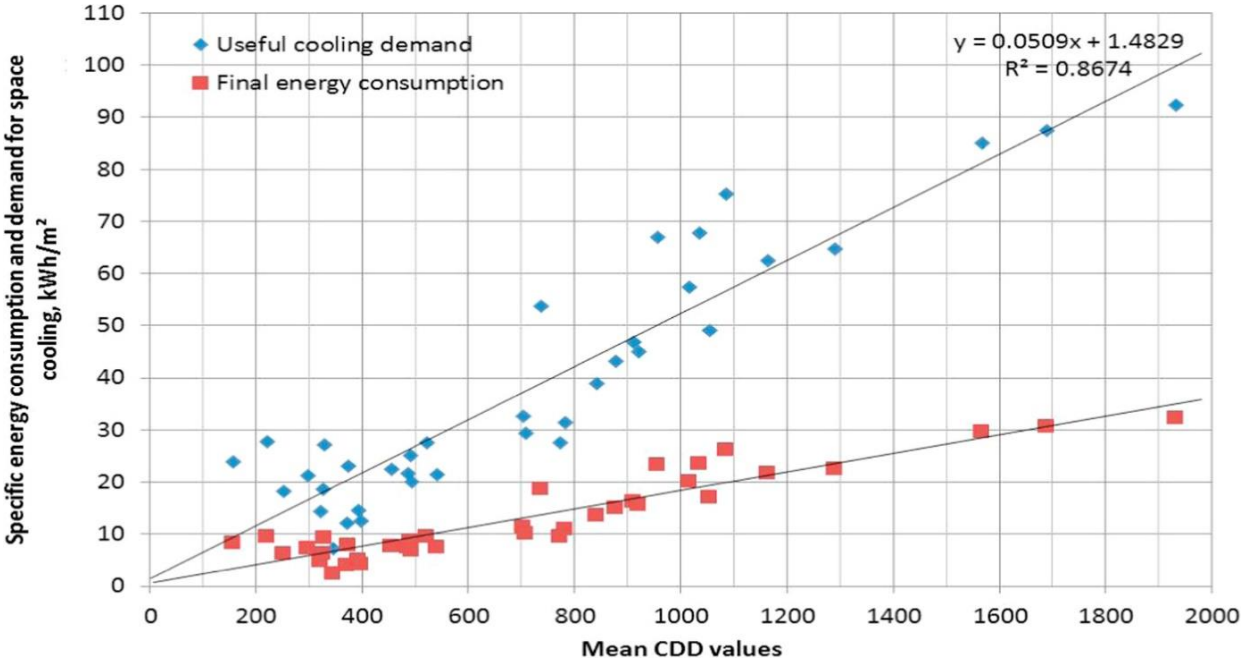

Figure 3: Dependency of final specific energy consumption for cooling and useful cooling demand in residencies of USA on climatic conditions in kWh/m² (of total dwelling surface)/year[7].

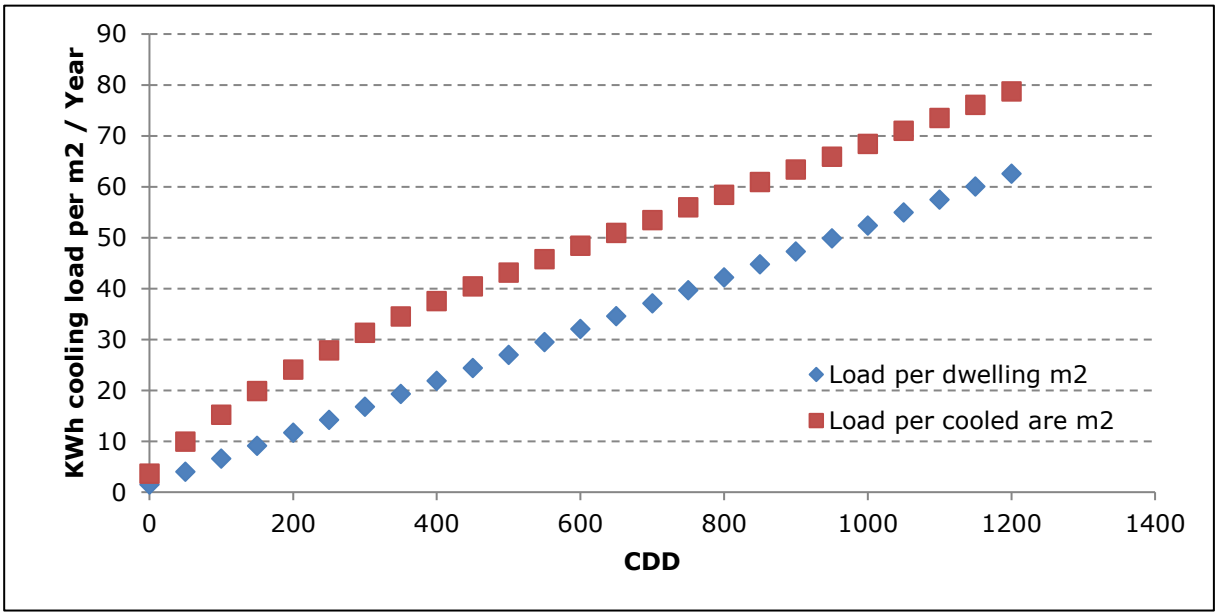

Figure 4: Dependency of final specific energy consumption for cooling and useful cooling demand in residencies of USA on climatic conditions reported to total dwelling are and to cooled area only, adapted from (Jakubcionis and Carlsson, 2017).

The ENTRANZE[8] project simulated cooling loads of typical old buildings (representative of very low insulation levels, typically built in years 1960 to 70's, i.e. before any building regulation) across Europe. We show here the results for houses in Figure 5. Cooling loads are also correlated to CDD (base temperature 18 °C). For offices, there is no marked difference with houses, while for apartments, the cooling loads are lower than in houses.

[7] Mindaugas Jakubcionis, Johan Carlsson, Estimation of European Union residential sector space cooling potential, In Energy Policy, Volume 101, 2017, Pages 225-235, https://doi.org/10.1016/j.enpol.2016.11.047
[8] Paolo Zangheri, Roberto Armani, Marco Pietrobon and Lorenzo Pagliano (eERG), Heating and cooling energy demand and loads for building types in different countries of the EU, D2.3. of WP2 of the Entranze, March 2014. http://www.entranze.eu

The comparison of all information sources for residential sectors are shown in Figure 5 and service sector in Figure 6.

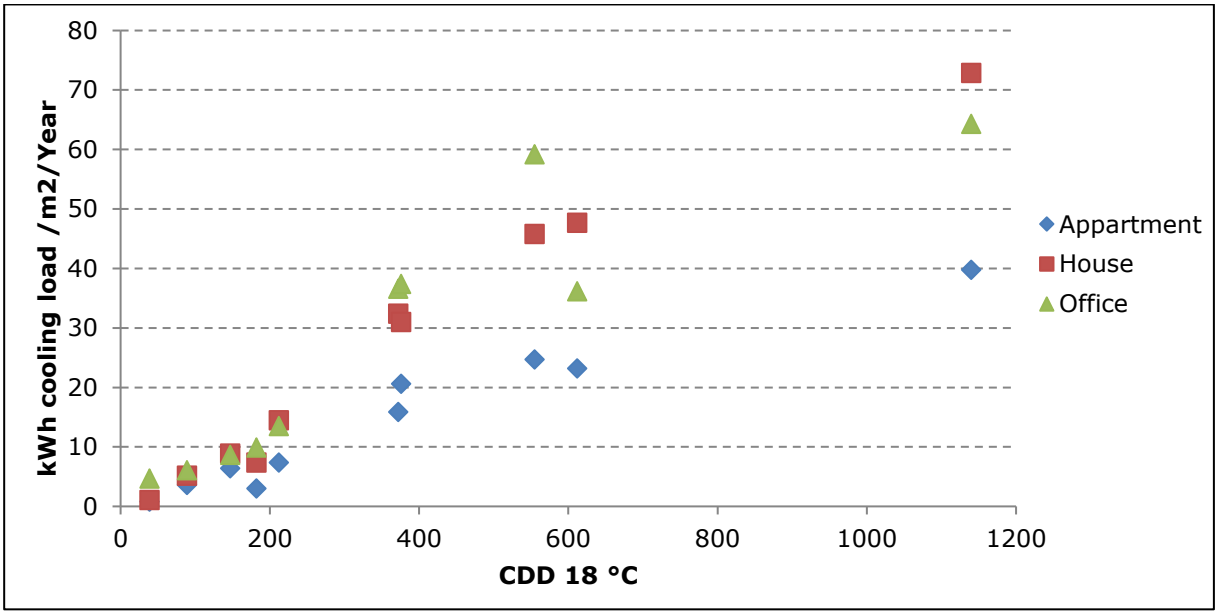

Figure 5: Simulation of cooling loads of typical old buildings, source ENTRANZE project

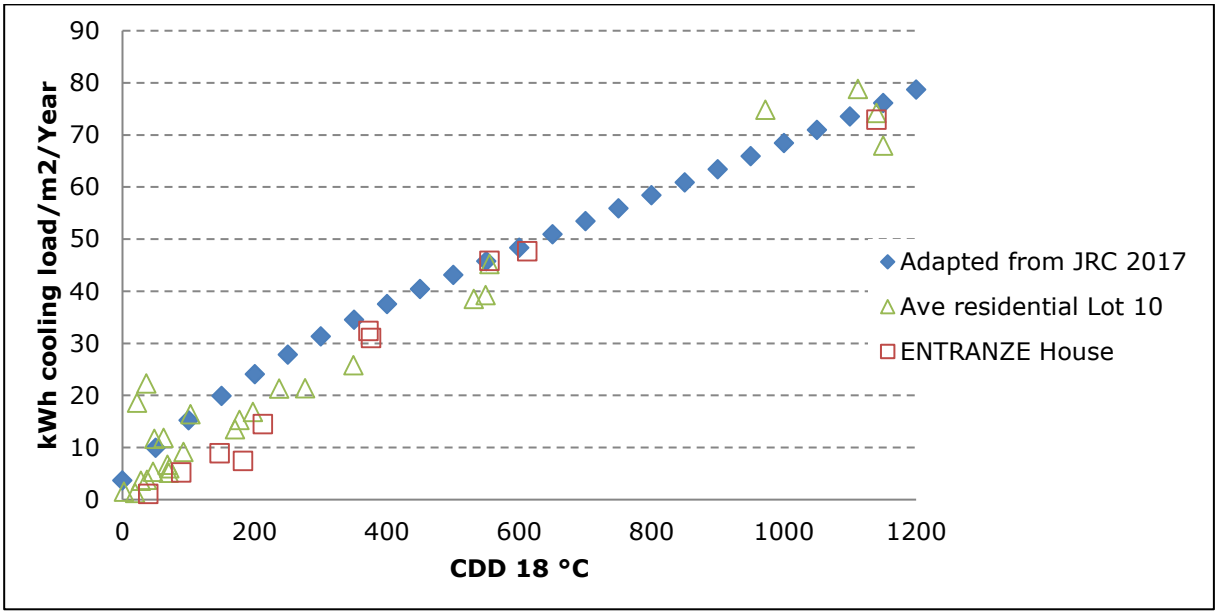

Figure 6: Comparison of residential cooling loads from different sources

For residences, all 3 sources are comparable at high loads; estimates from JRC are higher at low loads than in Lot 10 preparatory study simulation except for countries with very high insulation levels. The ENTRANZE simulations do not exhibit the heat trapping effect shown by the Preparatory study simulation, but this is in line with heat insulation properties selected for the simulation. Overall, there is a good agreement between the 3 sources, and values in Preparatory study still can be used. The only doubt is about apartment whose load in average seems lower than for houses according ENTRANZE simulations and which are not accounted for in the cooling load estimates for residences in Lot 10 preparatory study. The respective share of cooling system < 12 kW installed in apartments and houses in Europe is not available, therefore cannot be assessed.

For the service sector, real loads as seen at district cooling levels are much higher than simulated values. This is possibly linked with the building types connected to district cooling networks. Building Research Establishment (BRE) realized estimates of cooling loads in offices in the UK[9]. It was based upon field monitoring of electricity consumption and assessment of system efficiency from technical data. Average estimated cooling load in real buildings is about 30 kWh/m2/year (with about 30 % of the 99 office buildings considered having values of 40 kWh/m2 or more). So, it is possible to find buildings with high loads (up to 60 kWh/m^2/year for very low CDD values) as shown by cooling networks but it is probably not representative of typical buildings. Another striking point is the steeper slope for cooling load increase plotted against Cooling Degree Days (CDD) for district cooling buildings. It is difficult to explain the steeper slope without more knowledge of the loads being connected to the district cooling system. If this is due to the system, this can be linked to the decrease in the share of free cooling with increasing CDD and/or to the non-linear increase in heat released by pumps and fans with higher loads.

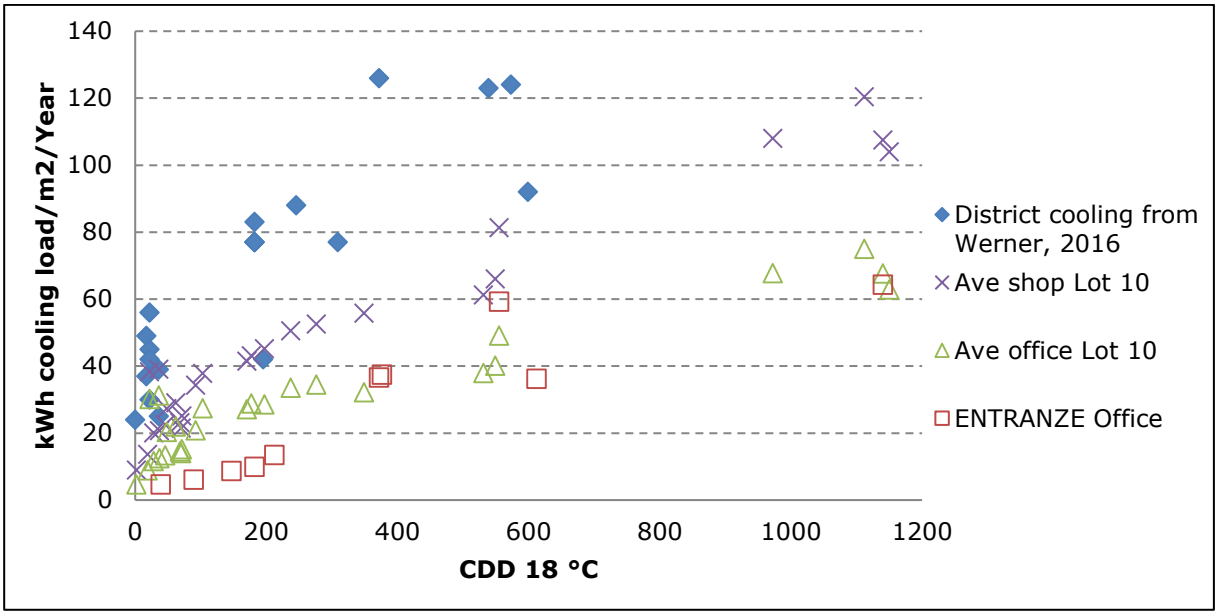

Figure 7: Comparison of service cooling loads from different sources

An audit campaign on more than 100 offices in Sweden[10] give also loads similar to the ones of Lot 10 simulation results for average office buildings: specific electricity consumption of 10.3 kWh/m^2/year for cooling, which for this climate, probably gives more than 30 kWh/m^2 cooling loads when multiplying by the average SEER of the cooling machines.

ENTRANZE simulation for offices give similar results at higher loads than Preparatory study simulation but much smaller loads at low CDD values: thanks to lower insulation level and higher infiltration air change per hour (ENTRANZE typical buildings are older buildings), internal loads are more easily mitigated, decreasing the cooling loads. Both sets of simulation are thus consistent. In fine, we will then continue using the Preparatory simulations.

Preparatory study loads include both latent and sensible load. Latent load is uncontrolled in general; it arises from the condensation of the water vapor of the air on the cooling coil

[9] https://www.bre.co.uk/filelibrary/pdf/projects/aircon-energy-use/StudyOnEnergyUseByAirConditioningFinalReport.pdf
[10] https://www.sintef.no/globalassets/project/eldek/publisering/tr-a6999-state-of-the-art-projects-for-estimating-the-electricity-end-use-demand.pdf

of the indoor unit when the coil temperature is below the air temperature dew point. However, in average, the share of the latent load is supposed to be low. In the Task 4 of the preparatory study, the sensible heat ratio (SHR, share of sensible to total cooling capacity) of the average unit was supposed to be about 0.9 (so 10 % latent load) for an average outdoor temperature of 23 °C and 50 % humidity (23 °C is close to the average outdoor temperature in cooling season[11]). With present split air conditioners, the air flow is constant at reduced capacity, which increases the evaporating temperature and increase the SHR. At 50 % load, the SHR is close to 1 so that there is no latent load.

So, the fact that the unit capability to dehumidify is decreasing because of higher evaporating temperatures and inverter operation at part load will probably tend to curb the specific cooling load and energy consumption of air conditioners in Europe by a maximum of 10 % in average in the future.

Conclusions regarding cooling loads

There is no or limited statistics on cooling load in Europe and on cooling energy consumption. Through reviewing other potential sources of load estimates, it appears appropriate to keep the Lot 10 Preparatory study simulations to estimate cooling loads. Available sources give comparable values.

In order to properly model the impact of climate change and to include in this review study countries not modelled in the Preparatory study (Bulgaria, Croatia, Romania), correlations between specific loads and CDD based on Lot 10 preparatory study are used.

Task 2 stock model does not link building age and air conditioning installations nor the type of building in the service sector. Hence, specific CDD - average loads correlations by sector (services / residential) are computed on the following basis (same for all EU countries):

- 15 % of installation in new buildings and 85 % in existing buildings,
- regarding the service sector, about 50 % in offices and 50 % in retail buildings following 2015 data purchased from BSRIA (note this was about 25 % and 75 % resp. in the preparatory study using the same BSRIA source for 2005)

[11] René Kemna (VHK), 2014. Final report on Average EU building heat load for HVAC equipment. Specific contract No. ENER/C3/412-2010/15/FV2014-558/SI2.680138 with reference to Framework Contract ENER/C3/412-2010. Prepared for the European Commission DG ENER C.3. Delft, 2014.

Correlations of these specific cooling loads are drawn versus CDD as shown in Figure 8 and Figure 9.

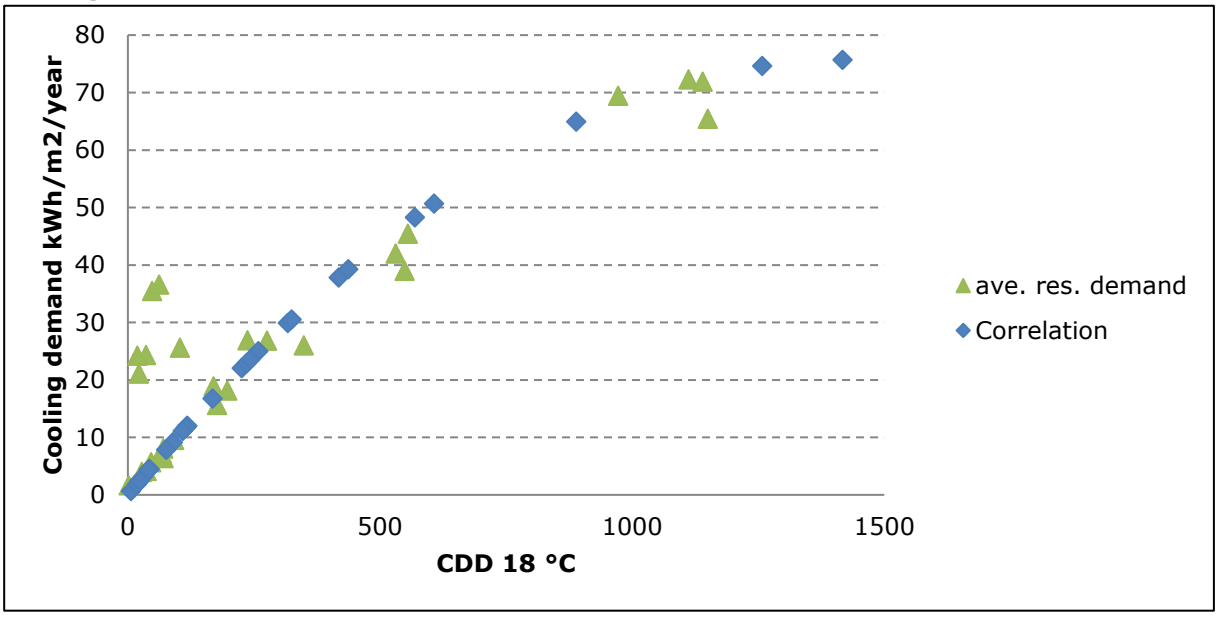

Figure 8: Specific demand per country in residences and correlation, adapted from preparatory study

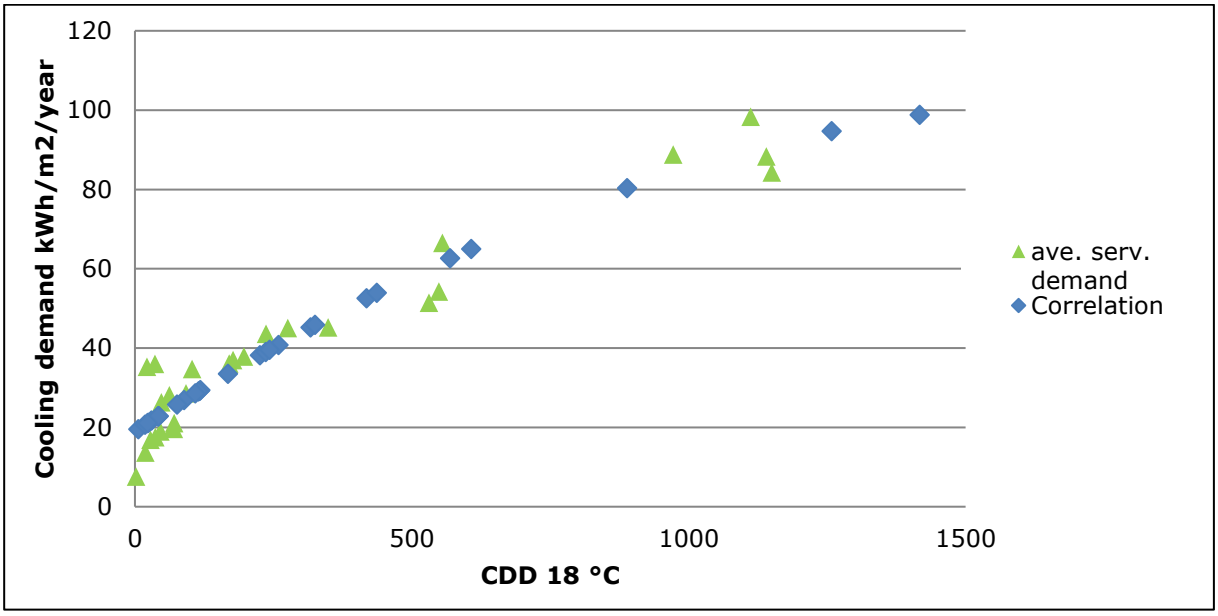

Figure 9: Specific demand per country in services and correlation, adapted from preparatory study

These correlations give specific cooling loads per country using CDD values per country as indicated in Task 2. When combining country specific loads with the stock model of Task 2, the EU-28 average specific cooling load can be calculated (Table 2). Weighted average values (per m^2 of cooled area) is of about 45 kWh/m^2/year, with limited planned evolution despite accounting for climate change impact, because of the faster increase of sales in countries with milder countries. This value is similar to the weighted average in Lot 10 study (it was 33 for cooling only and single duct units in 2005 and 39 for reversible split[12]). The weighted average CDD value is 474.

[12] Preparatory study, Task 4 report, table 4-30, page 89

Conclusively, the average EU28 load estimate in 2015 is slightly higher than in the Preparatory study. The EU average specific load of 45 kWh/m^2/year is to be used to compute the equivalent full load cooling hours below in section 3.1.2.3 and in Task 5 to compute the global environmental impacts of the use phase.

Table 2: Estimated weighted average (by cooled floor area) CDD and specific demand for EU28

Year	2015	2020	2025	2030	2035	2040	2045	2050
CDD residential	537	527	537	539	543	548	553	559
CDD services	311	294	304	318	296	335	342	350
CDD weighted average	474	456	464	471	469	487	495	504
Cooling demand residential kWh/m2/y	44	42	43	43	43	44	44	45
Cooling demand services kWh/m2/y	44	44	42	43	44	45	46	46
Average cooling demand kWh/m2/y	44	43	43	43	44	44	45	45

3.1.2.2 Sizing

The very few studies available (though not statistically significant) show that large oversizing is the rule in cooling mode in Europe. In the USA, even though cooling load calculation is mandatory and standardized[13], oversizing is also a common practice. It is thus not surprising that oversizing is common in Europe, where there is in most countries no agreed method to size air conditioners (liability of the installer in most cases for fix installations and following retailer advise for portable ones). In addition, part of the units is also sized to satisfy the whole building heating needs, which may also lead to oversizing in cooling mode in central and northern Europe.

Recent findings[14] using on-board performance measurement method (these methods are discussed in section 3.1.7.1 below) confirm this large oversizing although this regards larger systems (Variable Refrigerant Flow systems used in service buildings). Figure 10 shows that for 95 % of the time, the average load in cooling mode (or in heating mode) was lower than 80 % (respectively 85 % in heating mode) for all systems, and lower than 50 % (respectively 55% in heating mode) for most of them. Figure 10 shows although the efficiency axis is not given, that there is an impact on performances figured by the dot line: the lower the load and the lower the performance. This impact is particularly striking in cooling mode for the UK with a fast degradation of performances with lower maximal load. Despite much milder climate than Spain, seasonal efficiency appears lower in the UK than in Spain at lowest loads.

[13] ACCA Air Conditioning Contractor's Association of America Manual J available at: http://www.acca.org/
[14] Stefan Vandaele, Hiroshi Aihara, Optimisation of VRF systems in buildings by monitoring, in Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 9. Aalborg: Aalborg University, Department of Civil Engineering.

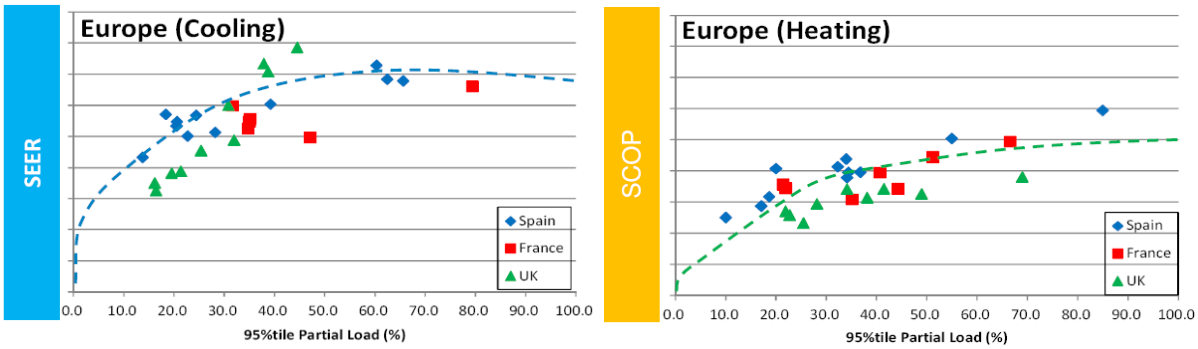

Figure 10: Link between field measured seasonal efficiency in cooling and in heating mode, climate and unit sizing (A 95%tile load of 50% means that during 95% of the time the part load ratio of the unit was 50% or lower - 100% partial load, means full capacity of the unit)

VRF air conditioners with less than 12 kW all use DC inverter compressors (in Task 2 it was mentioned that close to 100% of all split air conditioners sold in 2015 in Europe have DC inverter compressor motors). This does not seem enough to guarantee good performance when large oversizing occurs. These first field monitoring sizing results ever (for VRF) most likely show the impact of cycling below minimum compressor speed, thermostat-off, crankcase and standby consumptions and so the necessity to properly include these phenomena in Regulation 206/2012 (and in Regulation 2281/2016 for larger systems).

It also shows that the seasonal metrics hypothesis of "perfect sizing", in which the 100 % load of the building matches the declared rated capacity of the unit, does not correspond to real life situation. One possibility could be to change the Regulation 206/2012 seasonal performance metrics to account for this proven oversizing. However, it is not sure that such a modified metrics would lead to lower SEER/SCOP values than with "perfect sizing" because the cycling performance is accounted for with a simplified Cd factor, that would probably not translate in high enough performance degradation. In addition, the real-life sizing values and seasonal performance degradation due to oversizing are not known for split air conditioners, which makes it difficult to make design choices for a modified metrics.

So, it is advised to improve the cycling representation in Regulation 206/2012, including the test of cyclic behaviour at low loads for inverter driven compressors and to encourage the development of methods enabling to measure real-life efficiency measurement and real-life sizing (see section 3.1.7.1 below). Thus, if in the future, enough material an oversizing is gathered, an oversizing coefficient could be included in regulation to properly account for the impacts of oversizing[15]. Note also that the EU Energy Performance of Building Directive 2010/31, in articles 14 and 15, requires Member States to evaluate units larger than 12 kW oversizing and to propose solutions to improve real life efficiency. For air conditioners (smaller or larger than 12 kW), measurement on field can only be done by these internal measurement methods presented in section 3.1.7.1.

[15] The perfect sizing hypothesis, 100 % building load corresponds to rated capacity of the air conditioner, could be replaced by, e.g. 100 % + X %. SEER value would decrease because of lower loads and higher impact of auxiliary modes, and Hce as well. But at the moment, there is not enough information to calibrate the oversizing coefficient X %.

Note that portable air conditioners, a LBNL[16] field study led on 19 portable air conditioners gives average load ratio between 50% and 100 % suggesting that undersizing is more common than oversizing.

As information is missing on real life sizing and on the impact on performances, we will keep for now the sizing values used in the Preparatory study.

Sizing in W/m^2 for energy calculation is presently based on the same Lot 10 preparatory study simulations as used to compute loads. The values are maximal load values of annual hourly dynamic building simulation. They are presented for the different building types in Figure 11. In Figure 12 these sizing values are weighted for residential and service sectors as it was done for specific loads before (15 % new buildings 85 % existing, 50 % offices and 50 % retail for the service sector).

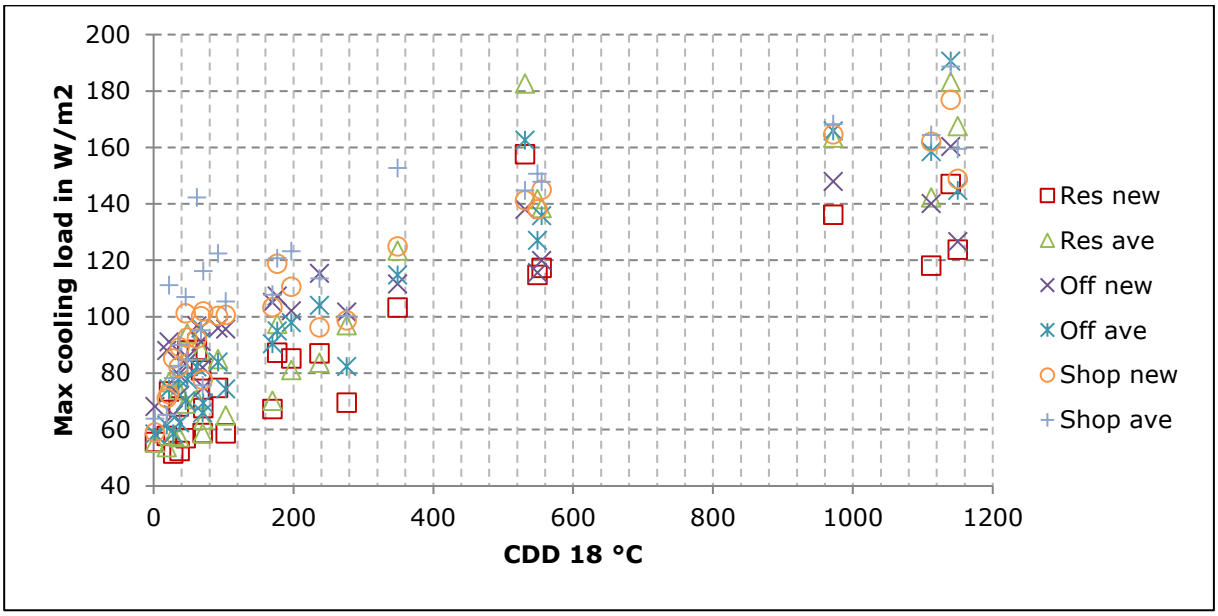

Figure 11: Maximum cooling load in W/m2 and cooling degree days, source preparatory study; CDD values not given in Preparatory study[17]

[16] T. Burke, et al., Using Field-Metered Data to Quantify Annual Energy Use of Portable Air Conditioners, Lawrence Berkeley National Laboratory, Report No. LBNL-6868E (December 2014). Available at: www.osti.gov/scitech/servlets/purl/1166989

[17] ASHRAE IWEC data available on https://energyplus.net/weather

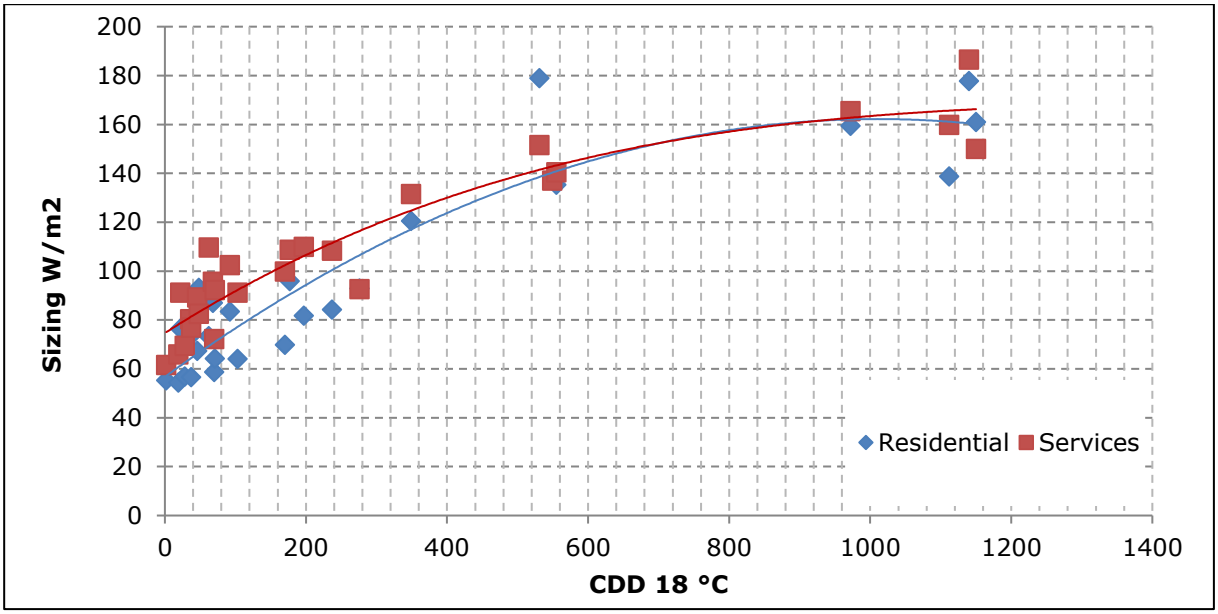

Figure 12: Residential and services average maximum cooling load in W/m2 and cooling degree days, source preparatory study

These values in figures above are in relatively good agreement with good practice indicated by the industry presented in Table 3.

Table 3: typical practices indicated by the industry

Sector / Climate	Warmer	Average	Colder
Residential	120-180 W/m2	100-120 W/m2	70-100 W/m2
Retail	-	100 W/m2	-

In conclusion, the sizing values from the Preparatory study are used in this review study under the form of two CDD correlations, respectively for residential and service sectors.

3.1.2.3 Standard equivalent full load hours

As mentioned in section 3.1.1, equivalent full load hours are essential to evaluate the energy consumption of products as the energy consumption of the unit is proportional to the equivalent full load hours.

In the preparatory study, the EU average cooling load was established at about 40 kWh/m2 by weighting the simulated cooling load by country (in kWh/m^2) by the share of the total installed cooling capacity (in % of kW) per sector and per country (stock weighted average). The weighted average CDD was 472, which was close to the CDD value estimate for Italy in the preparatory study (average of Milano and Rome climates). The specific demand of 40 kWh/m^2 was also the weighted average demand considering specific loads and share of installations in different building types for Italy. For this climate, the average value of sizing was 120 W/m^2 resulting in 333 full load hours (40 kWh/m^2 x 1000 W/kW / 120 W/m^2) was rounded to 350 equivalent full load hours.

Present review study average load estimate is a bit higher at 45 kWh/m^2/y. The increase is due to:

- the changes in the model used to assess the EU air conditioner stock of appliances, in which the weight of Eastern and Northern countries have been decreased according to available information for these countries (information not available for these countries at the time of the Preparatory study),
- the increasing weight and CDD (as compared to Preparatory study estimate) for Italy (estimated to represent about 30 % of the stock in 2015), which in turn increases significantly the specific cooling demand for this country and the EU.

The 45 kWh/m^2/year corresponds to CDD 474 (Table 2) and to sizing values in the range 130 to 140 W/m^2. This leads to similar values as in present regulation: between 320 and 345 hours, it is then suggested to keep the present full load hour number of 350.

In conclusion, the number of equivalent full load cooling hours H_{CE} is kept constant at 350 hours for this review study.

3.1.2.4 SEER temperature profile

Temperature profile has been established by weighting the temperature distribution of cooling season hours of capital cities[18] by sales of split air conditioners according to JRAIA sales publications of 2006 supplied by EPEE, as explained in the Preparatory study Task 4 report[19]. Weighting ASHRAE IWEC data by the % sales distribution of split air conditioners by country in numbers. Weighted average implied CDD value for air conditioner installations in Europe was about 455.

Looking at the resulting distribution of hours by temperature bin in Regulation 206/2012, it is supposed that cooling starts at 16.5 °C (0 % load at 16 °C bin). This is based on the Preparatory study simulation results for residences and service buildings (the latter supposedly represented about 60 % of the stock in GW of installed units in 2006 according to the Preparatory study). The present input gives a 50/50 repartition. So, the situation is not so different.

On this temperature profile, it was suggested by stakeholders to study whether it was justified to rate cooling units with temperatures below 26 °C. Here are a few references on that point. In Australia, Hart and de Dear[20] data over 136 dwellings suggest that in the residential sector, 18 °C is a good candidate for zero loads in average. More recently, in France, a study on 10 dwellings in the South of France indicated first loads occurring between 15 (but with centralized water based system) and about 25 °C average outdoor air temperature, with most systems zero loads around 19 to 21 °C. (Kemna, 2014)[11] using average residential building characteristics and internal load suggests 20.5 °C could be a good minimum value (20.5 °C outdoor leads to an average of 25 °C indoors because of electric internal loads and solar gains equivalent to about 3.5 °C overheat inside the building). 20.5 °C is also the reference used in the ISO/FDIS 16358-1:2013 standard[21], which is also targeting mainly residential units. In the USA, the AHRI standard uses 18.3 °C.

Hence, available information suggests values between 18 °C and 21 °C for the zero load in residences.

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[18] Spain climate selected was different here from before in Preparatory study: half Madrid and Barcelone (not half Madrid and Seville, which was considered to give too high average CDD values for Spain).
[19] Annex B.3 p 165 and below
[20] Melissa Hart, Richard de Dear, Weather sensitivity in household appliance energy end-use, In Energy and Buildings, Volume 36, Issue 2, 2004, Pages 161-174, https://doi.org/10.1016/j.enbuild.2003.10.009.
[21] See Task 1 for more information

However, for the service[22] sector, this temperature can drop to much lower levels. It is not uncommon to have cooling in large office buildings connected to district cooling at temperatures below 10 °C. The preparatory study simulations indicated balance points about 15 °C. So that the 17 °C (bin start 16.5 °C) was chosen as an average situation for buildings cooled by air conditioners. For residential air conditioners only as an average situation it may be too low. But being still at a 50/50 situation in installation proportions of residential products and service products, the 16 °C still seems adapted.

Regarding the number of hours per temperature bin, (Kemna, 2014)[11] studied a 3 month cooling season for Europe using population weighted average temperature bin for EU capital cities. The outdoor temperature for this weighted average is 23.2 °C, against 23 °C for the average temperature profile used in (EU) Regulation 206/2012. The evaluated monthly cooling degree days based on a simplified average model of a residential building has been calculated and is shown in Figure 12.

To build the temperature profile, cooling seasons of 3 months (Nordic countries) to 6 months (Southern countries) and 5 months for central Europe, have been used. This explains that the temperature profile, despite targeting southern Europe, gives more weight to lower temperature bins (in addition to the fact that base temperature is lower). If a residential metrics only were looked for, in addition to increasing the base outdoor temperature, the length of seasons in central European countries should probably be reduced to 3 to 4 months. This would tend to increase the average outdoor temperature of operation.

Other residential seasonal performance standard has indeed temperature profile corresponding to higher average outdoor temperature and load. What matters for SEER determination is the energy weighted average temperature and load of the profile (energy weights are obtained by multiplying load and number of hours):

- Regulation 206/2012 (50 residential / 50 services): energy weighted average load ratio 51 %, temperature 25.6 °C (eq. full load hours 350)
- AHRI 210/240 (residential): 27.8 °C, 57 % (equivalent full load hours 730)
- ISO 16348 (residential): 27.5 °C, 50 % (equivalent full load hours 800)

Weighted average energy values for temperature is lower in Europe as compared to USA and ISO standards, in agreement with milder average climate (lower equivalent full load hours) and to the fact that residential only is targeted.

[22] Service sector is sometimes also named tertiary or commercial sector and encompasses all non residential buildings except industrial ones.

Table 4: Evaluation of monthly residential cooling degree days base 20.5 °C[23]

	City, weather station	2013					2014							Total	Population %
		Aug	Sep	Oct	Nov	Des	Jan	Feb	Mar	Apr	May	June	July		
AT	Wien, Schwechat	85	7	0	0	0	0	0	0	1	11	44	65	213	1.6%
BE	Brussels, Zaventem	27	9	0	0	0	0	0	0	0	3	11	34	84	2.1%
BG	Sofia, Observ.	123	29	8	0	0	0	0	1	1	13	37	63	275	1.4%
CY	Larnaca, Cyprus	256	161	71	31	0	0	0	7	25	53	151	217	972	0.1%
CZ	Prague, Ruzyne	37	3	0	0	0	0	0	0	0	5	23	48	116	1.9%
DE	Berlin, Tempelhof	45	4	0	0	0	0	0	0	0	13	27	79	168	18.4%
DK	Copenhagen	10	0	0	0	0	0	0	0	0	1	2	44	57	1.2%
EE	Talinn, Talinn	12	0	0	0	0	0	0	0	0	14	4	48	78	0.3%
EI	Dublin, Dublin	0	1	0	0	0	0	0	0	0	0	1	3	5	0.7%
ES	Madrid, Barajas	208	96	16	1	0	0	0	2	22	40	103	164	652	7.0%
FI	Helsinki, Vantaa	15	1	0	0	0	0	0	0	0	15	6	60	97	1.2%
FR	Paris, Orly	48	15	1	0	0	0	0	0	0	2	20	52	138	13.3%
GR	Athens, Elefsis	265	135	33	5	0	0	0	1	9	57	156	232	893	1.9%
HR	Zagreb, Pleso	107	17	5	0	0	0	0	2	2	20	57	67	277	0.7%
HU	Budapest / Ferihegy	113	8	2	0	0	0	0	0	1	16	57	85	282	2.0%
IT	Roma, Ciampino	165	58	20	1	0	0	0	0	1	11	78	86	420	12.4%
LI	Vilnius, Vilnius	24	1	0	0	0	0	0	0	1	15	5	59	105	0.6%
LT	Riga, Airport	21	1	0	0	0	0	0	0	0	16	6	58	102	0.4%
LU	Luxembourg, LU	27	10	0	0	0	0	0	0	0	2	24	40	103	0.1%
MT	Valetta, Luqa	204	128	86	10	0	0	0	0	2	22	107	155	714	0.1%
NL	Amsterdam Schiphol	22	6	0	0	0	0	0	0	0	3	6	38	75	3.6%
PL	Warsaw, Mazowieckie	66	2	0	0	0	0	0	0	3	22	25	98	216	6.9%
PO	Lisbon, Rudela	106	74	16	0	0	0	0	1	4	23	42	58	324	1.8%
RO	Bucuresti / Imh	150	32	3	1	0	0	0	1	3	26	54	109	379	3.4%
SE	Stockholm (Arlanda)	15	2	0	0	0	0	0	0	0	8	2	54	81	2.1%
SI	Liubljana, Brnik	85	10	0	0	0	0	0	0	0	9	41	42	187	0.3%
SK	Bratislava, Ivanka	96	8	1	0	0	0	0	0	2	16	56	81	260	1.3%
UK	London, Heathrow	25	9	0	0	0	0	0	0	0	3	13	44	94	13.2%
EU	Total CDD	81	25	5	0	0	0	0	0	2	13	38	77	242	100.0%
EU	Average cooling season outdoor temperature at base 20.5 °C and 90 day cooling season, in °C													23.2	
EU	Average cooling season indoor temperature (including 4.5 K internal and solar gains), in °C													27.7	
EU	Average cooling season temperature difference ΔT with reference 25 °C, in °C													2.7	

Conclusively, the outdoor temperature profile for SEER computation corresponds to a mix of residential and service units. This leads to relatively low base temperature, high cooling season duration and relatively low average outdoor air temperatures and thus increases the rated SEER value. In the future, it is believed the mix of products will be more in favour to residential units and the metrics could then be updated to take this into account. If such a change was to happen however, it is highly recommended to plan a transition period during which both older and newer SEER values are published before to use the new profile to set label and MEPS requirements, given the sensitivity of the SEER values to the climate profile.

3.1.3 Heating loads and SCOP metrics parameters

The heating loads and SCOP metrics parameters from the preparatory study are discussed below and compared to other sources. This is done to check whether the assumptions should be updated.

[23] https://ec.europa.eu/energy/sites/ener/files/documents/2014_final_report_eu_building_heat_demand.pdf

3.1.3.1 Real use of reversibility

In the impact assessment study of (EU) Regulations 206/2012 and 626/2011, it was supposed based on stakeholder input that only 33 % of reversible air conditioners were used for heating[24].

In Commission decision 2013/114/EU[25], the percentage of reversible air conditioners supposed to be used for heating are: 10 % for Southern Europe, 40 % for Central Europe and 100 % for northern Europe (zones correspond to reference heating climates in (EU) Regulation 206/2012). The following explanation is given (footnote 10):

"*An Italian study (referred to on page 48 of 'Outlook 2011 — European Heat Pump Statistics') finds that in less than 10 % of the cases, heat pumps were the only installed heat generator. As reversible air-air heat pumps are the single most installed heat pump technology type (60 % of all installed units — mostly installed in Italy, Spain and France, as well as Sweden, Finland and Norway), it is important to adjust the figures appropriately. The Impact Assessment of Commission Regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans (OJ L 72, 10.3.2012, p. 7) assumes that EU wide, 33 % of reversible heat pumps are not used for heating. In addition, one can assume that a large number of the 67 % of reversible heat pumps are only used partly for heating, as the heat pump is installed in parallel to another heating system. The proposed values are therefore appropriate to reduce the risk of over-estimation*.".

Complementary information was received from stakeholders, which suggests that present rates of reversible units used for heating are higher, with residential rates between 20 % (only heating means) and 60 % (used in addition, partial replacement or replacement of an existing central systems) and commercial rates around 85 %. However, climate zone indications are not specified.

In this study, we will use the most recent available information in the Commission decision 2013/114/EU.

3.1.3.2 Heating load

In heating mode, it was decided at the time of the preparatory study to use the heating needs estimated in the preparatory study on space heating. The rationale is that reversible air conditioners installed for heating do compete with other heating means and should then be compared with the same heating loads, and that the heating needs identified from Lot 10 preparatory study are lower.

The equivalent full load hours have been defined based upon heating load and sizing estimates for the 3 climates.

[24] Impact Assessment [SWD(2012) 35]
[25] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013D0114

Table 5: Equivalent full load hours calculation in Regulation 206/2012

Climate	Warm (Athens)	Average (Strasbourg)	Cold (Helsinki)
Heating load (from Lot 1) kWh/m2/y	71	87	148
Sizing at Tdesign in W/m2	71	87	96
Equivalent full load hours	1000	1000	1542
Correction of oversizing in Lot 1 (setback 1.2 and multizone 1.15)	1.38	1.38	1.38
Calculated equivalent full load hours	1380	1380	2128
Regulation 206/2012 equivalent full load hours (rounded)	1400	1400	2100
Implicit equivalent sizing at Tdesign in W/m2	51	62	70

Note that some stakeholders have proposed to modify the hours to the weighted average equivalent hours implied by the temperature distribution and load per bin. These values were already adopted for air-to-water heat pumps in EN14825:2016 standard (harmonised standard for (EU) regulation No 813/2013 which includes air-to-water and water-to-water heat pumps) and in Commission Decision 2013/114/EU[26] establishing the guidelines for Member States on calculating renewable energy from heat pumps from different heat pump technologies. However, these hours lead to very low equivalent sizing in W/m2 at design conditions, or conversely to very high heating loads on units:

- warm climate: 1335 hours versus 1400 hours, no correction done,
- average climate: 2065 hours versus 1400 hours, implicit sizing comes down to 40 W/m^2,
- cold climate: 2465 hours versus 2100, implicit sizing comes down to 60 W/m^2.

Sizing practice according to stakeholders in heating mode for air-to-air heat pumps are shown in Table 6.

Table 6: Stakeholder view of good sizing practice in heating mode for air-to-air heat pumps (capacities indicated at + 7°C standard rated capacities according to EN14511-2 standard)

Climate	Warmer	Average	Colder
Residential	80-100 W/m2	100-120 W/m2	120-180 W/m2
Retail	-	100 W/m2	-

To compare these values with design values, it is necessary to correct the heating capacity (Ph) at +7 °C given by the industry with the ratio Pdesignh / Ph, which according findings in Task 4 of this study is close to 0.85 or 3.4 kW at -10 °C for 4 kW rated heating capacity at +7 °C (3 kW at -7 °C declared in average as Pdesignh). Hence for average climate, implied stakeholder sizing condition is 85 W/m^2 at -10 °C, already much higher than the 62 W/m^2 in the regulation. Hence, if equivalent full load hours had to be modified, it would rather be to be lowered; for the average climate, equivalent full load hours would come closer to 1000 hours (close to the 954 weighted average hours identified from simulations in Lot 10 preparatory study, Task 4). Better insulation should also lead to lower heating equivalent hours in the future, but with lower sizing demand, resulting in a small decrease of equivalent full load hours; the impact of climate change should also lead to decrease the equivalent hours.

[26] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013D0114

Hence, it does not seem justified to increase the number of equivalent full load heating hours. And if a change had to be made in the coming years, it would rather be to decrease the number of equivalent full load hours.

3.1.4 Crankcase heater in SEER and SCOP metrics

In the Regulation 206/2012, outdoor temperature for measurement of the crankcase heater power value was not specified (nor for other modes, but there should be no dependency to outdoor air temperature for other modes), although crankcase heater operation may be controlled as a function of outdoor air temperature (amongst other variables).

The reason for introducing the operation mode in the regulation was because it appeared frequently that the crankcase heater start operation as soon as the compressor stop, independently of the outdoor temperature, while operation is only required below a certain outdoor temperature point.

In standard EN14825:2016, crankcase heater consumption is measured in test condition D in cooling mode, i.e. at 20 °C outdoors (for heating only units this is 12 °C). This implies that for units with temperature control, crankcase heater is very low or zero. Only for units without a temperature control, crankcase value measured this way is high. Some stakeholders have indicated some units with temperature control of crankcase heaters between 12 and 20 °C, while others have more sophisticated control based on both indoor and outdoor temperature.

In the cooling season, crankcase heater hours are per design hours with temperature below 16 °C (for the thermostat-off period) and others when the unit is in standby mode with about 23 °C average (10/24 of the 2602 hours of cooling). In average, using 20 °C for crankcase hours of reversible units in cooling mode is acceptable.

In the heating season, for standard inverter controlled reversible air conditioners, as per standard temperature profile, the compressor is on most of the heating season. Nevertheless, for some part load hours above 7 °C most units still cycle on and off and crankcase consumption appears. Thermostat-off hours are hours with temperature above 16 °C. In average, using 12 °C for crankcase hours of reversible units in heating mode is acceptable.

It is then proposed as a first improvement to require two distinct crankcase power values, respectively for cooling mode - measured at 20 °C - and for heating mode - measured at 12 °C. Cooling (Heating) only unit crankcase power measurement should be done at 20 °C (12 °C), as already written in standard EN14825:2016. This modification is already included in draft standard prEN14825:2018.

3.1.4.1 Hours of operation per mode

The hours of operation adopted to the current study is presented in Table 7 and Table 8 for cooling and heating, respectively.

In Table 7 the hours per cooling mode is presented in the current regulation and the suggested changes. This table also includes other power modes such as standby.

Table 7: Hours per mode in cooling mode in Regulation 206/2012 and proposed changes

	Regulation 206/2012		Proposed changes	
Hours	**Mode**	**Value**	**Changes**	**Value**
Hours per year		8760		
Cooling season 5 months		3672		
Hours in standby mode (14/24*3672)	H_{SB}	2142		
Hours in other modes (active cooling or thermostat off 3672 - 2142)		1530		
Number of hours with outdoor temperature above 16 °C		2602		
Number of hours with outdoor temperature above 16 °C during operation period (10/24*2602)		1084		
Number of hours with outdoor temperature below 16 °C during operation period (=1530-1084) during the season		446		
Weighted average number of hours with outdoor temperature below 16 °C during operation period during the season	H_{TO}	221		
Crankcase hours	H_{CK}	2672	Change to H_{SB} + H_{TO}	2363 (=2142+221)

From the table it is visible that the only proposed changes are the crankcase heater hours (H_{CK}) that should be adjusted to the sum of hours in standby (H_{SB}) and weighted average number of hours with outdoor temperature below 16 °C during operation period during the season (H_{TO}), which gives a value of 2363.

For network connected products, standby is in fact network standby as it is in "networked standby", which according to Regulation (EU) No 801/2013 "means a condition in which the equipment is able to resume a function by way of a remotely initiated trigger from a network connection". It is therefore assumed that network standby hours are the same as standby hours in Table 7.

For the hour of heating no remarks was received regarding the low power mode hours for reversible units; that might be because the present impact of accounting for these modes on the SCOP is low (between 0.1 and 0.5 % according to available data in Task 4).

An issue in Regulation 206/2012 regarding heating mode hours of heating only units has been raised. Correction is proposed in Table 8 below.

Table 8: Correction of power mode hours of heating only heat pumps (values to be corrected in red)

	Climate	Warm	Average	Cold
Heating period	Heating season hours	4344	5088	6576
	H_{TO}	755	179	131
	H_{SB}	0	0	0
	H_{OFF}	0	0	0
	H_{CK}	755	179	131
Cooling season hours	Cooling season hours	4416	3672	2184
	H_{TO}	0	0	0
	H_{SB}	0	0	0
	H_{OFF}	4416	3672	2184
	H_{CK}	4416	3672	2184
Heating mode, if appliance offers heating only	H_{TO}	755	179	131
	H_{SB}	0	0	0
	H_{OFF}	4416	3672	2184
	H_{CK}	5171	3851	2315

In conclusion:

- Minor change (regarding crankcase hours) can be incorporated into a revised regulation as its impact on the SCOP value is supposedly low.
- There may be a need in the future to update the temperature profile for cooling to account for the larger proportion of residential units in the installations. However, in that case, it is strongly advised to have a transitional period with the two values published by all manufacturers so that proper labelling / MEPS scheme can be established.

3.1.5 Bivalent temperature in SCOP metrics

In Regulation (EU) no 206/2012, manufacturers choose a bivalent temperature; this is the outdoor temperature for which heating capacity of the unit matches building load. In general, this bivalent temperature is higher than the design heating outdoor temperature (Tdesignh) of the specific climate. It means that a backup heater needs to be used in addition to the unit at low ambient to reach the building load Pdesignh.

To design a real installation, the optimal bivalent point is the result of a life cycle cost minimization. For low bivalent point temperature, the share of the backup heater is lower. This means the system efficiency is high because backup heater energy consumption is low (few hours or days of use and so low consumption despite low efficiency). However, the system cost increases as the heat pump cost is proportional to its size and the heat pump price is higher than the backup price. Conversely, for high bivalent point temperature, the system efficiency decreases because of the increasing share of the backup heater and the cost decreases. So, purchase price is lower, but energy consumption is higher.

The optimal bivalent point is dependent on total heat load, load curve, heat pump performance curve, capacity and cost, backup fuel type and efficiency and energy price(s) (backup may consume another energy type than electricity).

Because of the infinite diversity of real life situations, real life bivalent temperatures may vary significantly. Therefore, as a standard value, depending on each manufacturer strategy, product, application, climate, it may be of interest to market lower price and efficiency to decrease the installation cost and thus show higher Pdesignh for the same capacity even if SCOP value is decreased.

To the knowledge of the study team, Europe is the only economy to apply a freely declared bivalent temperature, which in general are fixed values associated to climates defined in standards. And this seems justified given the diversity of climates, energy prices and main heating system types.

Present bivalent point allowance in Regulation (EU) no 206/2012 is as described in Table 9

Table 9: Bivalent and operation limit temperatures according to climate in Regulation (EU) no 206/2012

Climate	Tdesignh	Tbivalent	Operating limit
Average	– 10	max. 2	max. – 7
Warmer	2	max. 7	max. 2
Colder	– 22	max. – 7	max. – 15

Based on ECC database of certified products[27], it is possible to have an idea of the bivalent choices made by manufacturers (these are model based statistics, not sales weighted based).

For average climate, over 2851 product declarations for Tbivalent, only 18 (0.6 %) have bivalent temperatures above -7 (5 units use -3 °C, 3 units -4 °C, 1 unit -5 °C, 5 units -6 °C). 963 units (34 %) have bivalent temperature lower than -7 °C.

Other climate information is not supplied in public ECC database, but more information supplied by ECC was used to compute the same statistics for other climates[28]:

- For warm climate: out of a total of 2293 units, only 322 units have declarations for warm climate, amongst which 39 (12 %) have bivalent temperatures strictly higher than 2 °C (37 units use 5 °C and 2 use 6 °C).
- For cold climate: out of a total of 2293 units, only 151 units have declarations for cold climate, amongst which only 30 (20 %) have bivalent temperatures strictly lower than -7 °C (down to -20 °C for 3 % of units). Interestingly, declarations with lower than -7 °C bivalent temperatures are more frequent for the average climate than for the cold climate declared products.

So it can be seen that the variable bivalent temperature option is used: quite commonly for cold climate and warm climate, and to a less extent for the average climate for which the very large majority of products are declared for lower or equal to -7 °C bivalent temperatures.

Comments have been received from Northern European EU and EEA Member States that propose to increase the bivalent point at least for cold climates so that the Pdesignh declaration is closer to the real capacity delivered by the unit. It can be easily understood that for a bivalent temperature equal to Tdesignh, the capacity of the unit matches Pdesignh. Nevertheless, installing a low capacity heat pump to cover only half of the

[27] Extract from Nov 2016, http://www.eurovent-certification.com.
[28] See Task 4, paragraph 4.1.1, for more information on the ECC database used in this study.

heating needs or less may still be economical in some situations and the manufacturer may want to market such situations. So, this proposal does not seem in the interest of the end-user.

The problem is rather if the manufacturer at the same time can publish high SCOP values because choosing a high Tbivalent and showing a high heat pump capacity. In this matter, the indication of the backup heater capacity required to reach Pdesignh capacity indicated together with the Pdesignh chosen and the corresponding SCOP as proposed in Task 1 report should help in making the situation more transparent for the end-user.

3.1.6 Case of portable air conditioners

For portable air conditioners the most important factor to consider is the impact of air infiltration. Infiltration of air has been discussed in previous tasks and the impact is discussed in this subsection. Another important factor to discuss is the hours of use and how portable air conditioners are used (as supplementary equipment or instead of e.g. fixed air conditioners).

3.1.6.1 Different types of double duct air conditioners

There are two distinct types of double duct products:

- portable units, that are similar to single duct units but with two ducts

- units with fixed installation; one or two holes are to be made in a wall; these units can operate all year round, providing often both heating and cooling; they look like a radiator and for some models a supplementary indoor unit can be plugged to make a multi-split. These units compete with standard split systems or window / through the wall air conditioners and with other traditional heating means when reversible, as electric radiators. Thus, double duct units with fixed installation are to be considered in the regulation as standard air conditioners. The category double duct should refer to portable air conditioners only (and possibly renamed / redefined categorisation in the regulation is to be proposed). Consequently, SEER and SCOP metrics and similar energy labelling scale should be used for those products. Bivalent point temperatures probably need to be adapted.

What follows regards only portable air conditioners, with one or two ducts.

3.1.6.2 Updated information regarding portable air conditioners

Single duct air conditioners are peculiar because their inlet air at condenser is indoor air. To compensate this air flow, infiltration of outdoor air in the building is necessary.

Simulations in preparatory study were done to simulate the infiltration impact on cooling performance using dynamic simulations. However, there was no common consensus on the values of the preparatory study and there are consequently no hours in (EU) Regulation 206/2012 to compute energy consumption of portable air conditioners in cooling mode, nor for other modes. Manufacturers were mainly concerned by the complicated testing method and by the high number of hours in thermostat-off and standby mode.

Although it was not identified in the Preparatory study, the same effect has been highlighted for double duct products by the US DOE (see Task 1), that showed a difference between inlet and outlet condenser air flow rates and thus an infiltration effect albeit lower than for single duct units. In the USA, portable air conditioners are tested according to the

enthalpy method. In Europe, they are tested using the calorimeter room method. As temperatures in the two rooms are different in the standard rating test of double duct air conditioners, the infiltration is already accounted for in the rated performances of the double duct products. The same is true for window and through the wall air conditioners, for which infiltration also occurs.

As reported in Task 1, the US DOE proposed a quite simple method to rate the seasonal performance in cooling mode for portable air conditioners. But to compute the infiltration effects, it is necessary to measure the air flow at the condenser exhaust for single duct air conditioners, and at condenser inlet and exhaust for double duct units. This is not necessary to measure infiltration for double duct because this is already taken into account in the test method. For single duct, it is possible to make a supplementary test only to measure the condenser (cooling mode) air flow, according to EU test laboratories.

A US study by LBNL[29] for US DOE reports the field metering results (electricity consumption broken by compressor mode/fan mode/standby and off mode) of 19 portable air conditioners (named hereafter Burke study). It appears that fan mode (which is a thermostat-off mode according (EU) Regulation 206/2012 wording) power consumption above 100 W (average value for products of comparable size to this study base case). This is thus certainly a mode that should be integrated in regulation.

In addition, thermodynamic heating (reversible portable air conditioner using the electric vapor compression cycle in reverse mode for heating and not only an electric resistance), which had not been identified in the Lot 10 preparatory study, has been integrated in the Regulation 206/2012; efficiency is rated by the unit COP rated at max capacity and at 20 °C indoor (so at both condenser and evaporator inlets) using the calorimeter room method (see Task 1 section 1.2.1.1; this method is described in the paragraph dedicated to EN14511 standard).

3.1.6.3 Thermodynamic heating with portable air conditioners

To evaluate the importance of infiltration on the functional performance of the unit and on its efficiency, it is necessary to fix typical infiltration values; these are retrieved from US DOE tests presented in Task 1 (section 1.2.1.4: US DOE 10 CFR Parts 429 and 430. Energy Conservation Program: Test Procedures for Portable Air Conditioners; Final Rule):

- Single duct: typically 200 m^3/h/kW cooling (measured air flow per declared kW cooling)
- Double duct: typically 70 m^3/h/kW cooling (measured air flow per declared kW cooling)

Apparently, portable units have similar heating and cooling capacities, so that we use the average size of 2.6 kW; COP is 3 for both units. It is supposed that the unit is sized according to its rated heating capacity, which is likely given that this is the only information available to the end-user for these products. With these values it is possible to correct the capacity measured in standard EN14511-3 conditions with infiltration. This is done for single duct and double duct air conditioners in heating mode in Figure 13 and in Figure 14 respectively.

[29] T. Burke, et al., Using Field-Metered Data to Quantify Annual Energy Use of Portable Air Conditioners, Lawrence Berkeley National Laboratory, Report No. LBNL-6868E (December 2014). Available at: www.osti.gov/scitech/servlets/purl/1166989

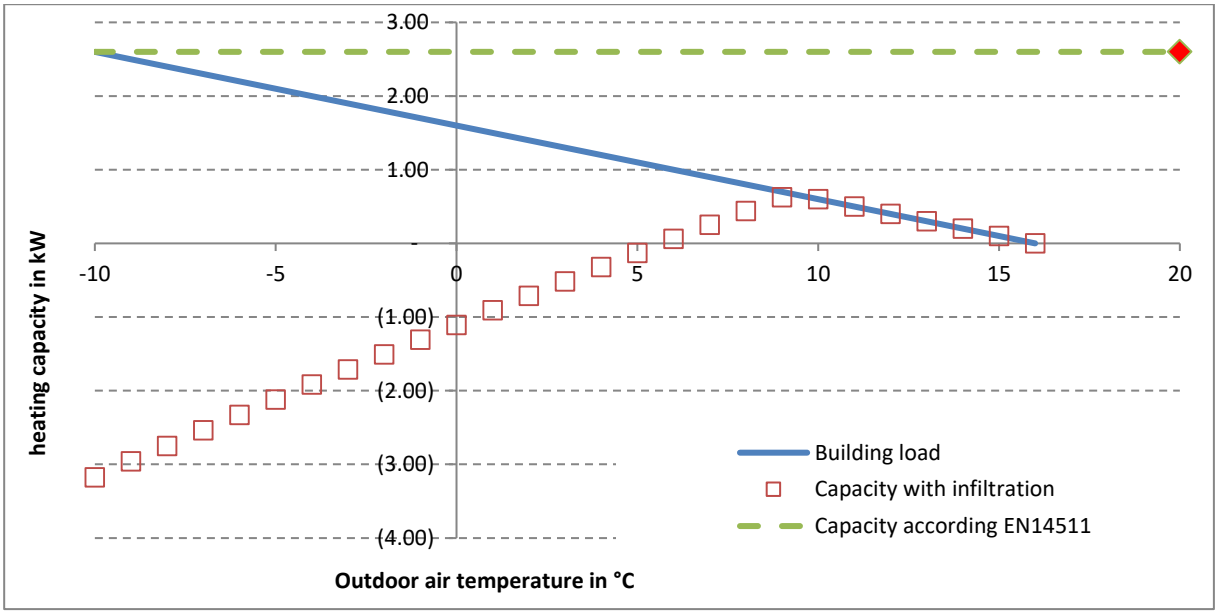

Figure 13: Impact of infiltration on heating capacity of reversible single duct unit in average climate. Red point is EN14511 rated heating capacity.

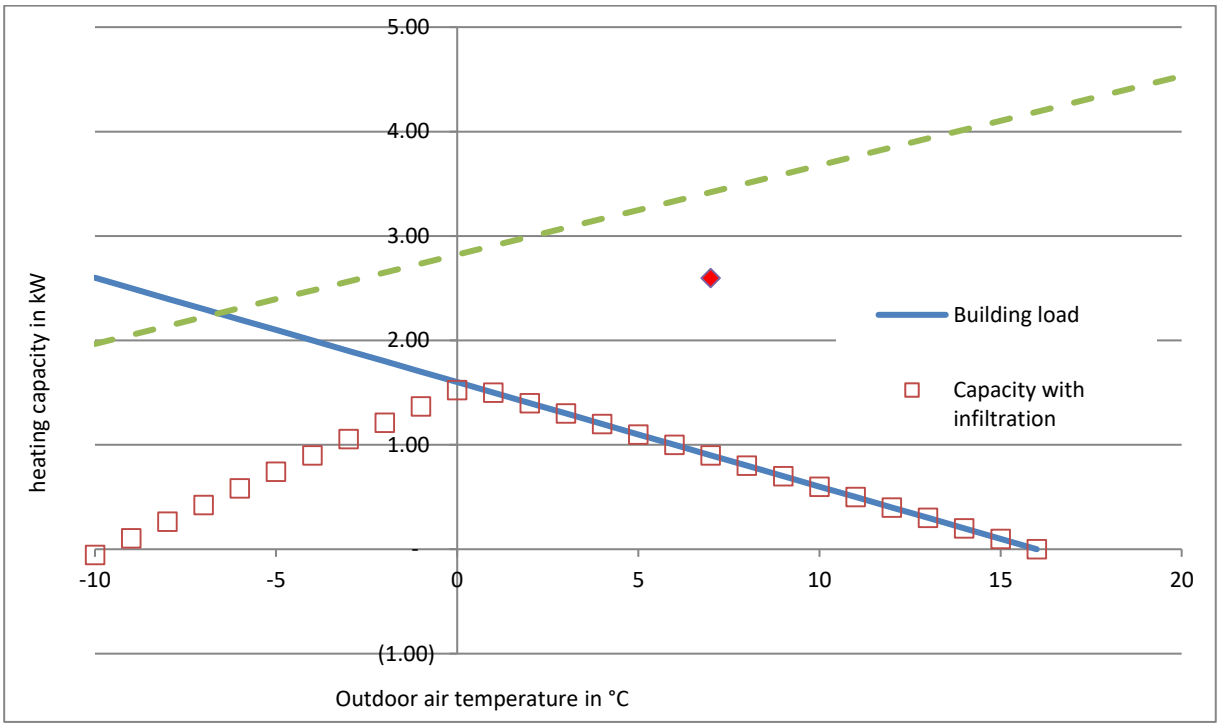

Figure 14: Impact of infiltration on heating capacity of reversible double duct unit in average climate. Red point is EN14511 rated heating capacity.

To plot these figures, it is assumed that the indoor air temperature is maintained at the indoor temperature set point, i.e. that another heating system compensates in case of negative net balance of the reversible portable air conditioner. For double duct, a capacity slope of 2.5 % per degree is used to calculate heating capacity. In addition, to the heating capacity, the net SCOP of the unit is calculated for average and warm climate; a Cd factor of 0.25 as in EN14825:2016 standard is used to correct the COP when the net unit capacity (unit rated capacity minus infiltration) is higher than the building load. The result is as follows:

- for single duct: below 10 °C, the unit cannot cope with the heating load; below 6 °C, the unit cools the building; the average SCOP if working all year long is negative (-0.4) for the average climate and equals 0.9 for the warm climate.
- for double duct: below 1 °C, the unit cannot cope with the heating load; but its contribution remains positive down till - 9 °C, reaching - 0.1 kW at -10 °C versus 2.6 kW capacity bought; the average SCOP if working all year long (but it does not satisfy the heating load below 1 °C) is 2.0 for the average climate and 2.9 for the warm climate.

Hence, reversible single duct operation in heating mode is likely to be worse than electric heating. Double duct operation is better in terms of performances, still it cannot deliver the capacity that the customer is buying.

Manufacturers suggest these products are used only in mid-season, when people are waiting for central heating systems to start, but there is no data available to sustain this claim. In the meanwhile, these products are competing with electric portable heaters and possibly in some cases with fix reversible air conditioners and the information to choose product based on functionality (here heating capacity) and on the often used "heat pump" wording advertisement is highly misleading.

Consequently, the present rating system for heating mode of portable products in Regulation (EU) 206/2012 and the associated label in Regulation (EU) 626/2011 is to be revised.

For single duct, estimated seasonal performance coefficient lies between -0.4 for average climate and 0.9 for the warm climate. In order to keep the thermodynamic benefit for highest outdoor temperatures and to maintain heating capacity at low outdoor temperature, a hybrid version combining a 2.6 kW electric resistance in addition to the 2.6 kW thermodynamic heating system can be added. However, this gives a SCOP of 1.005 for average climate and 1.09 for warm climate (below 10 °C, only the electric resistance operates).

Thus, SCOP of thermodynamic heating with single duct is presently well below 1 and including an electric heater could only bring little improvement over the present archetype, with SCOP only slightly better than 1. It then seems useless to use single duct thermodynamic heating, as an electric resistance alone, with a SCOP of 1, would be just as efficient for the end-user. A simple option is then to ban thermodynamic heating for single ducts.

But, for double duct products, a seasonal performance metrics could be developed.

For double duct, it is necessary to use the same scheme as for fixed air conditioners (SCOP measurement and calculation) and to declare comparable heating capacity and performance at design temperatures (note that infiltration impact is taken properly into account for double duct tests following EN14511-3). Because of the negative capacity at -10 °C, an evolution could be to add a complementary electric resistance. Bivalent point temperatures should be adapted in EN14825 for these new products.

For single duct thermodynamic heating, manufacturers may want to pursue the development of such reversible products. In that case, EN14825 procedure should be adapted to include the impact of infiltration on capacity and performance. Air flow rate of evaporator (in heating mode) should be measured in addition to performance test to enable

capacity and SCOP calculation. Bivalent point temperatures should be adapted in EN14825 for these new products. While waiting for a standard to measure the air flow rate, default values should be used, as the ones indicated above. It should be noted to the purpose of correcting capacities by infiltration, large uncertainties on the evaluation of the infiltration air flow may still give a better information on the unit that present rating values without the infiltration impact.

3.1.6.4 Capacity and performance in cooling mode for portable air conditioners

In the EU, the same requirements, 2.6 minimum EER value (Regulation 206/2012) and same energy label grades (Regulation 626/2011) are used for single duct and double duct despite significant differences in test procedures:

- Single duct air conditioners are tested at 35 °C dry bulb (24 °C wet bulb) both indoor and outdoor while double duct are tested like other air conditioner types at outdoor conditions 35 °C dry bulb (24 °C wet bulb) and indoor conditions 27 °C dry bulb (19 °C wet bulb).
- Infiltrations are accounted for in the performance tests of double duct air conditioners but not for single duct air conditioners.

It is of interest to notice that portable double duct products seem to have disappeared in Europe while these are still present in the USA. In the USA the rated performances are different: temperature conditions are 27/27 for single duct in the USA instead of 35/35 in Europe and 35/27 for double duct in the USA, same as in Europe, but infiltration is not taken into account in present rating for double ducts in the USA while it is accounted for in Europe. The USA regulation proposal[30] is now to include infiltration for both types of products and to rate the performance of products at equal outdoor temperature conditions. This goes into the direction of ensuring a level of playing field between both types of products and also to better inform the consumer by integrating infiltration impact.

In addition, it has been commented by EU test laboratories that some units can be supplied with one or two ducts so that the end-user may choose between both operating modes, albeit not having information on the consequences of operating in the two modes. In that case, it is clear that manufacturers should respect requirements for both types of configuration and supply corresponding information. The impact for the end-user is analysed hereafter.

Impact of part load and infiltration on seasonal performance

It is thus required to explore the impact of the differences in rated performances of portable air conditioners with one or two ducts and to evaluate the impact of infiltration (which are already part of the difference between both product types).

As infiltration depends on outdoor air temperature and humidity, it is necessary to show the impact of infiltration on a typical profile of use. A typical profile of use is similar to other air conditioners but keeping in mind the specifics of portable air conditioner use and considering only the residential sector (about 80 % of sales).

To that purpose, the average bin hours distribution of the Regulation 206/2012 is used but cut below an outdoor temperature of 23 °C (starting bin 22.5 °C), which according to (VHK, 2014)[11], corresponds to an average temperature of 26 °C indoor in residences, and can then be considered as the starting point of cooling for these units. Starting to cool at higher

[30] USA Federal Register, Vol 81, No. 105, Wednesday June 1, 2016.

outdoor (and thus indoor) air temperature than for fixed air conditioning installations translates the fact that most units are residential and that end-users may be reluctant to use these units unless really needed because of higher noise (compressor and 2 fans indoors). Hours per bin are shown in Table 10.

Table 10: Bin number j, outdoor temperature Tj in oC and number of hours per bin hj corresponding to the reference cooling season

j #	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tj °C	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
hj h	218	197	178	158	137	109	88	63	39	31	24	17	13	9	4	3	1	0

By definition, 0 % building load condition occurs at an outdoor temperature of 23 °C. 100 % load is supposed to occur at 35 °C. However, the capacity corresponding to this maximum load is presently different for single and double duct products:

- For single duct: the rated cooling capacity is measured at 35 °C db / 24 °C wb without accounting for the impact of infiltration. The sizing decision is however likely to be based on this value (as it is the only one available) or on indications supplied by manufacturers or salesmen based on room size equivalence ("this air conditioner is adapted for a room of XX m^2").
- For double duct: the rated cooling capacity is defined in the same conditions as for fix air conditioner types and so the rated cooling capacity is also the maximum cooling load at 35 °C outdoor condition but including infiltration.

Hence building load can be written as:

$$BL(Tj) = P_{designc} \times PLR(T_j) = P_{designc} \times (T_j - 23) / (35 - 23) \qquad \text{(Eq 1)}$$

with Pdesignc = Pc_{rated}, the portable rated cooling capacity.

In order to compute the capacity and efficiency of these units along the building load curve, it is necessary to compute the impact of infiltration on the unit capacity. This is done using a method similar to the one used by the US DOE to account for infiltration and also by integrating the potential variation of the cooling capacity with Tj.

$$Pc_corr(Tj) = Pc(Tj) + Q_{INF}(T_j) \qquad (Eq\ 2)$$

Where:

- *Pc_corr(Tj): maximum capacity of the unit corrected with infiltration*
- *Pc(Tj): maximum capacity in bin Tj without accounting for infiltration*
- $Q_{INF}(T_j)$ *: Heat loss by infiltration (W)*

The infiltration impact is calculated with the following formulas:

$$If\ Tj < 27, Q_{INF}(T_j) = \frac{27 - T_j}{27 - 20} \times \left[AF \times \left(rho_{air_{27}} \times h_{27} - rho_{air_{20}} \times h_{20}\right)\right]$$
$$If\ Tj > 27, Q_{INF}(T_j) = \frac{27 - T_j}{35 - 27} \times \left[AF \times \left(rho_{air_{35}} \times h_{35} - rho_{air_{27}} \times h_{27}\right)\right]$$

Where:

- $Q_{INF}(T_j)$ *: Heat loss by infiltration (W)*
- *Tj: outdoor temperature of bin j*

- *AF: infiltration air flow (m^3/s)*
- $rho_{air_{20}}$ *= 1.20 kg / m3, density of dry air at 20 °C (1 atm)*
- $rho_{air_{27}}$ *= 1.17 kg / m3, density of dry air at 27 °C (1 atm)*
- $rho_{air_{35}}$ *= 1.15 kg / m3, density of dry air at 35 °C (1 atm)*
- h_{20} *= 42.2 kJ/kg$_{da}$ specific enthalpy of infiltration air at 20 °C dry bulb and 15 °C wet bulb temperature per kg of dry air*
- h_{27} *= 54.2 kJ/kg$_{da}$ specific enthalpy of infiltration air at 27 °C dry bulb and 19 °C wet bulb temperature per kg of dry air*
- h_{35} *= 72.5 kJ/kg$_{da}$ specific enthalpy of infiltration air at 35 °C dry bulb and 24 °C wet bulb temperature per kg of dry air*

In order to show the impact of infiltration on capacity and EER, 4 different cases are considered:

- A: single duct base case (EER 2.65; Pcrated = 2.6 kW)
- B: double duct (EER 2.65; Pcrated = 2.6 kW)
- C: same as A but declared and used as double duct

A. Case of single duct

The indoor set point is rather 27 than 35 °C. Thus the capacity to be used at 27 °C is in fact lower than 2.6 kW and EER is higher[31]: capacity is about 2.43 kW and EER of about 3 at 27/27. Average infiltration air flow is of 200 m3/h and per kW of rated cooling capacity (as per EN14511-3).

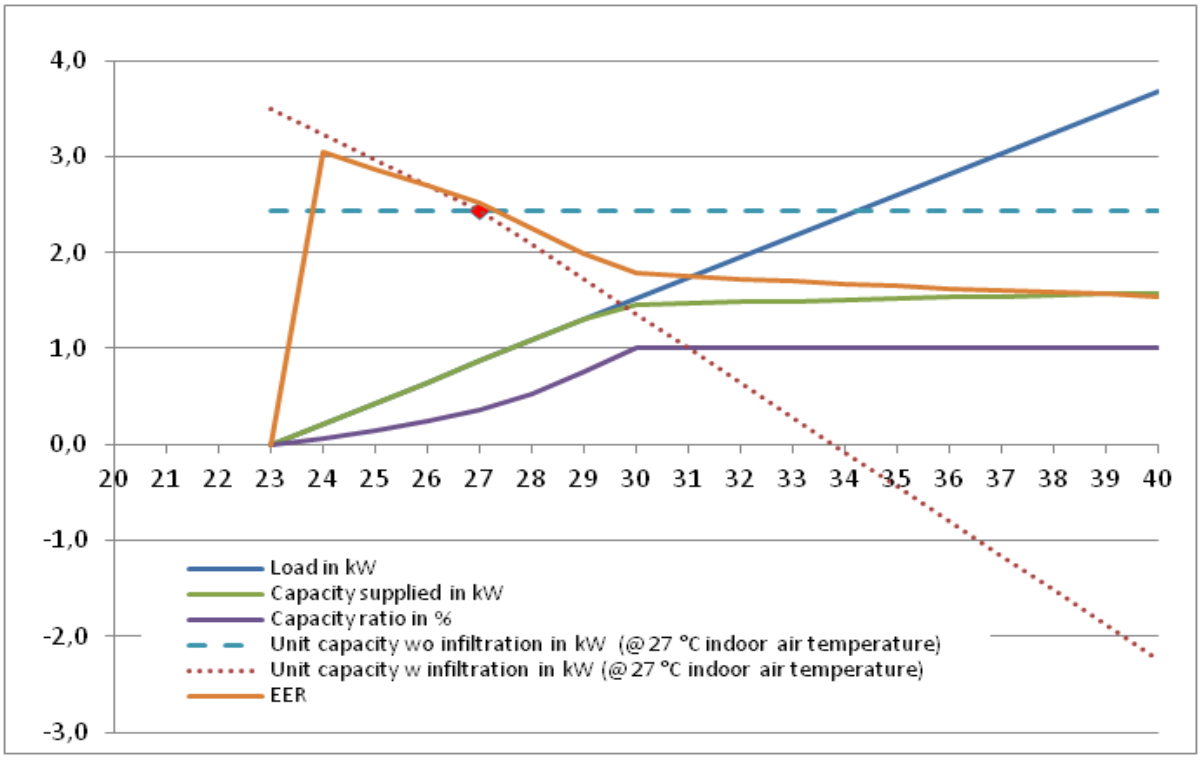

Figure 15: Evolution of load, capacity supplied, capacity with and without infiltration, capacity ratio and EER for base case single duct

[31] According to CECED information supplied during the Preparatory study regarding the variation of capacity and electric power at 27/27 and 35/35.

The Figure 15 shows the evolution of different variables for each temperature bin:

- the building load is a straight line between 0 kW at 23 °C and 2.6 kW at 35 °C.
- unit capacity at constant indoor temperature of 27 °C and without infiltration impact is constant and equal to rated capacity, here 2.44 kW.
- unit capacity corrected by infiltration is equal to unit capacity at 27 °C as the effect of infiltration is 0 kW; but it decreases sharply when outdoor temperature increases. At about 30 °C and 1.5 kW, the unit capacity corrected of infiltration is equal to the load for this temperature (equilibrium point). This intersection is computed by equalizing equations 1 & 2. It is interesting to note that in the US DOE regulatory project, the final capacity accounting for the effect of infiltration corresponds to the capacity at 29.7 °C (close to this intersection). This value is also observed in the Burke study. In Figure 16 below from this study, when the time spent in fan mode goes to zero, it means that the unit compressor is running continuously and so from that temperature and above the cooling load cannot be met. The point with nearly zero fan mode time occurs at temperature between 29.4 °C (85 °F) and 32.2 °C (90 °F).

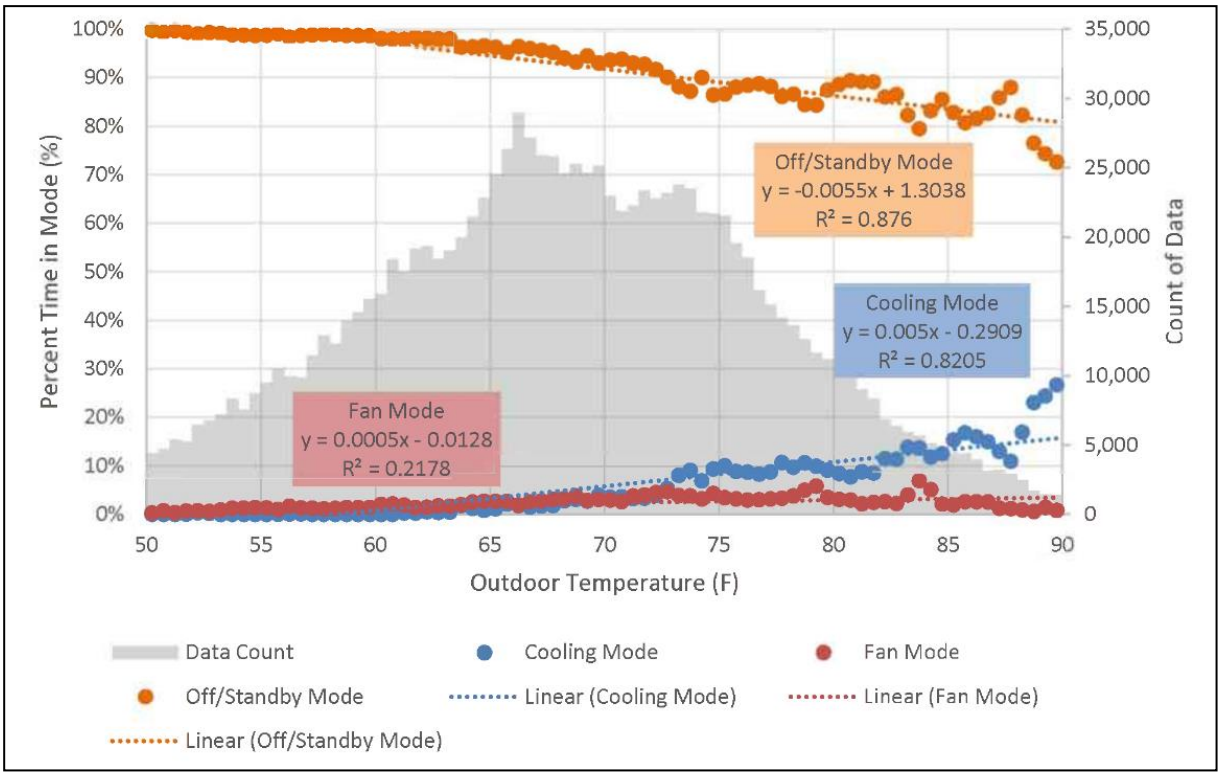

Figure 16: Hours of use per mode in the Burke study for residential portable air conditioner sites

- Above the equilibrium point temperature, the compressor is running continuously but the indoor set point of 27 °C cannot be maintained and indoor temperature begins to increase. On Figure 15, the capacity slightly increases because of the higher indoor temperature. At 35 °C outdoor air temperature, the indoor temperature reaches about 32.3 °C. So that the base case single duct is only able to maintain about 2.7 °C indoor / outdoor temperature difference.
- To compute the indoor air temperature equilibrium temperature above the intersection, equations 1 and 2 are modified by replacing the set point 27 °C by the equilibrium indoor air temperature ITj to be identified, as follows:

$$BL(Tj) = P_{designc} \times PLR(T_j) = P_{designc} \times (T_j + (ITj - 27) - 23) / (35 - 23) \ (Eq\ 1\ bis)$$

$$Qc_corr(Tj) = Qc(Tj) + Q_{INF}(Tj) \ (Eq\ 2\ bis)$$

$$\textit{With,}\ \ Q_{INF}(T_j) = \frac{ITj - T_j}{35-27} \times \left[AF \times \left(rho_{air_{35}} \times h_{35} - rho_{air_{27}} \times h_{27}\right)\right]$$

In conclusion, regarding capacity, present rated capacity is 2.6 kW, but the unit can only supply 1.5 kW at 2.7 K temperature difference indoor / outdoor. This information is not communicated to the end-user today, which thinks capacity indicated for single duct is comparable to kW cooling indications for fixed installations or mobile double ducts.

Regarding performances, infiltration modifies the capacity of the unit and modifies the capacity ratio and so the part load performances. This needs to be accounted for to compute seasonal performances.

The load ratio is computed by dividing the building load by the unit capacity corrected with infiltration below the equilibrium point. Above that it is equal to 1. It can be seen that below the equilibrium point, the capacity ratio of the unit is no longer a straight line because of the infiltration effect. EER is computed based on the capacity supplied and the electricity consumption of the unit, corrected by a cycling coefficient Cdc of 0.25 when load is lower than the supplied capacity. A SEERon value can be computed with this method using the following formula:

$$SEER_{on} = \frac{\sum_{j=1}^{n} hj \times Pc(Tj)}{\sum_{j=1}^{n} hj \times \left(\frac{Pc(Tj)}{EER(Tj)}\right)}$$

Where:

- *Tj = the bin temperature*
- *j = the bin number*
- *n = the amount of bins*
- *Pc(Tj) = below equilibrium point: the cooling demand of the building for the corresponding temperature Tj; above the equilibrium point: the capacity of the unit for the corresponding temperature Tj*
- *hj = the number of bin hours occurring at the corresponding temperature Tj*
- *EER(Tj) = the EER values of the unit for the corresponding temperature Tj.*

The SEERon value reached is of 2.13 versus 3 presently rated EER at 27/27 or a 29 % gap. The net effect of infiltration on SEERon is a 23 % gap, cycling then representing a 6 % loss.

<u>B. Case of standard double duct</u>

Double duct air conditioners need to reach an EER of 2.6 to satisfy Regulation (EU) 206/2012. We use here the same capacity as for single duct of 2.6 kW (at conditions outdoor 35 °C / indoor 27 °C) and same efficiency of 2.65. SEERon reaches 3.60.

Evolutions of capacity, load and load ratio, and efficiency with outdoor temperature are shown in Figure 17.

It is interesting to note that this unit if tested at 27 °C / 27 °C would have a capacity of 4.6 kW and an EER close to 5.15 (note it is lower on Figure 17 because of cycling losses). For matter of comparison, the scale of EER values on the EU market is 2.6 - 3.6. Thus,

despite the minimum performance level for EER for single and double duct is the same, this corresponds to very different units because of the differences in test conditions:

- the same published capacity for single duct and double duct products in fact correspond to a double duct unit with a size being 190 % (4.6/2.4) of the single duct unit;

- the same published EER for single duct and double duct products in fact correspond to a double duct unit with an EER being 170 % (5.15/3) of the single duct unit; the SEERon would be also 170 % (3.6/2.13) of the single duct unit.

Conversely, no single duct on the market fitted with a second air duct could reach the double duct minimum performance requirement using the present standard.

Hence, the present rating system needs to be modified as it does not give a level playing field for single duct and double duct air conditioners.

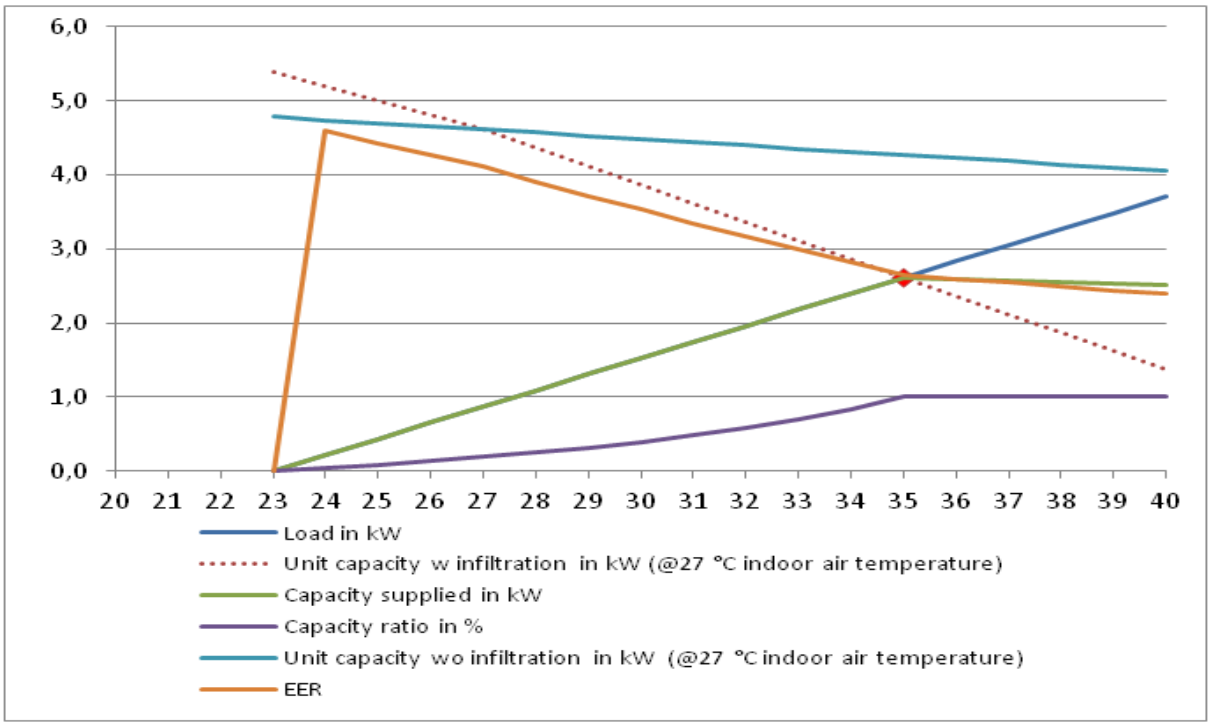

Figure 17: Evolution of load, capacity supplied, capacity with and without infiltration, capacity ratio and EER for standard double duct in the EU

C. Case of single duct (unit in case A) declared as single duct and used as double duct

In case of products being sold with 2 duct connections and that can be operated as single duct or double duct, it is likely that manufacturer declare their performances as the ones of a single duct only (as rating conditions are more favorable). We use the base case single duct product of case A of rated capacity 2.6 kW and EER of 2.65 (at 27/27, capacity is 2.44 and EER is 3). A supplementary consumption of 30 W is accounted for the fan because of the supplementary duct pressure losses, which reduces the EER at 35/35 to 2.57. Sizing would be done at 2.6 kW. Thus, the load treated by the double duct is much higher if declared as single duct than if declared as double duct. Despite being the same unit, this difference in sizing makes a difference. The standard rated capacity reached for the product in double duct configuration is of 1.4 kW accounting for the effect of infiltration using 70 m3/h/kW (the kW used here is the one of the rated capacity at 35 °C without infiltration). The capacity at 35 °C (outdoor) / 27 °C (indoor) without infiltration is of 2.3 kW. Indeed,

capacity is supposed to decrease of 1 % per °C outdoor temperature increase; electric power input increases by 1.3 % per °C increase[32].

Evolutions of capacity, load and load ratio, and efficiency with outdoor temperature are shown in Figure 18.

Maximum outdoor air temperature until which the unit can maintain the indoor temperature set point is 31.5 °C and thus at that point the maximum temperature difference between outdoor and indoor is 4.5 °C. Maximum capacity delivered at 35 °C is close to 1.8 kW, EER at 35 °C close to 1.6, and indoor temperature increases up to 30.7 °C at 35 °C. SEERon is 2.28 (versus 2.12 for single duct used as single duct).

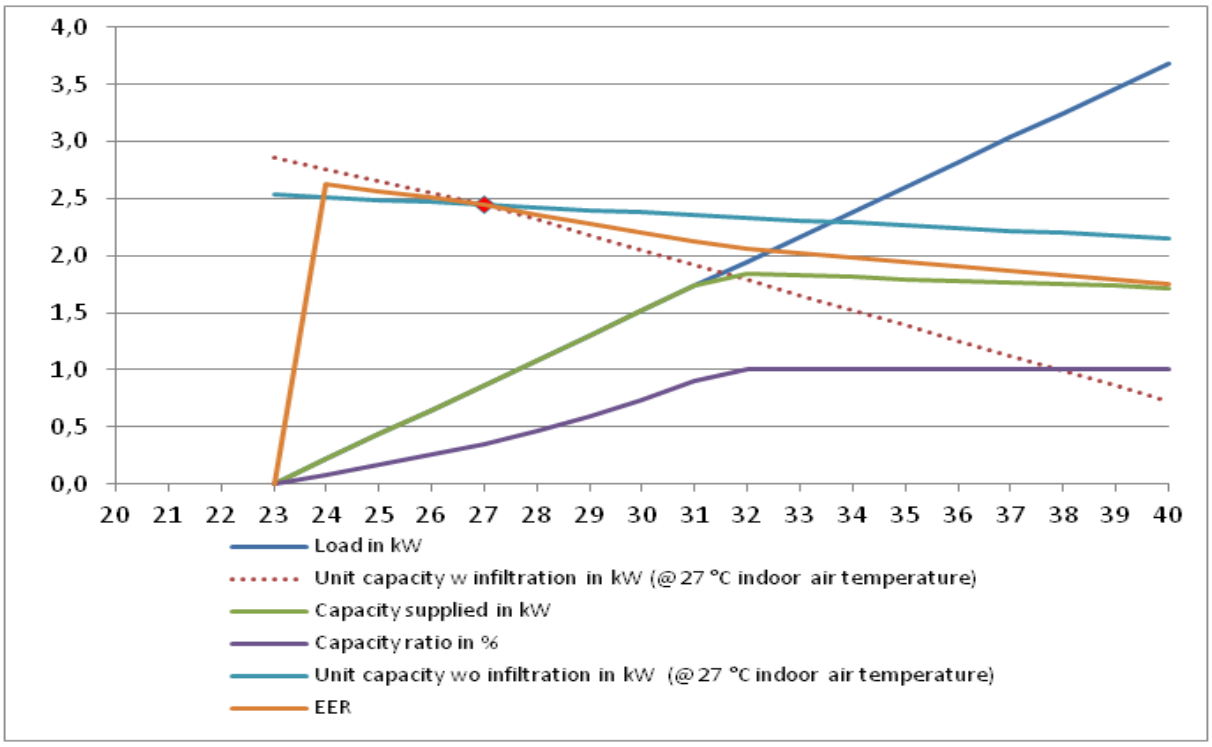

Figure 18: Evolution of load, capacity supplied, capacity with and without infiltration, capacity ratio and EER for single duct used declared as single duct and used as double duct

Conclusion

Table 11 below summarizes the results of the different scenarios envisaged.

[32] Values for split air conditioners in Preparatory study, Task 4.

Table 11: Summary of seasonal performance calculations, case A to C. Note 1: equilibrium is the intersection between load and unit capacity corrected for infiltration at 27 °C indoor temperature.

	Case A		**Case B**	**Case C**
	Base case SD		**Base case DD**	**Base case SD**
				Decl. as SD and used as DD
Rated values	Pc (kW)	2.6	2.6	2.6
	EER	2.65	2.65	2.65
	Ind. Out. Temp. °C	35 / 35	35 / 27	35 / 35
Design Load @ 35 °C	kW	2.6	2.6	2.6
Max capacity with infiltration	kW	1.5	2.6	1.8
Out. Temp. at equlibrium	°C	29.7	35.0	31.5
Temp. Diff. Ind. Out. at equlibrium	k	2.7	8.0	4,.5
SEERon	-	2.13	3.60	2.28
Cooling supplied (mult. 10/24)	kWh/a	365	405	384
Electricity consumption (mult. 10/24)	kWh/a	172	113	168

Despite that they have the same MEPS and labelling requirements, performances of single and double duct with present rating conditions are not comparable. Rated capacity and EER of double duct include infiltration and are measured at more classical 35 °C / 27 °C conditions. Thus, to get the same ratings, a double duct unit need in fact to be 90 % bigger and 70 % more efficient at comparable operating conditions. So, ratings should be reviewed to make rated performances comparable for all portable type products.

Capacity that can be expected from single duct decreases with the increase of difference between the outdoor air temperature and the indoor air temperature; from about 94 % of rated capacity for 0 K difference to about 0 kW at 34 °C (for the base case simulated). Typical conditions of operation were simulated: the maximum capacity of 1.5 kW is reached at about 30 °C outdoor for a 2.7 K outdoor / indoor temperature difference. Above 30 °C, the set point cannot be maintained and only a very limited outdoor / indoor temperature difference can be ensured. This is the main difference with a standard air conditioner which, if sized properly, should enable to maintain 8 K temperature difference between indoor and outdoor temperatures at 35 °C, and so to maintain the indoor temperature at the required set point. So, this type of unit is not working as it is generally expected from a standard air conditioner, but this is not known from the end-user. Capacity bought is not the one available above about 30 °C and the unit operates like an undersized fix type air conditioner. Capacity of single duct products is not comparable to the one of fix air conditioners.

In addition, based on a standardised load profile, it appears that seasonal performance (SEERon) of portable air conditioners is significantly influenced by infiltration and part load behavior.

It is then necessary both to revise rating conditions, to inform that the unit is not able to maintain the required set point above the equilibrium temperature, and to adopt a seasonal metrics.

Update of rating conditions

It appears that despite the points mentioned above regarding the lack of capacity of single duct and their limitation as regards outdoor / indoor temperature difference, there is a solid market for these products. Regarding portable double duct air conditioners, their market share is presently very low (can hardly be found in stores in Europe). This is probably at least partly due to the unfavorable rating conditions. Clearly, revised ratings should use the same temperature conditions including infiltration, if occurring for those conditions, to make both product types comparable.

In the USA, the US DOE kept a weighted average capacity (SACC) including infiltration corresponding to the following conditions 29.7 °C outdoor temperature for 27 °C indoor. This tends to decrease significantly the capacity and EER of single duct air conditioners (close to 40 % loss; for the hypothesis kept on infiltration, capacity decreases from 2.6 to about 1.6 kW) and to increase the capacity and EER of double duct air conditioner (from 1.5 kW to about 2.2 kW with infiltration).

Decreasing the capacity rating of single duct air conditioners may lead to increase the size of installed products, with limited comfort gains and with increased consumption (for case A before, oversizing by a factor 2 leads to 32 % increase in energy consumption, with only 5 % more cooling energy delivered with equilibrium occurring slightly above 31 °C instead of 30 °C; increase in consumption is thus mainly due to seasonal performance decrease because of cycling).

On the other hand, decreasing the capacity of single duct by including infiltration may make the comparison with fix air conditioners more realistic. It has been seen before that for a typical profile of use, a single duct air conditioner would not deliver more than 1.5 kW (against 2.6 kW rated). However, this maximum capacity delivered depends on the load curve (and so on the design condition) and on the capacity corrected by infiltration. And so, the maximum capacity delivered, and coincident outdoor temperature vary for each product and installation. Using this intersection between capacity and standardised load would lead to have a variable temperature for a given capacity (comparison of 1.5 kW at 30 °C or 1.9 kW at 32 °C is not straightforward).

On the other hand, the risk of oversizing is limited because capacity is not thought to be the main driver to choose a portable unit. Instead it is more likely that the end-users choose the size of the unit based on indications supplied by manufacturers regarding the area for which the product is adapted. This information may vary depending on the climate of the country where the product is sold.

This also means that it is not really an issue if capacity corresponds to a variable outdoor temperature depending on the unit.

So, capacity at equilibrium temperature should be kept as the unit capacity to be published on the product information. It gives the best possible estimate of the real service supplied by a specific portable unit. In addition, in order to show the difference with fixed appliances, it is necessary to add the following note to warn end-users:

above an outdoor temperature of XX °C (the "equilibrium" temperature), the equipment may not allow to maintain the indoor temperature at YY °C lower than the outdoor air temperature. Both XX and YY should be computed based on ratings. The formula are given below in the seasonal performance index part.

This applies to single duct and to double duct portable air conditioners.

Seasonal performance index

Using Regulation (EU) 206/2012 and taking a cooling season corresponding to hours above 23 °C, this leads to 1289 hours. As for fix installations, they are supposed to be used only 10 hours over 24, or about 58 % of the time, which leads to 750 hours in standby mode and leaves 549 hours for hours when the unit is on.

Using these figures and the standard SEERon simulation here before (2.6 kW single duct unit with EER 2.65, air flow at condenser of 520 m^3/h), this leads to the following figures:

- cooling energy supplied: 365 kWh/a

- electricity consumption (cooling mode only): 172 kWh/a

It is clear that integrating standby power consumption makes no difference; with 1 W power, standby power consumption is 0.75 kWh or 0.4 % or yearly electricity consumption for cooling. So further progress on standby power consumption cannot be expected from including standby in seasonal performance metrics.

In the Burke study, the fan mode includes both thermostat-off hours (hours with unit on and without cooling need in Regulation (EU) 206/2012) and fractions of hours when the unit is cycling. For these later hours, it is proposed to account for cycling by using a Cd factor and so these hours are not accounted for here. So the Burke study cannot be used to define thermostat-off hours. To do so the hours in bin 23 °C (no load) are considered; this corresponds to 218 hours, to be multiplied by 10/24 to only keep the hours when the unit is on or 91 hours. If thermostat-off power is slightly above 100 W, as measured for units of similar size as the one of the base case, this is still significant: 9 kWh or 4.5 %.

So, the following equations should be used to compute SEER, and maximum temperature operating conditions for rating portable products.

$$SEER = \frac{\sum_{j=1}^{n} hj \times Pc_corr(Tj)}{\frac{\sum_{j=1}^{n} hj \times Pc_corr(Tj)}{SEER_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB}}$$

$$SEER_{on} = \frac{\sum_{j=1}^{n} hj \times Pc_corr(Tj)}{\sum_{j=1}^{n} hj \times \left(\frac{Pc_corr(Tj)}{EER_{bin}(Tj)}\right)}$$

Where:

- *Tj = the bin temperature*
- *j = the bin number*
- *n = the amount of bins*
- *Pc_corr(Tj) = below equilibrium point: the cooling demand of the building for the corresponding temperature Tj; above the equilibrium point: the capacity of the unit for the corresponding temperature Tj*
- *hj = the number of bin hours occurring at the corresponding temperature Tj*
- *$EER_{bin}(Tj)$ = the EER values of the unit for the corresponding temperature Tj.*
- *H_{TO}, H_{SB}: the number of hours the unit is considered to work in thermostat-off mode*
- *P_{TO}, P_{SB}: the electricity consumption during thermostat-off mode*

<u>Calculation of *Pc_corr(Tj)* and *$EER_{bin}(Tj)$* for single duct air conditioners</u>

The capacity Qc(Tj) for temperature of bin j should be computed as follows.

$$Qc(Tj) = Qc(27) \quad (Eq\ 1)$$

Where:

- *Qc(27): rated capacity at 27(19) indoor and outdoor*

Capacity should then be corrected for infiltration as follows:

$$Qc_{corr(Tj)} = Qc(Tj) + Q_{INF}(Tj) \quad (Eq\ 2)$$

Where:

- Qc_corr(Tj): maximum capacity of the unit corrected with infiltration
- Qc(Tj): maximum capacity in bin Tj without accounting for infiltration

The infiltration impact is calculated with the following formulas:

$$If\ Tj < 27, Q_{INF}(T_j) = \frac{27 - T_j}{27 - 20} \times \left[AF \times \left(rho_{air_{27}} \times h_{27} - rho_{air_{20}} \times h_{20}\right)\right]$$

$$If\ Tj > 27, Q_{INF}(T_j) = \frac{27 - T_j}{35 - 27} \times \left[AF \times \left(rho_{air_{35}} \times h_{35} - rho_{air_{27}} \times h_{27}\right)\right] = \frac{27 - T_j}{35 - 27} \times INF$$

Where:

- $Q_{INF}(T_j)$ *: Heat loss by infiltration (W)*
- *Tj: outdoor temperature of bin j*
- *AF: infiltration air flow (m^3/s)*
- $rho_{air_{20}}$ *= 1.20 kg / m3, density of dry air at 20 °C (1 atm)*
- $rho_{air_{27}}$ *= 1.17 kg / m3, density of dry air at 27 °C (1 atm)*
- $rho_{air_{35}}$ *= 1.15 kg / m3, density of dry air at 35 °C (1 atm)*
- h_{20} *= 42.2 kJ/kg$_{da}$ specific enthalpy of infiltration air at 20 °C dry bulb and 15 °C wet bulb temperature per kg of dry air*
- h_{27} *= 54.2 kJ/kg$_{da}$ specific enthalpy of infiltration air at 27 °C dry bulb and 19 °C wet bulb temperature per kg of dry air*
- h_{35} *= 72.5 kJ/kg$_{da}$ specific enthalpy of infiltration air at 35 °C dry bulb and 24 °C wet bulb temperature per kg of dry air*
- *INF = infiltration in kW (cooling capacity loss - negative capacity value due to infiltration)*

Equilibrium temperature, which is the intersection between building load curve (Eq 3) and capacity corrected with infiltration (Eq 2) is determined and noted Teq.

$$Qc_corr(Tj) = Qc(27) + \frac{27 - T_j}{35 - 27} \times INF\ (Eq\ 2)$$

$$BL(Tj) = Qc(27) \times (T_j - 23) / (35 - 23)\ (Eq\ 3)$$

$$T_{eq} = \frac{Qc(27) + \frac{27}{35-27} \times INF + \frac{23}{(35-23)} \times Qc(27)}{\frac{Qc(27)}{35-23} + \frac{INF}{(35-27)}} \quad (Eq\ 4)$$

Pc_corr(Tj) is then computed as follows:

$$If\ Tj\ \leq\ Teq: Pc_corr(Tj) = BL(Tj)$$
$$If\ Tj\ >\ Teq: Pc_corr(Tj) = Qc_corr(Tj)$$

The unit capacity information to be published is Pc_corr(Teq).

To compute EERbin(Tj), two cases may occur. In both cases, the capacity ratio should be computed as follows:

$$CR(Tj)\ =\ min\ (1\ ;\ Pc_corr(Tj)\ /\ BL(Tj))$$

Case 1: on-off unit

$$If\ CR(Tj)\ <\ 1;\ EERbin(Tj)\ =\ EERrated\ x\ (1\ -\ Cdc\ x\ (1\ -\ CR(Tj)))$$

With Cdc cycling coefficient with a value 0.25 by default.

Case 2: inverter unit

A supplementary test should be made at 27 (19) / 27 (19) temperature conditions and at 33 % capacity ratio. The part load coefficient of EER variation noted PLc should be computed as follows:

$$PLc = \frac{\frac{EER(27;33\%) - EER(27;100\%)}{EER(27;100\%)}}{\frac{Qc(27;100\%) - Qc(27;33\%)}{Qc(27;100\%)}} \quad \text{(Eq 5)}$$

And EERbin(Tj) should be computed as follows:

$$If\ CR(Tj) \geq\ 0.33;\ EERbin(Tj)\ =\ EERrated\ x\ (1\ +\ PLc\ x\ (1 - CR(Tj)))$$

$$If\ CR(Tj)\ <\ 0.33;\ EERbin(Tj)\ =\ EERrated\ x\ \big(1\ +\ PLc\ x\ (1 - 0.33)\big) x \big(1 - 0.25\ x\ (1 - CR(Tj)/0.33)\big)$$

<u>Calculation of *Pc_corr(Tj)* and *EER$_{bin}$(Tj)* for double duct air conditioners</u>

$$Qc(Tj) = Qc(27)\ +\ (Qc(35) - Qc(27))/8\ x\ (Tj - 27)\ (Eq\ 1bis)$$

Where:

- *Qc(27): rated capacity at 27(19) indoor and outdoor*
- *Qc(35): rated capacity at 27(19) indoor and 35(24) outdoor*

Capacity should then be corrected for infiltration as follows:

$$Qc_corr(Tj) = Qc(Tj)\ (Eq\ 2bis)$$

Equilibrium temperature, which is the intersection between building load curve (Eq 3) and capacity corrected with infiltration (Eq 2) is determined and noted Teq.

$$Qc_corr(Tj) = Qc(27) + (Qc(35) - Qc(27))/8\ x\ (Tj - 27)\ (Eq\ 2bis)$$

$$BL(Tj) = Qc(27) \times (T_j - 23) / (35 - 23)\ (Eq\ 3)$$

$$T_{eq} = \frac{Qc(27) - 27 \times \frac{Qc(35) - Qc(27)}{8} + 23 \times \frac{Qc(27)}{(35-23)}}{\frac{Qc(27)}{35-23} - \frac{Qc(35) - Qc(27)}{(35-27)}}\ (Eq\ 4)$$

Pc_corr(Tj) is then computed as follows:

$$If\ Tj \leq Teq: Pc_corr(Tj) = BL(Tj)$$

$$If\ Tj > Teq: Pc_corr(Tj) = Qc_corr(Tj)$$

To compute EERbin(Tj), two cases may occur. In both cases, the capacity ratio (CR(Tj)) should be computed as follows:

$$CR(Tj) = min\ (1\ ;\ Pc_corr(Tj) / BL(Tj))$$

For double duct units, the efficiency at maximum capacity should be computed as follows:

$$EER(Tj) = EER(27) + (EER(35) - EER(27))/8\ x\ (Tj - 27)$$

Where:

- *EER(27): rated EER at 27(19) indoor and outdoor*
- *EER(35): rated EER at 27(19) indoor and 35(24) outdoor*

Case 1: on-off unit

$$If\ CR(Tj) < 1;\ EERbin(Tj) = EER(Tj)\ x\ (1 - Cdc\ x\ (1 - CR(Tj)))$$

With Cdc cycling coefficient with a value 0.25 by default.

Case 2: inverter unit

A supplementary test should be made at 27 (19) / 27 (19) temperature conditions and at 33 % capacity ratio. The part load coefficient of EER variation noted PLc should be computed as follows:

$$PLc = \frac{\frac{EER(27;33\%) - EER(27;100\%)}{EER(27;100\%)}}{\frac{Qc(27;100\%) - Qc(27;33\%)}{Qc((27;100\%)}}\ (Eq\ 5)$$

And EERbin(Tj) should be computed as follows:

$$If\ CR(Tj) \geq 0.33;\ EERbin(Tj) = EERrated\ x\ (1 + PLc\ x\ (1 - CR(Tj)))$$

$$If\ CR(Tj) < 0.33;\ EERbin(Tj) = EERrated\ x\ \left(1 + PLc\ x\ (1 - 0.33)\right) x \left(1 - 0.25\ x\ (1 - CR(Tj)/0.33)\right)$$

Calculation example for a standard single duct product

For an on-off unit of 2.44 kW capacity at @ 27/27 and an EER of 3 @ 27/27, the infiltration air flow is set to 520 m^3/h, the SEERon value is 2.12. and the SEER is 2.08 with P_{TO}=25 W and P_{SB}=1 W.

The capacity to be published as product information is

Above an outdoor air temperature of 30 °C (rounded from 29.89 °C), the equipment does not allow to maintain the indoor temperature 3 °C lower than the outdoor air temperature.

Calculation details are given in Table 12 below. Note that the total cooling energy and electricity consumption is to be multiplied by 10/24 which corresponds to hours during which the unit is on. This gives 343 kWh of cooling energy supplied and 162 kWh of electricity consumed.

Table 12: SEERon calculaiton details for a standard single duct unit

bin-n°	OAT °C	hours	BLc %	BLc kW	Qc(Tj)	INF(Tj) kW	Qc_corr (Tj)	IAT(Tj) °C	Pc_corr(Tj) kW	CR(Tj) %	EER(Tj)	Cool. Ener. kWh	Elec. Cons. kWh
	20				2.4	1.8	4.3	27.0					
	21				2.4	1.6	4.0	27.0					
	22				2.4	1.3	3.8	27.0					
	23	218	0%	0.0	2.4	1.1	3.5	27.0	0.0	0%	0.0	0.0	0.0
1.0	24	197	8%	0.2	2.4	0.8	3.2	27.0	0.2	6%	3.0	40.1	13.2
2.0	25	178	17%	0.4	2.4	0.5	3.0	27.0	0.4	14%	2.9	72.4	25.3
3.0	26	158	25%	0.6	2.4	0.3	2.7	27.0	0.6	23%	2.7	96.4	36.0
4.0	27	137	33%	0.8	2.4	0.0	2.4	27.0	0.8	33%	2.5	111.4	44.6
5.0	28	109	42%	1.0	2.4	-0.4	2.1	27.0	1.0	49%	2.2	110.8	49.7
6.0	29	88	50%	1.2	2.4	-0.7	1.7	27.0	1.2	71%	2.0	107.4	54.7
7.0	30	63	58%	1.4	2.4	-1.1	1.4	27.1	1.4	100%	1.7	88.2	51.2
8.0	31	39	67%	1.6	2.4	-1.4	1.0	28.1	1.4	100%	1.7	54.6	31.7
9.0	32	31	75%	1.8	2.4	-1.8	0.6	29.1	1.4	100%	1.7	43.4	25.2
10.0	33	24	83%	2.0	2.4	-2.2	0.3	30.1	1.4	100%	1.7	33.6	19.5
11.0	34	17	92%	2.2	2.4	-2.5	-0.1	31.1	1.4	100%	1.7	23.8	13.8
12.0	35	13	100%	2.4	2.4	-2.9	-0.4	32.1	1.4	100%	1.7	18.2	10.6
13.0	36	9	108%	2.6	2.4	-3.2	-0.8	33.1	1.4	100%	1.7	12.6	7.3
14.0	37	4	117%	2.8	2.4	-3.6	-1.2	34.1	1.4	100%	1.7	5.6	3.3
15.0	38	3	125%	3.1	2.4	-4.0	-1.5	35.1	1.4	100%	1.7	4.2	2.4
16.0	39	1	133%	3.3	2.4	-4.3	-1.9	36.1	1.4	100%	1.7	1.4	0.8
17.0	40	0	142%	3.5	2.4	-4.7	-2.2	37.1	1.4	100%	1.7	0.0	0.0
											Totals	824.2	389.3
											SEER on	2.12	

Required changes in test standards

Single duct air conditioner seasonal performance calculation only requires one test at 27/27 plus a test to measure condenser air flow rate. Additional measurements required are for

thermostat-off and standby (standby is already done). It is proposed that the capacity of single duct to be used is the capacity at 27/27 as it is then comparable with the one of double duct air conditioners.

For double duct, it is necessary to have two tests at 27/27 and 35/27 but there is no need to measure air flow rate. Additional measurements required are for thermostat-off and standby (standby is already done). It is proposed that the capacity of double duct to be used is the capacity at 27/27 as it is then comparable with the one of single duct air conditioners.

3.1.7 Real life versus standard performances

In the following section the real-life performance is discussed for both fixed and portable air conditioners.

For large efficiency increase of split air conditioners due to large indoor air flow increase, several comments have been received regarding the risk of designing units that operate very efficiently under EN14825 conditions but not in real life:

- In heating mode, temperature should not be blown below 32 °C (temperature of the skin) and probably closer to 40 °C to avoid "cold draft" effect. In case the temperature blown is too low, the end-user is likely to increase the indoor set point, thus increasing heating load and decreasing the real life SCOP and thus increasing the difference between standardized performance and real life one.
- In cooling mode, cooling without dehumidification does not allow to enter the comfort zone. This is likely to lead end-user to decrease the cooling temperature set point to feel more comfortable, with increased cooling load and decreased efficiency and thus increasing the difference between standardized performance and real life one.

Hence, building very efficient machines by increasing the indoor air flow may lead to disconnect the SEER and SCOP ratings from real life performances.

These comments were received for very large increase in indoor air flow rates over the base cases in Task 6. However, some of these air flow levels match the ones of existing products on the EU market (for products of the same capacity). It means there is a risk that some of the most efficient units on the EU market already have air flow levels which imply the savings expected by the end-user are not realized in practice.

It is thus proposed, for units in the scope of this study, to complete the data supplied in test report of EN14511-3 with a measurement of the blown air temperature in heating mode and blown air temperature and humidity in cooling mode. These temperatures are normally measured during tests but not disclosed/published. They should now be available in the technical documentation of the products.

These values are to be reviewed at the time of the next revision of Regulation 206/2012 and 626/2011. The review should evaluate the possible impacts and the required changes in the standard and the regulation to ensure that SEER and SCOPs remain representative of real life. Possible measures could include minimum air temperature supply in heating mode, minimum sensible to heat ratio for certain conditions in cooling mode or lowering the cooling temperature set point from 27 °C to lower values, particularly at low loads.

3.1.7.1 In situ continuous performance measurement

As explained in part 3.1.1, there is presently no agreed method to measure in-situ performance of air-to-air heat pump performance on sites, which makes it impossible to compare in-situ and standard performances as is currently done for other energy consuming products.

The reason why is that measuring capacity on the air side is cumbersome in real life. In a lab, indoor air flow and temperature inlet and outlet (and humidity) can be measured to evaluate cooling capacities at indoor unit side (although not precise enough). Stated in the standard, indirect measurement is done as follows: an electric heater heats the room and the air conditioner must stabilize the room temperature and the cooling capacity matches the heater energy and room losses, this is used for all air conditioners in scope. It is a more precise method but not possible to be done on field. As the above methods cannot be used on field, no measured capacity on field means real life efficiency cannot be measured.

However, on-board performance measurement on the refrigerant side is possible and highly precise (with the same or even better precision than standard measurement on the air side as performed today). At least one compressor manufacturer already developed such a method basing upon the compressor performance curves (sold as an option to system assembler with the compressor) and also one air conditioner manufacturer[33]. Several other methods are possible (using the expansion valve or the compressor energy balance)[34], and at least one of these methods is being developed[35].

These methods could be generalized and used by all manufacturers, but an important standardization work has to be done to ensure their reliability. This should 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.

This seems an important topic to improve further the efficiency and to reduce real life consumption of air conditioners, as well as to ensure that test standards are aligned with real life operating conditions as regards sizing, equivalent full load hours and other operating hours. As these methods could apply in practice to most types of vapor compression cycles, this would also help the unfortunate inspectors of HVAC systems (EPB Directive 2010/31/EU, articles 14 and 15), that presently have little information on system performance or adequate sizing.

3.1.7.2 Additional information to end-user to reduce real life consumption

UBA[36] suggests other ways to cut real life energy consumption to be studied and possibly become Ecodesign requirements:

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[33] Stefan Vandaele, Hiroshi Aihara, Optimisation of VRF systems in buildings by monitoring, in Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 9. Aalborg: Aalborg University, Department of Civil Engineering.

[34] 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

[35] C.T. Tran, P. Rivière, D. Marchio, C. Arzano-Daurelle, In situ measurement methods of air to air heat pump performance, In International Journal of Refrigeration, Volume 36, Issue 5, 2013, Pages 1442-1455, ISSN 0140-7007, https://doi.org/10.1016/j.ijrefrig.2013.03.021.

[36] Jens Schuberth (UBA) et al., Minimum requirements on monitoring equipment for assessing the energy efficiency of heating, ventilation and air conditioning products, Submission by the Federal Environment Agency (UBA) and the Federal Institute for Materials Research and Testing (BAM) on the Ecodesign Process, 14th March 2018.

- Electricity consumption measurement and display: in general, literature indicates small but non-negligible gains; this is already a common feature of many fix air conditioners although electricity consumption may not be measured but deducted from the measured variables of the unit;
- Energy efficiency monitoring by energy signature methods: use the change in correlations between electricity consumption and outdoor air temperature to detect change in consumption pattern and inform the end-user; this requires however large computing / data storage capacity which may not be available in the units and could only be available to smart appliances; plus this method may not work for all installations;
- mandatory saving mode allowing to control a fixed temperature difference between indoor and outdoor temperature, rather than a fixed indoor temperature set point;

It is proposed to include the electricity consumption measurement in the standardisation work to be done regarding in-situ continuous performance measurement. It is indeed necessary to fix a certain number of requirements (e.g. maximum uncertainty, minimum acquisition and averaging times, test of the functionality in the unit based on standard tests).

3.1.7.3 Compensation method

In the present standard test procedure for split air conditioners in EN14825 standard, the test points are obtained by fixing the control parameters of the unit; in a compensation method, the load is fixed (e.g. heat is added in a closed room) and the controls of the air conditioner sense the increase in temperature and adjust the air conditioner capacity to match the load; the intent is to include the impact of air conditioner controls in terms of seasonal performances. Compensation method investigations were already mentioned in Task 1. To note, a round robin test should begin in 2017/2018 to test a new compensation test method proposal for air-to-air units in different laboratories in Europe.

3.1.7.4 Impact of a lack of maintenance

To reach the 500 hours equivalent full load hours in the first EU label for air conditioners[37], a 20 % provision for fouling of the heat exchangers was accounted for following Breuker & al[38] findings. More recently in the IEE project Harmonac[39], it was found that cleaning the surface of indoor heat exchanger not equipped of filter could save 17 % energy consumption.

In the Lot 10 preparatory study, it was supposed that most units were fitted with filters and that for split units a regular maintenance check was the standard and thus the impact of heat exchanger fouling was not taken into account. This is still thought to be the case for fixed installations. If it was not the case, a measure as the one proposed by UBA - to equip units with a visual heat exchanger cleaning signal as in Regulation EU no 2014/1253 - could prove useful and would most likely be cost-effective.

[37] Commission Directive 2002/31/EC of 22 March 2002 implementing Council Directive 92/75/EEC with regard to energy labelling of household air-conditioners
[38] Value taken from the following reference, M. Breuker&J. E.Braun, Common faults and their impacts for rooftop air conditioners, July 1998, HVAC&R Research, p.303-318
[39] Ian Knight and James Cambray, Quantifying the Energy Conservation Opportunities found in Air-Conditioning Inspections as required by EPBD Article 9, IEECB conference, 2010.

There have been many developments in filtering options for split air conditioners, as reported by (Schleicher et al, 2017)[40] and this includes automatic filtering cleaning.

However, stakeholders report that for the portable range, filters are not always fitted to both heat exchangers and that all are not washable, which should be required for portable air conditioners as most likely the end-user has to perform the maintenance himself. It could then be proposed a mandatory requirement for washable filters on both heat exchangers for portable air conditioners.

3.1.8 Use patterns of comfort fans

The hours of use of comfort fans will be based on the preparatory study. The overall assumption is that comfort fans will be used the same way as air conditioners, but without the possibility of more advanced control e.g. pre-cooling. When a cooling need appears, the users will properly use either a comfort fan or an air conditioner. The preparatory study assumed an average value for EU of 320 hours per year.

3.2 End-of-life behaviours

3.2.1 Product use and stock life

The lifetime of products is of great influence of the products overall environmental performance. If a product has a long lifetime it is beneficial regarding resource consumption but at some points there might be some trade-offs after some years in terms of lower efficiency compared to a new model. The product lifetime can be interpreted in a numerous of ways and there exist different definitions of the lifetime of products. In the below table are three definitions of lifetime presented.

Table 13: Different definitions of lifetime

The design lifetime	The behavioural (or social) lifetime	Definition in current study
Is the intended lifespan regarding functioning time, the number of functioning cycles, etc., foreseen by the manufacturer when he designs the product, provided that it is used and maintained by the user as intended by the manufacturer. The design lifetime must not be confused with the guarantee period of products, which is a service offered by the Manufacturer and fulfils other constraints, namely commercial.	Is defined as the number of years until the device is replaced for other reasons than technical failure or economic unattractiveness. This generally regards social and consumption trends, a product including new feature has been released and is preferred, e.g. a more powerful computer	The term "lifetime" or "Economic product life" used in the current study must be understood as the period (i.e. the number of years) during which the appliance is used and consumes electricity ("actual time to disposal"). Therefore, it is a value included between the social lifetime and the design lifetime.

[40] Tobias Schleicher, Jonathan Heubes, Ran Liu, Pascal Radermacher, Jens Gröger. The Blue Angel for Stationary Room Air Conditioners – a national eco-label with international impact, Final Draft of the technical Background Report for German Federal Environment Agency. Freiburg, June 2017.

An accurate lifetime can be difficult to determine as many factors can affect the lifetime such as location, marine climate and the hours of operating in different modes. Depending on the type of air conditioners other factors can also have an impact e.g. if portable air conditioners are moved frequently they a subject to bump into doors or furniture which in the end can affect the lifetime. For fixed air conditioners, the lifetime can be significantly reduced due to customer installation. The main causes for replacement of air conditioners are listed below[41]:

- breakdown
- drop in performance
- rise in sound noise
- replacement by more energy efficient models,
- building renovation
- the end-user is moving

The overall assumptions regarding lifetime are unchanged since the preparatory study[42] and the previous assumptions used are briefly described below.

ENERGY STAR has published a brochure[43] about room air conditioners where it is written that the typical product life for a room air conditioner is ten years[44]. Furthermore, because models that are at least 10-years old use 20% more energy than a new ENERGY STAR model, ENERGY STAR advocates consumers to replace 10-year-old room air conditioner with a new ENERGY STAR qualified model.

White certificates in France had estimated the lifetime of air conditioners (only single split package and multi split package air conditioners) that were used in French overseas departments and territories at 9 years. However, these conditions were expected to be more intensive since the climate in general are hot and air is charged in salt leading to the accelerated corrosion of the heat exchange areas of the outdoor unit. The lifetime of reversible air conditioners (only single split package and multi-split package air conditioners) used in France was estimated to 16 years.

JRAIA informed at a stakeholder meeting during the preparatory study that the product life for residential units in Japan was estimated to be about 12 years based on an analysis of recycled products and for commercial units it is thought to be between 10 and 15 years. They thought it could be longer in Europe than in Japan because of less hours of usage in average, especially since a large part of the products are not reversible or not used as such, whereas in Japan residential air conditioners are used in winter and summer time. Today are most fixed air conditioners sold in Europe reversible.

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[41] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Contract TREN/D1/40-2005/LOT10/S07.56606. CO-ORDINATOR: Philippe RIVIERE, ARMINES, France. Air conditioners, final report. December 2008. This report can be downloaded from DG ENERGY website: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products.

[42] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Contract TREN/D1/40-2005/LOT10/S07.56606. CO-ORDINATOR: Philippe RIVIERE, ARMINES, France. Air conditioners, final report. December 2008. This report can be downloaded from DG ENERGY website: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products.

[43] http://www.energystar.gov/ia/partners/manuf_res/downloads/Room_Air_Conditioners_Partner_Resource_Guide.pdf

[44] 29th Annual Portrait of the U.S. Appliance Industry, Appliance Magazine, September 2006.

EERAC study[45] suggested the average lifetime expectancy for four types of products. The products and expected lifetime was:

- Window/wall package air conditioner 12.6 years
- Multi split package air conditioner 12.6 years
- Single split package air conditioner 12.5 years
- Single-duct package air conditioner 10.3 years

It was also found that the average life span of the four main air conditioner types in Spain and Italy was largely due to the desire for a new unit rather than equipment failure, due to good reliability and low annual usage.

CECED informed at a stakeholder meeting during the preparatory study that the estimated product life of portable air conditioners was about 12 years. They also added that premature replacement sometimes might occur as switch from portable air conditioners to fixed split systems. This observation is in good agreement with the fact that moveable air conditioners, that have the compressor located inside the room whose air is to be cooled, are noisier for the end-user that other air conditioner types. Many other causes can justify this willingness to change as being forced to install the air conditioner when it is to be used, having the indoor unit inside the room if space is constrained.

Lifetime assumptions in current study are based on the above-mentioned sources from the preparatory study. Below is a summary of the expected lifetime of fixed air conditioners and portable air conditioners.

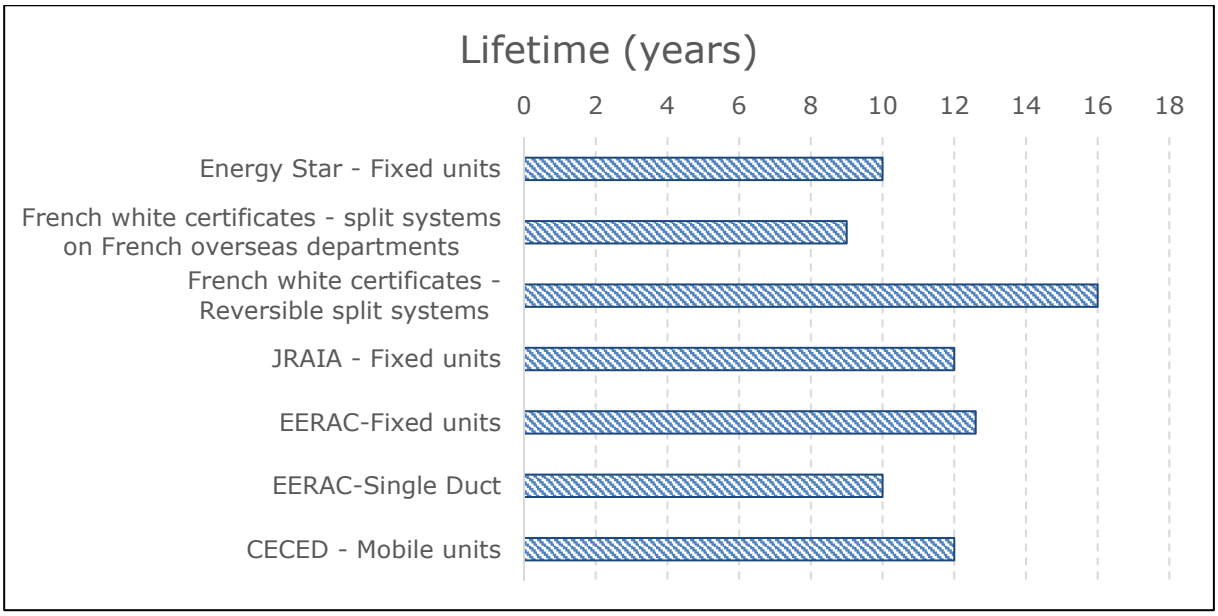

Figure 19 Lifetime for different types of air conditioners according to several sources

The expected lifetime for fixed air conditioners is in the range of 9-16 years and for portable air conditioners it is in the range of 10-12 years. A lifetime of 10 years for portable air conditioners was also used by the US DOE[46] recently. The expected lifetime for fixed and portable air conditioners in the current study are presented in Table 14. Regarding Variable Refrigerant Flow (VRF) units the expected lifetime is 15 years. These assumptions are

[45] ENEA, 1999, Survey on the behaviour of the end users of room air conditioners, Report within the frame of the EERAC study, ENEA, 1999.
[46] https://energy.gov/sites/prod/files/2016/12/f34/PAC_ECS_Final_Rule.pdf

based on the impact assessment[47] for air heating products, cooling products and high temperature process chillers above 12 kW. Regarding comfort fans the assumption on lifetime is kept in the current study. The lifetime was estimated to 10 years.

Table 14: Average lifetime assumptions adopted to the current study

Technology	Average lifetime (years)
Movables + Window Units	10
Small Split (<5 kW)	12
Large Split (>5 kW, incl. ducted)	12
VRF	15
Comfort fans	10

It is difficult to suggest any Ecodesign requirements regarding the lifetime of air conditioners and comfort fans as the expected lifetime currently are 10 years or above. If the lifetime is improved the trade-off between resource efficiency and energy efficiency should be considered, in addition, consumers may not be willing to repair their air conditioners due to high repair cost in comparison with the costs of purchasing a new equipment. This is discussed in the following section. Furthermore, requirements of lifetime would be difficult for the market surveillance authorities to control.

3.2.2 *Repair and maintenance practice*

The repair and maintenance practice are expected to be done by professionals for fixed air conditioner systems. The price of repair is then constituted of the labour costs and the cost of the spare parts, which means that the affordability of repair is very much dependent on the labour costs. The labour cost varies greatly across Europe and are presented in the below figure.

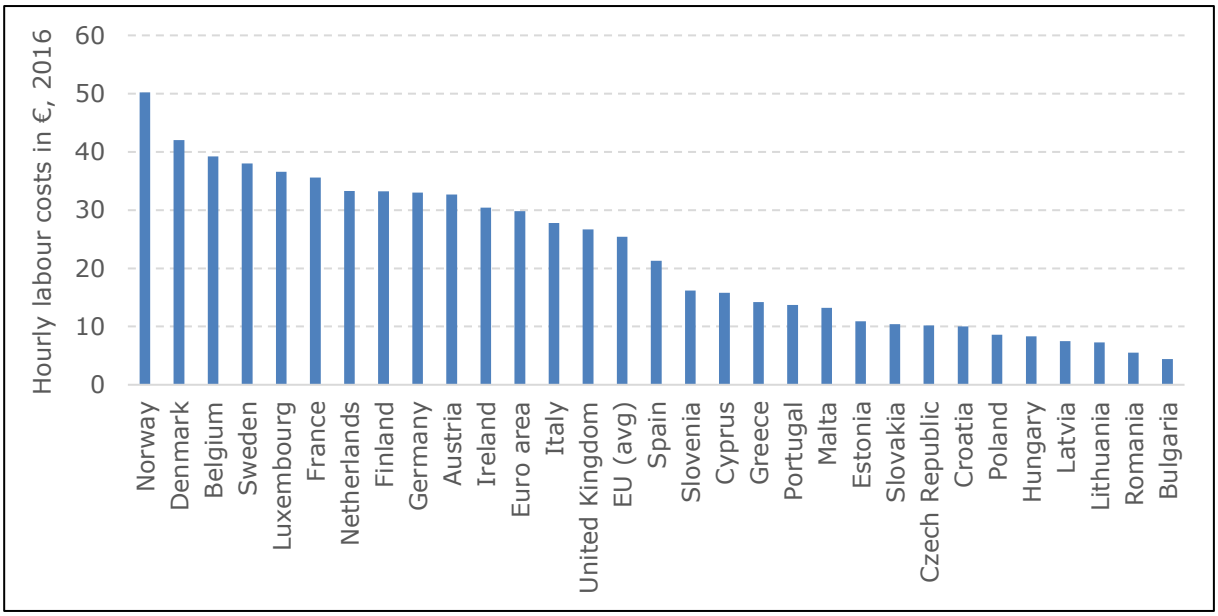

Figure 20 Hourly labour cost in €, 2016 for European countries

Based on labour cost the amount of repair is expected to be low in northern countries and higher in southern and south-eastern countries. Another important factor is also the age of the equipment. At end-of-life (above 9-10 years) air conditioners are probably too expensive to repair compared to the price of a new model. Furthermore, a new model is also expected to be more efficient so that the total cost of ownership is lower for the new

[47] http://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2016/swd_2016_0422_en.pdf

model compared to repairing the old one an extending the lifetime. This balance is dependent on the efficiency and price of a new model and the cost of repair. The amount of repair is assumed to be low currently but may change in the future since there is an increased focus on resource consumption within the EU. With an increased focus on resources and lower impacts of electricity (both renewable energy and more efficient products) the impact of the resource consumption may be more important. An improved lifetime of certain products could potentially save energy in the future as less materials are used. But, the electricity consumption is still believed to be the most important factor currently. Regarding comfort fans the repair and maintenance practice is assumed to be negligible. This is due to the low purchase price and simplicity of the product. The same assumption was made in the preparatory study.

Currently there are no observed problems with the repair service of air conditioners, but the high repair cost could pose a challenge even for relatively new products after the warranty expires. To avoid unnecessary replacement of efficient air conditioners it should be considered how Ecodesign requirements potentially could ease the repair and maintenance practice to lower the cost of repair and prevent premature failure. This subject will be discussed further in task 4. Though, it may be difficult for the market surveillance authorities to control.

Spare parts

Spare parts are available on the internet from some manufacturers[48,49] and third-party companies offering spare parts and sometimes also a repair service. In any case the most likely scenario is that the service is performed by a professional which would add extra expenses to the costs of the spare parts. Important technical problems like a compressor breakdown may occur when the appliance is old. Since the lifetime of a compressor is estimated around 12 years[50], it is very unlikely that a compressor change would occur during the lifetime of the air conditioner. If it happens after 10 or 12 years, it is most likely that the end-user will change the complete unit given the cost of the intervention. It is not known if repair actions are often carried out neither which ones and consequently, it is not possible to estimate additional material for repair. Stakeholders have indicated that the most bought spare parts are printed circuit boards. One stakeholder informed that the majority of their air conditioners was sold with a maintenance contract and their most sold spare part was the compressor. The most bought spare parts are properly affected whether the air conditioners are sold with a maintenance contract or not. The availability of the spare parts is assumed to be 10 years based on stakeholder inputs.

Normal maintenance like cleanliness of the filters, emptying and cleaning the condensate container requires no additional material. Manufacturers now propose washable filters. In general, for products in the scope, most of the air conditioners are assumed to be sold without a maintenance contract.

[48] http://www.daikin.com/products/ac/services/parts/index.html
[49] http://www.toshiba-aircon.co.uk/products/spare-parts
[50] Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation), Contract TREN/D1/40-2005/LOT10/S07.56606. CO-ORDINATOR: Philippe RIVIERE, ARMINES, France. Air conditioners, final report. December 2008. This report can be downloaded from DG ENERGY website: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products.

Based on the stakeholder consultation, the availability of spare parts seems reasonable, but it could be discussed with stakeholders how to maintain the availability of spare parts from all manufacturers.

Refrigerant fluid leakage rate

The refrigerant fluid leakage rate represents the amount of rejected fluid according to the initial charge and is an important factor both considering the efficiency of the unit and the release of CO_2-equivalents to the atmosphere. The release of CO_2-equivalents is both a consequence of using electricity for powering the air conditioner and by the leaking of refrigerants. The leakage of refrigerants is based on the findings in the preparatory study and stakeholder inputs which are briefly described below.

A French study[51] proposed different values for average yearly emission rates and presented in Table 15.

Table 15: Upper estimates of the annual leakage rate

	Single and double duct	Split	Multi split (<17.5kW)
Nominal charge [kg]	0.5	1	1.5
Lifetime [years]	10	12	12
Leak rate	2%	5%	15%

The values presented in the table above are an upper estimate of the annual leakage rate and will be used in a sensitivity analysis. Variable Refrigerant Flow(VRF) systems was not included in the preparatory study but values from the multi-split category will be adopted.

Portable units are in the preparatory study estimated to have an annual leakage rate of 1 % including the end of life losses. However, stakeholders have previously and currently indicated that many portable air conditioners are filled and hermetically sealed in factory which means that they have very low leakage. One stakeholder claimed that their annual leakage rate was as low as 0.2 %. To determine the correct leakage rate can be difficult since the end of life leakage also must be included. An annual leakage rate of 1 % will be used in the current study.

Split, multi-split systems and VRFs have a higher annual leakage rate than portable air conditioners. Split systems are in the preparatory study assumed to have an annual leakage rate of 3 %. A field study of leakage rates on air conditioning and refrigerating equipment was led in France[52] and estimates of 3.8 % were found in situ for two split units working with R22. The same order of magnitude was identified for small air to water heat pumps. According to this field study leaks are localized at connection of supplementary components (valves, pressure gauges, potential intrusive temperature measurements). Average leak rates of 1.68 % (without End-of-Life losses) was suggested at the "2013 Annual Conference of the Institute of Refrigeration – LEC Leakage & Energy Control

[51] Barrault, 2004, Stéphanie BARRAULT, Denis CLODIC, avec la participation de Carine SAYON, "Inventaire des fluides frigorigènes et de leurs émissions", 2004 Inventaire des fluides frigorigènes et de leurs émissions, France, 2004, Document 2 : Données de base pour les inventaires de fluides frigorigènes.

[52] CETIM, 2004, Centre d'Etudes Techniques des Industries Mécaniques, Résultats des actions collectives N° 695, Confinement des installations frigorifiques, 2004.

system". Including End-of-Life loses an annual refrigerant leakage rate of 3 % seems reasonable.

End-of-Life refrigerant leakage rates are difficult to estimate since the rate is depending on how the units are treated and which functions are available. Some products today are equipped with a "pump-down" function to recover refrigerant from indoor units and connecting pipes into the outdoor unit. These functions are facilitating recovery of refrigerants and are preventing refrigerants to be emitted to the atmosphere. Different scenarios are made in the sensitivity analysis to cover the importance of refrigerant leakage.

As many uncontrollable factors such as the installation of the equipment have an impact on the leakage rate, it is difficult to implement requirements in the Ecodesign regulation. The challenge may also be related the handling at End-of-Life. This leakage at End-of-life may be improved by pump-down systems and is further discussed in Task 4.

3.2.3 *Estimated second hand use*

The estimated second-hand market is based on the preparatory study which made some assumptions based of statement from UNICLIMA and a survey on Ebay carried out in preparatory study and supported by desk research over several online platforms during the current review study. The statement from UNICLIMA stresses that there were no incentive or economic justification for refurbishment or second-hand use of fixed air conditioners since the cost of reinstalling a fixed air conditioner and fill it with a new fluid costs more money than a new product. Regarding portable air conditioners, a second-hand market exists. The situation may change but there is at the moment very little second-hand use of the products. It was confirmed by a survey led on Ebay in the frame of the preparatory study where very few products were available, despite of direct imports from China of new products. Main second-hand market is thought to relate to people buying a portable air conditioner before the summer in case of heat wave and willing to recover the money once the summer has ended. The same assumption as for portable air conditioners can be made for comfort fans. A recent survey on Ebay and sites alike confirmed that a second-hand market also exist for comfort fans despite their low initial price.

If the air conditioner is barely used in its primary life, after being resold as a second-hand product, it could potentially increase its typical lifetime. However, the second-hand market exists for air conditioners is rather small, because of the high costs to uninstall/install and refurbish the equipment. Due to the small market in the EU, it is assumed that it has no or very limited impact on the average lifetime evaluation and can be neglected in the coming tasks. The impacts of a second-hand market could potentially negative impacts due to the trade-offs between material consumption and energy consumption. As reusing old and inefficient air conditioners means that although raw materials are saved but it is at the cost of higher electricity consumption.

3.2.4 Best practice in sustainable product use

Sustainable product use can minimise the energy consumption of air conditioners. A few best practices are listed in this section.

First it is important to purchase a properly sized air conditioner which is described in a previous section. Following the purchase of the air conditioners the end users can also

affect the energy consumption of the equipment. The end user should consider the following points[53]:

- **Proper positioning** – The air conditioners should be placed centrally in the room and on the upper part of the wall since cold air tends to go down and mix with warm air. The air conditioners should be free of obstacles that might prevent the diffusing of cold air into the room. Furthermore, is it important that the thermostat is clear of any potential heat source such as televisions which can cause the air conditioner to operate longer than necessary
    - **Number of air conditioners** – Installing one powerful air conditioner in e.g. a corridor is not sufficient as the only really cooled room would be the corridor, not the rest of the rooms.
- **Amount of cooling** – it is often adequate to lower the temperature with two or three degrees compared to outdoor temperature and use dehumidification. It is often the humidity that makes end user perceive a higher temperature than it is.
- **Closed windows and doors** – preventing warm air into the room.
- **Insulate the cooling circuit tubes outdoor** – direct sunlight can deteriorate the tubes. It is also important to make sure that the external part of the air conditioner be not exposed to direct sunlight and bad weather conditions.
- **Use the timer and the 'Night' mode** – reducing the hours of use.
- **Cleaning and correct maintenance** – Regular cleaning of air filters and fans at the beginning of the cooling season (importance of cleaning filters is discussed in previous section). A proper maintenance can reduce the cost for cooling and heating by up to 10 % and prolonging the life of the equipment[54].

Many of the above-mentioned suggestions are also applicable for air conditioners used for heating e.g. to properly place the air conditioner so it can supply heat to a large area/room. The temperature control is also of great importance as the temperature can be lowered during the night and during working hours when the house is empty.

Regarding comfort fans the best sustainable product use is based on preparatory study. The preparatory study suggests using fans with variable speeds and curved blades. Besides this proper sizing is also important. Tre proper fan size dependent on the room area is presented in Table 16.Table 16: Ideal fan width depending on the room area

Room Area (m^2)	Ideal Fan Width
Up to 10	900 mm
10-20	1200 mm
15-30	1400 mm
+30	Two or more fans

3.3 Local infrastructure

3.3.1 Electricity

The power sector is in a transition state moving from fossil fuels to renewable energy. The origin of the electricity is very important factor to consider both regarding the environmental impact by using an air conditioner and how it may affect the consumer behaviour. Within the EU there are a number of renewable energy targets for 2020 set out in the EU's renewable energy directive[55]. The overall target within the EU is 20 % final energy consumption from renewable sources. To achieve this goal the different EU

[53] http://www.enea.it/en/news/environment-10-tips-to-efficiently-use-air-conditioning-and-keep-bills-low-cost
[54] https://energy.gov/sites/prod/files/guide_to_home_heating_cooling.pdf
[55] https://ec.europa.eu/energy/en/topics/renewable-energy

countries has committed to set their own individual goal ranging from 10 % in Malta to 49 % in Sweden. In 2015 the share of renewable energy was almost 17 %[56].

The electricity consumption are a major part of the final energy consumption and the electricity mix is highly relevant for air conditioners. The electricity mix of 2015 is presented in the below figure.

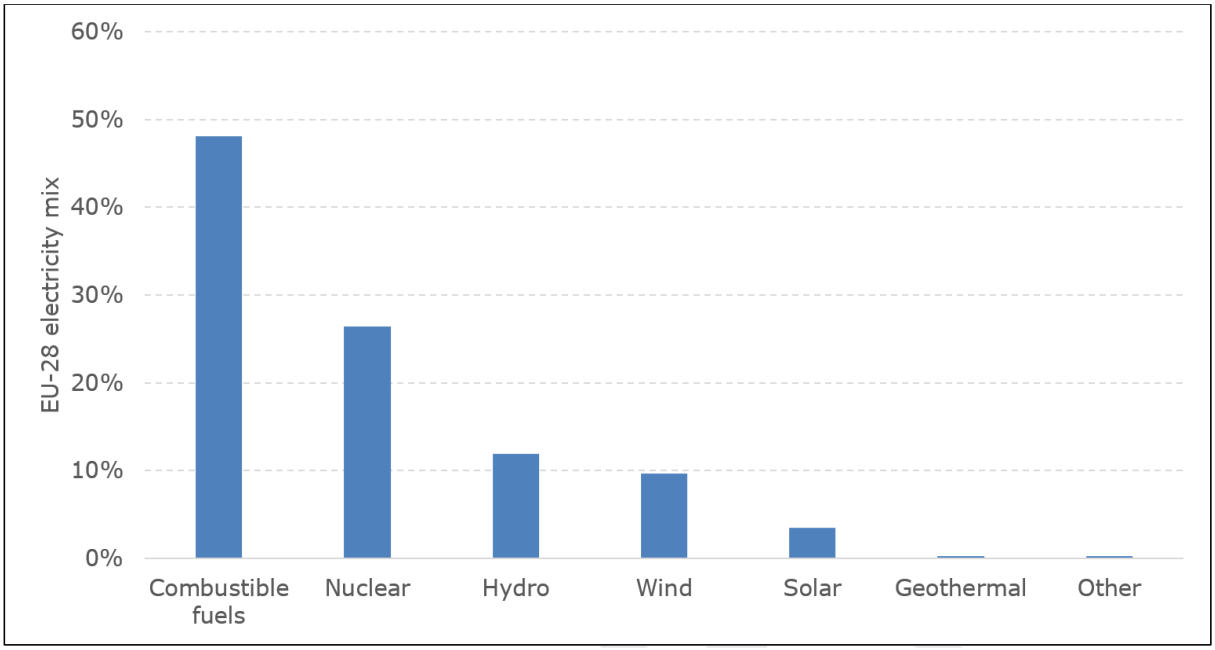

Figure 21: Net electricity generation, EU-28, 2015 (% of total, based on GWh)[57]

Almost half of the electricity consumption still originates from combustible fuels and renewable energy sources only constitutes about 25 % of the electricity generation in 2015.

The reliability of the electricity grid could be in some degree affected by the transition to a renewable energy system. With more renewable energy in the system new challenges occur e.g. with excess production of wind energy and the two-directional transfer of energy. Due to technological development, the reliability in many EU countries is ensured via the expansion of the electricity grid to distribute renewable energy. The quality of the electricity grid in Europe is considered to be high and among the best in the world. Every year the World Economic Forum release a Global Energy Architecture Performance Index report. The report is ranking the different countries on their ability to deliver secure, affordable, sustainable energy. In recent years European countries have dominated the top spots[58].

[56] http://ec.europa.eu/eurostat/documents/2995521/7905983/8-14032017-BP-EN.pdf/af8b4671-fb2a-477b-b7cf-d9a28cb8beea
[57] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Net_electricity_generation,_EU-28,_2015_(%25_of_total,_based_on_GWh)_YB17.png
[58] https://www.weforum.org/reports/global-energy-architecture-performance-index-report-2017

Country	2017 score	Economic growth and development	Environmental sustainability	Energy access and security
Switzerland	0.8	0.74	0.77	0.88
Norway	0.79	0.67	0.75	0.95
Sweden	0.78	0.63	0.8	0.9
Denmark	0.77	0.69	0.71	0.91
France	0.77	0.62	0.81	0.88
Austria	0.76	0.67	0.74	0.88
Spain	0.75	0.65	0.73	0.87
Colombia	0.75	0.73	0.68	0.83
New Zealand	0.75	0.59	0.75	0.9
Uruguay	0.74	0.69	0.71	0.82

The consumer behaviour might affect the electricity system in some countries since the use of air conditioners often occurs in the same time periods when it is either warm or cold. January is in general the month with the highest monthly electricity consumption across EU except for some of the southern countries like Spain, Italy and Greece which all peaks in July. In the below table are the monthly electricity consumption presented for most of the EU countries[59]. In the below table is the peak consumption marked with red and the lowest consumption marked with blue.

[59] Data provided by ENTSO-E

Table 17: Monthly electricity consumption

MONTHLY CONSUMPTION (IN GWh)													
Country	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Total**
Austria	6498	5984	6203	5542	5468	5376	5588	5436	5271	5900	6005	6234	69505
Belgium	8057	7312	7653	6940	6795	6657	6548	6609	6731	7221	7202	7284	85009
Bulgaria	3455	3068	3111	2639	2404	2363	2611	2537	2416	2703	2766	3171	33244
Cyprus	368	364	338	283	314	343	452	495	441	351	298	358	4405
Czech Republic	6019	5584	5774	5200	4972	4818	4859	4641	4865	5509	5553	5624	63418
Germany	48952	45608	46179	40889	39607	39875	41470	39824	40911	45723	46280	45289	520607
Denmark	3188	2909	2916	2306	2648	2907	2556	2692	2697	1943	2555	3113	32430
Estonia	816	719	743	679	634	573	574	593	624	719	714	751	8139
Spain	23883	22048	22279	19837	21016	21614	24972	22341	20897	20964	20985	22069	262905
Finland	8437	7336	7645	6756	6268	5838	5941	6008	6118	7138	7279	7730	82494
France	52475	48579	45707	36847	33873	33225	34887	31582	33483	39167	40985	44593	475403
United Kingdom	32243	29083	31380	26097	26044	24327	24569	24361	25082	28320	30380	30768	332654
Greece	4829	4299	4504	3772	3823	3965	4855	4687	4086	3835	3895	4610	51160
Croatia	1538	1429	1461	1314	1292	1288	1573	1494	1336	1351	1369	1539	16984
Hungary	3629	3316	3507	3218	3209	3249	3484	3342	3313	3507	3490	3491	40755
Ireland	2498	2279	2397	2154	2192	2055	2100	2087	2120	2276	2353	2445	26956
Italy	26786	24948	26793	24169	25027	26328	31970	24458	26449	25907	25675	25818	314328
Lithuania	1005	891	920	873	862	825	846	863	866	955	958	995	10859
Luxembourg	574	538	579	516	497	503	542	512	492	554	547	514	6368
Latvia	692	616	635	589	571	522	549	568	562	625	626	654	7209
Netherlands	10343	9183	9588	8741	8881	8823	9191	9049	9149	9685	9763	10119	112515
Norway	13526	12065	12244	10410	9989	8880	8391	8585	8979	10632	11726	12872	13526
Poland	13546	12327	13116	12060	12011	11716	12333	12295	12099	13257	13066	13254	151080
Portugal	4713	4232	4167	3727	3939	3964	4280	3907	3883	3987	3977	4189	48965
Romania	5023	4598	4791	4435	4258	4202	4636	4398	4266	4665	4634	4877	54783
Sweden	14100	12610	12851	10967	10494	9602	8907	9561	9888	11578	12242	13130	135930
Slovenia	1233	1130	1178	1067	1092	1088	1149	1073	1099	1175	1164	1199	13647
Slovakia	2470	2277	2393	2194	2157	2115	2191	2136	2128	2360	2350	2405	27176

Spain, Italy and Greece are all among the countries with the highest share of air conditioners installed. This is properly one of the reasons that these countries all have their peak consumption of electricity in July. The lowest monthly electricity consumptions are for most countries within EU in June. The hourly load values for a random Wednesday in March 2015 for selected countries are presented in the figure below.

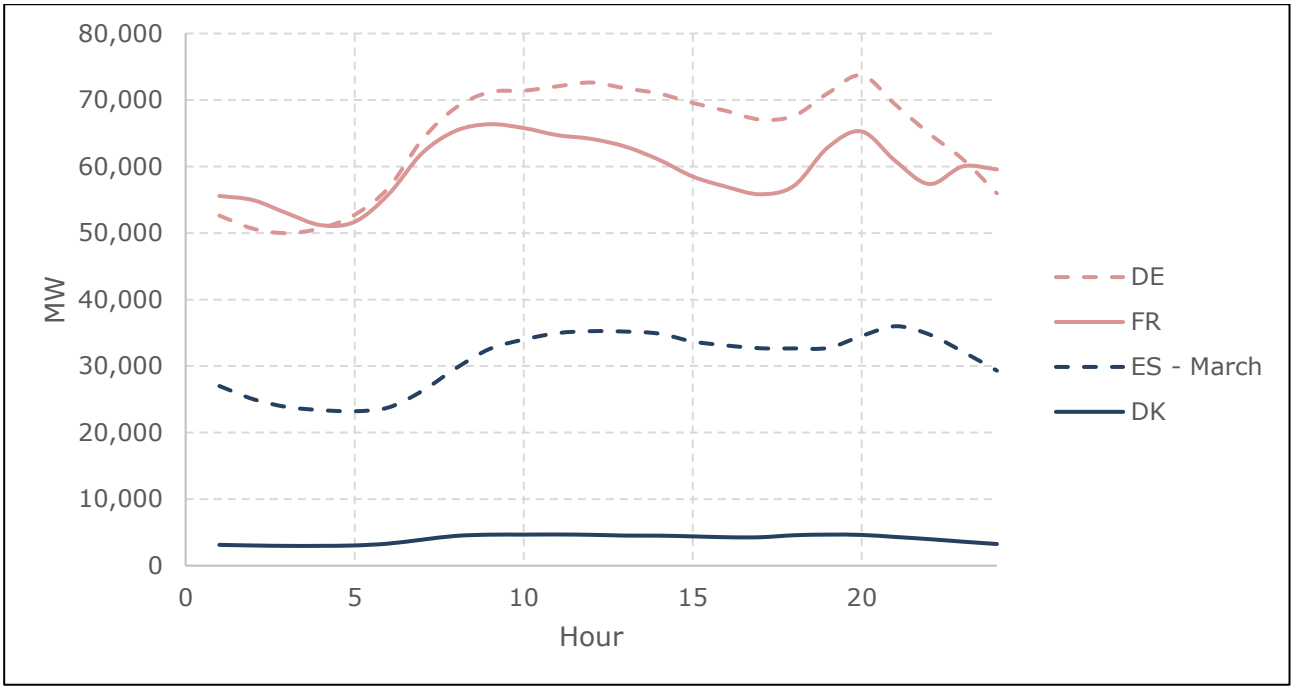

Figure 22: Hourly load values a random day in March

All presented countries have similar hourly load values with two peaks, one in the morning and one in the evening. It is barely visible for Denmark but this is due to scale of the graph. There are though small shifts in the peaks. In Denmark, the peaks occur a little earlier than in Spain. The first peak fits well with the start of the workday and the second peak fits with the end of the workday. Between the two peaks there is a falling trend in the energy consumption. The lowest electricity consumption across the different countries are at 5 AM. For most countries, this hourly load curve fits this description the majority of the days. For months and days with a higher or lower consumption tendency the profile are the same it is just shifted up or down. In the southern countries such as Spain, Italy and Greece the hourly load consumption is different in July. The hourly load consumption for Spain in March and July is presented in Figure 23.

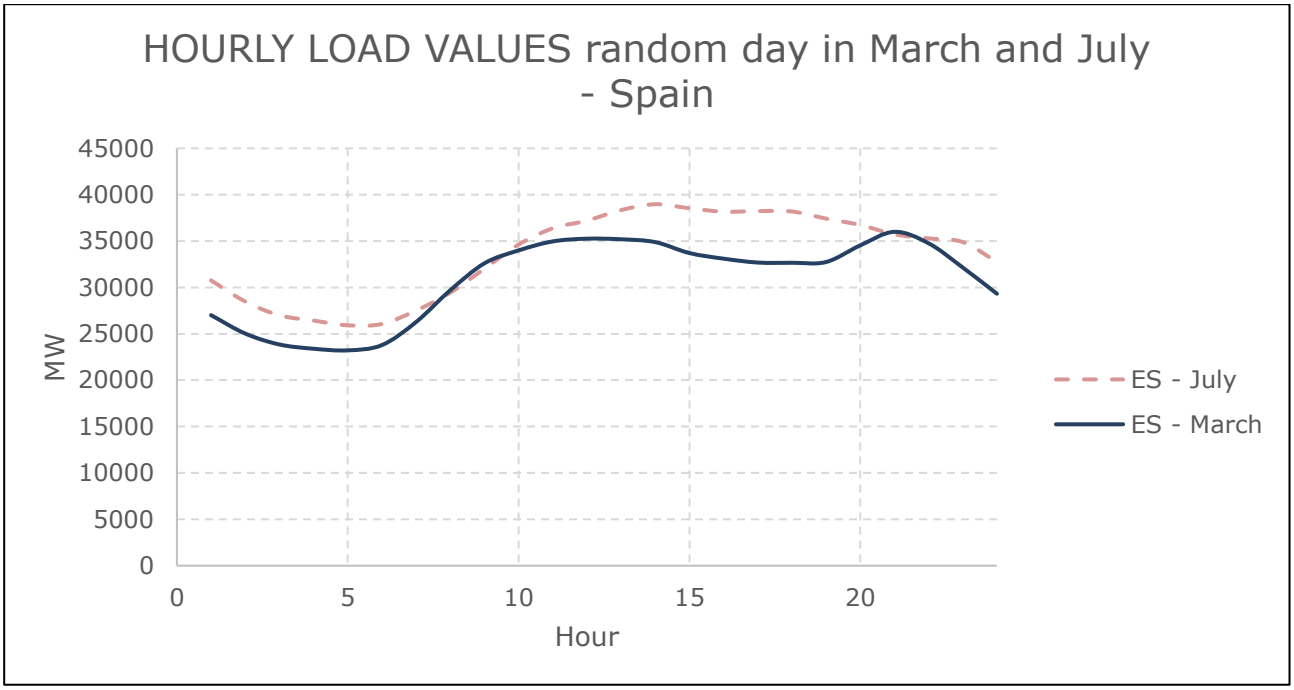

Figure 23:Hourly load values a random day in March and July - Spain

In Spain, the hourly load values only have one peak at 3 PM. The same pattern is also visible for e.g. Greece and Italy in July. This change in values is properly caused by the increased use of air conditioners. In this specific time period, it is also expected that the photovoltaic production in warm countries are peaking. The installed capacity of air conditioners is below 5 GW while the installed photovoltaic capacity is above 5[60] GW. This does not mean that air conditioners solely are operating on renewable energy but a comment on possible synergies between air conditioners and the photovoltaic technology.

3.3.2 Smart appliances

More smart appliances are expected to enter the market and air conditioners in this category. Smart appliances are defined in the ecodesign preparatory study on smart appliances (Lot 33)[61] as an appliance that supports Demand Side Flexibility (in a more recent report of the preparatory study, these called **Energy Smart Appliances**, to be more specific about the type of smart the appliance is capable of):

- It is an appliance that is able to automatically respond to external stimuli e.g. price information, direct control signals, and/or local measurements (mainly voltage and frequency);
- The response is a change of the appliance's electricity consumption pattern. These changes to the consumption pattern are what we call the 'flexibility' of the smart appliance;

Whereby:

- The specific technical smart capabilities do not need to be activated when the product is placed on the market; the activation can be done at a later point in time by the consumer or a service provider.

[60] https://www.worldenergy.org/data/resources/country/spain/solar/
[61] http://www.eco-smartappliances.eu/Documents/Ecodesign%20Preparatory%20Study%20on%20Smart%20Appliances%20_Tasks%201%20to%206.pdf

Overall air conditioners have the potential to have some flexibility in their use patterns and have a certain impact on the electricity system. Although shown in Task 2, there are already air conditioners with network capability available on the market that can be controlled via smart phones, tablets and other devices remotely via network, and grid communication capability that allows control of device according to electricity prices, these are not Energy Smart Appliances as defined in Lot 33 yet. Furthermore, these networked air conditioners on current market do not vary significantly from products without network capabilities.

Depending on the number of energy smart appliances in the system these appliances can provide energy system services both in day-ahead and in real-time by shifting operation. Day-ahead services leads to a reduced cost and CO2 emission compared to a situation without smart appliances, since additional generation by conventional power plants (e.g. coal) could be avoided due to a smart shift in load. The same benefits can be observed regarding real-time services[62]. With energy smart appliances it is possible to fit the demand to the production.

Some of the current barriers for energy smart appliances are estimated high prices (not always the case, but for many premium products), limited consumer demand, long device replacement cycles and the fragmentation within the connected home ecosystem. There are many different ways of connecting to the "smart home". Without any common standards for the smart home it is difficult and confusing for the consumer to set up and control multiple devices. An additional reason is the fact that the electricity suppliers do not currently offer demand response.

The limited consumer demand for energy smart appliances can very well be related to the low availability of these products and the current electricity prices in the different countries. In most of the EU countries more than half of the electricity prices constitute of taxes and network cost, so if the electricity price is low there is no or only little incentive to use electricity in these periods since it is only a minor part of the costs (note that other ways of paying consumers exist in the smart grid[63]). In Figure 24 is the composition of the electricity prices for household consumers presented[64]. The countries are listed after the lowest energy and supply costs.

Furthermore, although some air conditioners have the potential of being energy smart appliance, savings at large scale can only be realised when the standards and infrastructure are ready for all types of energy smart appliances for the whole EU in the coming years, as a result of the Ecodesign work on Smart Appliances.

[62] http://www.eco-smartappliances.eu/Documents/Ecodesign%20Preparatory%20Study%20on%20Smart%20Appliances%20_Tasks%201%20to%206.pdf
[63] https://www.smartgrid.gov/the_smart_grid/consumer_engagement.html
[64] Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

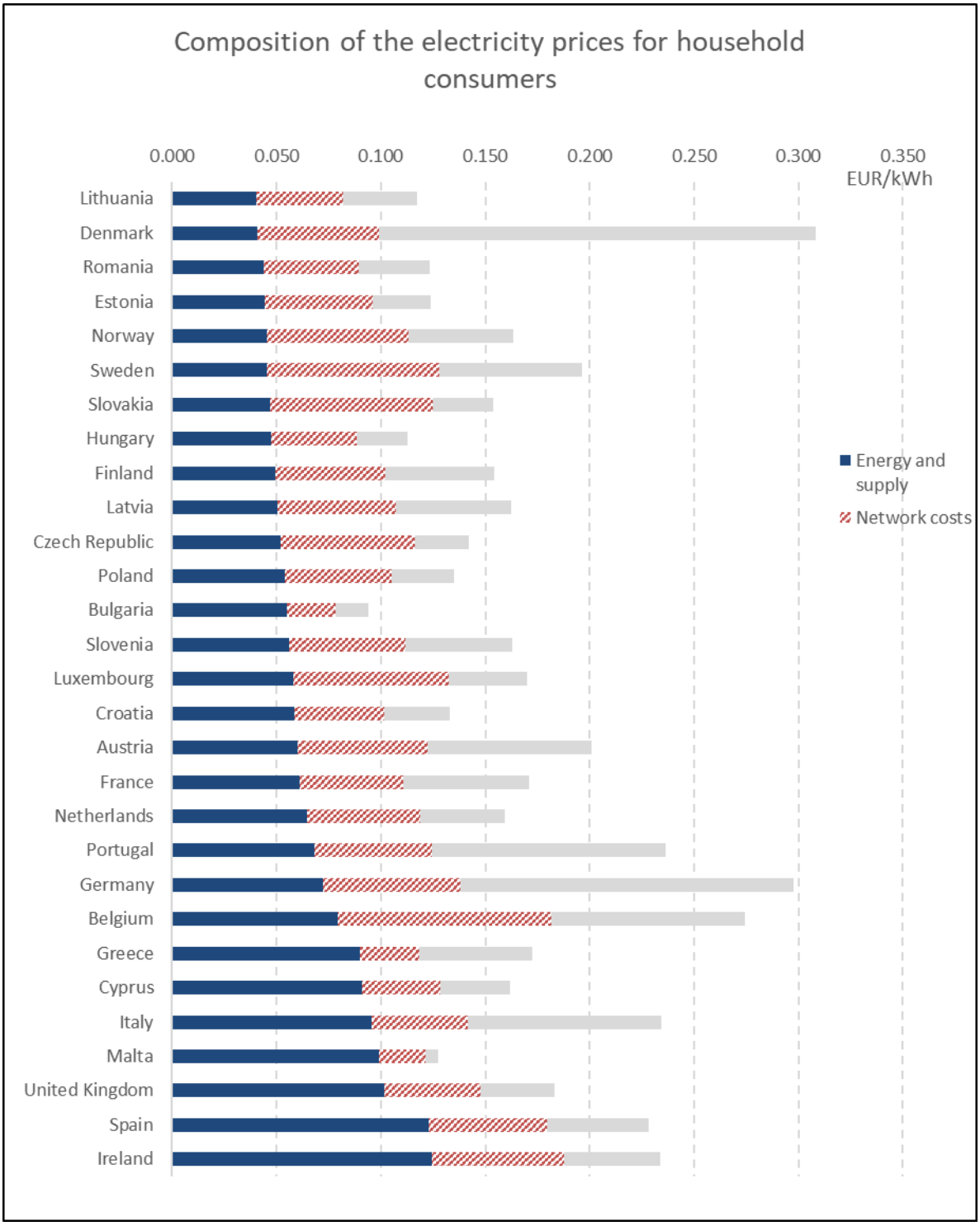

Figure 24: Composition of the electricity prices for household consumers[65]

[65] Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

3.4 Conclusions and recommendations

System aspects use phase
Base on the assessment on use phase in section 3.1, the following conclusions and recommendations can be summarised.

One of the most important point for **air conditioner use phase energy consumption** is the number of equivalent full load hours that is used to compute the energy consumption and seasonal performances, this is the ratio of the specific yearly cooling load (in kWh/m^2/year) divided by the sizing coefficient (in W/m^2). For reversible air conditioners, the equivalent full load hours for heating is also important.

The seasonal performance metrics used to rate SEER and SCOP of fix air conditioners was thoroughly reviewed to evaluate the need for changing some of the **SEER and SCOP metrics parameters**, assessment and considerations have been presented.

Available data for **cooling loads** has been reviewed and compared to preparatory study simulations. It is recommended to keep these values presented in section 3.1.2.1. Correlations versus Cooling Degree Days (CDD) are proposed to enable to account for climate change and to derive cooling load values for EU28 countries which was not modelled in the preparatory study.

Significant **oversizing** of air conditioners is observed in practice and begins to be quantifiable due to the development of on-board performance measurement methods. Nevertheless, data is not yet available to properly quantify the oversizing and the consequences in terms of energy efficiency. In addition, present rating of very low loads (impact on performance of inverter compressor cycling below minimum speed) should be improved so that that effect might be included in the SEER metrics. It is therefore proposed to maintain the metrics hypothesis of "perfect sizing" where it is assumed the 100 % load of the building matches the declared rated capacity of the unit for now.

Available data of **sizing coefficients** has been reviewed and compared to preparatory study simulations. It is recommended to keep the preparatory study values.

The evaluation of the weighted average EU28 specific cooling load and sizing coefficients leads to a figure close to the one obtained in the preparatory study for **equivalent full load hours in cooling mode**, which is close to 350 hours. it is thus recommended to keep this value.

Regarding heating, the **heating loads and sizing coefficients** are derived from the space heating preparatory study and there is no change proposed regarding these values. Note that oversizing is also a concern here and might be included in future studies. To evaluate the environmental impact of **reversible air conditioner**s in Tasks 5 and 7, it is necessary to account for the fact that part of the reversible air conditioners is not used for heating in Europe. Most recent data source from Commission decision 2013/114/EU and stakeholder inputs results in the assumption of ca. 30 % of reversible air conditioners used for heating in average for stock units and 50 % for new units.

Low power mode hours have been reviewed. It is proposed to require two distinct **crankcase power values** for reversible units, respectively for cooling mode - measured at 20 °C - and for heating mode - measured at 12 °C. Cooling (or heating) only unit crankcase power measurement should be done at 20 °C (12 °C), as already written in

standard EN14825:2016. Minor adjustments of **crankcase hours** are proposed. Above that, it is suggested that to include network standby for products with network capability, present standby hours can be used.

Regarding **portable air conditioners**, the impact of air infiltration on unit's capacity has been studied in heating and in cooling mode for both single duct and double duct units. It appears as a major factor for the product functionality and performance. A seasonal performance metrics is proposed in cooling mode for both products that include this effect. In heating mode, the seasonal efficiency of these units is very low. It is questionable to have at all reversible single duct units on the market as their seasonal performance is most likely lower than the one of a fan electric heater. For single duct and double duct reversible units in heating mode, it is recommended to adopt a SCOP metrics derived from the one for fixed reversible air conditioners and including the infiltration effect. This requires developing a test method to measure the condenser air flow rate of single duct air conditioners.

Stakeholders have underlined a risk that some of the highest efficiency units with high air flow at indoor unit may not be comfortable to the end-users and thus may lead to **higher consumption in real life.** To that purpose it is proposed to complete the test results of EN14511-3 with outlet temperature and humidity conditions and to require these values to be included in the technical documentation of products. Crucial **real life performances** are not available for fixed and portable air conditioners and the development of on-board measurement methods should be encouraged (it is proposed to start a standardisation work on this subject and to include electricity consumption measurement as well). Additionally, the impact of heat exchanger fouling may be important (as high as 20 % consumption increase) but it is supposed to be mitigated by a proper and regular maintenance, and with the help of filtering (including now automatic cleaning of filters). It is proposed to make washable filters on both heat exchangers mandatory for portable air conditioners as maintenance is currently not common for these units.

Regarding **comfort fans use patterns**, there is no new insight since the preparatory study and the number of equivalent full load hours are maintained at an average value for EU of 320 hours per year.

End of life behaviours

Through reviewing preparatory study and different sources, the average lifetime of air conditioners and comfort fans used in the current review study is presented in Table 18.

Table 18 Average lifetime assumptions adopted to the current study

Technology	Average lifetime (years)
Movables + Window Units	10
Small Split (<5 kW)	12
Large Split (>5 kW, incl. ducted)	12
VRF	15
Comfort fans	10

During the lifetime, air conditioners are more likely to be repaired in southern and south-eastern countries due to lower labour costs. The effect of a long lifetime should be assessed in later tasks to reveal to possible trade-offs between a long lifetime and efficiency. The most likely parts to malfunction or to be repaired by replacement is

printed circuits boards and compressors based on stakeholder inputs. These parts are also available through the entire life of the products. When comforts fans malfunctions, they are expected to be discarded due to their low purchase price.

There are opportunities for Ecodesign in terms of product lifetime, enabling easy repair and maintenance as well as refrigerant leakage, however these can be problematic for market surveillance to verify, and Ecodesign which sets requirements at the beginning of the product's life may have limited impact on these aspects at the end of life.

The second-hand market for fixed air conditioners are very limited, but for both portable air conditioners and comfort fans this market is more widespread. Though, it is still assumed to be negligible and therefore not included in later tasks.

Regarding the best practice in sustainable product use it is important that the air conditioner is properly sized, well-placed and regularly maintained to reduce the energy consumption. These factors can reduce the cost of heating and cooling by up to 10%. It should therefore be discussed whether these information's should be made mandatory in the user manual.

Local infrastructure

The power sector is in a transition state moving from fossil fuels to renewable energy which challenges the existing infrastructure. In Europe the electricity system is characterized by a high share of renewable energy and high reliability.

Most countries have similar hourly load values with two peaks, one in the morning and one in the evening. The first peak fits well with the start of the workday and the second peak fits with the end of the workday. Between the two peaks there is a falling trend in the energy consumption. Though, it seems like the need for cooling is affecting the hourly load values for southern countries in the summer period. In these countries the peak load occurs in the middle of the day which could indicate a high use of air conditioners.

The consumer demand of energy smart appliance is still low due to the lack of products and the relatively small cost saving as a result of the non-flexible electricity prices and composition. Although some air conditioners have network and grid communication capability, but savings at large scale can only be realised when the standards and infrastructure are ready for all types of energy smart appliances in the coming years.

Annex 1: Preparatory study Building Energy Simulation input

The preparatory study for Lot 10 used simulations to derive cooling loads of air-conditioned buildings. Three different simple buildings were simulated, one house, one office and one shop, envelope insulation characteristics and air change properties for existing buildings and for new buildings built after 2006. The main characteristics of the three buildings are given in this annex.

Geometry

Residence

The residence is modelled as an apartment with characteristics as defined in Table 19. The exposed surfaces are the roof and facades in four orientations, while the floor is detached to a fully symmetric zone with identical boundary conditions. The exterior dimensions are 8 by 12.5 m with a total floor area of 100 m^2. The exposed wall area is 98 m^2. Distinct windows are placed in each wall with a window to wall ratio of 0.15, where operable shades are employed. The conditioned area represents the 30% of the total floor area, with south and west exposed facade.

Office

The office is modelled as a rectangular building with a core, conditioned zone and characteristics as described in Table 20. The exterior dimensions are 10 by 10 m with a total conditioned space of 100 m^2. The flour is detached to a fully symmetric zone with identical boundary conditions.

Retail

The retail store is modelled as a rectangular building with a single zone, as part of a strip mall with adjacent zones on two sides, characteristics as identified in Table 21 and in two orientations (north-south). The exterior dimensions are 25 by 25 m^2 with 50 m^2 of total conditioned floor area. Windows to wall ratio was set equal to 0.6, with operable shades.

Table 19: Construction, Internal Load and cooling equipment characteristics for Residence

Construction	Characteristic	Old	New
Zones	1 (conditioned)		
	1 (unconditioned)		
Floor area	100 m^2		
Roof	U-values range (W/m^2K)	0.2-0.9	0.2-0.5
Wall constructions	U-values range (W/m^2K)	0.2-1.2	0.3-1.2
Windows	16 m^2		
	Clear with operable shades		
Interior Load			

Infiltration	Air Change per hour (ACH)	0.8-1.5	0.2-0.4
Lighting	7-15 (W/m2)		
Equipment	7-10 (W/m2)		
Occupancy	1 person / 20 m2		
Equipment			
Thermostat	Cooling set point	25-26	25-26
Natural ventilation	Window operation available		

Table 20: Construction, Internal Load and cooling equipment characteristics for Office

Construction	Characteristic	Old	New
Zones	1 (conditioned)		
	1 (unconditioned)		
Floor area	100 m^2		
Roof	U-values range (W/m^2K)	0.2-0.9	0.2-0.5
Wall constructions	U-values range (W/m^2K)	0.2-1.2	0.3-1.2
Windows	25 m^2		
	Clear with operable shades		
Interior Load			
Infiltration	Air Change per hour (ACH)	0.8-1.5	0.2-0.4
Lighting	15-18 (W/m^2)		
Equipment	12-15 (W/m^2)		
Occupancy	1 person / 9 m2		
Equipment			
Thermostat	Cooling set point	24-26	24-26
Natural ventilation	Window operation available		

Table 21: Construction, Internal Load and cooling equipment characteristics for retail

Construction	Characteristic	Old	New
Zones	1 (conditioned)		
Floor area	50 m^2		
Roof	U-values range	0.2-0.9	0.2-0.5
Wall constructions	U-values range	0.2-1.2	0.3-1.2
Windows	30 m^2		
	Clear with operable shades		
Interior Load			
Infiltration	Air Change per hour (ACH)	0.8-1.5	0.2-0.4
Lighting	15-25 (W/m^2)		
Equipment	5 (W/m^2)		
Occupancy	1 person / 5 m2		
Equipment			
Thermostat	Cooling set point	22-26	22-26
Natural ventilation	Window operation available		

Building Envelope

Since the focus is to perform a comparative analysis, building characteristics were selected to be representative and adaptive to weather variation. Opaque and transparent surfaces exhibit local variation in Europe, so they were not selected to be uniform.

Roof, wall, floor and window characteristics, were initially identified through national questionnaires and the calculated U-values were in good agreement with Ecofys/Eurima data concerning old and new constructions. U-values for both opaque and transparent elements, as well as for old and new constructions, were classified in five groups, being representative of building characteristics adaptive to climate Table 22.

Table 22: U values for old and new construction in different climates

U-values (W/m²K)	Old Construction	New Construction
COLD: FI, SE		
Roof	0.2	0.15
Wall	0.3	0.2
Floor	0.2	0.18
Windows	2	1.4
MODERATE: AT, BE, DK, FR, DE, IE, LU, NL, UK		
Roof	0.5	0.25
Wall	1.2	0.45
Floor	0.8	0.53
Windows	3.44	2.95
WARM: GR, IT, PT, ES, CY, MT		
Roof	0.9	0.5
Wall	1.2	0.6
Floor	0.8	0.53
Windows	5.68	3.44
CENTRAL EASTERN EU COUNTRIES: PL, SK, SI		
Roof	0.5	**0.23**
Wall	0.6	0.34
Floor	0.53	0.44
Windows	3.44	1.4
BALTIC REPUBLICS: EE, LV, LT		
Roof	0.5	0.2
Wall	0.6	0.26
Floor	0.53	0.29
Windows	3.44	1.4

Internal gains

Internal loads in buildings are due to occupancy (people / m^2), lighting and electrical equipment. We have assumed that there is no local variation, but there is a clear dependence on the type of use. Magnitude and schedules are listed in Table 23, Table 24, Table 25 and Table 26, respectively.

The heat input per person was considered according to ISO 7730, while for the artificial lighting it was assumed that 60 % of the input contributes to the zone heat balance as convective heat and 40 % as radiative.

Table 23: Internal Gains

	Office	Resident	Shop
Lighting (W/m^2)	15	10	25
Equipment (W/m^2)	15	7	10
Occupancy (person / m^2)	1/9	1/20	1/5

Table 24: Schedules for shop

Working Day				
HOUR	**OCCUPANCY**	**TEMPERATURE**	**LIGHTING**	**EQUIPEMENT**
00-08	0	SetBack	0.05	0.05
08-09	0.1	SetPoint	1	1
09-10	0.25	SetPoint	1	1
10-19	0.5	SetPoint	1	1
19-24	0	SetBack	0.05	0.05
Weekend				
00-08	0	SetBack	0.05	0.05
08-09	0.1	SetPoint	1	1
09-10	0.25	SetPoint	1	1
10-19	0.5	SetPoint	1	1
19-24	0	SetBack	0.05	0.05
00-08	0	SetBack	0.05	0.05

Table 25: Schedules for office

Working Day

HOUR	OCCUPANCY	TEMPERATURE	LIGHTING	EQUIPEMENT
00-08	0	SetBack	0.05	0.05
08-09	0.1	SetPoint	1	1
09-10	0.25	SetPoint	1	1
10-19	0.5	SetPoint	1	1
19-24	0	SetBack	0.05	0.05
Weekend				
00-24	0	SetBack	0.05	0.05

Table 26: Schedules for residences

Working Day				
HOUR	**OCCUPANCY**	**TEMPERATURE**	**LIGHTING**	**EQUIPEMENT**
00-07	0	SetBack	0	0.05
07-09	1	SetPoint	1	1
09-17	0	SetBack	0.05	0.05
17-23	1	SetPoint	1	1
23-24	0	SetBack	0	0.05
Weekend				
00-09	0	SetBack	0	0.05
09-23	1	SetPoint	0.05	1
23-11	0	SetBack	0	0.05

Infiltration and Ventilation

Infiltration rates were set equal to 0.4 and 0.6 air change per hour for new and old constructions respectively. Ventilation rates have been calculated as a function of occupancy (number of people and schedule of use) using the standard value of 8 l/s/person.

European Commission

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 4 report

Technologies

Final version

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As agreed with Policy Officer Veerle Beelaerts, some of the budget for data purchase was reallocated for project work.

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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.

[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).

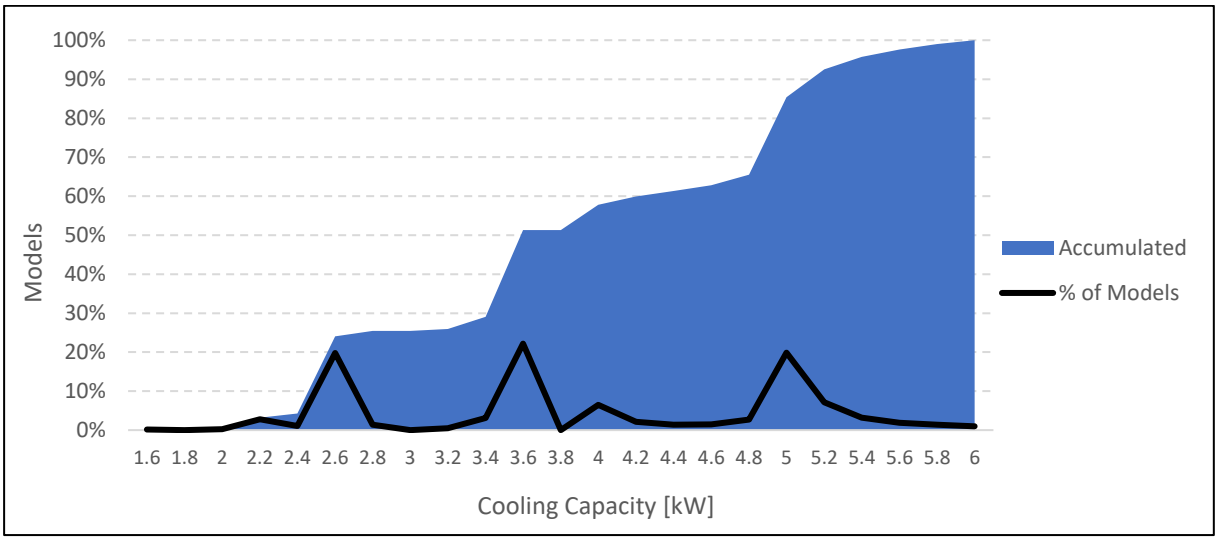

Figure 1: Distribution of models per size in the 0-6 kW range, adapted from ECC directory[2]

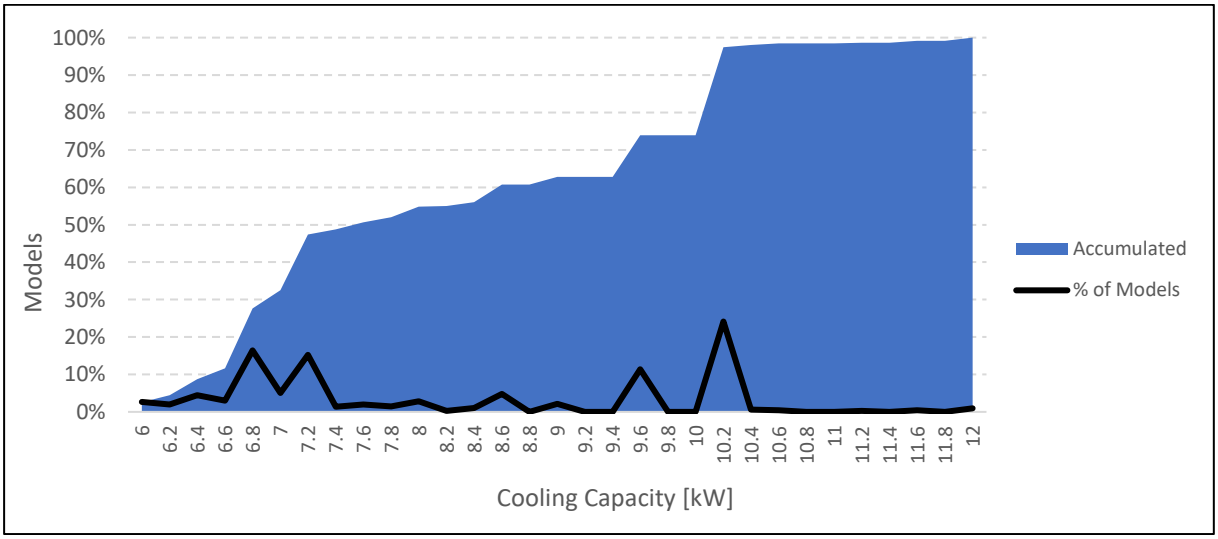

Figure 2: Distribution of models per size in the 6-12 kW range, adapted from ECC directory

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

[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.

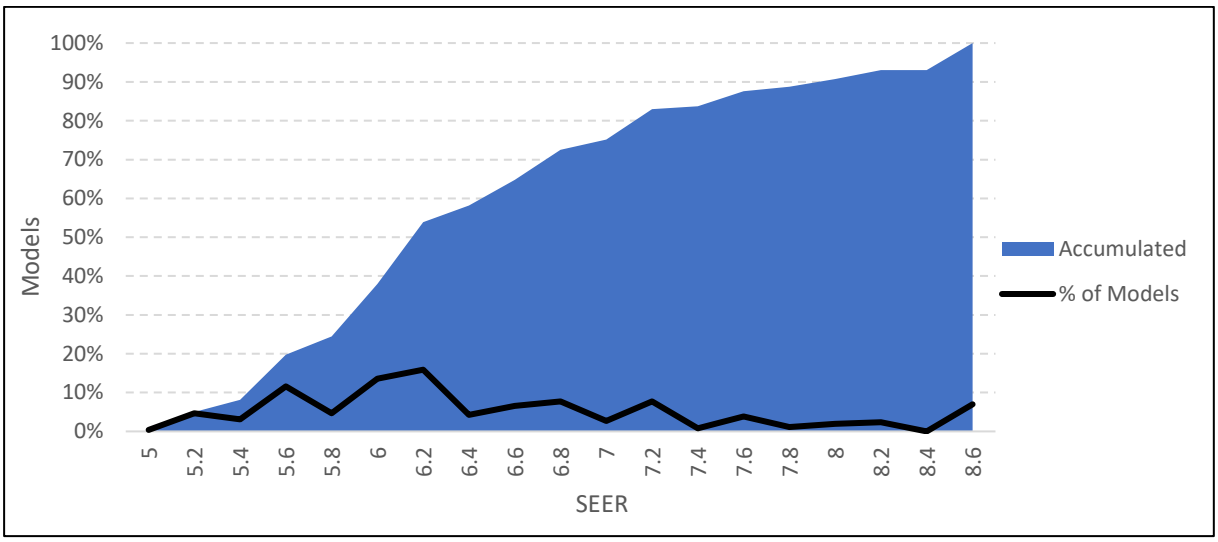

Figure 3: SEER distribution by model between 3.4 and 3.6 kW, adapted from ECC directory

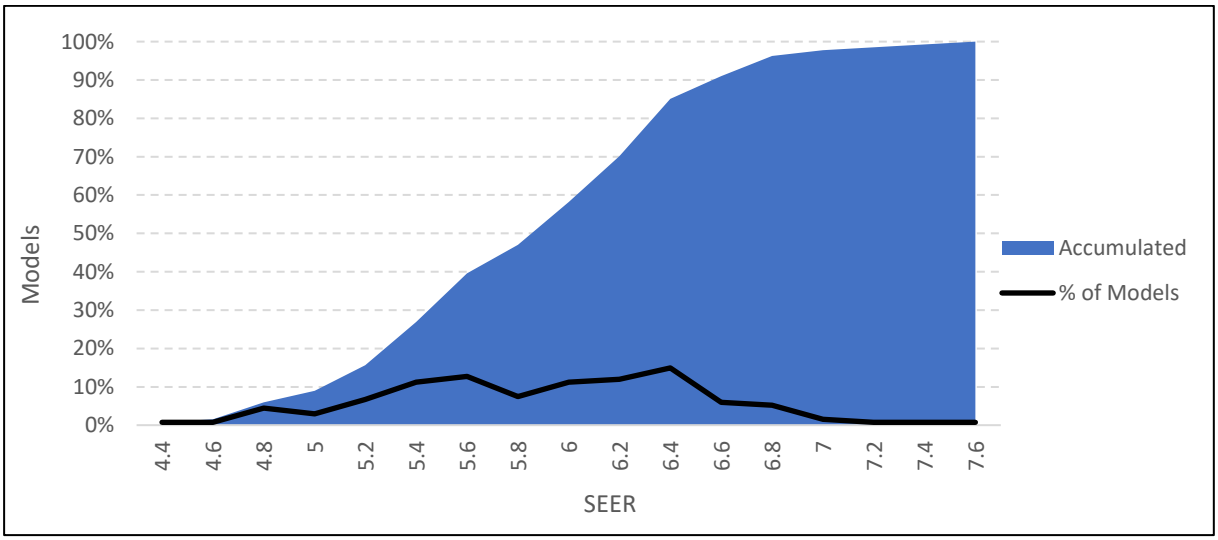

Figure 4: SEER distribution by model between 7.0 and 7.2 kW, adapted from ECC directory

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 %.

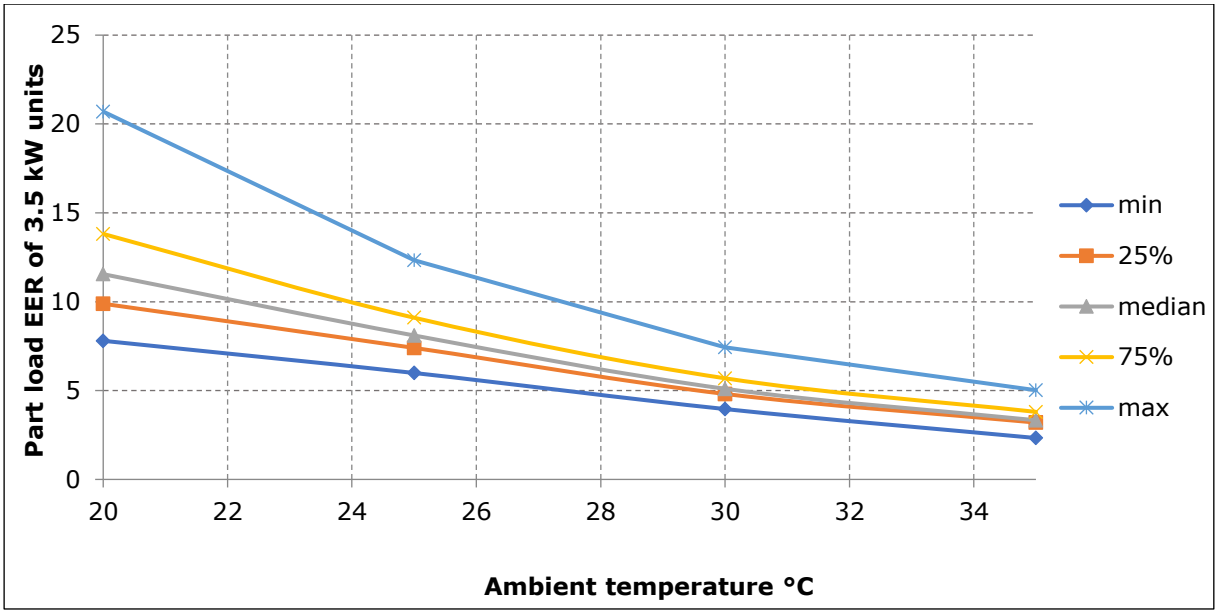

Figure 5: Part load EER of 3.5 kW units distribution in cooling mode, source Eurovent Certita Certification

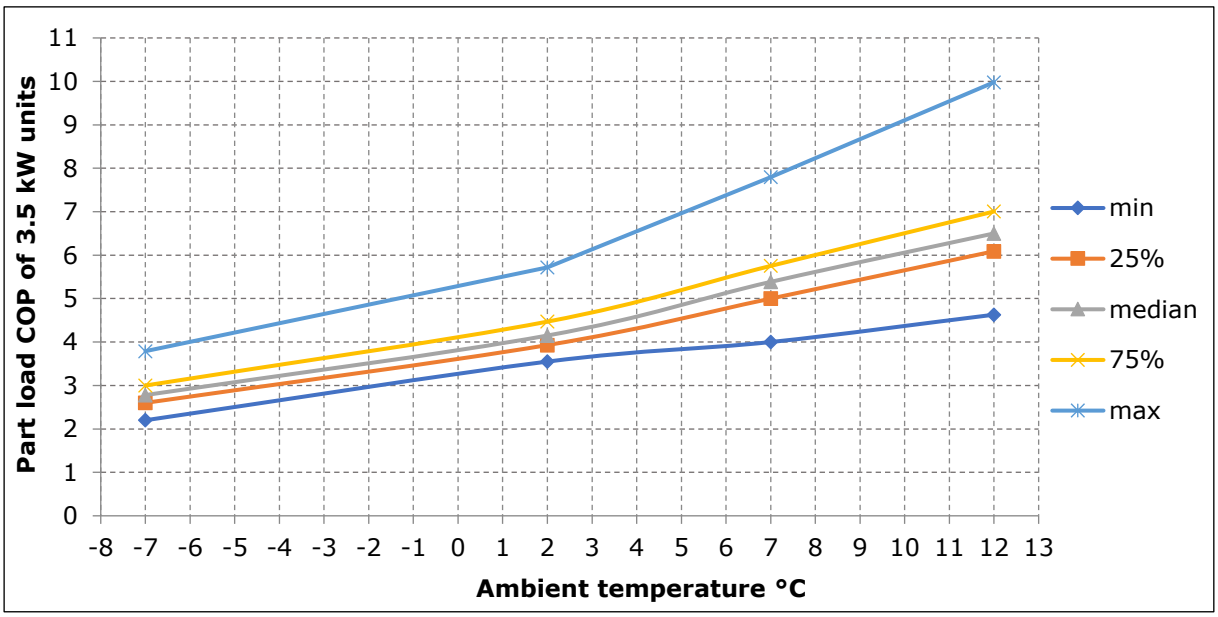

Figure 6: Part load COP of 3.5 kW units distribution in heating mode, source unknown manufacturers part of Eurovent Certita Certification

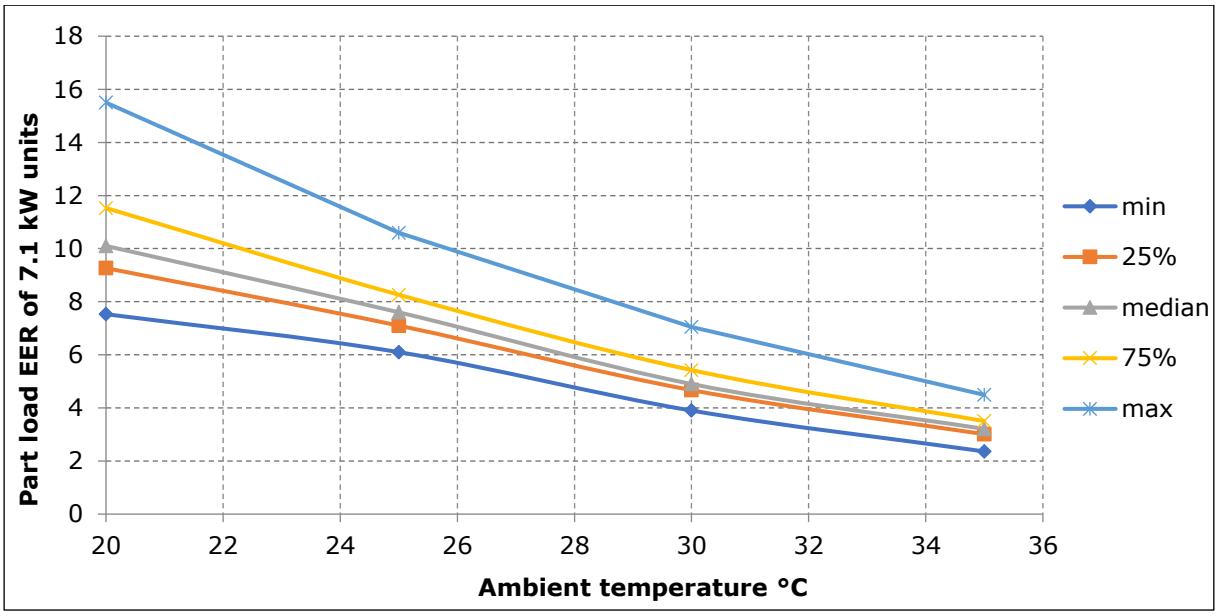

Figure 7: Part load EER of 7.1 kW units distribution in heating mode, source unknown manufacturers part of Eurovent Certita Certification

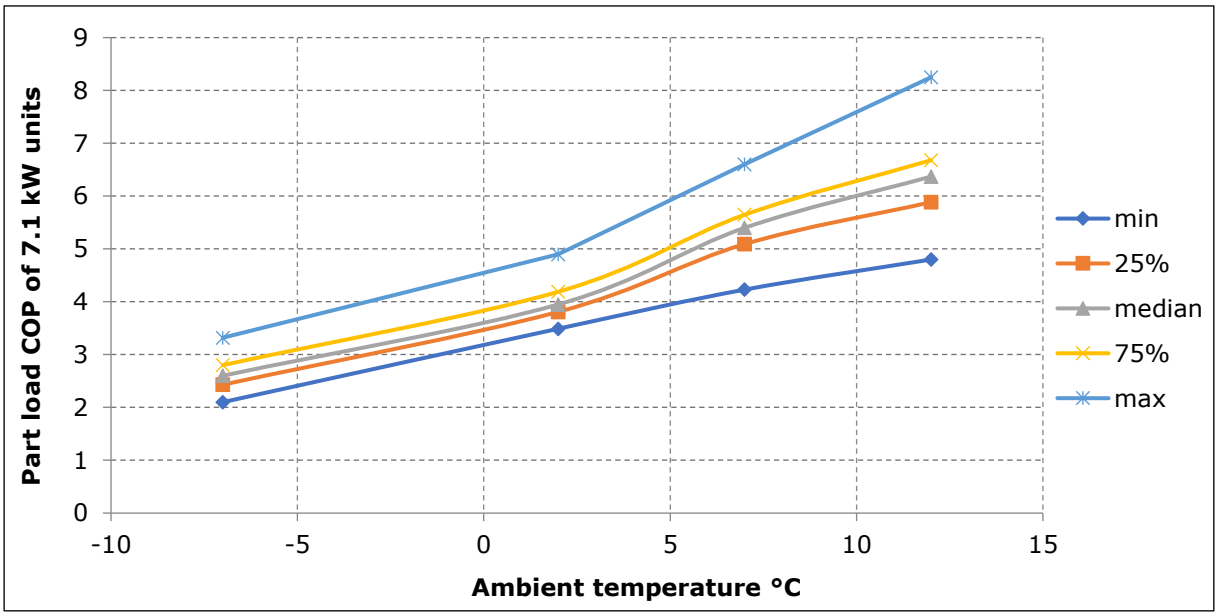

Figure 8: Part load COP of 7.1 kW units distribution in heating mode, source unknown manufacturers part of Eurovent Certita Certification

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).

[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).

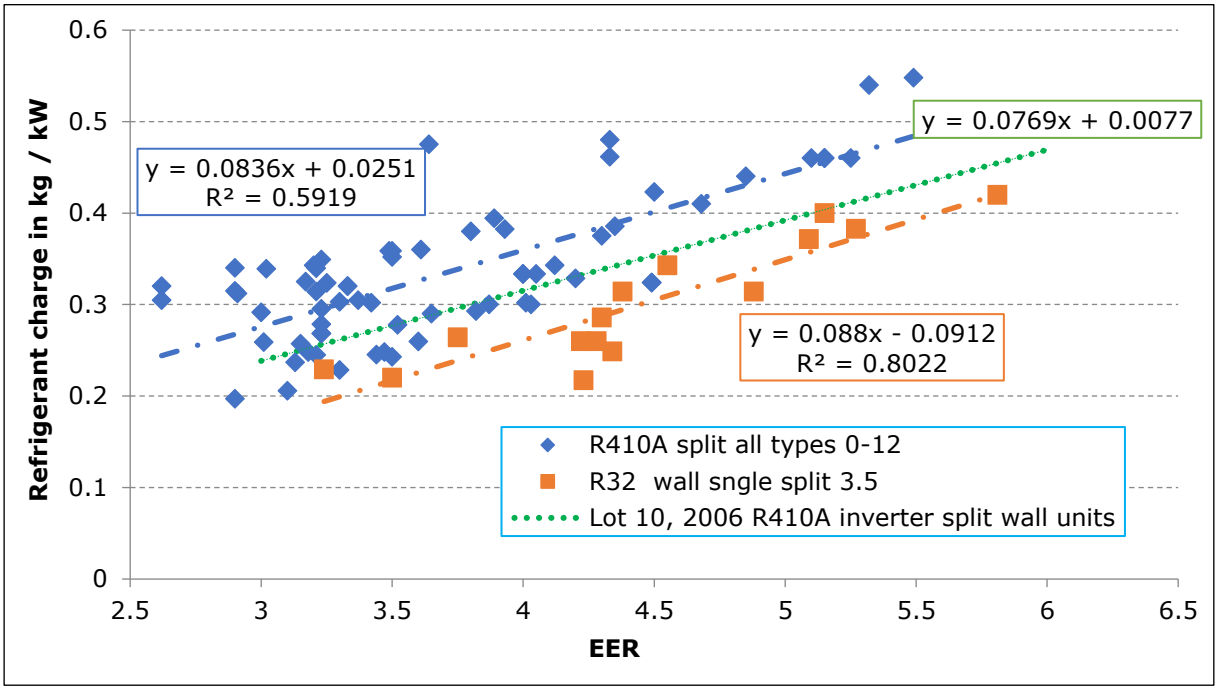

Figure 9 EER versus specific refrigerant charge in kg/kW (capacity and EER at T1 condition), 5 m piping length

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

[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.

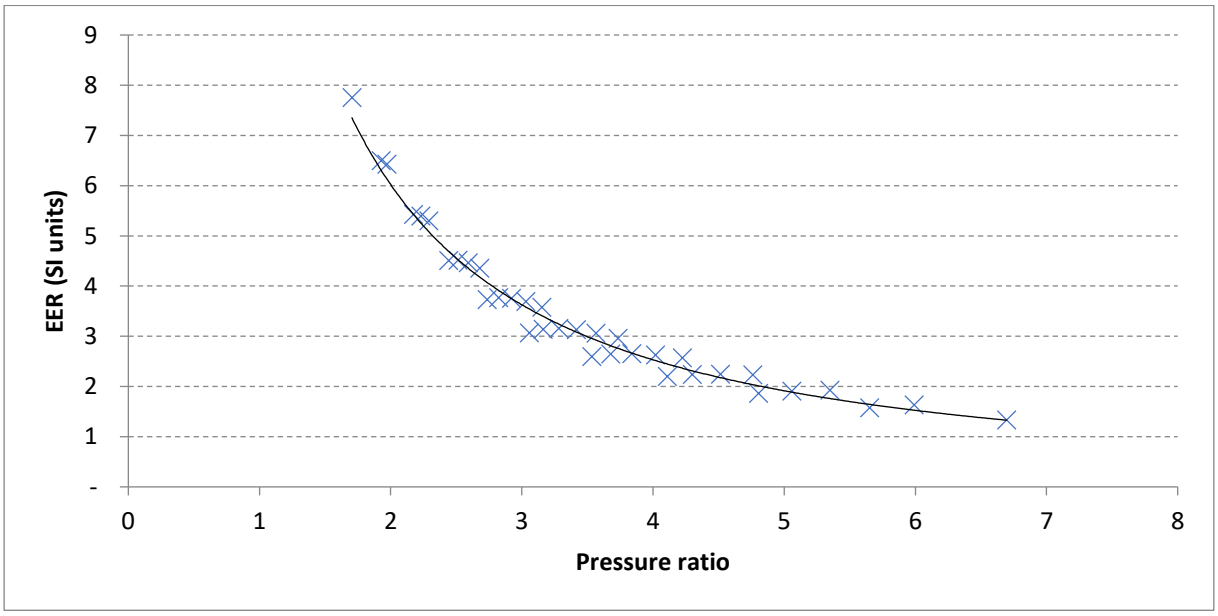

Figure 11: R410A single speed AC motor rotary compressor EER plotted against pressure ratio, source (Lei et al, 2013)[7]

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.

[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

[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

[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

[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

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

[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

[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.

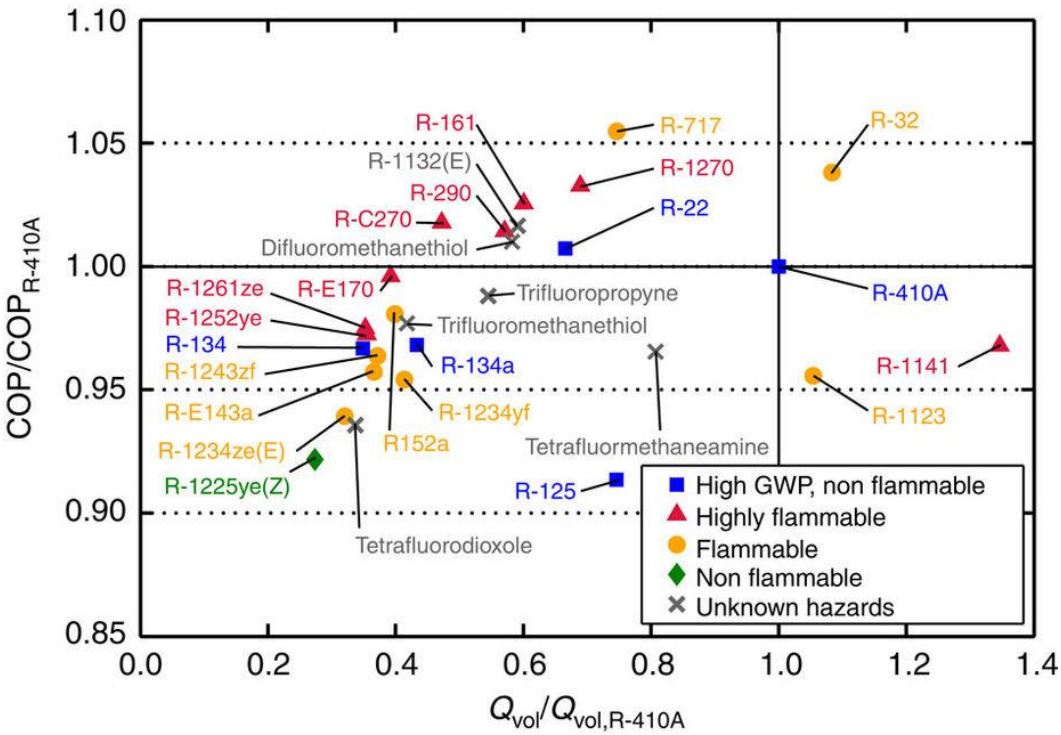

Figure 12: Coefficient of performance and volumetric capacity of selected low-global-warming-potential fluids[24]

[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.

[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.

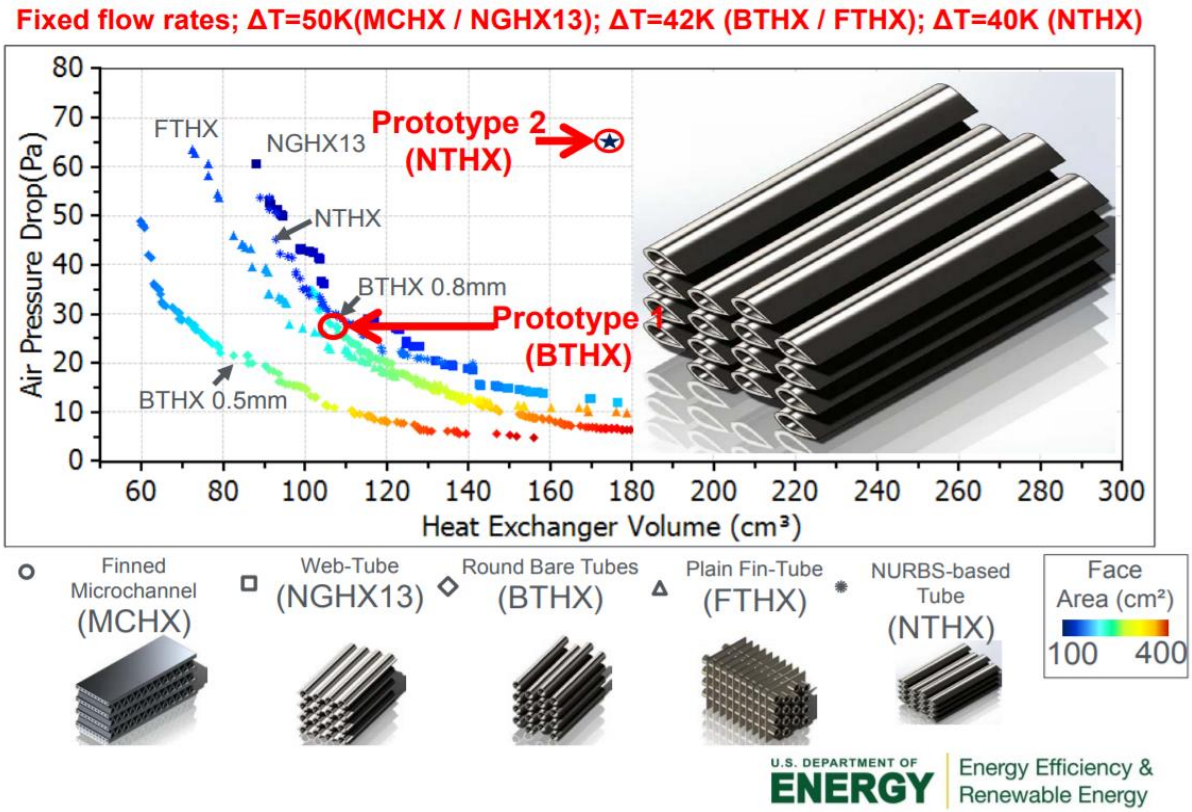

Figure 13: Miniaturized Air -to-Refrigerant Heat Exchangers research project findings illustration[28]

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

[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.

[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.

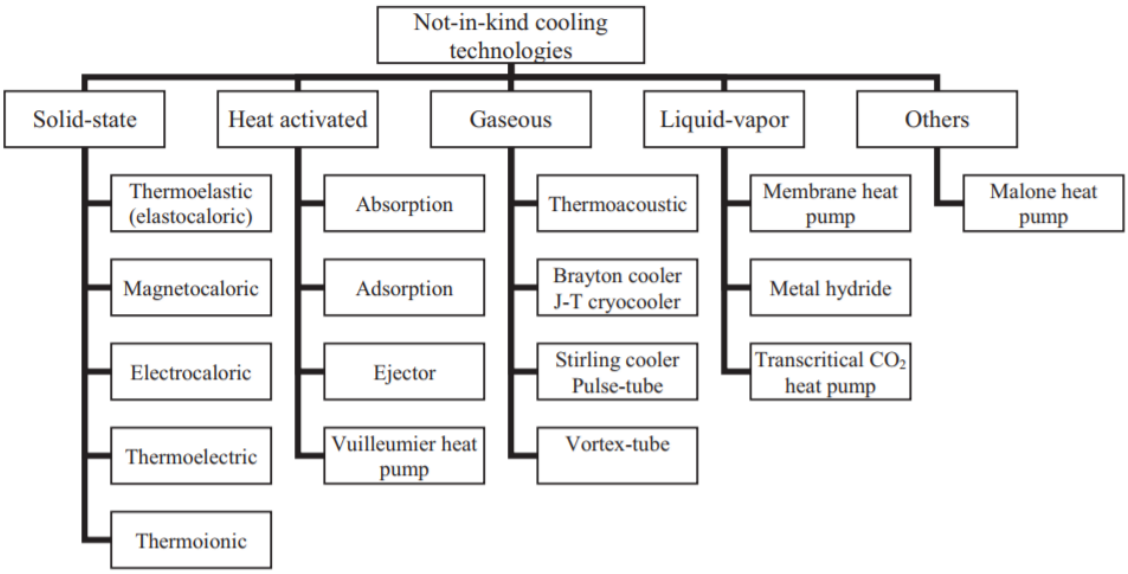

Figure 14: Alternative cooling technologies identified in (Goetzler et al., 2014)

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.

[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.

[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.

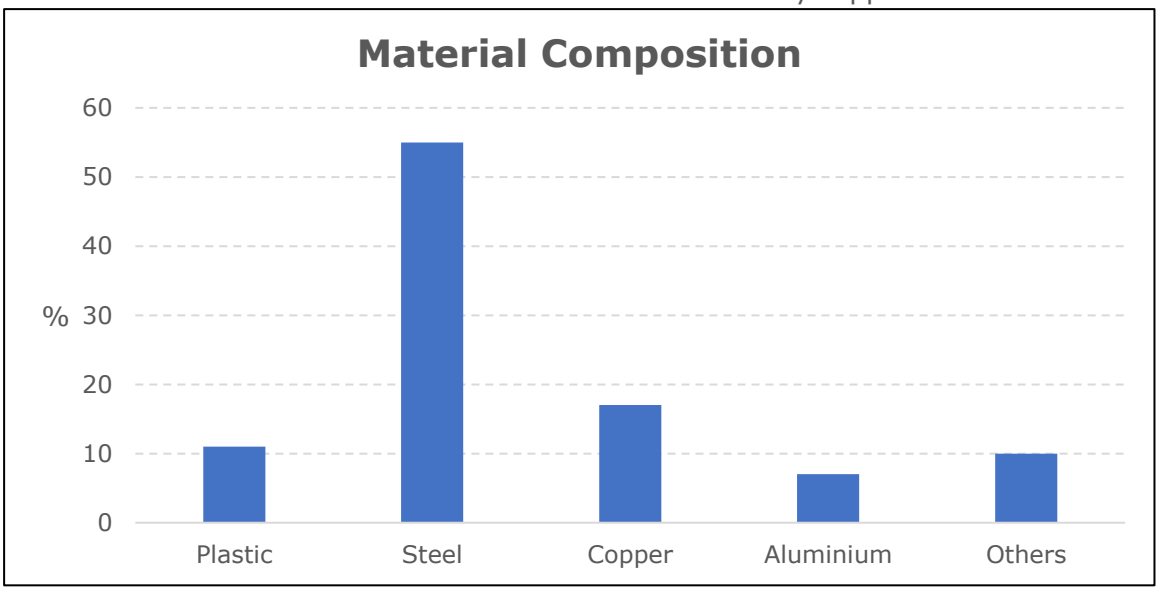

Figure 15: Material composition of fixed air conditioners based on information from a manufacturer's homepage.

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:

[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].

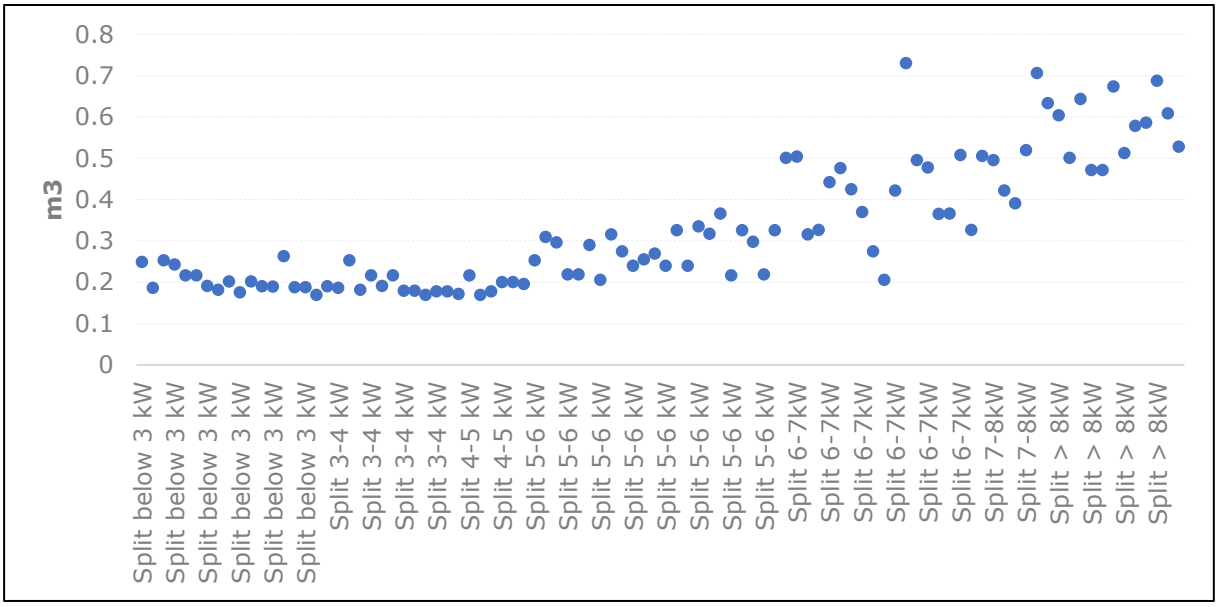

Figure 16: Combined size of indoor and outdoor unit

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

[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:

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.

[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.

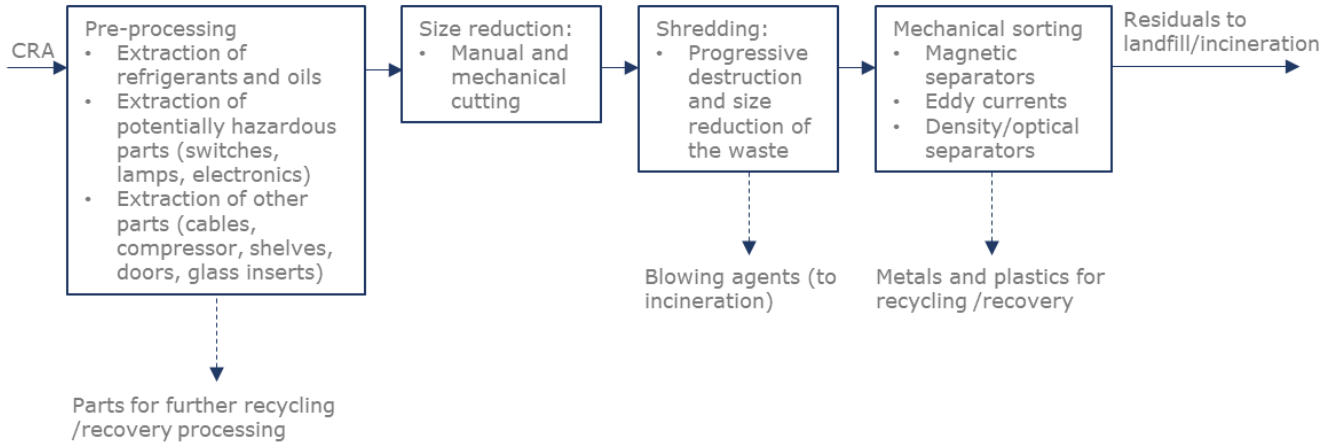

Figure 17: The waste process flow for commercial refrigerants appliances

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.

[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

[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

[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

[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:

[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

[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

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

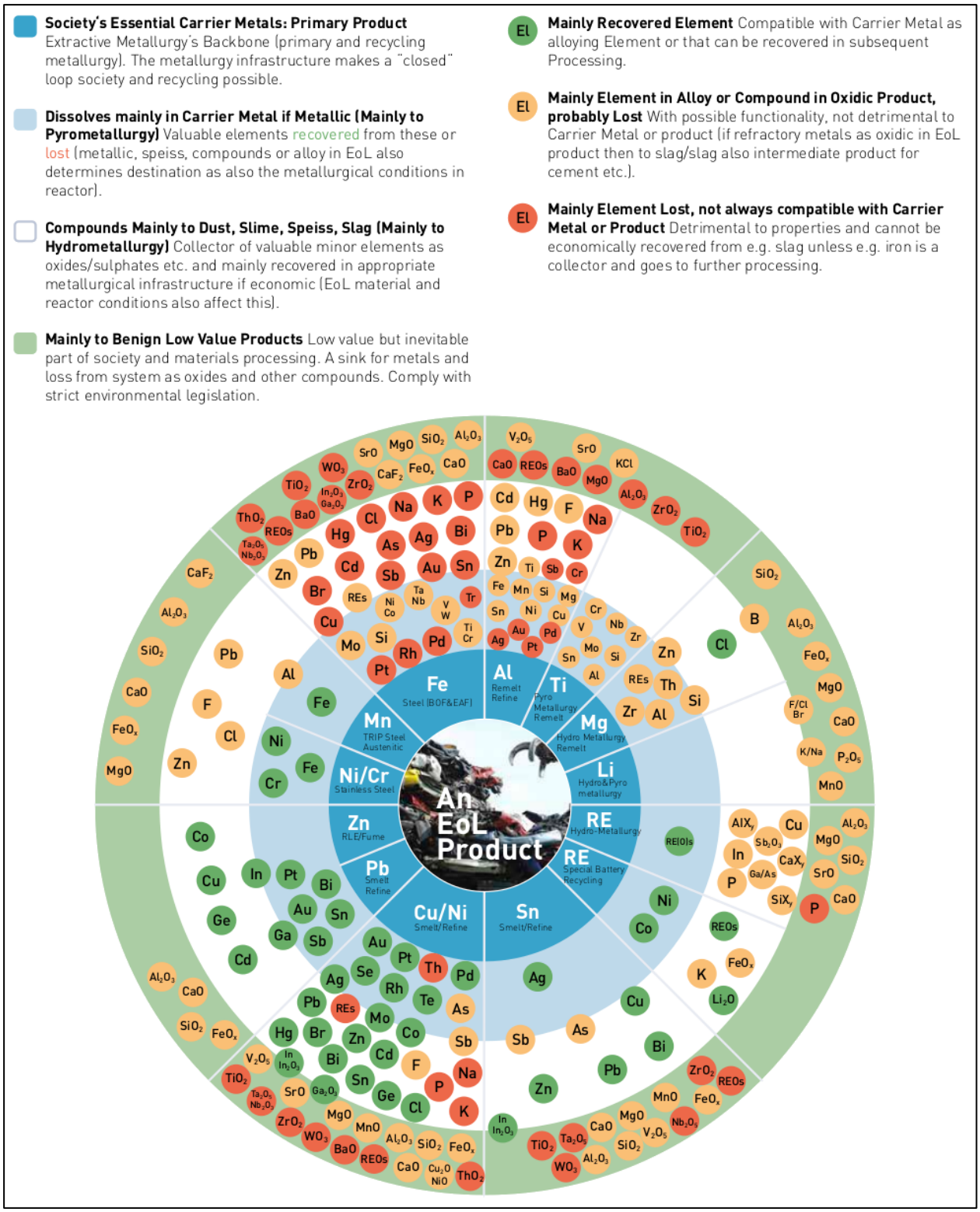

Figure 18: Metal wheel. The metal wheel shows which resources that can be recovered at the different types of smelters[57]

[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

[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.

[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.

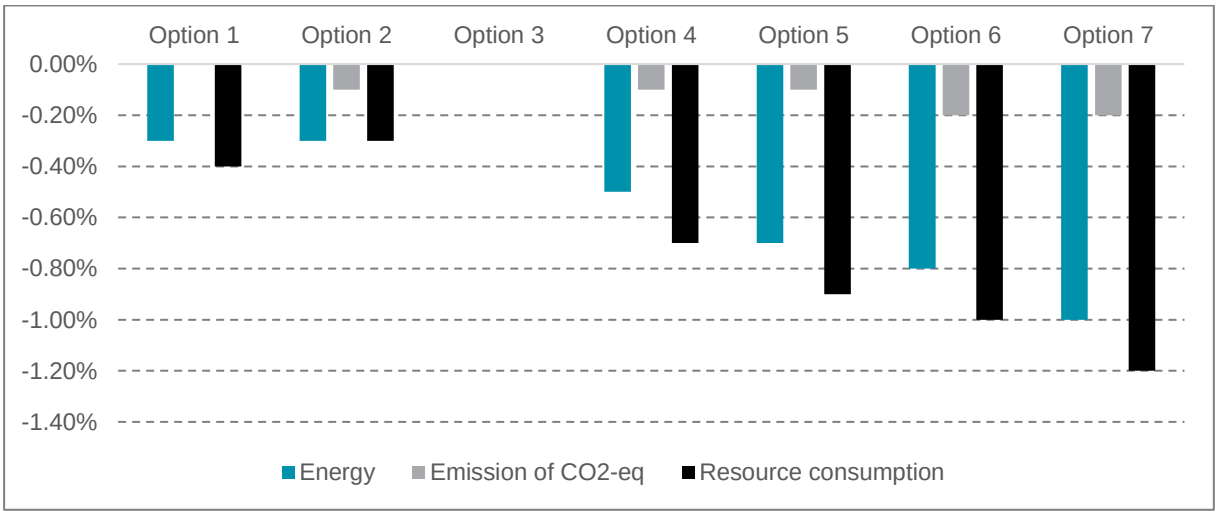

Figure 19: Impact of all options towards increased reparability

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.

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 5 report

ENVIRONMENT & ECONOMICS

Final version

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Abbreviations

AC	Alternating current
BAT	Best Available Technology
BAU	Business as Usual
BC	Base case
BNAT	Best Not Yet Available Technology
COP	Coefficient of Performance for air conditioners in heating mode
EER	Energy Efficiency Ratio for air conditioners in cooling mode
EoL	End-of-life
Eq	Equivalents
GWP	Global warming potential
LCA	Life cycle assessment
LCC	Life cycle costs
LLCC	Least Life Cycle Costs
PCB	Printed circuit board
PWF	Present worth factor
SCOP	Seasonal Coefficient of Performance for air conditioners, heating mode
SEER	Seasonal Energy Efficiency Ratio for air conditioners, cooling mode
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.

5 Introduction to Task 5

Task 5 follows the MEErP methodology and aims to identify base cases based on findings from previously performed tasks. The base cases are used to quantify the environmental impacts and the life cycle costs of air conditioners and comfort fans. The base cases will also be used in later tasks to identify the improvement potential. Task 5 includes the following sections:

1. Product-specific inputs: Base cases based on previous tasks.

2. Base-Case Environmental Impact Assessment: Using the EcoReport tool to calculate emission/resource categories

3. Base-Case Life Cycle Costs for consumer: Life Cycle Costs (LCC) of air conditioners and comfort fans

4. EU Totals: Aggregated environmental impacts and Life Cycle Costs

5. Conclusions and recommendations

5.1 Product-specific inputs

In this task, three base cases are defined based on the data and information from Task 4:

- Base case 1: for fixed reversible air conditioners < 6 kW, 3.5 kW wall single split
- Base case 2: for fixed reversible air in range of 6 – 12 kW, 7.1 kW wall single split
- Base case 3: for portable air conditioner, 2.6 kW single duct

The final EcoReport Tool inputs for the base cases built through the work of tasks 1 – 4 are presented in this task.

Task 1 analyses show the relevance of extending the scope to include ventilation exhaust air conditioners in the regulation, however it is not identified as a separate base case due to lack of reliable data for sales and performance.

Base-Case Environmental Impact Assessment and Base-Case Life Cycle Costs for the consumers have been established per base case and aggregated at EU level.

This task summarises the data, assess the environmental and economic impact of the products in scope, and list improvement potentials and barriers for use in Tasks 6-7

Regarding comfort fans no changes have been suggested in the previous tasks, so the base cases and impacts of the base cases are unchanged since the preparatory study. The comfort fans will therefore not be further assessed.

5.1.1 Test standard for performance and consumption data

The most appropriate test standard for performance and consumption have been identified in Task 1.

For other than single duct, double duct and evaporatively cooled air conditioners, the standard EN14825 defines the calculation and testing points to calculate the seasonal energy efficiency (SEER) and seasonal coefficient of performance (SCOP) and completes where required measurement methods defined in standard EN14511.This means for the two base cases of split air conditioners, **EN14825** can be used for measuring performance and consumption data, while keeping the equivalent full load hours in Regulation No 206/2012.

EN14511 defines the rated performance and measurement methods to be used for all air conditioners in cooling and in heating mode, with the exception of air conditioners with evaporatively-cooled condensers whose ratings are defined in EN15218 standard. This means for the single duct portable air conditioner base case, **EN14511** standard, complemented by the proposed equivalent full load hours (Task 3) of 350 hours as well as thermostat off and standby hours and powers, can be used for performance and consumption data.

For ventilation exhaust air conditioners, although it is not established as a separate base case, it is already identified in Task 1 that standard EN14825 for part load can be used for measuring performance and consumption.

5.1.2 Economic data

This subsection presents the EU-27 annual sales and estimated stock in units, purchase price, the installation costs, repair and maintenance costs, unitary rates for energy, discount, inflation, interest and escalation rates to be applied, product service life. These values have been derived and presented in task 2 and task 4.

Table 1: EU 28 annual sales and estimated stock of all air conditioners in scope

	2010	2015	2020	2025	2030	2035	2040	2045	2050
EU28 annual sales, (000) units									
BC 1	2385	1954	2528	3059	3541	4095	4827	5537	6415
BC 2	1482	1473	1648	1898	2142	2403	2711	3022	3381
BC 3	583	557	446	460	474	488	503	518	534
Total	4450	3984	4622	5418	6156	6986	8041	9077	10330
EU28 estimated stock, million units									
BC 1	29.6	29.7	25.5	28.7	34.6	25.8	25.5	56.0	64.9
BC 2	17.7	17.8	16.3	18.1	20.9	16.4	16.3	30.6	34.5
BC 3	4.3	4.4	4.3	4.5	4.6	4.8	4.9	5.0	5.2
Total	51.6	51.9	46.1	51.3	60.1	69.6	80.1	91.7	104.5

EU 28 annual sales and total estimated stock for all air conditioners are presented in Table 1 . Stock estimated for portable air conditioners in 2015 is 4.44 million units, 29.7 million units for > 6 kW split air conditioners, 17.8 million units for 6 – 12 kW split air conditioners. Annual sales for base case 1 and 2 are presented in Table 2 and were already described in Task 4. Base case 3 portable air conditioner annual sales are derived with annual sales for all air conditioners in 2015 and subtracted the annual sales for base case 1 and 2 in 2015.

Table 2: Repartition of split product per class in number and capacity in 2015

	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

Product prices for the base cases have been derived in Task 2 and corrected to account for the higher efficiency of base cases in task 4. As seen in Task 2, repair and maintenance costs is derived as 4%/year of the initial investments and in a life time of 12 years for fixed split units. A lifetime of 10 years for portable unit is applied, and no repair and maintenance costs assumed.

The commission have decided to use data from PRIMES[1], and prices and projection are presented in Task 2. The residential electricity rate is 0.204 euro/kWh for households and 0.171 euro/kWh for service sector based on the electricity price in 2021. The distribution of air conditioners installed in households and the service sector are used to calculate the average electricity rate for the different base cases. The distribution of users is:

- For BC 1, the ratio is: 71% households and 29% service premises
  - Resulting average electricity price: 0.195 euro/kWh
- For BC 2, the ratio is: 46% households and 54% service premises
  - Resulting average electricity price: 0.187 euro/kWh
- For BC 3, the ratio is: 79% households and 21% service premises
  - Resulting average electricity price: 0.198 euro/kWh

The distribution between residential and service sectors for air conditioners stock are described in Task 2.

In EcoReport Tool, there is an input for the ratio between average efficiency of the stock and average efficiency of the new sales, this is to account for the difference of average efficiency of the stock and the higher efficiency of the new sales, so the energy consumption calculated would not be underestimated. Since the efficiency is found to be different for residential and service sectors, the ratio is derived using the residential and service sector distribution presented above:

- For BC 1, the average new sales SEER in 2015 is 6.05. The average stock efficiency in 2011 is 3.2 for the residential sector and 2.9 for the service sector, resulting in 3.113 (3.2 x 71% + 2.9 x 29%). SCOP and SEER ratio has not changed since preparatory study so resulting SCOP for new sales 2015 is 5.35 and SCOP for stock 2011 is 2.413.
- For BC 2, the average SEER in 2015 is 5.75. The average stock efficiency in 2011 is 2.9 for the residential sector and 2.5 for the service sector, resulting in 2.684 (2.9 x 46% + 2.5 x 54%). SCOP and SEER ratio has not changed since preparatory study so resulting SCOP for new sales 2015 is 5.15 and SCOP for stock 2011 is 2.084.

[1] PRIMES 2016

- For BC 3, the average EER 2015 is 2.6. The average stock efficiency 2011 is 2.3 for the residential sector and 2.2 for the service sector, resulting in 2.279 (2.3 x 79% + 2.2 x 21%).

The average stock efficiency for 2011 should be then corrected with a consumption ratio[2] of new sales and stock, as it is assumed that stock is used for 30% heating hours and new sales are used for 50% heating hours:

  - For BC1, resulting SEER ratio: 0.781, resulting SCOP ratio: 0.685
  - For BC2, resulting SEER ratio: 0.787, resulting SCOP ratio: 0.683
  - Resulting EER ratio for BC3: 0.877

Note the ratio for BC 1 and BC 2 split air conditioners is low, because the regulation led to the change from single speed compressor and fan to DC inverter compressor and fan.

All economic inputs for EcoReport Tool are presented in Table 3.

Table 3: Input economic data for EcoReport tool

Description	Unit	BC 1	BC 2	BC 3
Product Life	years	12	12	10
Annual sales	mln. Units/year	2.468	0.959	0.557
EU Stock	mln. Units	29.7	17.8	4.44
Product price	Euro/unit	743	1992	386
Installation/acquisition costs (if any)	Euro/ unit	800	800	N/A
Electricity rate	Euro/kWh	0.195	0.187	0.198
Repair & maintenance costs	Euro/ unit	741	1310	N/A
Discount rate (interest minus inflation)	%	4%	4%	4%
Escalation rate (project annual growth of running costs)	%	1%	1%	1%
Present Worth Factor (PWF)	(years)	9.97	9.97	8.54
Ratio efficiency STOCK: efficiency NEW, in Use Phase		0.733	0.735	0.877

5.1.3 Annual resources consumption (energy)

The annual energy consumption in the use phase are calculated for each of the base cases and presented in the following section. Based on inputs from previous tasks it is possible to calculate the energy consumption in the use phase for fixed air conditioners and portable air conditioners.

The energy consumption for fixed air conditioners can be calculated based on the values presented in Table 4. The table presents the full load hours in heating and cooling mode and some main characteristics such as capacity, SEER and SCOP.

[2] Consumption ration is found as follows: (Pc*Hc/SEER2011+Ph*0.5*Hh/SCOP2011) / (Pc*Hc/SEER2016+Ph*0.3*Hh/SCOP2016)

Table 4: An extract of information from task 3 and 4 to calculate the energy consumption

Type	Reversible split [0-6kW]	Reversible split [6-12kW]
Pdesignc kW	3.5 kW	7.1 kW
SEER	6	5.8
Hours (cooling full load)	350	350
Pdesignh kW	3.1 kW (-7°C)	6 kW (-10°C)
SCOP	4	4
Hours (heating)	1400	1400

The full load hours are essential to evaluate the energy consumption of products as the energy consumption of the unit is proportional to the equivalent full load hours.

The equivalent full load hours for cooling can be established by weighting the simulated cooling load by country (in kWh/m^2) by the share of the total installed cooling capacity (in % of kW) per sector and per country (stock weighted average). The equivalent full load hours are 350 hours for cooling and are discussed in task 3, section 3.1.2.3.

The equivalent full load hours for heating are established upon heating load and sizing estimates for the 3 climates which are warmer, average, and colder. Previously it was decided to use the heating needs estimated in the preparatory study on space heating. The rationale is that reversible air conditioners installed for heating do compete with other heating means and should then be compared with the same heating loads. The equivalent full load hours are 1400 hours for heating and are discussed in task 3, section 3.1.3.2. Though, the impact of air conditioners should be calculated based on real-life conditions where the hours in heating mode on average are lower than 1400 hours.

In Commission decision 2013/114/EU, it is supposed that 10 % of the reversible air to air conditioners are used for heating in warm climates, 40 % in average climates and 100 % in Northern climates. This amounts to about 25 % (weighting by 2015 stock numbers and 28 % weighting by capacity) reversible units used for heating. This is close to the value declared for Italy for 2015 in the Energy Efficiency Directive[3]. Furthermore, in the Impact assessment for Regulations (EU) 626/2011 and 206/2012[4], a value of 33 % was assumed.

However, stakeholders of the current review study suggest that the present rates of reversible units used for heating are higher, with residential rates between 20 % (only heating) and 60 % (used in addition, partial replacement or replacement of an existing central systems) and commercial rates around 85 %. Using 20 % for residential and 85 % for services, this leads to about 50 % reversibility use with 2015 sales.

Hence, it is assumed that only 30 % of the fixed air conditioners currently are used for heating purposes, but this number is expected to increase to 50 % from now and over the next 12 years. This means that the hours of use in heating mode are corrected to 50 % of the full load hours presented in Table 4 for new units and 30 % for the EU stock.

The average capacities are estimated based on the sales/stock model. This model is built on the 0-5 kW and 5-12 kW capacity intervals. These numbers are then adjusted to fit the capacity categories in the regulation which are 0-6 kW and 6-12 kW. This is done by shifting

[3] http://ec.europa.eu/eurostat/web/energy/data/shares
[4] Impact Assessment of Commission Regulation (EU) No 206/2012 of 6 March 2012 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for air conditioners and comfort fans (OJ L 72, 10.3.2012, p. 7)

about 15 % of total sales from "> 5 kW" class to "< 5 kW" class as this gives comparable weighted average kW to BSRIA sales data. The BSRIA data indicates weighted average capacities of 3.8 kW in the 0-6 kW interval and of 7.8 kW in the 6-12 kW interval. For air conditioners equal to or below 6 kW the most common type of air conditioner is the 3.5 kW according to the Eurovent. This value is adopted as the reference value. Above 6 kW the most common product capacities are 6.8, 7.1 and 10 kW. The 7.1 kW model is the closest to the weighted average value and is adopted as the reference value. The cooling capacities of the base cases for fixed air conditioners are discussed in Task 4 section 4.1.1.1.

The heating capacity, SEER and SCOP are then derived from the base cases as the median product characteristics of products around the base case (cooling) capacities in the ECC database.

- Reversible 3.5 kW wall single split base case: SEER 6.00, SCOP 4.0, Pdesignh= 3.1 kW
- Reversible 7.1 kW wall single split base case: SEER 5.80, SCOP 4.0, Pdesignh= 5.6 kW

These values are extracted from Task 4 section 4.1.1.2.

The data presented in Table 4 can then be used to calculate the annual energy consumption by the following equation:

$$Energy\ consumption_{annual} = \frac{Pdesignc \times H_{CE}}{SEER} + \frac{Pdesignh \times H_{HE} \times 50\ \%}{SCOP}$$

Where:

- *Pdesignc = the maximum building cooling needs in kW, which is equal to the maximum cooling capacity of the unit*
- *H_{CE}: the equivalent number of full load cooling hours*
- *Pdesignh = the maximum building heating needs in kW, which is equal to the maximum heating capacity of the unit*
- *H_{CE}: the equivalent number of full load heating hours*

The annual energy consumption for fixed split air conditioners equal to or below 6 kW (BC1) is then calculated to:

$$Energy\ consumption_{annual} = \frac{3.5\ kW \times 350h}{6} \times \frac{3.1\ kW \times 1400h\ \times 50\ \%}{4.1} = 747\ kWh$$

The annual energy consumption for fixed split air conditioners above 6 kW (BC 2) is then calculated to:

$$Energy\ consumption_{annual} = \frac{7.1\ kW \times 350h}{5.8} + \frac{6\ kW \times 1400h\ \times 50\ \%}{4} = 1478\ kWh$$

These values are used in the EcoReport tool.

The energy consumption for portable air conditioners (BC 3) can be calculated based on the values presented in Table 5. The table presents the hours in cooling (full load), thermostat-off mode and in standby and the energy consumption in these modes. The

energy consumption in cooling mode is determined by the cooling capacity and the EER which also are presented in the table below.

Table 5: An extract of information from task 3 and 4 to calculate the energy consumption

Type	Portable
Cooling capacity kW	2.6 kW
EER	2.65

The hours of use are established by using Regulation (EU) 206/2012 and taking the cooling season (above 23 °C), which leads to 1289 hours. As for fixed installations, they are supposed to be used only 10 hours over 24, or about 58 % of the time, which leads to 750 hours in standby mode and leaves 549 hours for hours when the unit is on.

Using these figures and the standard SEERon simulation presented in Task 3, section 3.1.5.4 the cooling capacity is 2.6 kW unit with EER 2.65 (air flow at condenser of 520 m^3/h), which leads to the following figures:

- cooling energy supplied: 365 kWh/a

- electricity consumption (cooling mode only): 172 kWh/a

It is clear that integrating standby power consumption makes no difference; with 1 W power, standby power consumption is 0.75 kWh or 0.4 % or yearly electricity consumption for cooling. So further progress on standby power consumption cannot be expected from including standby in seasonal performance metrics.

These values are used in the EcoReport tool.

The lifetime of fixed and portable air conditioners is also of great importance regarding the energy consumption over the lifetime as it defines how many years air conditioners with the current efficiency are in use. The average lifetime of air conditioners for the three base cases are presented in Table 3. The technical product life is described in task 3.

5.1.4 Resources and End-of-Life

Besides the energy consumption during the use phase, the materials in the product itself contain a considerable amount of embedded energy e.g. calorific value but also the energy used to mine the raw materials and produce the finished materials. Some of this energy can be recovered at End-of-Life when products are either reused, recycled, or burned. When products are landfilled this energy is lost. It is therefore important to describe the most likely End-of-Life scenario to quantify the impact of the material consumption.

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 6.

Table 6: The weight to size ratio of air conditioners (base cases)

	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable
Size (kW)	3.5	7.1	2.6
Weight (kg)	41	96	32
Weight to size ratio (kg/kW)	11.8	13.5	12.3

The material composition of air conditioners is expected to be unchanged since the preparatory study, therefore the same assumptions are adopted to the current review study. The assumed average material composition of air conditioners is presented Table 7 and are discussed in detail in Task 4.

Table 7: Average material composition of air conditioners

Material Type	Monosplit
	Average %
Bulk Plastics	16
TecPlastics	2
Ferrous	45
Non-ferrous	24
Coating	0
Electronics	3
Misc.	11

The average material composition and weight of the different air conditioners are used to calculate the material composition of the base cases. Note that the values in Table 7 for the non-ferrous are divided into a copper and aluminium fraction. It is estimated that air conditioners contain of 17 % copper and 7 % aluminium.
Based on these inputs the material composition of each of the base cases are calculated in Table 8.

Table 8: The calculated material composition

Description	Share	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable	Material group	Material
		Weight (g)				
Plastics	16%	6355	14880	4960	1-BlkPlastics	4 -PP
Plastics	2%	615	1440	480	2-TecPlastics	12 -PA 6
Ferrous metals	45%	18450	43200	14400	3-Ferro	24 -Cast iron
Non-ferrous metals	17%	6970	16320	5440	4-Non-ferro	31 -Cu tube/sheet
Non-ferrous metals	7%	2870	6720	2240	4-Non-ferro	27 -Al sheet/extrusion
Coatings	0%	0	0	0	5-Coating	
Electronics	3%	1230	2880	960	6-Electronics	98 -controller board
Various other materials	11%	4510	10560	3520	7-Misc.	
Total		**41**	**96**	**32**		

It should be noted that the weight of the refrigerant in the base cases is included in the category "various other materials", however EcoReport Tool cannot properly calculate the impacts of refrigerants (or the impacts of leakage), therefore the impact of refrigerant and

leakage are then calculated separately and incorporated back to the EcoReport result in this review study. See more details about the method in Annex 1: Impact of refrigerant.

The primary scrap production is set to 25 % which is the default value in the EcoReport tool.

The distribution phase is included in the calculations but have a very limited impact on the overall analysis. The transport volume is previously discussed in Task 4, and the volume of the package for the three base cases are:

- Fixed reversible split [0-6kW]: 0.25 m^2
- Fixed reversible split [6-12kW]: 0.50 m^2
- Portable: 0.25 m^2

These values have been used for EcoReport Tool.

The recycling rate depends on how the air conditioners are treated End-of-Life. As presented in Task 4, the collection rate for EU was just below 40 % in 2014 which could pose a challenge for the resource efficiency. After collection, the air conditioners are handled together with other appliances containing refrigerants such as refrigerators. These appliances are treated at specialised shredders which can handle the refrigerants and are discussed in Task 4.4.1.
The effectiveness or recycling rate of the shredder (the share of recovered, recycled, and reused materials) is based on the default values in EcoReport tool[5] but updated regarding plastics[6]. The values used in the current study are presented in Table 9.

Table 9: 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 default values in EcoReport tool[7]*

The consumption on critical raw materials are mainly focusing on copper in the heat exchanger and the gold in the printed circuit boards (PCBs). The copper is included in the calculated material composition in Table 8 and in the recycling rates in Table 9. The amount of e.g. gold in the printed circuit boards is included in the "electronics" fraction. Based in

[5] http://ec.europa.eu/growth/industry/sustainability/ecodesign_da
[6] Plastic Europe, Available at: http://www.plasticseurope.org/documents/document/20161014113313-plastics_the_facts_2016_final_version.pdf
[7] Plastic Europe, Available at: http://www.plasticseurope.org/documents/document/20161014113313-plastics_the_facts_2016_final_version.pdf

stakeholder inputs[8] there are 2 printed circuits boards in an average air conditioner and has a combined weight of 428 grams in air conditioners below 6 kW. For large air conditioners the combined weight of the PCBs amounts to 1392 grams. No information on portable air conditioners was provided so it is assumed that the weight of PCBs is 50 % of the PCBs in small air conditioners.

The average composition of a printed circuit board is assumed as follows[9]:

- 70% - non-metallic e.g. glass-reinforced polymer
- 16% - Copper
- 4% - Solder (containing tin)
- 3% - iron, ferrite (from transformer cores)
- 2% - Nickel
- 0.05% - Silver
- 0.03% - Gold
- 0.01% - Palladium
- <0.01% - other (bismuth, antimony, tantalum etc.)

This means that air conditioners contain gold in the range of 0.06 grams to 0.4 grams which originates from the printed circuit boards. The grade[10] of printed circuit boards in air conditioners can be discussed, but the complexity of the air conditioners is increasing which imposes higher grades of printed circuit boards to be used. In general, there are many different grades for PCBs for different electronic or electrical products depending on the level of complexity of the purposes and tasks.

The environmental impacts and commodity prices of gold and copper are:

- Gold – 250 GJ/kg, 22500 CO_2-eq/kg[11] and 35150 euro/kg[12]
- Copper – 50.9 MJ/kg, 2.7 CO_2-eq/kg[13] and 5.9 euro/kg[14]

The recycling rate of copper and electronics are presented in Table 9 and is estimated to 94 % for non-ferrous (copper) and 50% for electronics (including the gold in printed circuit boards). However, if printed circuit boards are removed before shredding the recycling rate of gold is assumed to be above 90 %. According to stakeholders the design of air conditioners is already in favour of easy removal of printed circuit boards, as they consider southern EU countries where manual labour cost is low, the air conditioners with faulty PCBs would be repaired and therefore the PCBs need to be easily accessible for the repairer.

5.2 Base-Case Environmental Impact Assessment

The impacts of the three base cases are presented and discussed in this section. The following impacts are generated by the EcoReport tool and based on the data inputs previous presented:

[8] Data collection questionaire on resource efficiency from stakeholders, November 2017
[9] http://www.wrap.org.uk/sites/files/wrap/Techniques%20for%20recovering%20printed%20circuit%20boards%2C%20final.pdf
[10] The grade of PCBs is dependent on the amount of precious metals (e.g. gold and silver), which can vary between the category of WEEE and its age.
[11] http://ec.europa.eu/environment/integration/research/newsalert/pdf/302na5_en.pdf
[12] Price assessed in November 2017 at: http://www.infomine.com/investment/metal-prices/gold/1-day-spot/
[13] EcoReport tool
[14] Price assessed in November 2017 at: http://www.infomine.com/investment/metal-prices/copper/1-year/

- Other Resources & Waste
    - Total Energy (MJ)
    - of which, electricity (MJ)
    - Water – process (litre)
    - Water – cooling (litre)
    - Waste, non-hazardous/ landfill (g)
    - Waste, hazardous/ incinerated (g)
- Emissions (air)
    - GWP100 (kg CO_2-eq.)
    - Acidification (g SO_2-eq.)
    - Volatile Organic Compounds (VOC) (g)
    - Persistent Organic Pollutants (ng i-Teq)
    - Heavy Metals (mg Ni eq.)
    - PAHs (mg Ni eq.)
    - Particulate Matter (g)
- Emissions (Water)
    - Heavy Metals (mg Hg/20)
    - Eutrophication (g PO_4)

All impacts are further divided in the different life phases of the units which are the material phase, manufacturing phase, distribution phase, use phase, disposal phase and the recycling phase. The different phases are shortly described below:

- **The material phase**: In this phase the weight of the materials is multiplied with the LCA Unit Indicators[15] so the impacts of using the different materials can be calculated.
- **The manufacturing phase**: The manufacturing phase describes the (OEM) manufacturing of metals and plastics materials. The specific weights per process are calculated automatically from the material phase.
- **The distribution phase**: This phase covers all distributing activities from OEM components to the final customer.
- **The use phase**: For the use phase, the average product life in years and annual energy consumption are multiplied together to calculate the energy consumption during the whole lifetime.
- **The disposal and recycling phase**: These phases deal with the impacts End-of-Life. In the recycling phase, the recycling of the different materials is credited, and a negative value can appear (due to avoiding the production of new materials).

In recent year, the dominant impact category has been CO2-emission due to an increased focus on global warming, therefore the energy consumption and Global Warming Potential (GWP) expressed in kg CO_2-eq in the different life phases for the base cases are presented in the below figures:

[15] see MEErP 2011 Methodology, Part 2

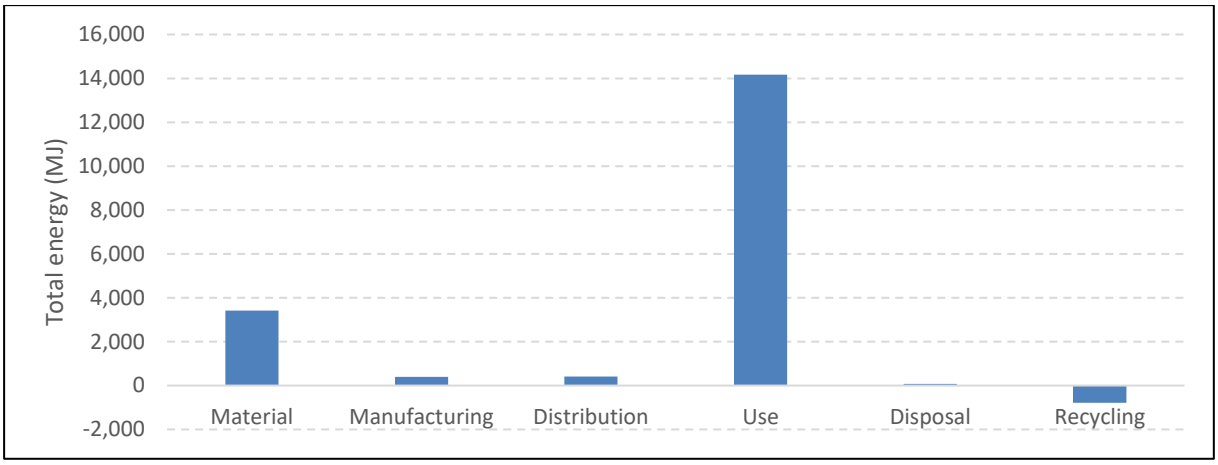

Figure 1: Total energy consumption BC 1 Reversible split [0-6kW]

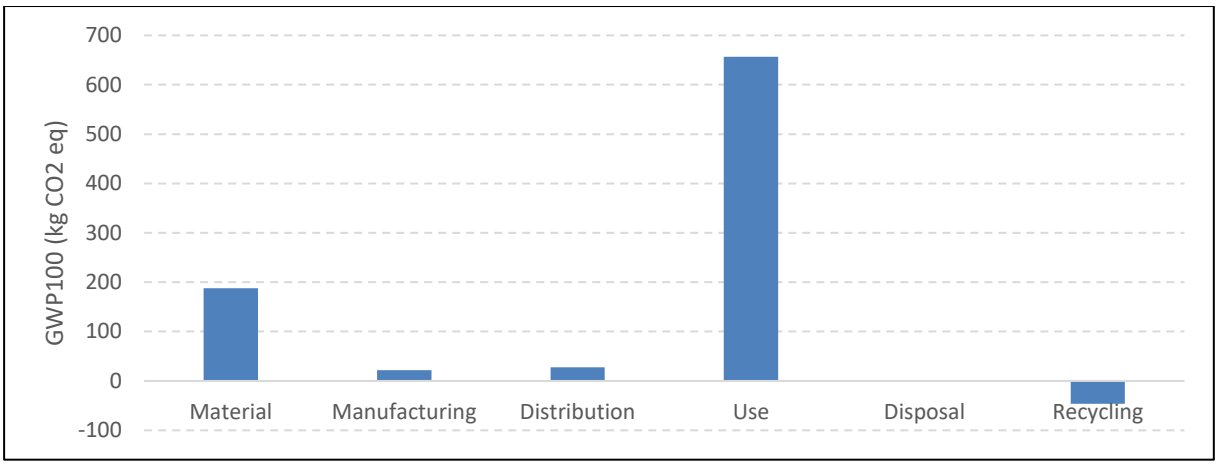

Figure 2: Global warming potential BC 1 Reversible split [0-6kW]

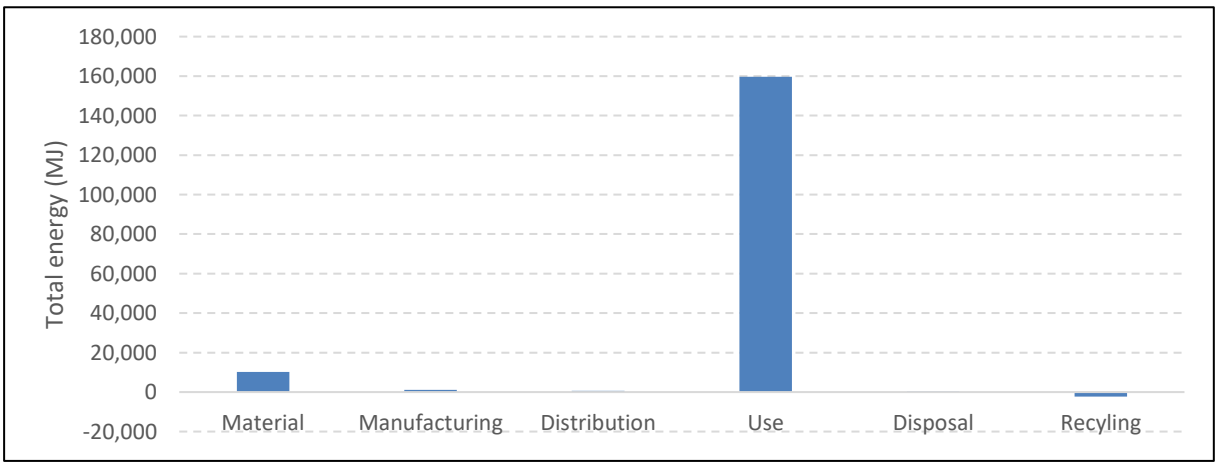

Figure 3: Total energy consumption – BC 2 Reversible split [6-12kW]

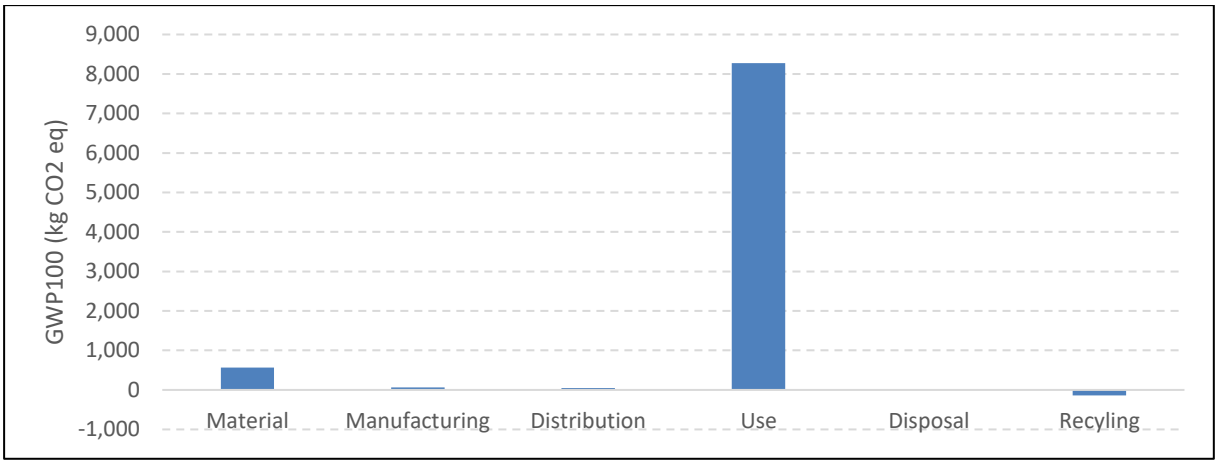

Figure 4: Global warming potential – BC 2 Reversible split [6-12kW]

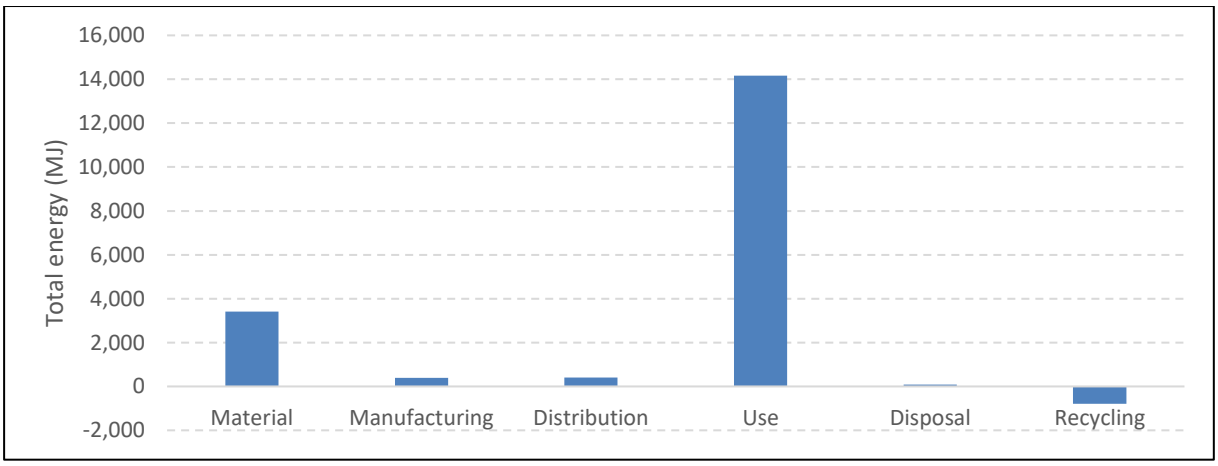

Figure 5: Total energy consumption – BC 3 Portable air conditioner

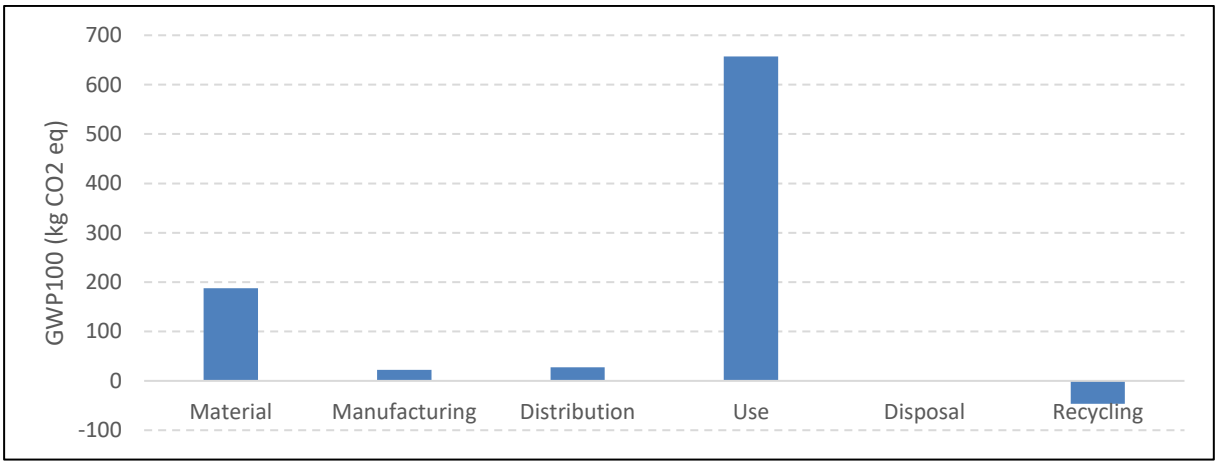

Figure 6: Global warming potential – BC 3 Portable air conditioner

The energy consumption and the emission of CO_2-eq are closely connected and there is a high correlation between the figures. In all base cases the highest energy consumptions are related to the use phase independently on the type of air conditioner. In all cases, above 90 % of the energy consumption and above 88 % of the CO_2-eq emissions appears in the use phase. The share is presented in the below tables.

Table 10: Impacts BC 1 Reversible split [0-6 kW]

	Material	Manufacturing	Distribution	Use	Disposal	Recycling	Total
Total Energy share	5%	1%	0%	95%	0%	-1%	100%
GWP100 share	6%	1%	1%	95%	0%	-1%	100%

Table 11: Impacts BC 2 Reversible split [6-12 kW]

	Material	Manufacturing	Distribution	Use	Disposal	Recycling	Total
Total Energy share	6%	1%	0%	94%	0%	-1%	100%
GWP100 share	6%	1%	1%	94%	0%	-2%	100%

Table 12: Impacts – BC 3 Portable air conditioner

	Material	Manufacturing	Distribution	Use	Disposal	Recycling	Total
Total Energy share	19%	2%	2%	80%	0%	-4%	100%
GWP100 share	24%	3%	3%	76%	0%	-6%	100%

In general, the use phase is responsible for the highest impacts for most categories calculated in the EcoReport tool. All impact categories are presented in the below tables and for each of the categories is the life cycle phase with the highest impact highlighted with red text. The leakage of refrigerants is not assumed to have any impacts on the energy consumption, but only on the emission of CO_2-eq.

- BC 1: 671 kg CO_2-eq, responsible for 15 % of the emitted CO_2-eq
- BC 2: 1451 kg CO_2-eq, responsible for 16 % of the emitted CO_2-eq
- BC 3: 0.08 kg CO_2-eq, responsible for < 1 % of the emitted CO_2-eq

The leakage rate is included in all tables below, and the shares presented above are representative in all scenarios.

Table 13: All impact categories for BC 1- Reversible split [0-6 kW]. The life cycle phase with the highest impact for each of the categories is highlighted with red text.

	Material	Manufacturing	Distribution	Use	Disposal	Recycling	Total
Other Resources & Waste							
Total Energy (MJ)	4,379	504	410	80,720	106	-1,009	**85,110**
of which, electricity (MJ)	2,289	298	1	80,699	0	-466	**82,820**
Water – process (litre)	583	4	0	6	0	-119	**474**
Water – cooling (litre)	499	135	0	3,591	0	-68	**4,155**
Waste, non-haz./landfill (g)	9,799	1,929	256	41,673	208	-3,224	**50,641**
Waste, hazardous/ incinerated (g)	160	0	5	1,274	0	-28	**1,412**
Emissions (Air)							
GWP100 (kg CO_2-eq)	240	28	28	4,073	0	-59	4,310
Acidification (g SO_2-eq.)	1,971	122	83	15,259	6	-524	16,918
VOC (g)	8	0	5	1,802	0	-2	1,813
Persistent Organic Pollutants (ng i-Teq)	210	26	1	190	0	-78	350
Heavy Metals (mg Ni eq.)	803	62	13	824	5	-216	1,491
PAHs (mg Ni eq.)	380	0	14	192	0	-134	453
Particulate Matter (g)	1,335	19	855	336	44	-332	2,258
Emissions (Water)							
Heavy Metals (mg Hg/20)	541	2	0	353	1	-180	716
Eutrophication (g PO_4)	6	0	0	15	1	-1	21

Table 14: All impact categories for BC 2 Reversible split [6-12kW]. The life cycle phase with the highest impact for each of the categories is highlighted with red text.

	Material	Manufacturing	Distribution	Use	Disposal	Recycling	Total
Other Resources & Waste							
Total Energy (MJ)	10,253	1,179	710	159,727	248	-2,362	169,755
of which, electricity (MJ)	5,360	697	1	159,678	0	-1,092	164,644
Water – process (litre)	1,366	10	0	14	0	-280	1,110
Water – cooling (litre)	1,167	315	0	7,106	0	-160	8,429
Waste, non-haz./ landfill (g)	22,945	4,516	406	82,489	487	-7,548	103,294
Waste, hazardous/ incinerated (g)	374	0	8	2,522	0	-65	2,840
Emissions (Air)							
GWP100 (kg CO_2-eq)	563	66	47	8,104	1	-139	8,641
Acidification (g SO_2-eq.)	4,616	286	142	30,197	15	-1,227	34,030
VOC (g)	19	1	10	3,565	0	-5	3,590
Persistent Organic Pollutants (ng i-Teq)	492	62	2	377	0	-183	751
Heavy Metals (mg Ni eq.)	1,881	144	21	1,633	12	-505	3,185
PAHs (mg Ni eq.)	891	0	25	381	0	-313	984
Particulate Matter (g)	3,127	44	1,710	670	104	-777	4,877
Emissions (Water)							
Heavy Metals (mg Hg/20)	1,266	5	1	700	1	-422	1,551
Eutrophication (g PO_4)	13	1	0	30	1	-3	43

Table 15: All impact categories for BC 3 Portable air conditioner. The life cycle phase with the highest impact for each of the categories is highlighted with red text.

	Material	Manufacturing	Distribution	Use	Disposal	Recycling	Total
Other Resources & Waste							
Total Energy (MJ)	3418	393	410	14,164	83	-787	17,681
of which, electricity (MJ)	1787	232	1	14,148	0	-364	15,804
Water – process (litre)	455	3	0	5	0	-93	370
Water – cooling (litre)	389	105	0	632	0	-53	1,073
Waste, non-haz./ landfill (g)	7648	1505	256	7,358	162	-2,516	14,414
Waste, hazardous/ incinerated (g)	125	0	5	224	0	-22	332
Emissions (Air)							
GWP100 (kg CO_2-eq)	188	22	28	605	0	-46	796
Acidification (g SO_2-eq.)	1539	95	83	2,684	5	-409	3,998
VOC (g)	6	0	5	316	0	-2	326
Persistent Organic Pollutants (ng i-Teq)	164	21	1	35	0	-61	160
Heavy Metals (mg Ni eq.)	627	48	13	149	4	-168	673
PAHs (mg Ni eq.)	297	0	14	36	0	-104	242
Particulate Matter (g)	1042	15	855	67	35	-259	1,755
Emissions (Water)							
Heavy Metals (mg Hg/20)	422	2	0	65	0	-141	349
Eutrophication (g PO_4)	4	0	0	3	0	-1	7

The same pattern is visible for fixed air conditioners where the use phase has the highest impact in 9 out of the 15 impact categories, and the material phase has the highest impact in the remaining 6 categories. For portable air conditioners the use phase has the highest impact in 7 out of the 15 impact categories, and the material phase has the highest impact in the remaining 8 categories. Regarding the impacts of the heating and cooling mode of reversible air conditioners, approximately 30 % of the energy and thereby 30 % of the impacts in the use phase are related to the cooling mode. This share is lowered in the future as more people are expected to use their reversible air conditioner for heating purposes.

In the above tables it is also visible that air conditioners above 6 kW have the highest impact in all categories compared with the other base cases. This is due to the size of the equipment and the higher energy consumption. Though, it should be noted that they are not used at the same premises and are not fully comparable. To make a fully comparable analysis between the 3 base cases, the same functional unit shall be defined. The purpose of the base cases is not to compare the different air conditioners but to determine the impact of each of them individually.

The impacts of each base case per product have been presented above, in section 5.4, the total EU impact of air conditioners are presented.

The consumption of critical raw materials is also determined for the base cases per product. For each of the base case, the amount of gold and copper calculated and the derived impacts regarding energy, emission of CO_2-eq and market value in euros.

- For BC 1:
  - 0.128 grams of gold, 32.1 MJ, 2.9 kg CO_2-eq. and 4.5 euros
  - 6970 grams of copper, 355 MJ, 21 kg CO_2-eq. and 41 euros
- For BC 2:
  - 0.4176 grams of gold, 104.4 MJ, 9.4 kg CO_2-eq. and 14.7 euros
  - 16320 grams of copper, 831 MJ, 49 kg CO_2-eq. and 96 euros
- For BC 3:
  - 0.0642 grams of gold, 16.1 MJ, 1.4 kg CO_2-eq. and 2.3 euros
  - 5440 grams of copper, 277 MJ, 16 kg CO_2-eq. and 32 euros

Both copper and gold have limited impacts compared with the impacts of the use phase. Copper is responsible for less than 1 % of the emission of CO_2-eq over the lifetime and gold has an even lower impact.

5.3 Base-Case Life Cycle Costs for consumer

The base-case life cycle costs for the consumer are calculated based on the data presented in section 5.1.2. The life cycle costs for consumers are calculated by the following equation:

$$LCC = PP + PWF \times OE + EoL$$

Where:

- LCC is Life Cycle Costs
- PP is the purchase price
- OE is the operating expense
- PWF (Present Worth Factor)
- EoL is End-of-life costs (disposal costs, recycling charge) or benefit (resale).

The present worth factor is automatically calculated in the EcoReport tool. The formula to calculate the present worth factor is:

$$PWF = \{1 - 1/(1 + r)^N \}/r$$

Where:

- N is the product life
- r is the discount rate minus the growth rate of running cost components (e.g. energy, water rates)

The discount rate is assumed to be 4 % and the escalation rate (annual growth rate of running costs) are assumed to be approximately 1% and the resulting values for the different base cases are:

- BC 1 – 9.97
- BC 2 – 9.97
- BC 3 – 8.54

The life cycle costs of the three different base cases calculated in the EcoReport tool are presented in Table 16.

Table 16: Life cycle cost of the three base cases

	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable
Product price (€)	743	1929	386
Installation/ acquisition costs (€)	800	800	0
Electricity (€)	1238	2350	367
Repair & maintenance costs (€)	741	1310	0
Total (€)	3521	6389	692

For fixed air conditioners the highest expenses are related to the use phase and the electricity consumption. For portable air conditioners the highest expenses are related to the purchase due to low hours of use assumed. Note, that the cost of electricity in the three base cases varies, because the electricity price for each base case is derived based on the share of residential users and service sector users as described above on section 5.1.2.

5.4 EU Totals

The EU totals are the environmental impacts and the life cycle costs aggregated to EU-27 level. For the EU totals the following is calculated:

- **Environmental impacts during the entire lifetime of air conditioner sold in 2015** is calculated by multiplying the annual sales with the impacts of each of the base cases and presented in Table 17.
- **Environmental impacts of air conditioner (EU-27 stock)** is calculated by multiplying the current stock with the impacts of each of the base cases and presented in Table 18.
- **Environmental impacts of air conditioners as a share of EU total impacts** is calculated as the ratio of impacts from air conditioners compared to EU totals (total impacts of all energy-related products in 2011) and presented in Table 19.
- **Annual consumer expenditure in EU27** is calculated based on the life cycle costs per product multiplied by the annual sales and presented in Table 20.
- **The EU consumption of critical raw materials in air conditioners** is calculated by multiplying the current stock with the amount of gold and copper in each of the base cases.

Table 17: Environmental impacts during the entire lifetime of air conditioner sold in 2015

Materials	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable	Total
Bulk Plastics (kt)	5	4	1	10
TecPlastics (kt)	0	0	0	0
Ferro (kt)	2	2	0	4
Non-ferro (kt)	1	1	0	2
Electronics (kt)	2	1	0	3
Misc. (kt)	4	3	1	8
Total weight (kt)	**14**	**13**	**2**	**29**
Other resources & waste				
Total Energy (PJ)	210	163	10	383
of which, electricity (PJ)	204	158	9	371
Water (process) (mln.m^3)	1	1	0	2
Water (cooling) (mln.m^3)	10	8	1	19
Waste, non-haz./ landfill* (kt)	125	99	8	232
Waste, hazardous/ incinerated* (kt)	3	3	0	6
Emissions (Air)				
GWP100 (mt CO_2-eq.)	10	8	0	18
Acidifying agents (AP) (kt SO_2-eq.)	42	33	2	77
Volatile Org. Compounds (kt)	4	3	0	7
Persistent Org. Pollutants (g i-Teq.)	1	1	0	2
Heavy Metals (ton Ni eq.)	4	3	0	7
PAHs (ton Ni eq.)	1	1	0	2
Particulate Matter (kt)	6	5	1	12
Emissions (Water)				
Heavy Metals (ton Hg/20)	2	1	0	3
Eutrophication (kt PO_4)	0	0	0	0

The combined energy consumption during of all air conditioners sold will account to 383 PJ during their lifetime resulting in 18 mt CO_2-eq. emitted. The highest impacts are connected with small fixed air conditioners as the have the highest annual sales.

In Table 18 the annual impact of all air conditioners (stock) is calculated which allows for comparison with the EU totals from all energy-related products. The share of impacts originating from air conditioners are calculated in Table 19.

Table 18: Environmental impacts of air conditioner (EU-27 stock)

Materials	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable	EU totals
Plastics (Mt)	0.017	0.016	0.003	48
Ferrous metals (Mt)	0.046	0.042	0.008	206
Non-ferrous metals (Mt)	0.025	0.022	0.004	20
Other resources & waste				
Total Energy (PJ)	286	359	10	75697
of which, electricity (TWh)	31	39	1	2800
Water (process)* (mln.m^3)	1	1	0	247000
Waste, non-haz./ landfill* (Mt)	0.17	0.21	0.01	2947
Waste, hazardous/ incinerated* (kton)	0.00	0.01	0.00	89
Emissions (Air)				
GWP100 (mt CO2-eq.)	14	18	0	5054
Acidifying agents (AP) (kt SO2eq.)	57	70	2	22432
Volatile Org. Compounds (kt)	6	8	0	8951
Persistent Org. Pollutants (g i-Teq.)	1	1	0	2212
Heavy Metals (ton Ni eq.)	5	6	0	5903
PAHs (ton Ni eq.)	2	2	0	1369
Particulate Matter (kt)	7	6	1	3522
Emissions (Water)				
Heavy Metals (ton Hg/20)	3	3	0	12853
Eutrophication (kt PO_4)	0	0	0	900

Table 19: Environmental impact share of EU total impacts (EU-27 stock)

Materials	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable	Total
Plastics (Mt)	0.036%	0.033%	0.006%	0.075%
Ferrous metals (Mt)	0.022%	0.020%	0.004%	0.046%
Non-ferrous metals (Mt)	0.123%	0.112%	0.022%	0.257%
Other resources & waste				
Total Energy (PJ)	0.377%	0.474%	0.013%	0.864%
of which, electricity (TWh)	1.107%	1.399%	0.033%	2.539%
Water (process)* (mln.m^3)	0.001%	0.001%	0.000%	0.002%
Waste, non-haz./ landfill* (Mt)	0.006%	0.007%	0.000%	0.013%
Waste, hazardous/ incinerated* (kton)	0.005%	0.007%	0.000%	0.012%
Emissions (Air)				
GWP100 (mt CO_2-eq.)	0.29%	0.36%	0.01%	0.660%
Acidifying agents (AP) (kt SO_2-eq.)	0.25%	0.31%	0.01%	0.570%
Volatile Org. Compounds (kt)	0.07%	0.09%	0.00%	0.160%
Persistent Org. Pollutants (g i-Teq.)	0.06%	0.06%	0.01%	0.130%
Heavy Metals (ton Ni eq.)	0.08%	0.09%	0.01%	0.180%
PAHs (ton Ni eq.)	0.12%	0.12%	0.01%	0.250%
Particulate Matter (kt)	0.19%	0.17%	0.03%	0.390%
Emissions (Water)				
Heavy Metals (ton Hg/20)	0.02%	0.02%	0.00%	0.040%
Eutrophication (kt PO_4)	0.01%	0.01%	0.00%	0.020%

The annual energy consumption of all air conditioners in Europe is calculated to 655 PJ which leads to 32 mt CO_2-eq released to the atmosphere. This means that air conditioners are responsible for 0.86 % of the energy consumption (2.5 % of the electricity consumption) in the EU and 0.66 % of the CO_2-eq. Air conditioners are also responsible

for 0.57 % of the acidifying agents released within EU. The remaining impact categories are all below 0.5 % of the EU totals.

The annual consumer expenditures in EU-27 of the average air conditioners are presented in Table 20. The product price and installation costs per product is multiplied by annual EU sales to arrive at the annual consumer expenditure for EU27. The lifetime electricity costs per product multiplied by the annual EU stock and divided by the lifetime to arrive at the annual consumer expenditures for electricity in the EU-27, the same is done for repair & maintenance costs.

Table 20: Annual consumer expenditure in EU27

	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable	Total
Product price (mln. €)	1834	1910	215	3959
Installation/ acquisition costs (mln. €)	1974	767	0	2741
Electricity (mln. €)	4326	3920	138	8384
Repair & maintenance costs (mln. €)	1834	1943	0	3777
Total (mln. €)	9968	9540	353	19861

The highest costs are related to fixed air conditioners which have the highest annual sales. As the table above shows, every year EU consumers are spending 19.7 billion euros in the purchase and operation of their air conditioners. Approximately 42 % (8.4 billion euros) are related to electricity expenses.

The EU consumption of critical raw materials is also determined for the base cases for the EU stock. For each of the base cases the amount of gold and copper is calculated and the derived impacts regarding energy, emission of CO_2-eq and value are presented below.

- For BC 1
  - 3.8 tonnes of gold, 0.95 PJ, 85803 tonne CO_2-eq. and 134 million euros
  - 207009 tonnes of copper, 11 PJ, 564716 tonne CO_2-eq. and 1221 million euros
- BC 2
  - 7.4 tonnes of gold, 1.86 PJ, 167249 tonne CO_2-eq. and 261 million euros
  - 290496 tonnes of copper, 15 PJ, 792467 tonne CO_2-eq. and 1714 million euros
- BC 3
  - 0.3 tonnes of gold, 0.07 PJ, 167249 tonne CO_2-eq. and 10 million euros
  - 24154 tonnes of copper, 1 PJ, 65891 tonne CO_2-eq. and 143 million euros

The impacts of the raw materials are limited[16] compared with the other impacts imposed by air conditioners in the use phase. The value for the amount of gold and copper present in the EU stock are significant. The combined impact and value of gold and copper in all air conditioners (stock) are presented in Table 21.

[16] Taking environmental impacts beyond energy and GWP into account, raw materials are connected to very severe environmental and health issues (gold: use of mercury; copper: acid mine drainage, water contamination in mining etc.) though these aspects are difficult to assess with MEErP methodology.

Table 21: The combined impact and value of gold and copper in all air conditioners (stock)

	Total Energy (PJ)	GWP100 (mt CO_2-eq.)	Total (mln. €)
Gold	2.88	0.26	405
Copper	26.56	1.42	3078
Total	**29.44**	**1.68**	**3483**

Gold and copper are accountable for an energy consumption of 29.44 PJ and an emission of 1.68 million tonne of CO2-eq. The combined value of copper and gold in the EU stock amounts to more than 3 billion euros. Based on stakeholder inputs the PCBs are located easily available for repair which also implies that the PCBs can be easily removed at End-of-Life. This means that most of the critical raw materials are recycled and the value is recovered. To make the critical raw materials easier to remove at End-of-Life could also impose a safety risk (e.g. risk of electric shock) for the consumers, if they believe they can repair the air conditioners by them self as the components are easy to remove.

5.5 Conclusions and recommendations

For fixed air conditioners, the use phase has the highest impacts for 9 out of the 15 investigated impact categories including electricity consumption and the derived CO_2-eq emission. For portable air conditioners the highest impacts for 7 out of the 15 investigated impact categories including electricity consumption and the derived CO_2-eq emission are also related to the use phase. The material phase has the highest impact in the remaining 6 impact categories. The energy consumption, emission of CO_2-eq and emission of SO_2-eq for the different base cases are:

- BC 1: Energy consumption - 85,110 MJ, emission of CO_2-eq - 4,310 kg, emission of SO_2-eq - 16,918 g.
- BC 2: Energy consumption - 169,755 MJ, emission of CO_2-eq - 8,641 kg, emission of SO_2-eq – 34,030 g
- BC 3: Energy consumption - 17,681 MJ, emission of CO_2-eq - 796 kg, emission of SO_2-eq – 3,998 g

The life cycle impacts of the base cases will serve as a baseline or reference for the improvement options and policy scenarios assessment in Task 6 and 7. The comparison between the annual impacts of all air conditioners and the EU total impacts (from all energy-related products) reveals that air conditioners are responsible for 2.5 % of the total EU electricity consumption, 0.66 % of the total EU emitted CO_2-eq and 0.57 % the emitted acidifying agents within the EU. These are the categories with the highest share and are mostly related to the electricity consumption in the use phase. In total, all EU air conditioners over a lifetime account for 655 PJ of energy consumption, which leads to 32 mt CO2-eq released to the atmosphere. When more air conditioners are used for heating mode, this energy consumption and CO_2-eq emission will also increase.

The life cycle costs for air conditioners reveal that the highest expenses are related to the use phase as well. Within the EU, all consumers are spending 19.7 billion euros annually in the purchase and operation of their products. Approximately 42 % (8.4 billion euros) are related to electricity expenses.

The critical raw materials consumed during production have limited impacts and constitutes below 1 % of the impacts imposed by air conditioners over a lifetime. In the EU stock, the raw materials (gold and copper) embedded account for an energy consumption of 29.44 PJ and an emission of 1.68 million tonnes of CO2-eq. The combined value of copper and gold in the stock amounts to more than 3 billion euros. The majority of these raw materials are considered to be recycled at End-of-Life as most air conditioners already are facilitating easy dismantling and repair.

Annex 1: Impact of refrigerant

In the EcoReport Tool inputs, the refrigerant weight is included in the category "various other materials". However, it cannot properly calculate the impacts of refrigerants (or the impacts of leaking). The impact of the refrigerant and leakage are then calculated separately in this review study. The yearly leakage is presented in Table 22.

Table 22: Calculated leakage of refrigerants per year

	Reversible split [0-6kW]	Reversible split [6-12kW]	Portable
Refrigerant charge	0.98 kg	2.01 kg	0.26 kg
Annual leakage rate	3 %	3 %	1 %
GWP	R410A (GWP 2088)	R410A (GWP 2088)	R290 (GWP 3.3)
Average Leakage kg/year	0.027 kg/year	0.058 kg/year	0.0025 kg/year

The leakage of refrigerants during the lifetime of the air conditioners is included directly in the EcoReport tool manually, as kg CO_2-eq in the use phase, in the result sheet under the "Life cycle Impact per product". This includes the impact of leakage in all of the results by the EcoReport tool.

Regarding the EU stock, as the leakage rate of older air conditioners in the stock are difficult to determine, the values presented in Table 22 are used for calculating the emission of CO_2-eq of stock as well.

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 6 report

DESIGN OPTIONS

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
COP	Coefficient of Performance for air conditioners in heating mode
DC	Direct current
EER	Energy Efficiency Ratio for air conditioners in cooling mode
Eq	Equivalents
GWP	Global warming potential
K	Kelvin
LLCC	Least Life Cycle Costs
MHE	Microchannel heat exchangers
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
PWF	Present Worth Factor

Introduction to the task reports

This is the introduction to the Review of Regulation 206/2012 and 626/2011 for air conditioners and comfort fans. The report has been split into seven 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.

6 Introduction to Task 6

Task 6 follows the MEErP methodology and aims to identify design options and their monetary consequences in terms of Life Cycle Cost for the consumer, their environmental costs and benefits and pinpointing the solution with the Least Life Cycle Costs (LLCC) and the Best Not Available Technology (BNAT). Life Cycle Cost functions as an indicator on whether the suggested design solutions have a negative or positive impact on the consumer expenditures over the total life of air conditioners and comfort fans. Task 6 includes the following sections:

1. Options: Identification and description of design options taken into account

2. Impacts: The environmental improvement per design option based the EcoReport tool

3. Costs: The effect on price due to implementation of the suggested design options

4. Analysis LLCC and BAT: The impact at EU level considering both costs and environmental impacts

5. Long-term targets: The long-term technical potential (BNAT)

6. Conclusions and recommendations

6.1 Options

In this section, different improvement options for air conditioners are discussed. The individual EcoReport Tool result of each option is not investigated here (as it will be presented in later section) but only the energy consumed in each case.

6.1.1 Refrigerant

For split air conditioners, R32 is likely to replace R410A in the coming years, with a complete conversion to happen before 2025 for single split according to Regulation (EU N° 517/2014) ban according to EPEE (European Partnership for Energy & the Environment)[1]. Note that even if this regulation only applies to single split systems, the conversion covers also multi-split systems with the logics that as for these products there are possible replacement fluids; the ban pushes for their adoption in order to reserve quotas for other sectors. GWP consequently will decrease from 2088 to 675 for split air conditioners. R32 has higher performances (with charge and expansion valve optimization, as compared to R410A for a split unit, COP increases by 4 % and capacity by 5 %) than R410A[2,3], but it also has higher costs for safety measures because of its flammability. As in the EU, the price of R32 units (at equal efficiency level) is now about similar to the ones of R410A units

[1] Andrea Voigt, INPAC, 2017
[2] RTOC 2014, UNEP TECHNICAL OPTIONS COMMITTEE, ASSESSMENT REPORT OF THE REFRIGERATION, AIR CONDITIONING AND HEAT PUMPS MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER, 2014
[3] AHRI low GWP program, http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_Final_Reports/AHRI_Low_GWP_AREP_Rpt_062.pdf

(this means that the gain in performance more or less compensates for the increased cost due to safety measures), no option is proposed for R32 as an alternative to R410A. The improvement potential is evaluated for R410A and is thought to be similar for R32 and R410A.

For portable air conditioners, propane is the only alternative to R410A presently available on the market with GWP lower than 150. It has been available for more than a decade, but its share remains low and there is no trend that its share increases. In this review study, R290 and R1234yf are considered the two alternatives of R410A portable air conditioners.

6.1.2 Compressor

Compression efficiency

Split systems basic DC compressor EER (ASHRAE conditions SI units) has been identified to be about 3.13. The first option to improve efficiency is to use a higher efficiency rotary compressor with EER 3.4. A second option is to use a 3.4 EER rotary compressor with improved oil management which enables to operate at lower compression ratio (minimum compressor ratio down to 1.1 versus 1.2 for other compressors). The improvement options are noted as CP1 and CP2 for base case 1 and 2.

For single duct air conditioners, the R410A base case is fitted with a 2.7 EER (ASHRAE conditions) AC rotary compressor. At equal global compressor efficiency and standard testing conditions, the compressor EER with R290 or R1234yf is higher because of the alternative fluid properties (R290 EER = 2,98; R1234yf EER = 3,02). We suppose here that it is possible to build rotary compressors for alternative refrigerant with similar global efficiencies as for R410A levels of 3.13 and 3.4. This leaves to maximum EER compressor values in standard conditions of 3.75 for R290 and up to 3.8 for R1234yf with best inverter DC compressor. For R1234yf, this hypothesis bases upon DC rotary compressor using R134a that can indeed reach such performance levels in small capacity ranges for the same ASHRAE conditions. For propane, in India, high efficiency units with propane (at performance levels comparable to the ones of best R32 or R410A DC inverter split) are available.

Intermediate values are used to define improvement levels. The improvement options are noted as CP1 (3.45 EER for R290 and 3.5 EER for R1234yf) CP2 (3.75 EER for R290 and 3.80 EER for R1234yf)

Vapour injection and phase separation

Efficiency improvement is estimated to be of about 0.5 % on the SCOP value. The significant increase in capacity at low outdoor temperature has limited economic value for the average climate as product price is mainly depending on their cooling capacity and efficiency (as seen in Task 2, price premium of split air conditioners can be drawn with SEER and cooling capacity and not with SCOP or capacity at heating design conditions). It is thus not considered as an option.

6.1.3 Heat exchangers and fans

Heat exchanger area and air flow are increased proportionally to maximize the gain of heat exchanger oversizing. Doing so, fan power is considered to remain constant by increasing proportionally to the air flow the fan and/or motor efficiency. For more efficient products, it is observed that the fan mechanical efficiency and motor efficiency increase to reach

levels that correspond to a total fan and motor efficiency of about 60 % for axial fans and 40 % for cross flow fans (BAT levels).

Maximum air flow rates are limited by sound power maximum requirements. Maximum overall conductance of the unit or UA values[4] considered in design options (maximum UA increase of heat exchangers) give proportionally larger air flows; these air flows are thought to push sound power emissions to the maximum sound power level allowed by Regulation (EU) 206/2012 indoor and outdoor, except for the 7.1 kW unit. This point is discussed in more details in section 0. In addition, increasing the heat exchange area leads to larger refrigerant charges. This translates into higher refrigerant leaks over lifetime (as leaked quantity is supposed proportional to the product refrigerant charge), which is accounted for in sections 6.2.2 and 6.4.3.

The quotas in Regulation (EU) 517/2014 are set in CO2 ton equivalent (mass of fluid multiplied per GWP) and thus depend on yearly sales value of products. The reduction levels to be reached are set in Regulation (EU) 517/2014 by comparison with period 2009 - 2012 as 45 % for period 2021-2023, 31 % by 2024-2026, 24 % by 2027-2029 and 21 % by 2030. But clearly, higher UA values and thus higher unitary charges reduce the available fluid and product quantities that can be placed on the market.

For portable products which will shift refrigerant to very low GWP, the impact to increase charge for efficiency improvement is negligible (to compare the GWP of R410A of 2088, versus the one of propane, 3, and 4 for R1234yf). The only limitation on charge is for propane, because of safety limits. But UA increase for portable is limited in the options and thought to be compatible with safety limits (it exists R290 units with comparable charge levels to the ones obtained by UA increase).

For split which will shift from R410A to R32, the GWP is decreasing from 2088 to 675. Refrigerant charge is thought to be about 15 % lower for R32 units at equal capacity and efficiency (Task 4). So refrigerant change for split units enables to reach an equivalent CO2 emission of about 27 % (= 675 / 2088 * 0.85) as compared to present R410A units. Most efficient units (with largest UA increase) have a R32 charge of about 0.4 kg/kW or about 35 % increase above present average R410A unit. So this makes a significant difference and is to be taken into account when proposing minimum performance requirements.

In addition, it is possible to extend the heat exchange area without increasing the air flow. This can be done, for instance, with micro-channel heat exchangers because of their higher compactness. This type of heat exchanger is reserved for the condenser (in cooling mode) and is supposed to give a further 3.5 % gain on SEER (2 % on SCOP) for split air conditioners. This improvement option is noted as MHE (Micro-channel Heat Exchangers) for base case 1 and 2. However, this option is not available for single duct products according to stakeholders[5].

As a result of LLCC analysis presented in section 6.4, it was found that for 700 heating full load equivalent hours, the LLCC value for 3.5 kW and 7.1 kW split units matches lower efficiency level than the one of the base case. For this reason, two negative options are simulated; they correspond to a decrease in outdoor heat exchanger size by 10% and 20%

[4] UA value is defined as the product of the overall heat transfer coefficient and the heat transfer area.
[5] Stakeholder consultation, November 2017.

, these options are noted as -10%UA_cond and -20%UA_cond, and consequently the energy consumption for these options would increase.

6.1.4 Standby, thermostat-off and crankcase heater

As presented in Task 4 the best available products already have very low consumption in the low power modes of air conditioners. The following values can be reached:

- Standby 0.4 W
- Thermostat-off to 2 W by using a movement sensor or an external indoor thermostat for split units and thermostat-off of half the fan power for portable units by fan speed reduction

This improvement option is noted as LPM (Low Power Modes).

6.1.5 Summary of options by product type

The improvement options presented are summarised in the tables below for each of the base case.

Table 1: list of individual options for base case 3.5 kW

Improvement options 3.5 kW	Option CP1	Rotary compressor 3.4 EER
	Option CP2	Rotary compressor 3.4 EER w improved oil management
	Option HE1	UA value of indoor heat exchanger increased by 40 %
	Option HE2	UA value of indoor heat exchanger increased by 80 %
	Option HE3	UA value of outdoor heat exchanger increased by 40 %
	Option HE4	UA value of outdoor heat exchanger increased by 80 %
	Option LPM	Lowest values achievable for SB and TO
	Option MHE	Microchannel heat exchangers for the outdoor unit
Negative option	Option -10% UA_cond	UA value of outdoor heat exchanger decreased by 10 %
	Option -20% UA_cond	UA value of outdoor heat exchanger decreased by 20 %

The options for the 7.1 kW unit are about the same as for the 3.5 kW units. Only the UA values are lower.

Table 2: list of individual options for base case 7.1 kW

Improvement options for 7.1 kW Unit	Option CP1	Rotary compressor 3.4 EER
	Option CP2	Rotary compressor 3.4 EER w improved oil management
	Option HE1	UA value of indoor heat exchanger increased by 30 %
	Option HE2	UA value of indoor heat exchanger increased by 60 %
	Option HE3	UA value of outdoor heat exchanger increased by 30 %
	Option HE4	UA value of outdoor heat exchanger increased by 60 %
	Option LPM	Lowest values achievable for SB and CK
	Option MHE	Microchannel heat exchangers for the outdoor unit
Negative option	Option -10% UA_cond	UA value of outdoor heat exchanger decreased by 10 %
	Option -20% UA_cond	UA value of outdoor heat exchanger decreased by 20 %

Table 3: list of options for base case, single duct 2.6 kW

Improvement options	Option CP1	R290: Rotary compressor 3.45 EER (DC inverter) R1234yf: Rotary compressor 3.5 EER (DC inverter)
	Option CP2	R290: Rotary compressor 3.75 EER (DC inverter) R1234yf: Rotary compressor 3.80 EER (DC inverter)

	Option HE1	R290 & R1234yf: UA value of evaporator heat exchanger increased by 10 %
	Option HE2	R290 & R1234yf: UA value of evaporator heat exchanger increased by 20%
	Option LPM	Lowest values achievable for SB, TO
	Option DC	Evaporator fan 10 W for HE1 and 12 W for HE2. Condenser fan 30 W

6.2 Impacts

In order to assess the impacts of different improvement options, a model is needed to simulate the contribution of each improvement option to increase efficiency. In the following section, the energy efficiency model and its constraints are described.

The environmental improvement per option has been assessed quantitatively using the EcoReport tool. The outcomes and impacts of each are compared and reported later in this section.

6.2.1 Energy efficiency modelling

General outline of the simplified evaluation tool
It is necessary to use a thermodynamic based evaluation tool to compute the impact of options on the energy efficiency indicators of the products, in particular, for the options that regard compressor performance and heat exchanger efficiency. A simplified tool to evaluate the impact of the options on the SEER and SCOP for split systems and for EER at rated conditions for single duct air conditioners has therefore been built.

SEER calculation requires to model the performance of the EER values (for reduced outdoor temperature and capacity ratios) at the following test points: A (100%/35 °C), B (74%/30 °C), C (47 %/25 °C) and D (21 %/20 °C).

In the same manner, SCOP calculation requires to compute at least 5 performance points for varied outdoor temperature and part load conditions: F (-10 °C/max declared capacity), A (88%/-7 °C), B (2 °C/54 %), C (7 °C/35 %) and D (12 °C/15%).

EER and COP depend both on the cooling (respectively heating) capacity of the unit and on the compressor electricity consumption. Capacity is imposed by the testing points and the choice of design parameters, Pdesignc (capacity corresponding to Tdesignc) in cooling mode, and respectively in heating mode, Pdesignh, Tdesignh, Tbiv, and unit capacity at Tdesignh. These parameters are fixed to the values of the base cases. This leads to that the unit capacity required is fixed to match the building load for the different outdoor temperature.

At low loads in both cooling and heating mode, units may have difficulties to reach the low capacities required (point D in both modes, sometimes also point C in cooling mode); in that case, the capacity declared for base cases and improved units supposedly cannot reach the required capacity and the Cd degradation factor is used to correct the EER or COP of the unit according to standard EN14825:2016.

Evaporating and condensing temperature estimates
<u>Evaporation temperature in cooling mode</u>

For the evaporator in cooling mode, the cooling capacity to be exchanged is known. There are two distinct situations to compute the evaporating temperature:

CASE 1: for single duct rated capacity, for split EER_A (100%/35 °C) and in most cases for EER_B (74%/30 °C) test conditions, there is dehumidification. In that case, the heat exchanger capacity is computed from an assumed heat exchanger effectiveness value (also called bypass factor for a coil with dehumidification) and a given air flow rate. Cooling capacity is decreased by the fan motor power (supposing that all motor losses convert to heat in the air stream and that useful fan energy converts to pressure losses and then to heat in the air stream ultimately). Refrigerant fluid evaporating temperature (Tev) is identified by iteration so that the sum of the sensible and latent capacities reaches the cooling output of the simulated point.

CASE 2: for EER_C and EER_D, there is no dehumidification. In that case, Tev is identified by iteratively equalizing two DTLM (the logarithmic mean temperature difference between air and refrigerant) values computed with the help of the equations below:

- $DTLM1 = Q / UA;\ with\ UA = NUT_A \times mCp;\ NUT_A = ln(1/(1-\varepsilon_A))$
- $DTLM2 = ((Ta_i - Tev) - (Ta_o - Tev)) / Ln((Ta_i - Tev)/(Ta_o - Tev))$

With:

- Q: cooling capacity to be exchanged at evaporator
- UA: global heat exchange coefficient of the heat exchanger in W/K
- m: air flow rate in kg/s
- Cp: air specific heat at constant pressure in J/kg/K
- NUT: number of unit transfer (ratio of UA to mCp). NUT_A refers to the reference point used to fix UA, in that case point A (100% load and 35 °C outdoor). This is a constant for all 4 points simulated.
- ε: heat exchanger effectiveness; ε_A refers to the reference point used to fix UA, in that case point A (100% load and 35 °C outdoor); this is a constant for all 4 points simulated.
- Ta_i: evaporator inlet air temperature
- Ta_o: evaporator outlet air temperature
- Tev: refrigerant fluid evaporating temperature

UA is variable and varies proportionally to the air flow rate, while NUT_A is supposed constant whatever the testing point[6].

and with:

$$Ta_o = Ta_i - Q / mCp$$

Note that in both cases superheat is not considered in the heat exchanger calculation, evaporating side is considered isothermal. Refrigerant fluid pressure losses are not considered either.

<u>Condensation temperature in cooling mode</u>

[6] This might lead to slightly underestimate the UA value at lower air flow as U is in first order proportional to the air speed v in power of 0.75 to 0.8 and so NUT (UA/mCp) should be proportional to $v^{-0.2}$ and so slightly increase with decreased air flow. However, the refrigerant side conduction coefficient also decreases with more complex effect to model. So this simplification is considered an acceptable first order estimate and allows the model to correctly fit part load performances.

The same iterative method on DTLM is applied at condenser as in CASE 2 for the evaporator. Condenser heat capacity for the specific point is the sum of the cooling capacity and of the compressor electricity consumption computed below so that there is an iteration on the condensing temperature value Tc.

Sub-cooling and superheat horn[7] are not considered in DTLM2 calculation (formula above in this section - CASE 2) at the condenser; thus, condenser refrigerant temperature is supposed to be constant and equals Tc value.

Case of single duct

Most single duct units use evaporator condensates to increase condenser performance. Water condensates are evaporated on the condenser coil. Water which is not directly evaporated flows down in a tray below the condenser and a wheel pump runs permanently to sprinkle water on the condenser. All water condensate helps to increase the heat transfer at the condenser due to evaporation. Calculating the amount of energy to evaporate condensed water, this corresponds to about 25 % of condenser heat release without the water condensate. It is supposed in DTLM calculation of the condenser that the heat to be rejected is lower by 25 % (only 75 % of the heat extracted corresponds to sensible heating of the air at the condenser). This value is adjusted when evaporating temperature varies (case of larger evaporator or of inverter use with new metrics).

Condensing temperature in heating mode

The calculation is the same as for condensing temperature in cooling mode except the power consumption of the fan is added to the heating capacity and that the capacity of the heat exchanger is defined by the heating part load ratio of the test point simulated.

Evaporating temperature in heating mode

Evaporator capacity is the difference between the heating capacity and the compressor power. The DTLM iteration is used to compute the evaporating temperature.

Evaporator superheat (SH)

It is constant to 2 K (electronic expansion valve) for all split simulations and to 6 K (capillary tube or thermostatic expansion valve) for single duct. As it only intervenes in the model in modifying the compressor work, its variation has very limited impact on the global efficiency (less than 0.5 % when changing from 2 to 6 K).

Condenser subcooling (SC)

Condenser subcooling is set constant for single duct.

A reference value is defined in standard rating conditions in cooling mode and at declared unit capacity at -10 °C in heating mode. In part load, subcooling value is supposed equal to the product of the reference subcooling value multiplied by the ratio of the specific test point temperature difference between the condensing temperature and the inlet air temperature to the same ratio for the reference test conditions[8]. For example, in cooling mode:

$$SC_{B,C,D} = SCA \times (Tc_{_B,C,D} - Ta_i_{_B,C,D}) \,/\, (Tc_{_A} - Ta_i_{_A})$$

[7] Superheat horn means the transformation occurring in the condenser during which the refrigerant fluid at high temperature and high pressure flowing out of the compressor is cooled down to high pressure saturation temperature.

[8] Approximation suggested by manufacturers to model air cooled chiller SEPR performance point in the frame of Lot 1 commercial refrigeration impact assessment study.

With:

- $SC_{A,B,C,D}$: subcooling in test conditions A or B or C or D in K
- $Tc_{}_{A,B,C,D}$: condensing temperature in test conditions A or B or C or D in K
- $Ta_i_{}_{A,B,C,D}$: condenser inlet air temperature in test conditions A or B or C or D in K

<u>Air flow reduction at low loads for split units (with inverter compressor and fans)</u>
At low loads in cooling mode, condenser fan power is reduced to maintain performance. This is also the case at low loads in heating mode at the evaporator. In these conditions, compressor power is low and fan power is no longer small in comparison to compressor electricity consumption; so, it is more efficient to decrease fan power, even if compressor power increases.

Refrigerant temperature is found with the same iteration of CASE 2 for evaporation temperature in cooling mode above, with changed flow rate. UA is assumed proportional to flow and NUT is constant as discussed above.

Fan power is assumed to vary with flow rate as follows for these test conditions with reduced air flow rates:

$$Pf = PfN \times (0.1 + 0.9 \times AFR^3)$$

With:

- Pf_N: nominal electric power of the fan motor
- AFR: ratio of the reduced air flow to the nominal air flow

Compressor efficiency estimate
EER (respectively COP) of the compressor is calculated from Tev and Tc. Superheat and subcooling are also considered.

A correlation between the global efficiency of the compressor and the compression ratio (Pc/Pev) is used:

$$\eta g = f\left(\frac{Pc}{Pev}\right)$$

The compressor EER (respectively COP) is then computed as the ratio of the EERis (respectively COPis) obtained for the isentropic cycle defined by Tev, SH, Tc, SC, an isentropic compression and an isenthalpic expansion. The properties of the fluid at the different state points are computed using Refprop 9[9].

$$EER\ (COP) = EERis\ (COPis) / \eta_g$$

with:

- EERis (COPis): EER(COP) of the isentropic cycle

Performance curves of a 2.9 EER (ASHRAE standard conditions, SI units) AC rotary compressor were published recently[10] in the frame of the AHRI Low-GWP Alternative

[9] https://www.nist.gov/srd/refprop
[10] http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/PasswordProtected/AHRI%20Low-GWP%20AREP-Rpt-026.pdf

Refrigerants Evaluation Program. This curve is used to model AC rotary compressor for single duct.

For DC inverter rotary compressor, this curve has been corrected by the AC motor efficiency following information published by (Lee and al., 2015)[11]. DC motor losses are supposed constant so that this performance curve is simply adjusted using a constant correction coefficient required to reach the different EER levels:

- EER of 3.15 which is the reference for split unit and the first level of improvement for single duct unit
- EER of 3.4 to reach best DC inverter rotary compressor. For the rotary with improved oil management, the compression ratio is allowed to decrease down to compression ratio close to 1.1, while it is limited to 1.2 for other DC inverter compressors.

The curves of the different rotary compressor efficiency curves (η_g) are given in Figure 1. η_g values close to nominal ASHRAE condition values can be read at compression ratio of 3.4 on the different curves, with η_g values ranging from 0.61 (EER 2.7) to 0.77 (EER 3.4).

The impact of frequency variation on compressor efficiency is not included.

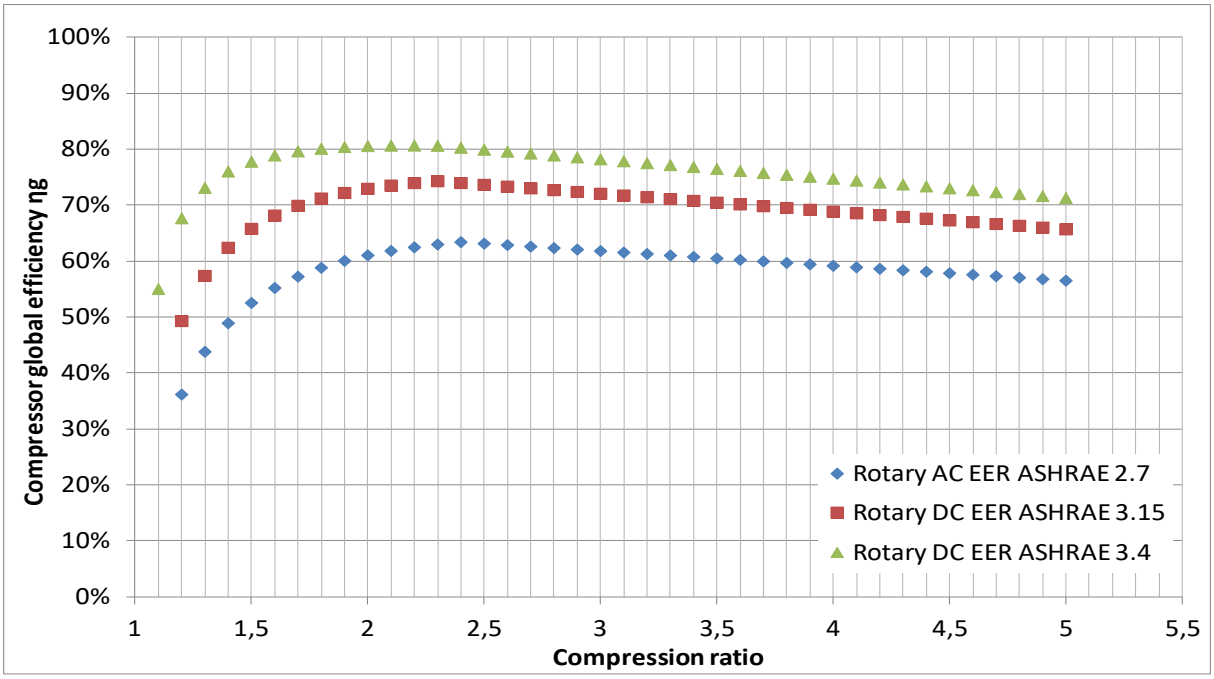

Figure 1: Compressor efficiency curve as a function of the compression ratio for the different compressor options

EER, SEER, COP and SCOP calculation

EER and COP are then corrected for:

- Fan power
- Power required for electronics (controls when unit is on)
- Frost/defrost cycles: 5 % decrease in COP at 2 °C

[11] Seung-jun Lee, Jaesool Shim, Kyung Chun Kim, Development of capacity modulation compressor based on a two stage rotary compressor – part I: Modeling and simulation of compressor performance, In International Journal of Refrigeration, Volume 54, 2015, Pages 22-37.

Thermostat-off, crankcase and standby power are input to the calculation.

SEER (and respectively SCOP) then follows Regulation (EU) N° 206/2012 and standard EN14825:2016.

Base case identification

There are a large number of parameters to be adjusted in the model despite the model being extremely simplified. Identification is made possible thanks to detailed characteristics of products close to the base cases and BAT levels supplied by manufacturers[12]. Main parameters for the base cases used in the model are given in Table 4 and **Error! Reference source not found.**, for the 3 base cases.

For split units, in cooling mode, $P_{designc}$ is the refrigerating capacity at 100 % load. In heating mode, Pdesignh (manufacturer declaration of maximal heat load at - 10 °C) was identified in Task 4 when defining the base cases. It was 3.1 kW for the 3.5 kW unit and 5.6 kW for the 7.1 kW units. However, for the 3.5 kW unit for instance, the heating capacity of 2.7 kW at - 7 °C (88 % load) has been identified to 2.74 with the energy efficiency model. This small difference led to 3.06 kW at - 10 °C and the Pdesignh value of 3.0 kW has been adjusted to 3.1 kW due to the restraints of the model. The same rationale applies for the 7.1 kW unit for which the Pdesignh value used is 5.70.

For single duct unit, the model simulates the base case unit as it is presently tested. Capacity is 2.6 kW at rated conditions, thus without accounting for infiltrations (impact of infiltration is discussed in section 6.4.3).

The single duct units base case using R1234yf and R290 were determined by adapting the base case of R410A. AHRI report regarding the "soft adaptation" (larger compressor, different circuiting of heat exchanger to limit pressure losses, change of expansion valve) of a R410A unit to use R1234yf[13] was used; if compressor had had the same global efficiency for R1234yf as for R410A unit, the loss in capacity would have been of 7 % and the electric consumption 5 % higher. These figures were used to adapt the R410A base case single duct with the same methodology but to supply the same capacity (i.e. increasing heat exchanger size to compensate the capacity loss), using a compressor with the same global efficiency Eta_g. In total, the efficiency loss at equal capacity is estimated to about 13 % or EER 2.62 at 27/27 conditions. For propane, the same procedure was done for a 3 % capacity loss and about 10 % increase in compressor EER of same Eta_g leading to an efficiency gain of 6 % or EER 3.16 (versus EER 3 at 27/27 conditions for R410A base case).

[12] Data collection for current and BAT technologies from stakeholders, September 2017

[13] http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/AREP_Final_Reports/AHRI%20Low-GWP%20AREP-Rpt-010_with%20addendum.pdf

Table 4: Main parameters for the base cases for split 3.5 kW and 7.1 kW

	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

Table 5 : Main parameters for the base case for single duct 2.6 kW

	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

Impact of options:
The impact of options is modelled by altering the model parameters as described in the subsection above:

- UA values increased by 40 to 80% for 3.5 kW split, by 30 to 60 % to 7.1 kW split and by 10 to 20 % for 2.6 kW single duct unit;
- Regarding single duct base case 3, the options HE3 and HE4 lead to higher condenser air flows and thus to higher infiltration. Under the assumption that the metrics is changed these options are less favorable. Consequently, options HE3 and HE4 are not considered.
- Microchannel heat exchanger directly increases the SEER value by 3.5 % and the SCOP by 2 %;
- "Low power modes": values for thermostat-off, standby and crankcase is directly changed to BAT values presented;
- Regarding compressor options, note these differ for split and single duct units as explained before, but still are noted equally CP1 and CP2. For split, CP1 is a compressor with EER 3.4 with same performance curve as for base case; CP2 option regards EER 3.4 DC inverter compressor working at lower pressure ratio. For single duct, CP1 is a compressor EER increase to 3.13 and change of performance curve (AC to DC); CP2 is a rotary DC motor 3.4 EER compressor.
- For single duct air conditioners, CP1 and CP2 reach higher EER values with the new metrics as EER is measured at 100% and 33% load and so enables to benefit from a lower compressor ratio than at maximum capacity. These options are noted equally CP1 and CP2, with DC inverter compressor (CP1 : 3.45 EER for R290 and 3.5 for R1234yf, CP2 : 3.75 EER for R290 and 3.8 for R1234yf)

See the impacts in terms of energy consumption and efficiency by each improvement option for all three base cases in Table 6, Table 7, Table 8 and Table 9.

Table 6: Impact of individual options on performance of the unit for split 3.5 kW (1% electricity price increase and for 50% heating hours)

	BC	HE1	HE2	LPM	CP1	HE3	HE4	CP2	MHE
SEER	6.00	6.86	7.21	6.28	6.41	6.74	7.17	6.67	6.21
Cooling consumption (kWh/y)	204	179	170	195	191	182	171	184	197
SCOP	4.00	4.41	4.66	4.01	4.27	4.25	4.41	4.27	4.08
Heating consumption (kWh/y)	543	492	466	541	508	511	492	508	532
TOTAL consumption (kWh/y)	747	671	636	736	699	692	663	692	729
Reduction kWh/y	0	76	111	10	47	54	84	55	18
Reduction kWh/y (%)	0%	10%	15%	1%	6%	7%	11%	7%	2%

Table 7: Impact of individual options on performance of the unit for split 7.1 kW (1% electricity price increase and for 50% heating hours)

	BC	HE1	HE2	LPM	CP1	HE3	HE4	CP2	MHE
SEER	5.80	6.50	6.82	6.06	6.23	6.51	7.00	6.43	6.00
Cooling consumption (kWh/y)	428	382	364	410	399	382	355	386	414
SCOP	4.00	4.32	4.54	4.01	4.28	4.24	4.40	4.29	4.08
Heating consumption (kWh/y)	1050	972	925	1047	981	991	955	979	1029
TOTAL consumption (kWh/y)	1478	1355	1289	1457	1380	1372	1310	1365	1443
Reduction kWh/y	0	124	189	21	98	106	169	113	35
Reduction kWh/y (%)	0%	8%	13%	1%	7%	7%	11%	8%	2%

Table 8: Impact of individual options on performance of the unit for single duct 2.6 kW, for R290 (cooling only)

	BC	HE1	HE2	CP1	CP2	DC
EER (100%)	3.16	3.32	3.43	4.18	4.5	3.41
EER (33% if inventer)				4.48	4.74	
SEER	2.2	2.3	2.38	3.18	3.39	2.37
TOTAL consumption (kWh/y)	157	149	145	108	101	145
Reduction kWh/y	0	8	12	49	56	12
Reduction kWh/y (%)	0%	5%	8%	31%	36%	8%

Table 9: Impact of individual options on cost and on performance of the unit for single duct 2.6 kW, for R1234yf (cooling only)

	BC	HE1	HE2	CP1	CP2	DC
EER (100%)	2.62	2.79	2.94	3.54	3.83	2.8
EER (33% if inverter)				4.41	4.67	
SEER	1.83	1.95	2.05	2.89	3.1	1.95
TOTAL consumption (kWh/y)	188	177	168	119	111	176
Reduction kWh/y	0	11	20	69	77	12
Reduction kWh/y (%)	0%	6%	11%	37%	41%	6%

For both base cases 1 and 2, the improvement option HE2 yields the highest reduction in total annual energy consumption, followed by option HE4.

Whereas for base case 3, the highest reduction in consumption is yield by improvement option CP2, followed by CP1.

6.2.2 Environmental improvement assessment

In Task 5 it is concluded that the energy consumption, emission of CO2-eq and the emission of SO2-eq is the most significant environmental impacts imposed by air conditioners. This environmental assessment will focus on these impacts for each of the improvements options and compare them. The improvement options are predominantly differentiated in their energy consumption which are presented in Table 6, Table 7, Table 8 and Table 9.

Besides the energy consumption, also the material composition is slightly changed. The following modifications are considered to compute the environmental impacts of the options:

- Option CP1, CP2 and CP2**: 10 % more copper
- Option CP1*: 10 % more copper and 10% more electronics (one additional PCB (printed circuit board))
- Option HE1, HE2, HE3 and HE 4 (UA increase ranging from 10 % to 80%): corresponding to the same increase in % of mass in copper and in aluminium depending on option.
- Option MHE: replacement of copper in condenser coil by aluminium, supposing a 1 to 1 metal volume for the outdoor coil;
- Option LPM: 20 % more electronics (1 additional PCB for standby, 1 additional PCB and a movement sensor, 1 temperature probe and cables to control crankcase power)

Additionally, the refrigerant charge is increased in some of the options. The assumed refrigerant charge for each improvement option is presented in the table below.

Table 10: Refrigerant charge for the different improvement options

	Refrigerant charge in kg									
	BC	**CP1**	**CP2**	**HE1**	**HE2**	**HE3**	**HE4**	**LPM**	**MHE**	**DC**
BC 1 R410A	0.98	0.98	0.98	1.10	1.17	1.18	1.31	0.98	1.11	0.98
BC 2 R410A	2.01	2.01	2.01	2.22	2.35	2.34	2.56	2.01	2.24	2.01
BC 3 R290	0.26	0.26	0.26	0.27	0.28	-	-	-	-	0.26
BC 3 R1234YF	0.51	0.51	0.51	0.54	0.56	-	-	-	-	0.51

Base case 1: 3.5 kW split unit

The impacts of the different improvement options for split 3.5 kW are presented in Figure 2, Figure 3 and Figure 4.

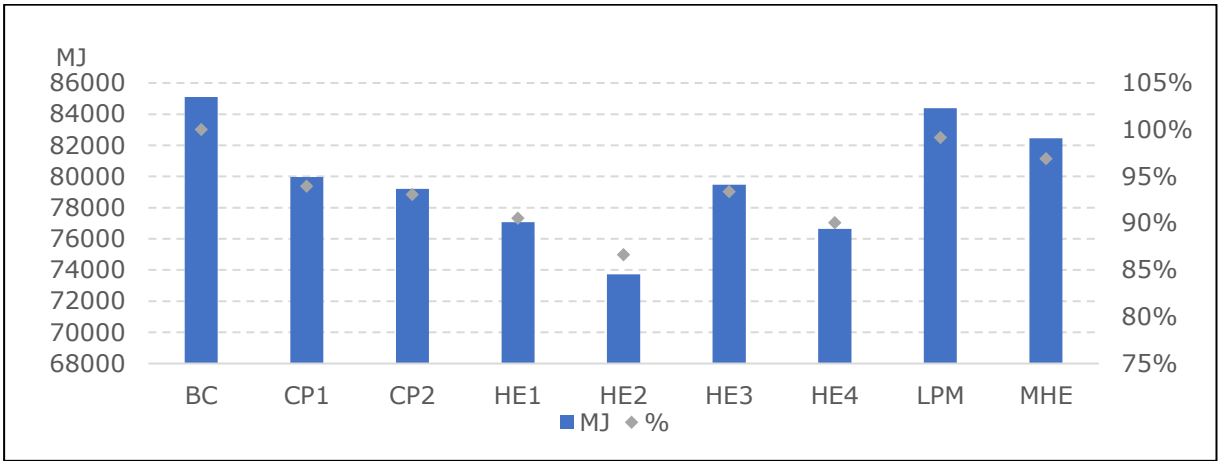

Figure 2: Total energy consumption of the base case and the different improvement options – for BC 1 (split 3.5 kW)

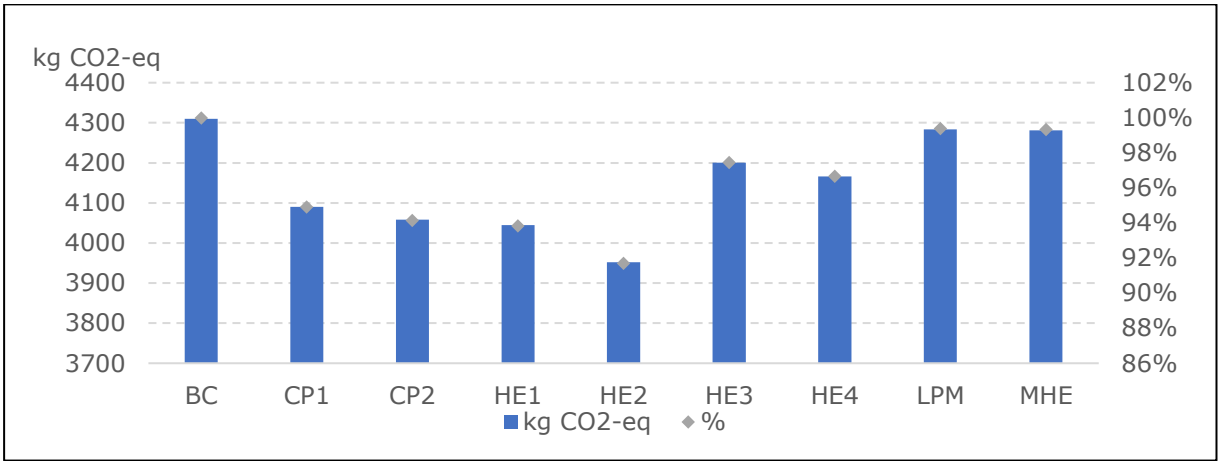

Figure 3: Emission of CO_2 (kg CO_2-eq) of the base case and the different improvement options – for BC 1 (split 3.5 kW)

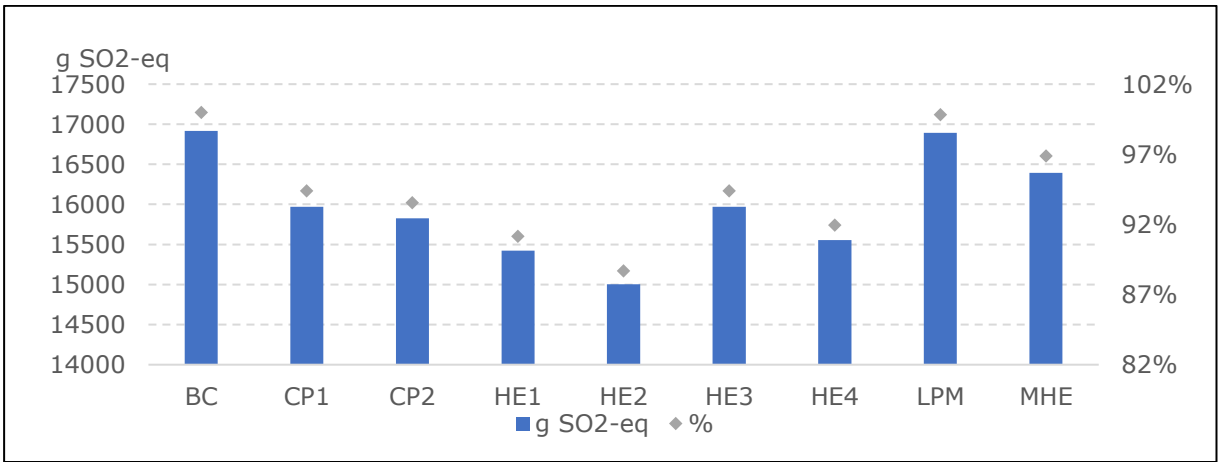

Figure 4: Emission of acidifying agents (g SO_2-eq) of the base case and the different improvement options – for BC 1 (split 3.5 kW)

The best improvement option is HE2 regarding all environmental indicators. The reduction in the different categories is:

- Total energy consumption: HE2 with a reduction of 11388 MJ (13 %)
- Emission of CO_2-eq: HE2 with a reduction of 358 kg (8 %)
- Emission of SO_2-eq: HE2 with a reduction of 1913 g (11 %)

The changed material composition only has limited influence on all impacts. The increased amount of refrigerant has an impact on the emission of CO_2-eq, so the HE2 option is less beneficial regarding emission of CO_2-eq but is still the option with the lowest impact.

Base case 2: 7.1 kW split unit

The impacts of the different improvement options for split 7.1 kW are presented Figure 5, Figure 6 and Figure 7.

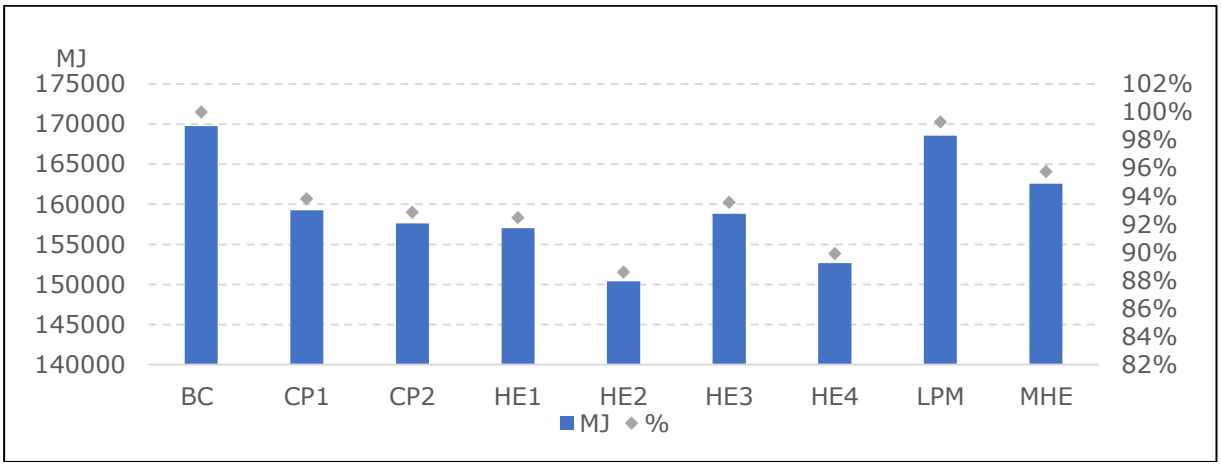

Figure 5: Total energy consumption of the base case and the different improvement options – for BC 2 (split 7.1 kW)

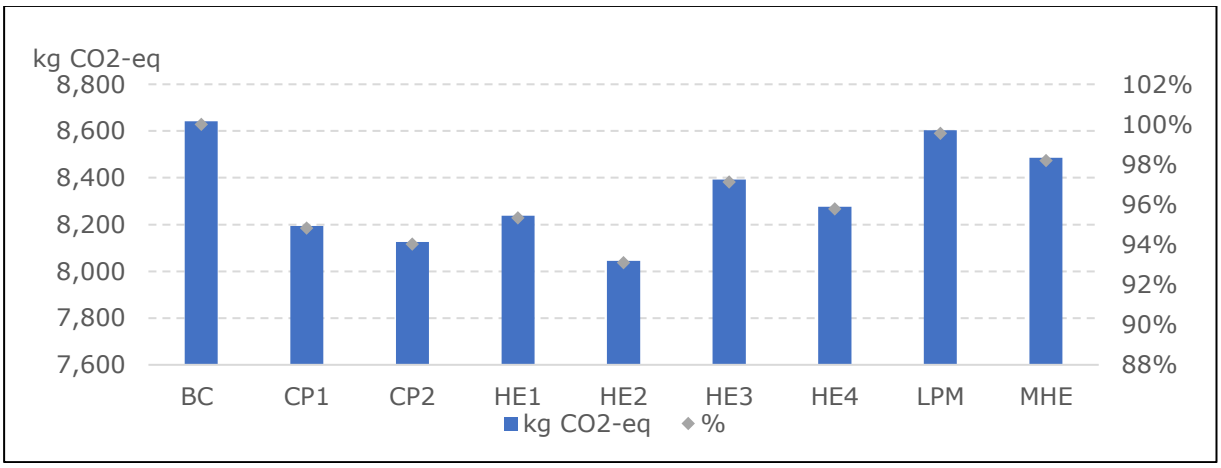

Figure 6: Emission of CO_2 (kg CO_2-eq) of the base case and the different improvement options – for BC 2 (split 7.1 kW)

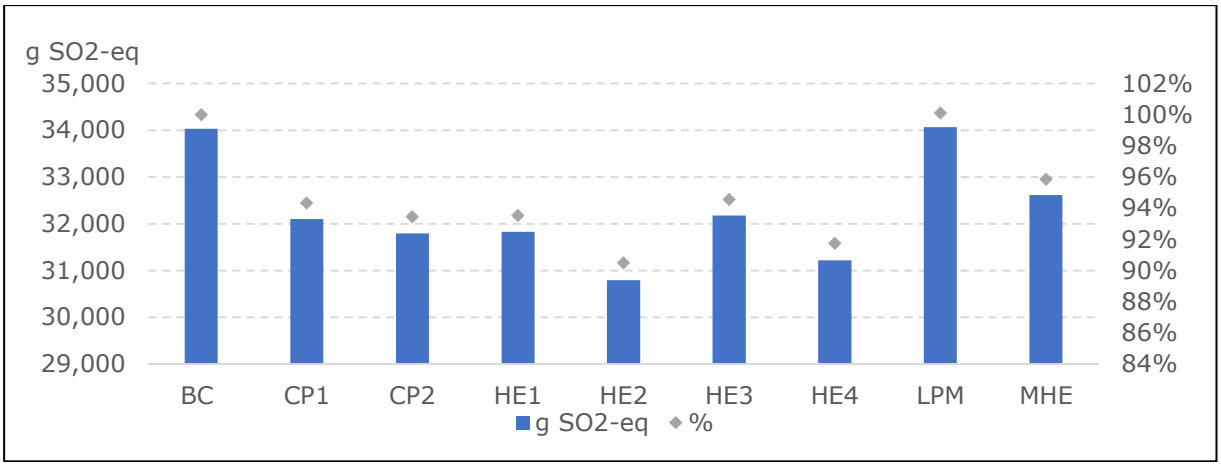

Figure 7: Emission of acidifying agents (g SO_2-eq) of the base case and the different improvement options – for BC 2 (split 7.1 kW)

For split air conditioners of 7.1 kW the options with the highest reductions are HE2 and HE4 despite the increased consumption of copper and aluminium and increased refrigerant charge. The option with the greatest reduction in each category is:

- Total energy consumption: HE2 with a reduction of 19358 MJ (11 %)
- Emission of CO_2-eq: HE2 with a reduction of 597 kg (7 %)
- Emission of SO_2-eq: HE2 with a reduction of 3229 g (10 %)

Due to higher energy consumption the leakage of refrigerant has smaller impact. With the conversion to R-32 the HE2 option will perform even better.

Base case 3: 2.6 kW portable unit – R290 and R1234yf

The impact of the different improvement options for single duct of 2.6 kW - R290 and R1234yf are presented in Figure 8, Figure 9 and Figure 10.

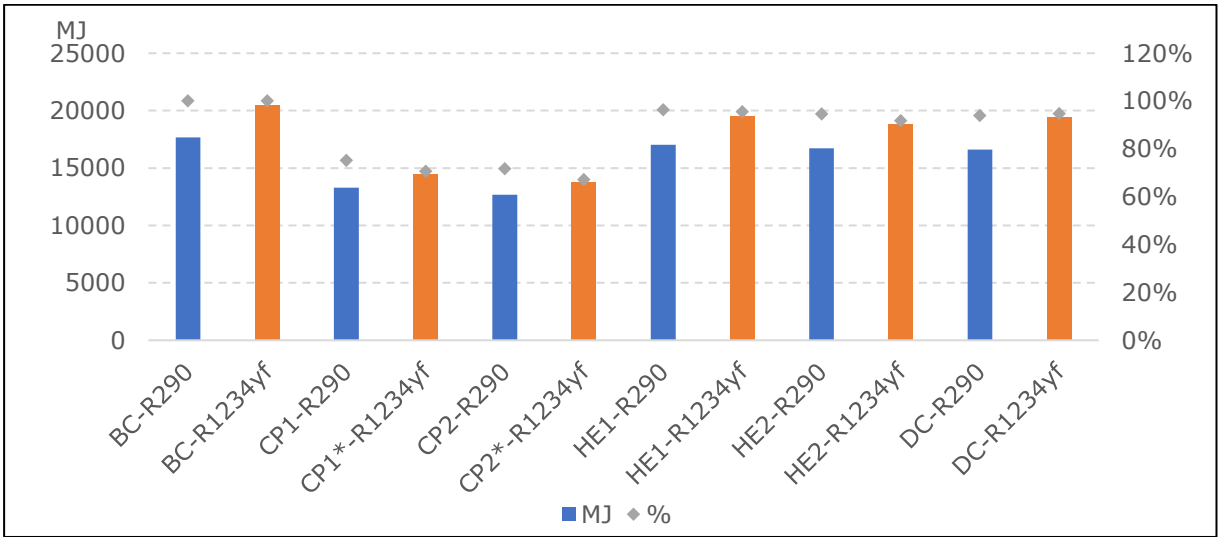

Figure 8: Total energy consumption of the base case and the different improvement options – for BC 3 (single duct 2.6 kW – R290 and R1234yf)

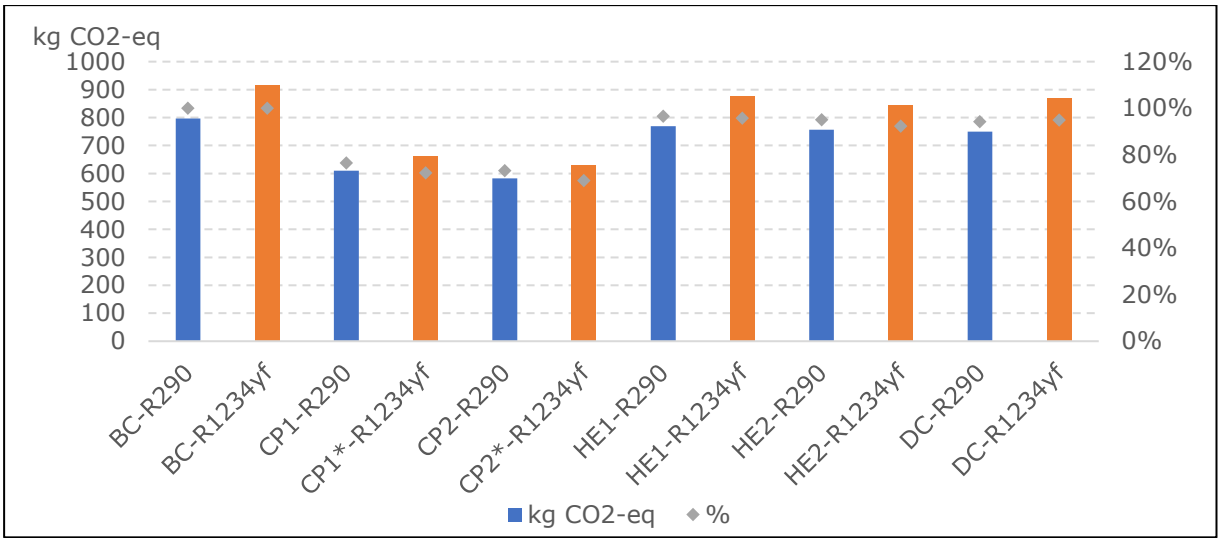

Figure 9: Emission of CO_2 (kg CO_2-eq) of the base case and the different improvement options – for BC 3 (single duct 2.6 kW– R290 and R1234yf)

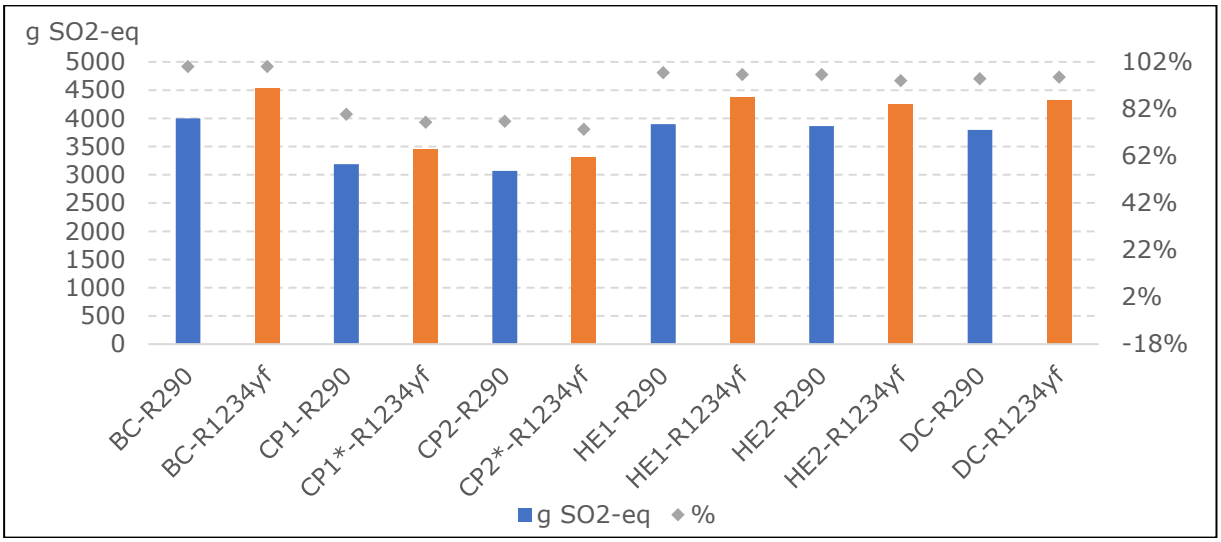

Figure 10: Emission of acidifying agents (g SO_2-eq) of the base case and the different improvement options – for BC 3 (single duct 2.6 kW– R290 and R1234yf)

For single duct 2.6 kW – R290 the options with the highest reductions are CP2 despite the increased consumption of copper and aluminium. The option with the greatest reduction in each category is:

- Total energy consumption: CP2 with a reduction of 5013 MJ (28 %)
- Emission of CO_2-eq: CP2 with a reduction of 214 kg (14 %)
- Emission of SO_2-eq: CP2 with a reduction of 917 g (12 %)

For single duct 2.6 kW – R1234yf the options with the highest reductions are CP2* despite the increased consumption of copper and aluminium. The option with the greatest reduction in each category is:

- Total energy consumption: CP2* with a reduction of 6723 MJ (33 %)
- Emission of CO_2-eq: CP2* with a reduction of 285 kg (31 %)
- Emission of SO_2-eq: CP2* with a reduction of 1208 g (27 %)

6.3 Costs

Cost model is based on the preparatory study[14] with adjustments, which include:

- price and mark-up adjustment (following Task 2 input),
- cost reduction for certain component that became more common as DC inverter rotary compressors for split units,
- Indications by manufacturers for new options.

Manufacturer overcosts (additional costs due to design options) are directly passed to the final end-user with the markup factors from manufacturer cost to manufacturer selling price.

Concerning the price increase of heat exchanger coils, the reference is the price in the preparatory study[14]. Having a unit with doubled capacity increases the manufacturing cost of heat exchangers by 100 %; and the price increases with power of 0.8 of the heat exchanger area increase. See the following equation:

$$cost_Heat_exchanger = A + B \times (UA^{0.8})$$

A and B are constants to be determined with the initial cost and its double at 100% increase of UA. The coefficient 0.8 gives higher price for large increase than for smaller ones, which is coherent with the larger adaptation requirements (for instance casing size change, fan size change).

In addition, the cost of the fan (larger fan), the cost of the refrigerant fluid mass used and the cost of the casing (bigger size) also vary. For these components, the same method is applied as for heat exchangers. These costs are shared between indoor and outdoor units with a respective prorate of 45% and 55% for BC1 and of 35% and 65% for BC2.

The cost of microchannel heat exchanger is 1.3 times the cost of Cu-Al composed tube and fin (of the outdoor unit).

Table 11: percentage of cost per component for three base cases, BC 3 with three refrigerant types

	BC 1, 3.5 kW	BC 2, 7.1 kW	BC 3, 2.6 kW R410A	BC 3, 2.6 kW R290	BC 3, 2.6 kW R1234YF
Compressor	18%	18%	23%	27%	23%
Condenser	18%	21%	16%	15%	12%
Evaporator	12%	11%	8%	8%	6%
Outdoor fan	9%	11%	9%	9%	7%
Indoor fan	6%	7%	6%	6%	5%
Working fluid	4%	3%	4%	0.4%	19%
Refrigerant line	6%	6%	8%	8%	6%
Controller + Elec	6%	5%	8%	7%	6%
Casing	10%	9%	12%	11%	10%
Others	11%	8%	6%	6%	6%
Total Original Parts	100%	100%	100%	100%	100%

Tables are given below by product type, indicating the overcost per option and more details on the corresponding component relative cost increase.

[14] Ecodesign Preparatory study for Lot 10 residential room conditioning appliances, 2009.

Table 12: Overcost of individual options for reversible 3.5 kW units

	Purchasing Price €	Manufacturer overcost estimate	Price increase %
Base case	743 €	-	-
CP1	831 €	Compressor price increase by 67 %	12%
CP2	919 €	Compressor price increase by 133 %	24%
HE1	871 €	Indoor unit price increase by 40 %	17%
HE2	1003 €	Indoor unit price increase by 80 %	35%
HE3	909 €	Outdoor unit price increase by 40 %	22%
HE4	1069 €	Outdoor unit price increase by 80 %	44%
LPM	765 €	Controller + Elec price increase by 50 %	3%
MHE	826 €	Outdoor unit price increase by 30 %	11%

Table 13: Overcost of individual options for reversible 7.1 kW units

	Purchasing Price €	Manufacturer overcost estimate	Price increase %
Base case	1 948 €	-	-
CP1	2 181 €	Compressor price increase by 67 %	12%
CP2	2 416 €	Compressor price increase by 133 %	24%
HE1	2 175 €	Evaporator price increase by 30 %	12%
HE2	2 410 €	Evaporator price increase by 60 %	24%
HE3	2 310 €	Condenser price increase by 30 %	19%
HE4	2 654 €	Condenser price increase by 60 %	36%
LPM	1 992 €	Controller +Elec price increase by 50 %	2%
MHE	2 190 €	Condenser price increase by 30 %	12%

For base case 1 and 2, the most expensive options are HE 4 where UA value of evaporator heat exchanger increased by 40 % or 30% respectively, while the cheapest improvement option is to achieve BAT low power mode consumption option LPM.

An overcost multiplier is used for options HE1 to HE4 if sound power litigation is required for the unit to respect maximum sound power levels in Regulation EC n°206/2012: 4% increase in heat exchanger price per dB attenuation.

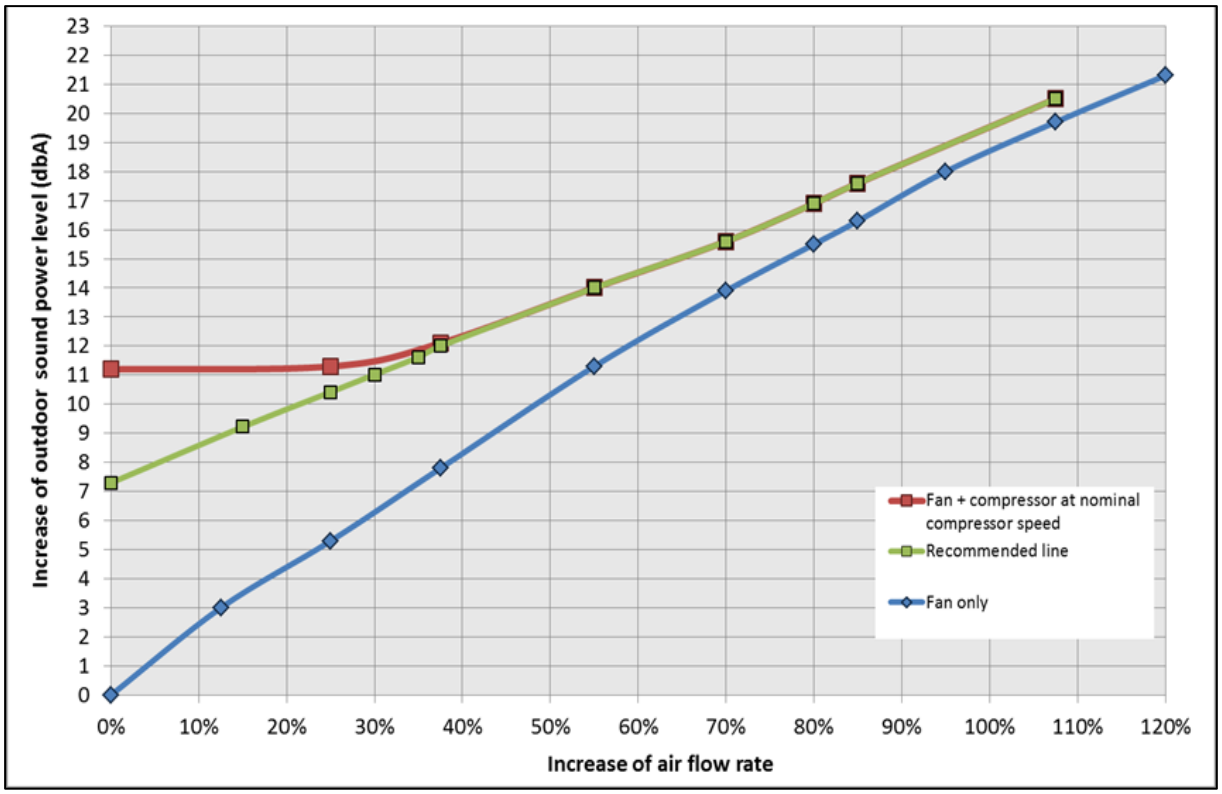

Figure 11: increase of sound power vs increase of airflow rate[15]

The graph above shows the increase of indoor/outdoor sound power as a function of the increase in airflow rate. For example increasing the indoor air flow rate by 40% leads to an increase of 8 decibels (8 db increase for 40% airflow rate and 0db for 0% airflow rate), and consequently 32% of indoor heat exchanger price increase (attenuator cost : 4% of heat exchanger per db attenuation), the same estimation method is used for outdoor air flow increase (green curve)

Overcost estimates of propane and R1234yf product versus R410A vary between 0 and 30 %[16] depending on what is included in the costs (only product modification or accounting also for manufacture adaptation and insurances which remains negligible, given the number of products to be produced per year).

The table below gives the variation in system component material costs compared to R410A[15].

Table 14: Variation in system component material costs of using R290 and R1234yf compared to R410A

	Typical variation of overall system material costs			
Refrigerant	Compressor	Heat exchangers	Piping and valves	Safety features
HC-290	5%	3%	1%	3%
HFC-1234yf	7%	7%	1%	2%

[15] Source: Daikin position on the draft task reports 3 to 7 for the review study of Ecodesign Lot 10, Feb 2018
[16] MONTREAL PROTOCOL ON SUBSTANCES THAT DEPLETE THE OZONE LAYER, UNEP, REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL, MAY 2012, VOLUME 2, DECISION XXIII/9 TASK FORCE REPORT, ADDITIONAL INFORMATION ON ALTERNATIVES TO OZONE-DEPLETING SUBSTANCES

Table 15: Variation of costs compared with R410A

Refrigerant	Cost %
HC-290	8%
HFC-1234yf	35%

The variation of refrigerant cost and charge is given in the table below[17].

Table 16: Variation of refrigerant costs and charge compared with R410A

Refrigerant	Refrigerant charge /R410A	Refrigerant price /R410A
HC-290	35%	25%
HFC-1234yf	80%	800%

Table 17: Overcost of individual options for single duct 2.6 kW units. For R290

	Purchasing Price	Manufacturer overcost estimate	Price increase %
Base case	386 €	-	-
CP1	523 €	Compressor price increase by 133 %	35%
CP2	608 €	Compressor price increase by 215 %	58%
HE1	396 €	Evaporator price increase by 10 %	3%
HE2	405 €	Evaporator price increase by 20 %	5%
DC	443 €	fans price increase by 100%	15%

Table 18: Overcost of individual options for single duct 2.6 kW units. *For R1234YF*

	Purchasing Price	Manufacturer overcost estimate	Price increase %
Base case	482 €	-	-
CP1	621 €	Compressor price increase by 125 %	29%
CP2	705 €	Compressor price increase by 200 %	46%
HE1	496 €	Evaporator price increase by 10 %	3%
HE2	508 €	Evaporator price increase by 20 %	5%
DC	538 €	fans price increase by 100%	12%

For base case 3, the most expensive option is the CP2 (using DC inverter rotary compressor with 3.75 EER for R290), while the cheapest options are HE1 and HE2.

6.4 Analysis LLCC and BNAT

In this section, the life cycle costs (LCC) of each individual improvement options have been presented, through mix and match of combinations and individual options, the least life cycle costs (LLCC) option is found, as well as the best not available technology (BNAT), which incorporate all identified improvement options.

6.4.1 Ranking of the individual improvement options

With the assumptions of tasks 2 and 5, the life cycle cost of the product has been computed, and a simple payback has been used to classify the options by order of merit.

Hypothesis for LCC calculation:

- Life time: 12 years (10 years for single duct)
- PWF[18] = life time, as discount rate of 4 % equals to escalation rate of energy prices

[17] REPORT OF THE TECHNOLOGY AND ECONOMIC ASSESSMENT PANEL MAY 2012
[18] Present Worth Factor (in economic calculations) discussed in Task 5.

- Electricity price: 0.195 €/kWh for 0-6 kW units and 0.187 €/kWh for 6-12 kW units.
- PWF: 0.71 (0.71 for single duct)
- Heating hours: 700 hours
- Maintenance for split only: 4% of the initial investment (purchase price plus installation; slightly increases with unit price).
- Installation for split only: 800 Euros.

For split units, the number of equivalent full load hours is of 1400 hours, as in the Regulation.

The options are listed in the following by the order of increasing payback times.

6.4.1.1 Base case 1: 3.5 kW split unit

Table 19: Ranking of individual options by simple payback time, reversible 3.5 kW unit (1% electricity price increase and for 50% heating hours)

	SEER	SCOP	Energy Cons (kWh)	Purchasing Price €	Energy Cost €	Payback time (years)	LCC
BC	6.00	4.00	747	743	103	-	3521
HE1	6.86	4.41	671	871	93	12	3585
CP1	6.41	4.27	699	831	97	13	3573
LPM	6.28	4.01	736	765	102	15	3537
HE2	7.21	4.66	636	1003	88	17	3721
HE3	6.74	4.25	692	909	96	22	3677
CP2	6.67	4.27	692	919	96	23	3691
HE4	7.17	4.41	663	1069	92	28	3865
MHE	6.21	4.08	729	826	101	34	3616

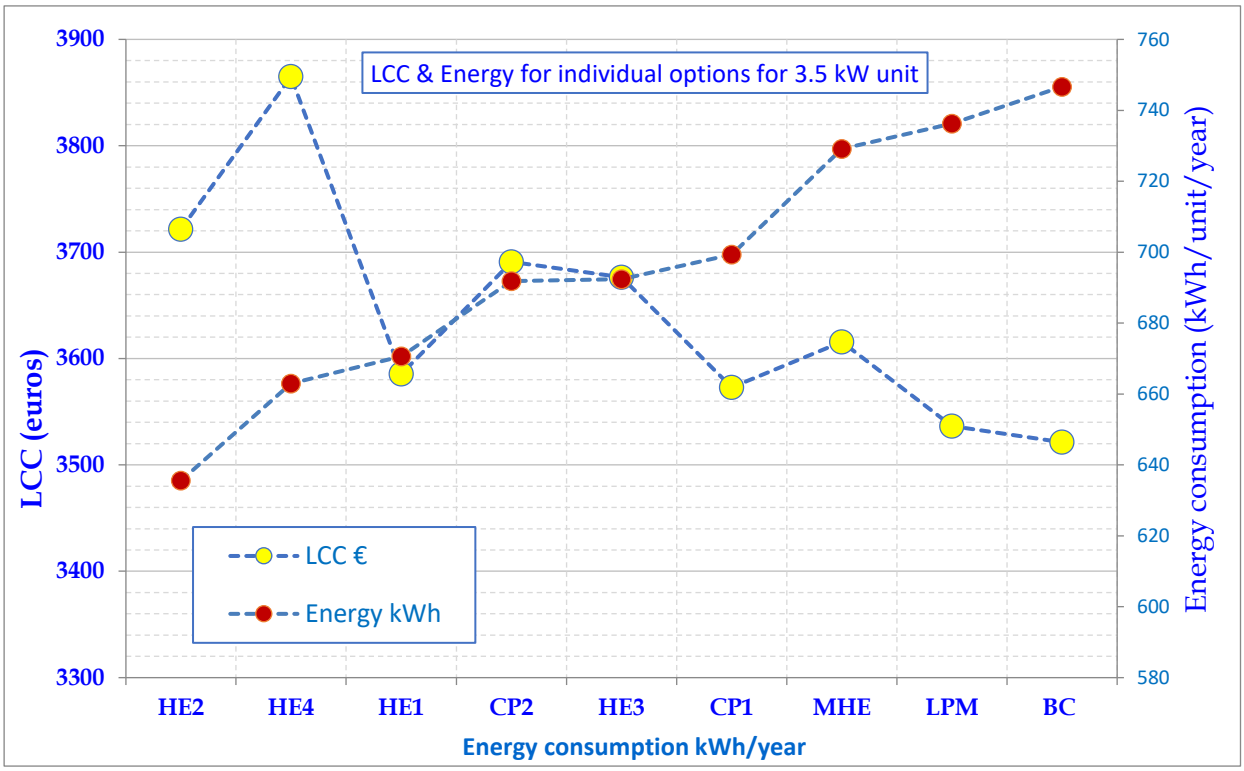

Figure 12: LCC and Energy consumption for split 3.5 kW unit, ranking by decreasing energy consummation

Most of the individual options have simple payback time higher than the lifetime of the product and thus aren't of interest for the customer on a LCC basis.

6.4.1.2 Base case 2: 7.1 kW split unit

Table 20: Ranking of individual options by simple payback time, reversible 7.1 kW unit (1% electricity price increase and for 50% heating hours)

	SEER	SCOP	Energy Cons (kWh)	Purchasing Price €	Energy Cost €	Payback time (years)	LCC
BC	5.8	4	1478	1929	196	-	6389
HE1	6.5	4.32	1355	2156	179	14	6419
LPM	6.06	4.01	1457	1973	193	16	6400
CP1	6.23	4.28	1380	2161	183	18	6465
HE2	6.82	4.54	1289	2391	171	18	6551
HE3	6.51	4.24	1372	2290	182	26	6582
MHE	6.09	4.2	1408	2170	187	26	6519
CP2	6.43	4.29	1365	2397	181	31	6678
HE4	7	4.4	1310	2635	173	32	6827

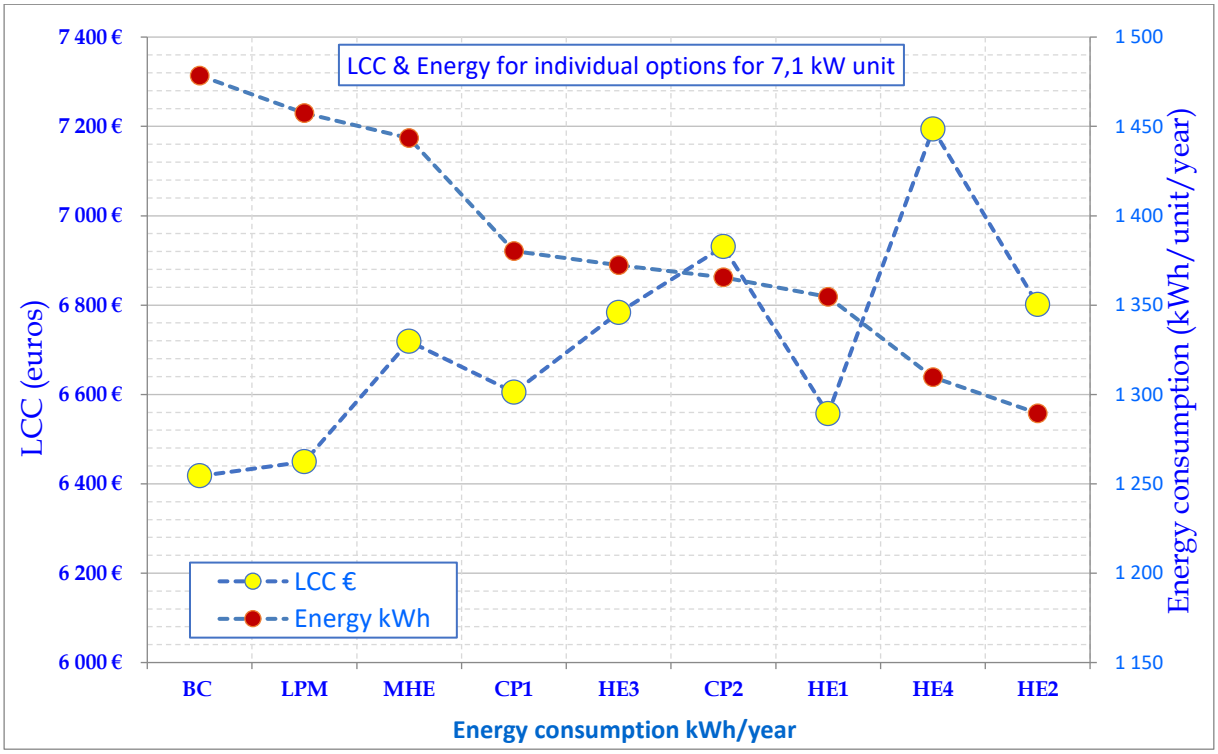

Figure 13: LCC and energy consumption for split 7.1 kW unit, ranking by decreasing energy consumption

All of the individual options have simple payback time higher than the lifetime of the product and thus aren't of interest for the customer on a LCC basis.

6.4.1.3 Base case 3: 2.6 kW portable unit

Table 20: Ranking of individual options by simple payback time, single duct 2.6 kW unit, R290

	EER	SEER	Energy Cons (kWh)	Purchasing Price €	Energy Cost €	Payback time (years)	LCC
HE1	3.32	2.3	149	396	21	9	602
HE2	3.43	2.38	145	405	20	11	605
CP1	4.18	3.18	108	523	15	20	672
CP2	4.5	3.39	101	608	14	29	747
DC	3.41	2.37	145	443	20	34	643
BC	3.16	2.2	157	386	22		603

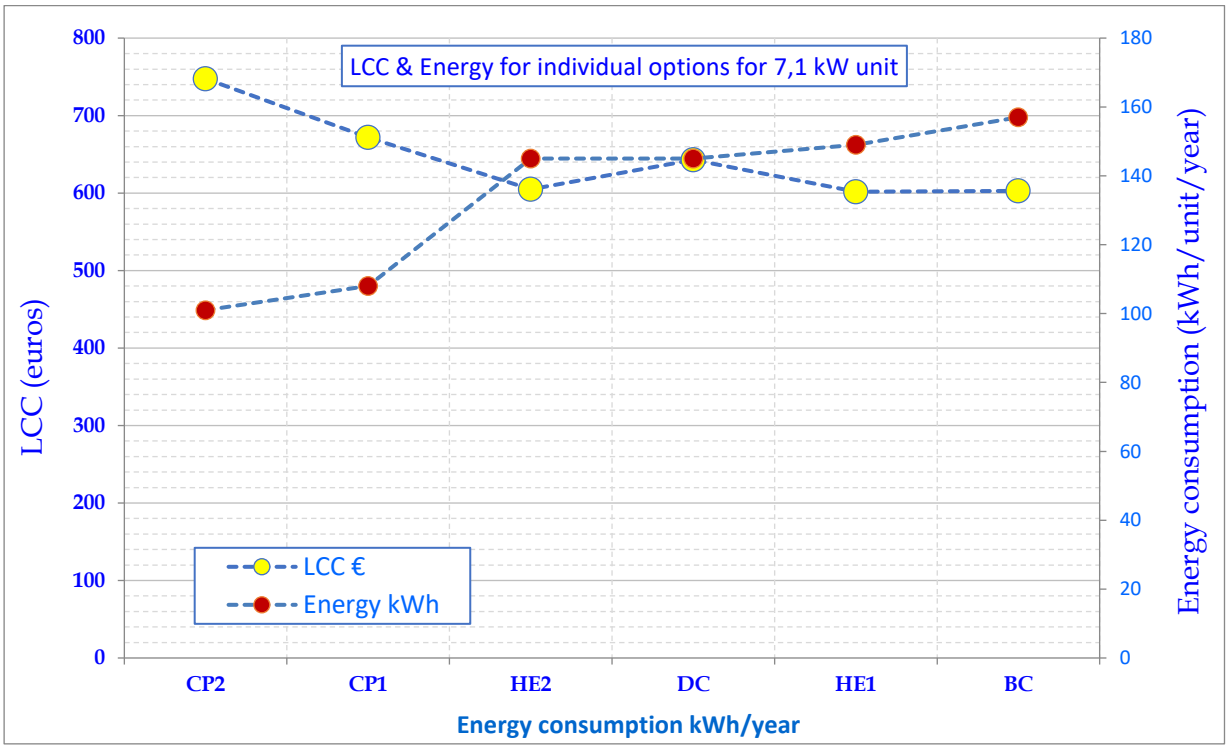

Figure 14 : LCC and energy consumption for single duct 2.6 kW unit (only cooling), R290

Table 21: Ranking of individual options by simple payback time, single duct 2.6 kW unit, R1234yf

	EER	SEER	Energy Cons (kWh)	Purchasing Price €	Energy Cost €	Payback time (years)	LCC
BC	2.62	1.83	188	482	26	-	742
HE1	2.79	1.95	177	496	24	9	740
HE2	2.94	2.05	168	508	23	9	740
CP1	3.54	2.89	119	621	16	15	785
CP2	3.83	3.1	111	705	15	21	858
DC	2.8	1.95	176	538	24	34	781

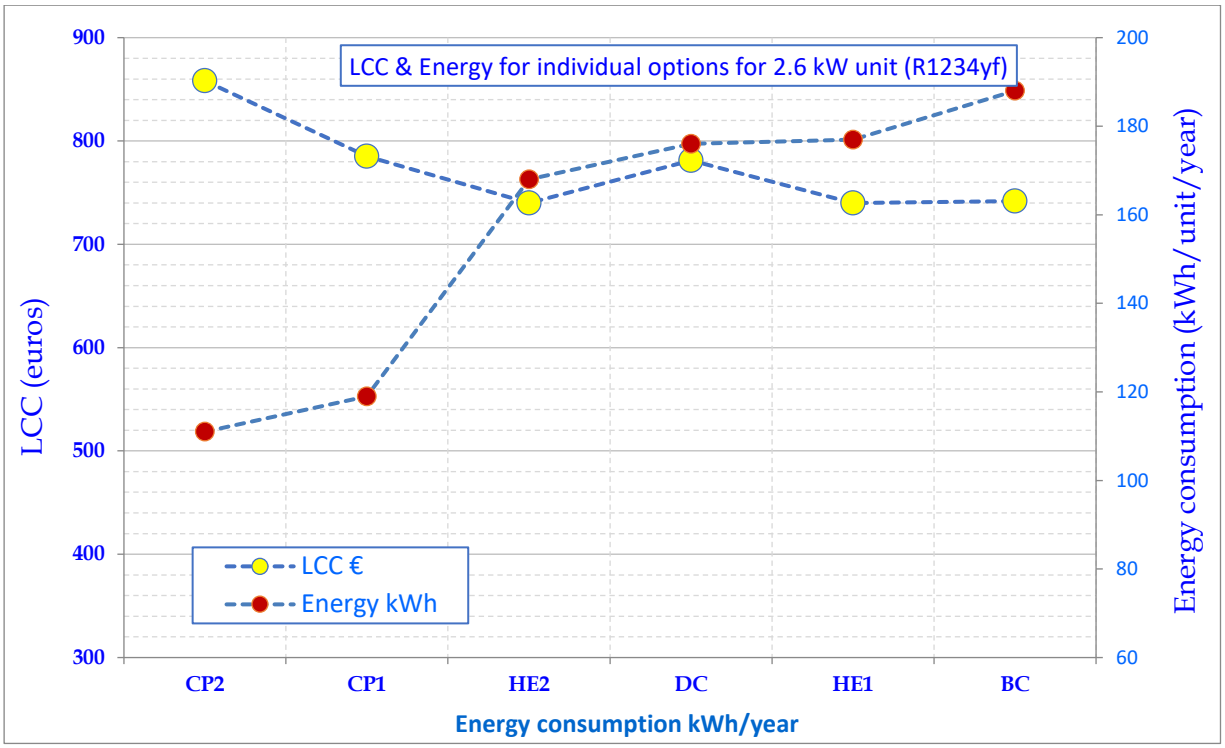

Figure 15 : LCC and energy consumption for single duct 2.6 kW unit (only cooling), R1234yf

Most of the individual options have simple payback time higher than the lifetime of the product (10 years) and thus aren't of interest for the customer on a LCC basis.

6.4.2 Positive or negative effects of improvement options

Interactions between options are taken into account via the thermodynamic based model used to compute the individual EER and COP values.

Regarding negative effects, design measures corresponding to increasing UA values require increased air flows and thus lead to higher sound power levels for options HE1, HE2, HE3 and HE4.

The effect of increasing air flow, which leads to higher sound power level, is known, however it is a difficult task to link air flow and sound power, because even though air flow is clearly one of the main factors in determining sound power levels, others important factors vary with the unit design according for instance to the type of fan, the design of the air flow pathways (more or less pressure losses), the size of the casing (larger casing allows both to include more noise insulation and to benefit from a larger mass to absorb vibrations). The approach in this review study thus consisted in observing existing units, with however a myopic view, as the number of products with known air flow as well as sound power level is limited.

For split units, information supplied by some of the Eurovent Certita Certification manufacturers and by other manufacturers[19] has been compiled to extract highest air flows that can still comply with indoors and outdoors sound power requirements according to Regulation (EU) N° 206/2012. Sound power levels and air flows are given in Table 22.

Table 22: Sound power and air flow for base case and larger air flows, split units

[19] Data collection on current and BAT technology, July - September 2017

Base Case			
Product range		**0 - 6 kW**	**6 - 12 kW**
Indoor	Sound power dB(A) (wall unit)	57	60
	Air flow m3/h (wall unit)	600	1200
Outdoor	Sound power dB(A)	62	66
	Air flow m3/h	1500	2915
Products with larger air flows			
Indoor	Sound power dB(A) (wall / cassette)	60/54	64/62
	Air flow m3/h (wall / cassette)	1080/1080	2100/1850
Outdoor	Lwo	63	66
	Air flow	2400	6800

Regarding the 0-6 kW range outdoor unit, increasing air flows to values between 2400 m^3/h and 3000 m^3/h is feasible. 2700 m^3/h was kept to match the 65 dB(A) regulation limit.

Regarding the 0-6 kW range indoor unit of wall type, the maximum air flow for 60 dB(A) observed is 1080 m^3/h. Interestingly, cassette indoor units may allow to reach much lower sound power level with the same air flow for this capacity range.

These air flow potential increases and corresponding UA value (+ 80%) increase have been used for option HE2 and HE4 for base case 1.

Regarding the 6-12 kW range outdoor unit, increasing air flow up to more than 6800 m^3/h is feasible, although not used in practice. When comparing to the base case, the impact of the design choices appears clearly: with twice as air flow as for the base case, it is still possible to reach the same sound power level.

Regarding the 6-12 kW range indoor unit of wall type, increasing air flow up to about 2100 m^3/h for wall units is feasible, although not used in practice. Interestingly, in that capacity range, cassette indoor units do not allow to reach much lower sound power level at equivalent air flow.

These air flow potential increases and corresponding UA value have been kept to a low end value of + 60% increase to match option HE2 and HE4 for base case 2. This is in line with the fact that single split wall units of 7.1 kW BAT units are not as efficient as 3.5 kW units.

For single duct, there is even less available information, which is presented in Table 23 below.

Table 23: Sound power and air flow for base case and BAT, single duct 2.6 kW unit

		Base case (R410A)	**BAT product example**
Whole unit	Sound power dB(A)	63	64
Evaporator	Air flow m^3/h	300	360
Condenser	Air flow m^3/h	500	500
Whole unit	EER	2.65	3.6

For single duct units, the BAT level with slightly larger air flow in evaporator side was found via an actual product on the EU market (see Table 23 BAT product example). Based on

this, it is then assumed that UA increase to 20 % on the evaporator side, or 360 m3/h would lead to 65 dB(A) sound power levels.

The options were simulated to reach close to maximum sound power according to regulation for 3.5 kW unit, indoor and outdoor, and for single duct unit. Hence to reach BNAT levels of efficiency, it is not possible to further decrease sound power levels than the current regulation level. Note however that 70 dB(A) is high for 7.1 kW units, because it fits better sound power levels of more units with larger sizes (10 to 12 kW). Future sound power regulations would better fit physical principles if sound power limitations were proportional to the unit size.

For the 7.1 kW unit, sound power levels of units with larger heat exchanger is lower than regulation thresholds. Stakeholders have suggested that market acceptance of large air flows on large wall units may be limited. On the other hand, on the current market, larger air flows in e.g. 10 kW units are used. Hence, limited efficiency of best large wall single split of 7.1 kW on the EU market is probably due to economic reasons.

As already discussed in Task 3, the increase in air flow at HE2 level for split air conditioners might be an issue because of too low air temperature blown in heating mode and decreased dehumidification capability.

6.4.3 Cumulative improvement

Improvement impact has been computed for a large number of possible combinations. Only the lowest LCC value at a given energy consumption level are shown (bottom line of all LCC points). BNAT option is the combination of all improvement options together, this means that in some cases this leads to higher efficiency than the BAT (based on actual product information on the current market) and closer to BNAT levels indicated in Task 4.

The summary of energy gains, price increase and LCC variations are gathered in the tables with computed energy consumption and economic information. Graphs are also drawn to show LCC variation with energy consumption and LLCC and BNAT values.

For split units, it has been explained in Tasks 3 and 5 that only part of the units is thought to be used in heating mode, 50 % for new units on average in Europe (this is an increase from the existing stock which is assumed with 30% of the full load heating hours). The impact of changing the equivalent number of full load heating hours to 30% is shown in Annex 1.

For base case 3 single duct air conditioners, the improvement options impacts, LLCC and BNAT have been assessed for current EER metrics and proposed new SEER metrics which accounts for infiltration.

6.4.3.1 Base case 1: 3.5 kW split unit

Regarding the 0 - 6 kW split units, SEER BNAT level of 11.4 can be reached with options simulated for 3.5 kW base case in Task 6 (same as BNAT value in Task 4). The model however, due to the simplifications made in the model and in the choice of options, was not able to deliver the corresponding SCOP level of 6.3, the BNAT value derived in Task 4 based on actual products improved by using microchannel heat exchanger (only 5.9 could be reached). This is a modelling bias[20], -5 %, which is acceptable for a model, however,

[20] This is probably linked to changes in detailed designs of heat exchangers favoring heating versus cooling, which are not included in the model.

for considering the BNAT of the entire range of 0 – 6 kW split units, it is better to keep the Task 4 value of 6.3.

As mentioned previously, for 700 heating full load equivalent hours, the LLCC value for 3.5 kW split unit matches lower efficiency level than the one of the base case. Therefore two negative options are simulated; they correspond to a decrease in outdoor heat exchanger size (-10%UA_cond and -20%UA_cond) and consequent energy consumption increase; cost corrections follow the same methodology developed to compute the impact of heat exchanger increase.

Table 24: Ranking of individual and combined options (used to find LLCC) by simple payback time, reversible 3.5 kW unit (50% heating hours and 1% electricity price increase)

	SEER	SCOP	TOTAL	Purchasing price €	Instal-lation	Mainten-ance	Initial Investment	Energy Cost €	Payback time (years)	LCC
-20% UA_Cond	5.44	3.81	795	692	800	60	1492	110	-	3525
-10% UA_Cond	5.77	3.92	766	718	800	61	1518	106	-	3515
BC	6	4	747	743	800	62	1543	103	-	3521
LPM	6.28	4.01	736	765	800	63	1565	102	15	3537
CP1	6.41	4.27	699	831	800	65	1631	97	13	3573
HE1 (LLCC+)	6.86	4.41	671	871	800	67	1671	93	12	3585
HE1+LPM	7.23	4.42	660	893	800	68	1693	91	13	3601
HE1+CP1	7.29	4.71	629	959	800	70	1759	87	13	3646
HE1+CP1+LPM	7.71	4.73	618	981	800	71	1781	85	13	3660
HE1+HE3+CP1+LPM	8.72	5.05	570	1121	800	77	1921	79	15	3788
HE2+HE3+CP1+LPM	9.21	5.36	538	1278	800	83	2078	74	19	3968
HE2+HE3+CP2+LPM	10.04	5.4	524	1366	800	87	2166	72	20	4075
HE2+HE4+CP1+LPM	9.87	5.6	512	1412	800	88	2212	71	21	4122
HE2+HE4+CP2+LPM	10.88	5.63	498	1527	800	93	2327	69	23	4269
HE2+HE4+CP2+LPM+MHE	11.42	5.91	474	1689	800	100	2489	66	25	4469

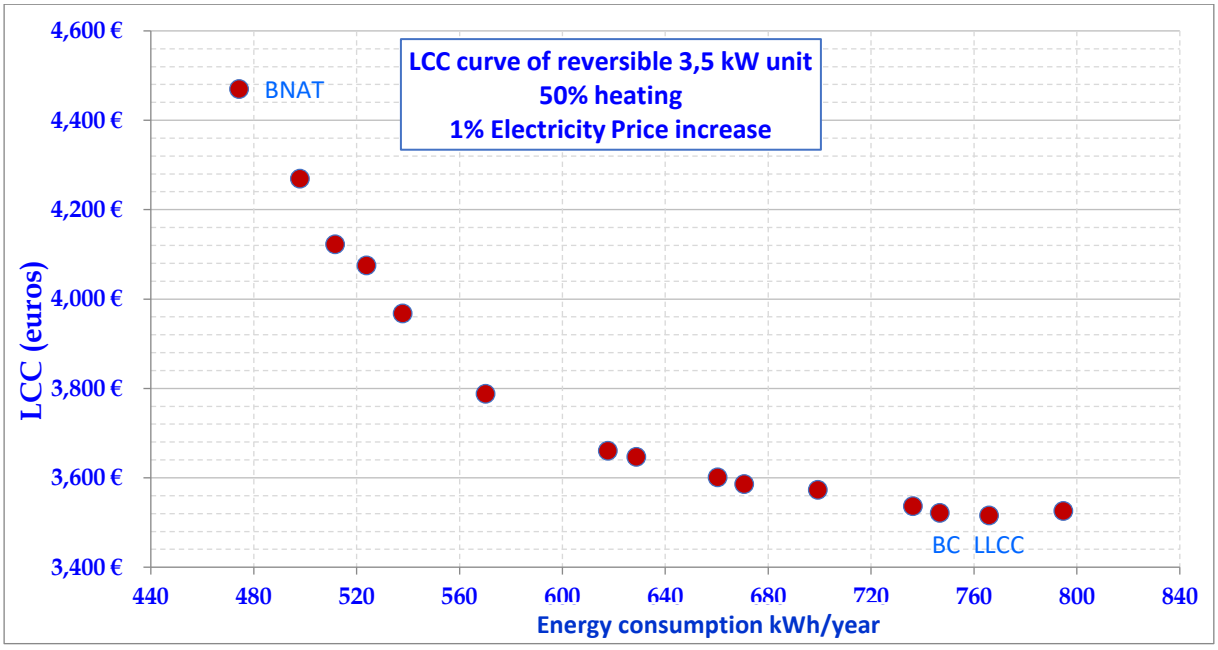

Figure 16: LCC curve of reversible 3.5 kW unit (50% heating hours and 1% electricity price increase)

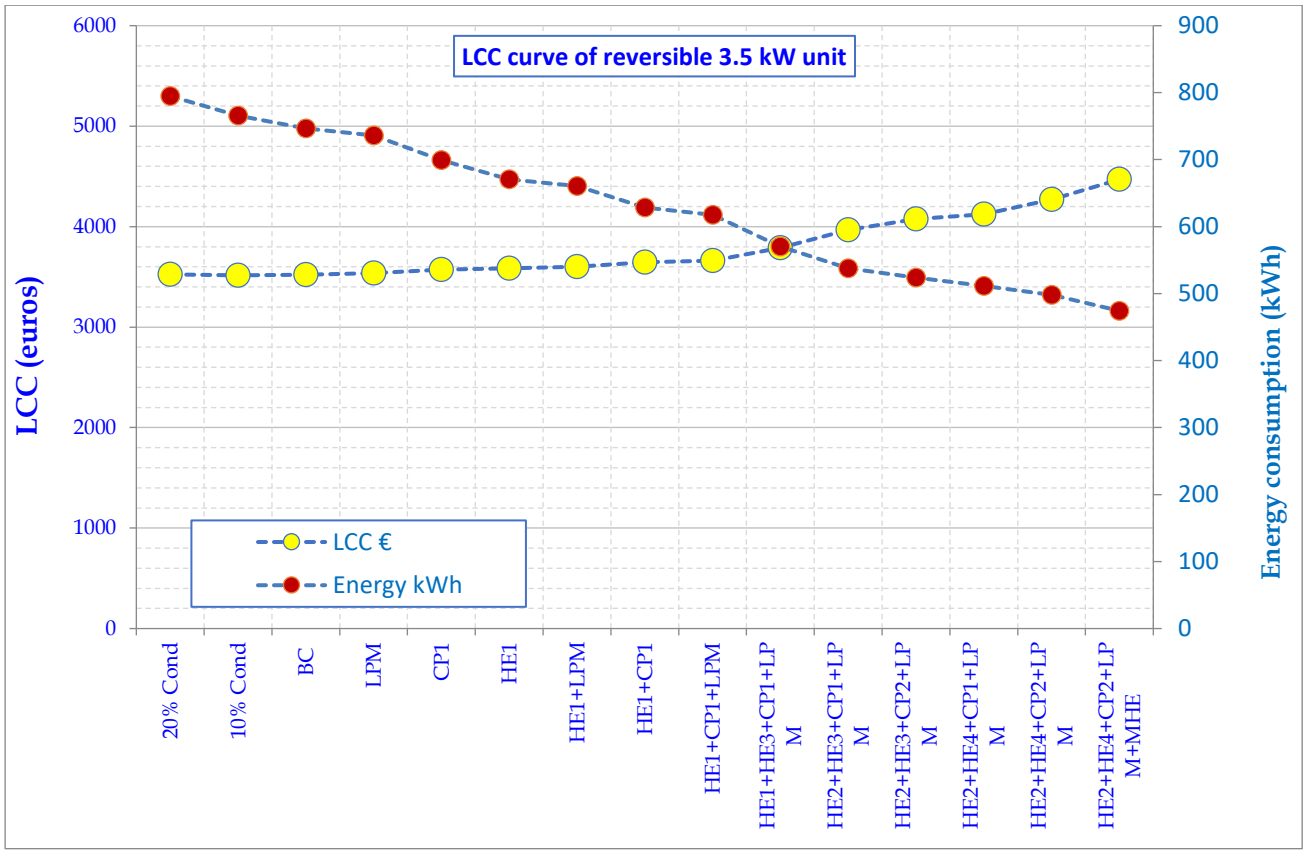

Figure 17: LCC & Energy consumption of reversible 3.5 kW unit (50% heating hours and 1% electricity price increase)

LLCC curve is relatively flat between the option -10% UA_cond (SEER of 5.77 and LLCC of 3515 Euros), the LLCC (base case, SEER of 6.00 and LLCC of 3521 Euros) and the option HE1 (SEER of 6.86 and LLCC of 3585 Euros) with a relative difference of LCC of 1.8% and 0.2% for HE1 and -10%UA_cond respectively compared to the base case. For a scenario of 30% heating hours and 0% electricity price increase, relative differences can increase to 3.5% and 0.65% respectively. The LLCC chosen is then the base case:

- SEER 6.00
- SCOP 4.00
- LCC = 3521 €

BNAT (all options): SEER= 11.4, SCOP = 5.9, LCC= 4469 €, 25 years of payback time

To summarize:

- LLCC: Base case, SEER 6.00, SCOP 4.00
- BAT: SEER 10.5, SCOP 6.2
- BNAT: SEER 11.4, SCOP 5.9

Environmental impacts of the LLCC and BNAT – 50% heating

The impacts of the base case (LLCC) and the BNAT for split 3.5 kW are presented in Figure 18, Figure 19 and Figure 20. The presented impact categories are the energy consumption, emission of CO_2-eq and emission of SO_2-eq.

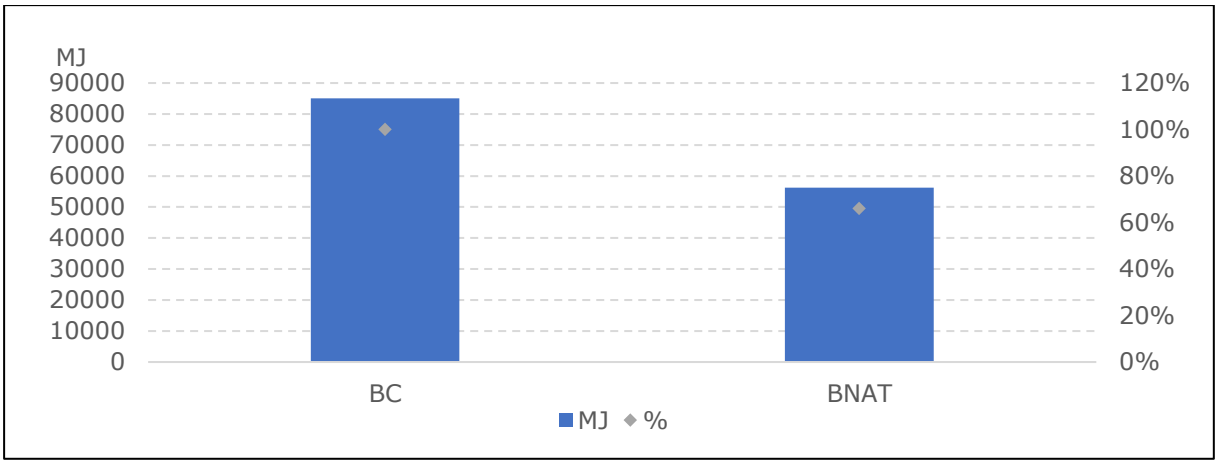

Figure 18: Total energy consumption of the base case, LLCC and BNAT – for BC 1 (split 3.5 kW)

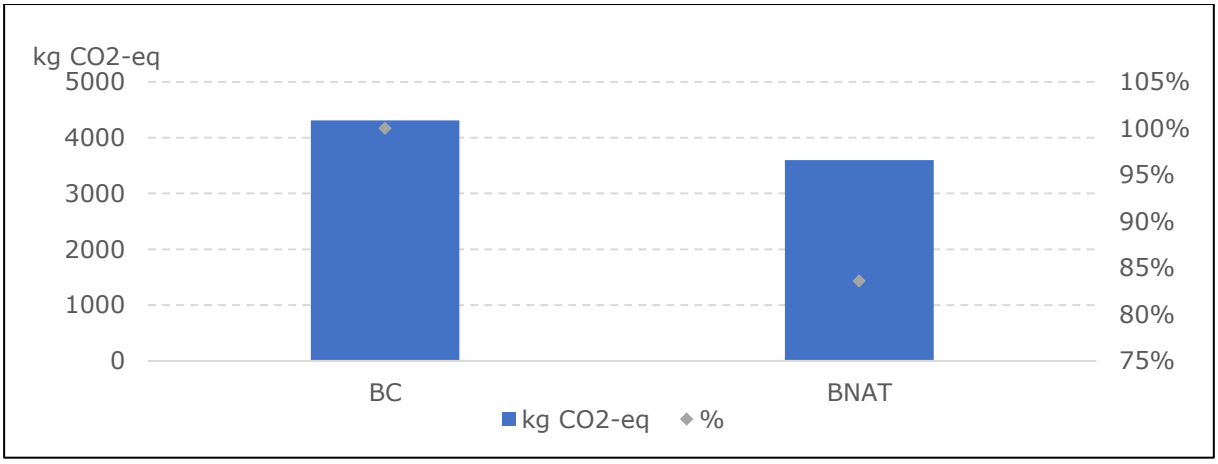

Figure 19: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 1 (split 3.5 kW)

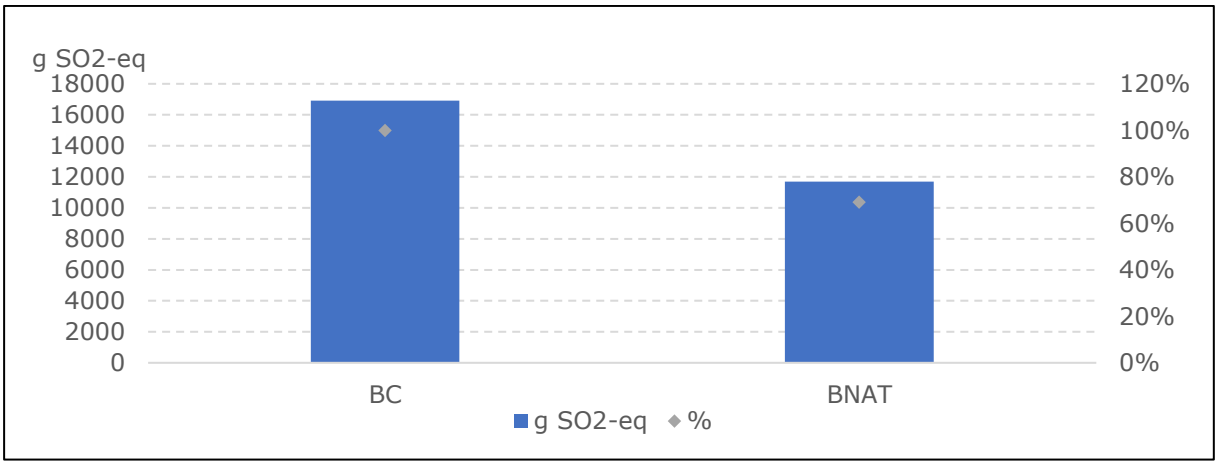

Figure 20: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 1 (split 3.5 kW)

The BNAT have environmental improvements in all categories compared with the base cases (LLCC). The increased material composition has only limited impact, but the increased charge of refrigerants is visible in the emission of CO_2-eq as the reductions in percentage from base case are lower compared to energy consumption and emission of SO_2-eq.

6.4.3.2 Base case 2: 7.1 kW split unit

Regarding 6 - 12 kW split units, BAT level simulated in Task 6 for 7.1 kW unit (SEER 11 and SCOP 5.7) are thought to be too high when looking at best available units in the whole capacity range; BAT levels of SEER 8 and SCOP 4.5 were identified in Task 4. But as explained in Task 4, there is no physical reason why efficiency levels of 3.5 kW units could not be reached by larger units. It is thus assumed possible to achieve the BNAT target values in Task 4 (same as for 3.5 kW split wall units, SEER 11.4 and SCOP 5.9). LLCC could also be too high considering that there are other than single split wall units in that product range. It has been seen in Task 2 that cassette air conditioner potential for improvement on a LCC basis is most likely lower (price of efficiency premium increases faster than for split air conditioners).

Table 25: Ranking of individual and combined options (used to find LLCC) by simple payback time, reversible 7.1 kW unit (50% heating hours and 1% electricity price increase)

	SEER	SCOP	TOTAL	Purchasing price €	Instal-lation	Mainte nance	Initial investment	Energy Cost €	Payback time (years)	LCC
-20% UA_cond	5.11	3.78	1597	1802	800	104	2602	212	9	6390
-10% UA_cond	5.49	3.90	1530	1875	800	107	2675	203	11	6391
BC	5.8	4	1478	1948	800	110	2748	196	0	6418
HE1 (LLCC+)	6.5	4.32	1355	2175	800	119	2975	179	14	6557
HE1+LPM	6.83	4.34	1332	2219	800	121	3019	176	14	6585
LPM	6.06	4.01	1457	1992	800	112	2792	193	16	6449
HE1+CP1	6.97	4.63	1264	2408	800	128	3208	167	16	6756
HE1+CP1+LPM	7.34	4.64	1244	2452	800	130	3252	165	16	6789
HE2+CP1+LPM	7.71	4.86	1187	2687	800	139	3487	157	19	7046
HE1+HE3+CP1+LPM	8.29	4.92	1153	2813	800	145	3613	153	20	7181
HE2+HE3+CP1+LPM	8.73	5.17	1097	3048	800	154	3848	145	22	7439
HE2+HE4+CP1+LPM	9.45	5.39	1042	3393	800	168	4193	138	25	7862
HE2+HE4+CP2+LPM	10.26	5.42	1017	3629	800	177	4429	135	27	8171
HE2+HE4+CP2+LPM+MHE	10.62	5.53	994	3989	800	192	4789	132	32	8667

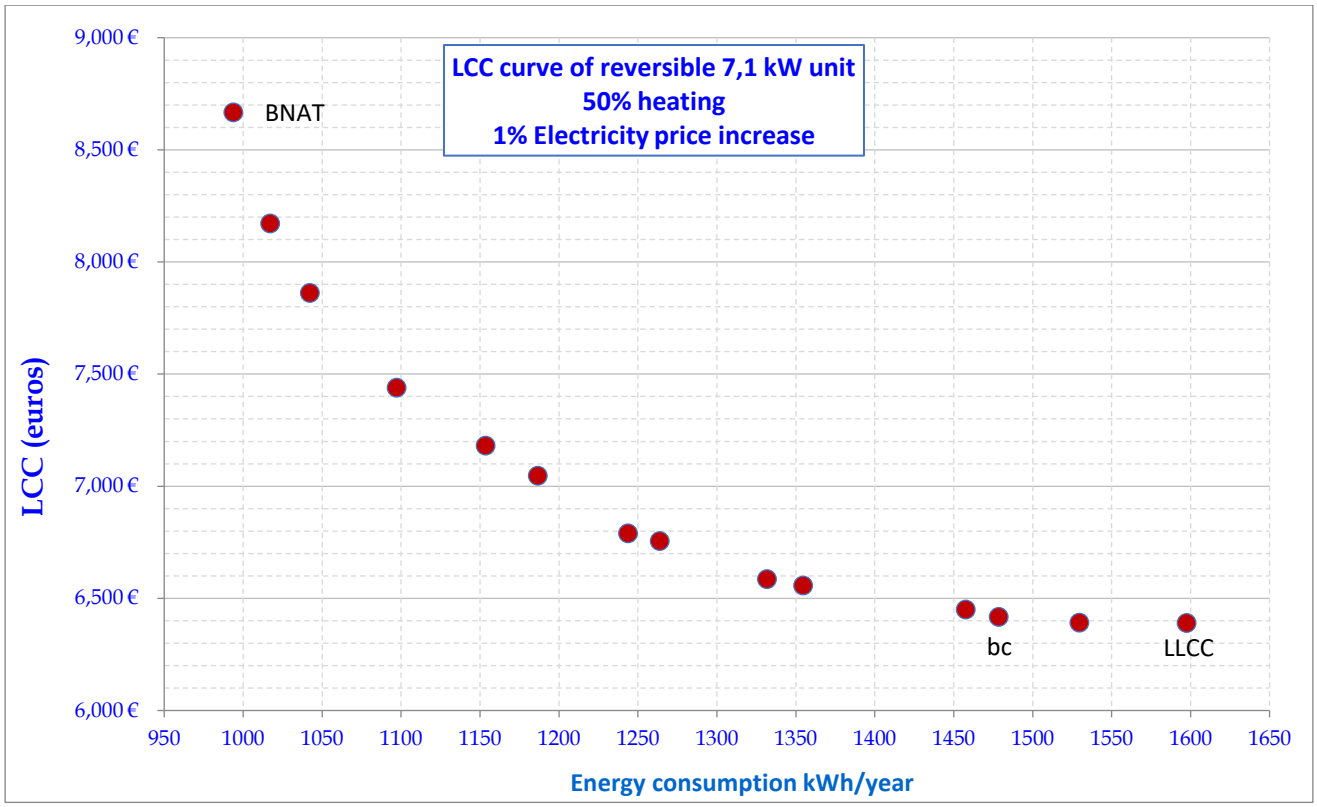

Figure 21: LCC curve of reversible 7.1 kW unit (50% heating hours and 1% electricity price increase)

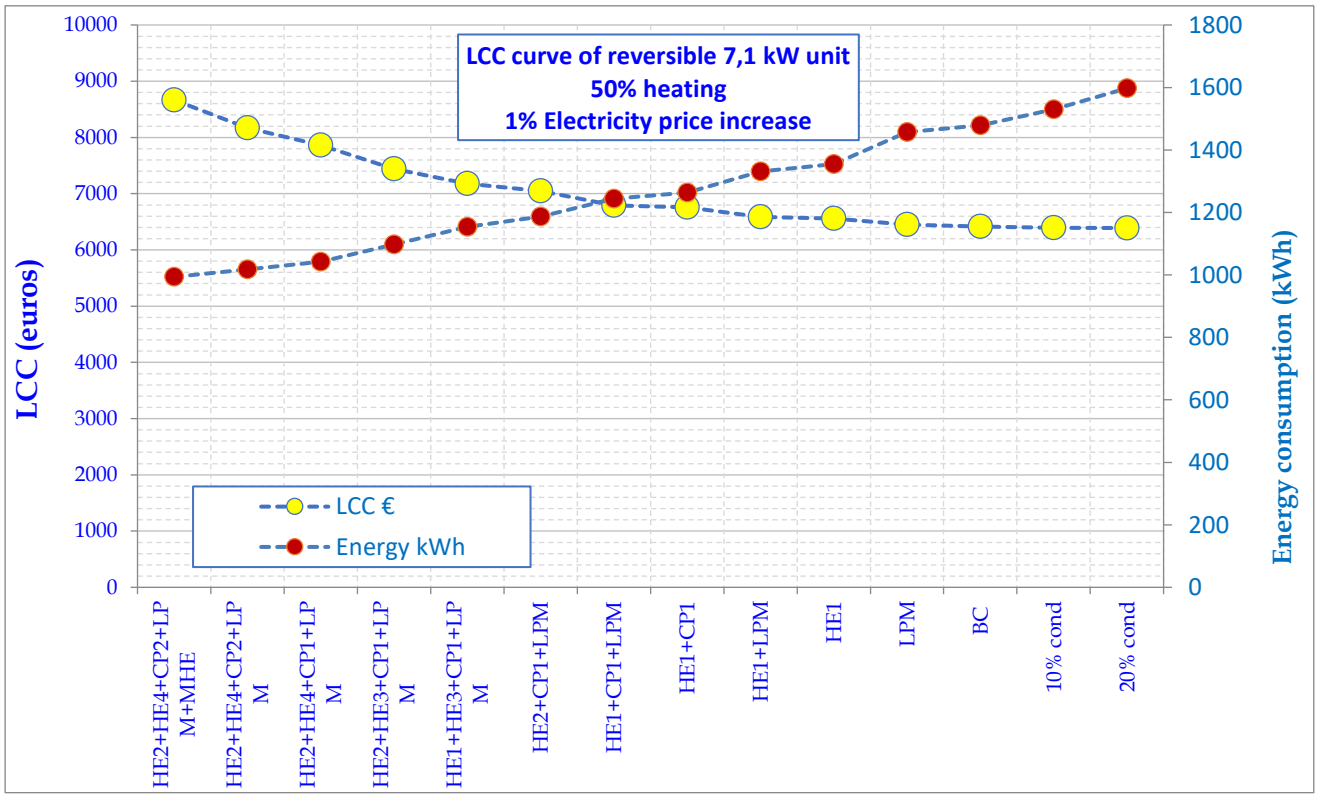

Figure 22: LCC & Energy consumption of reversible 7.1 kW unit (50% heating hours and 1% electricity price increase)

As mentioned previously, for 700 heating full load equivalent hours, the LLCC value for 7.1 kW is below the base case. The LLCC is the negative option of reducing the outdoor heat exchanger size by 10%, which is noted as -10% UA_cond.

LLCC curve is relatively flat between the LLCC (the option -10%Ua_cond, SEER of 5.5 and LLCC of 6391 Euros) and the option HE1 (SEER of 6.5 and LLCC of 6557 Euros) with a relative difference of 2.2% and 0.4% for HE1 and LLCC respectively compared to the base case. For a scenario of 30% heating hours and 0% electricity price increase, relative differences can increase to 3.6% and 1.4% respectively. The LLCC chosen is then the option -10%Ua_cond.

The LLCC for 7.1 kW split units (for 50% heating hours) is the option -10% UA_cond

- SEER 5.49
- SCOP 3.90
- LCC = 6391 €

BNAT (all options): SEER= 10.6, SCOP = 5.5, LCC= 8660 €, 32 years of payback time

To summarize:

- LLCC: SEER 5.5, SCOP 3.9
- BNAT: SEER 10.6, SCOP 5.5

Environmental impacts of the LLCC and BNAT – 50% heating

The impacts of the base case, LLCC and the BNAT for split 7.1 kW are presented in Figure 23, Figure 24 and Figure 25. The presented impact categories are the energy consumption, emission of CO_2-eq and emission of SO_2-eq.

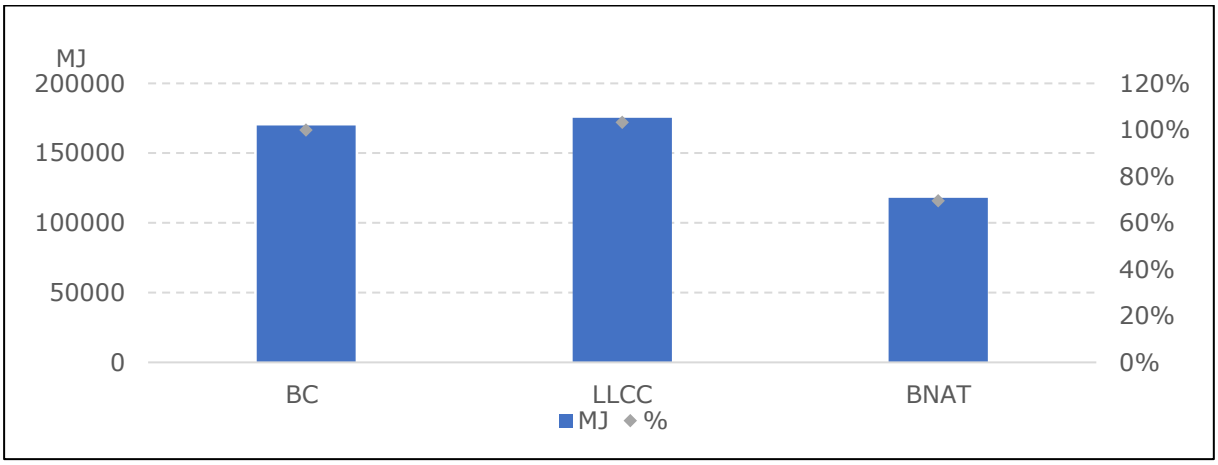

Figure 23: Total energy consumption of the base case, LLCC and BNAT – for BC 2 (split 7.1 kW)

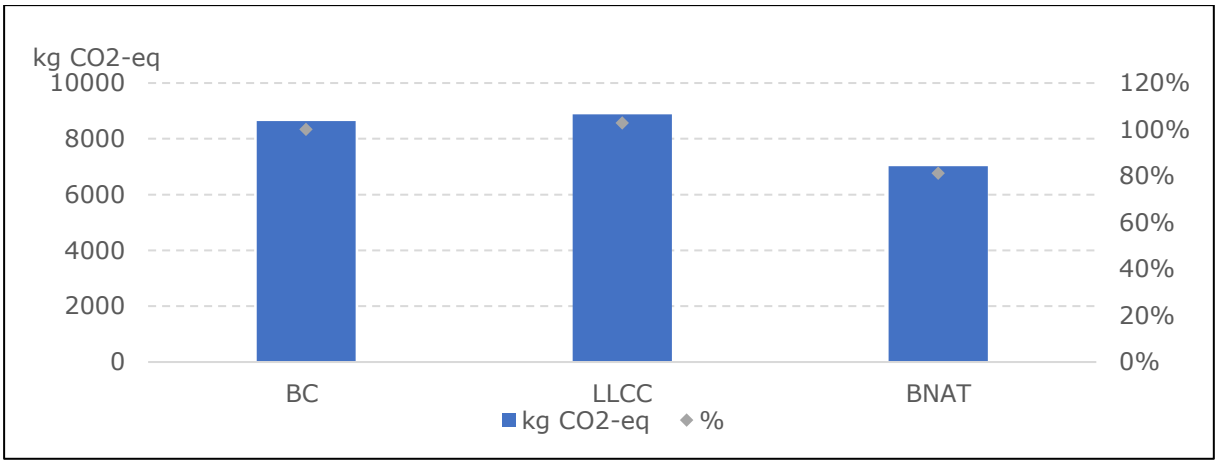

Figure 24: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 2 (split 7.1 kW)

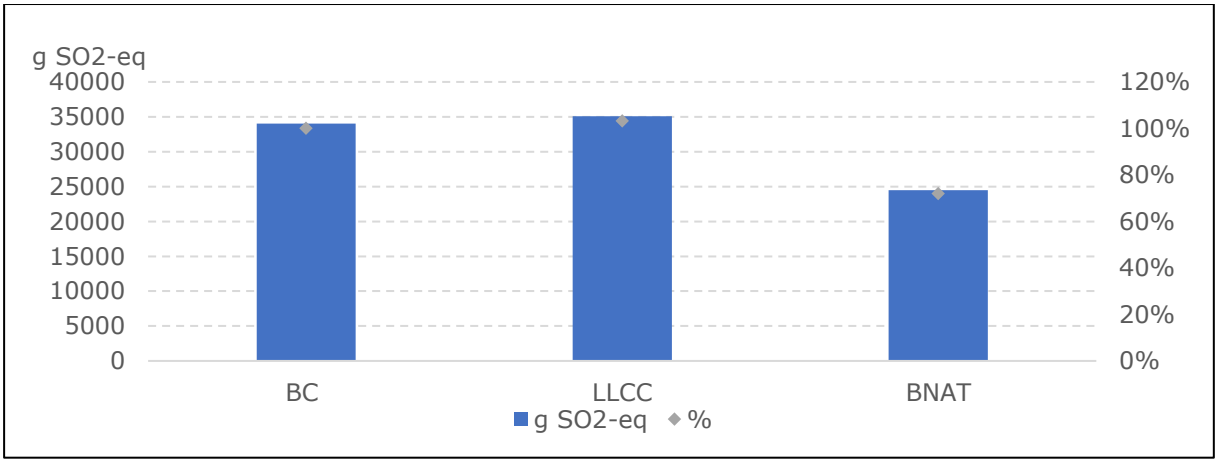

Figure 25: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 2 (split 7.1 kW)

The BNAT have environmental improvements in all categories compared with the base cases and the LLCC perform worse than the base case in in all categories. The increased material composition in the BNAT scenario has only limited impact, but the increased charge of refrigerants is visible in the emission of CO_2-eq as the reductions are lower compared to the other categories. With the conversion from R-32 the impacts due to refrigerants are lowered and the BNAT option will perform even better. The LLCC option is worse than the base case in all presented impact categories.

6.4.3.3 Base case 3: 2.6 kW portable unit

6.4.3.3.1 Base case 2.6 KW: R290

Table 26: Ranking of combined options by simple payback time, single duct 2.6 kW, R290

	SEER	Elec total (kwh)	Purchasing price €	Energy Cost €	Payback time (years)	LCC
BC	2.20	157	386	22	0	603
HE1	2.30	149	396	21	9	602
HE2	2.38	145	405	20	11	605
HE1+CP1	3.31	104	533	14	20	676
HE2+CP1	3.41	101	541	14	20	681
CP1	3.18	108	523	15	20	672
HE1+CP1+DC	3.89	88	592	12	22	713
HE2+CP1+DC	3.99	86	603	12	22	722
HE2+CP2+DC	4.29	80	688	11	28	798

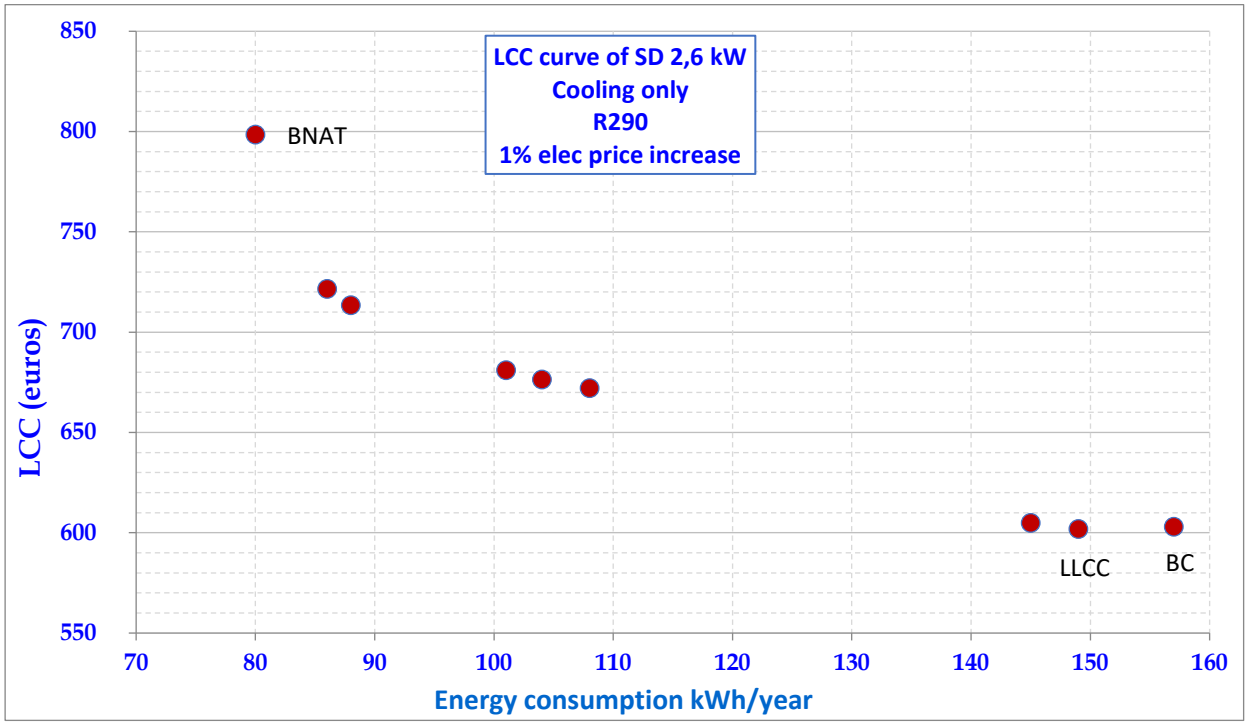

Figure 26: LCC curve of single duct 2.6 kW unit (cooling only, 1% electricity price increase), R290

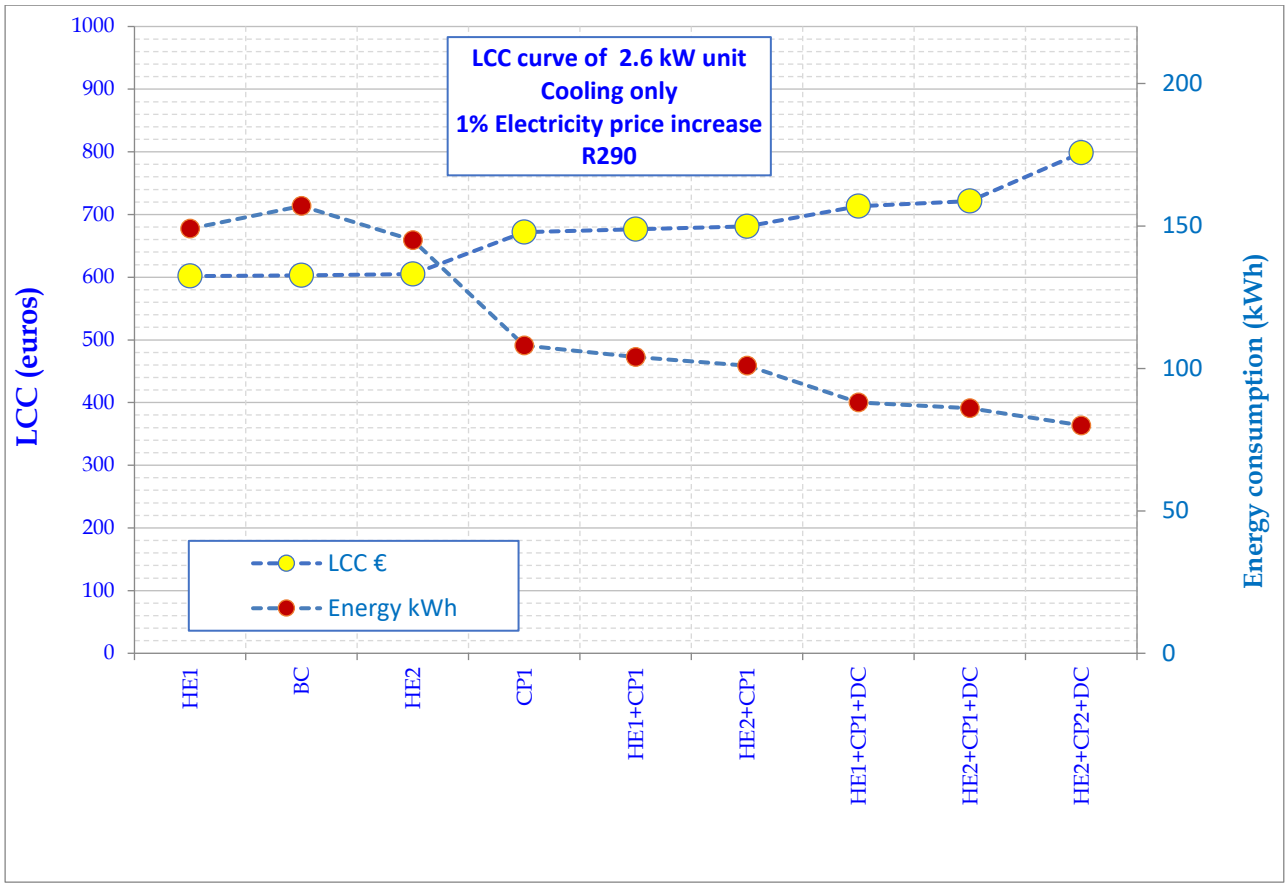

*Figure 27: LCC & Energy consumption of single duct 2.6 kW unit (*cooling only, 1% electricity price increase*), R290*

The LLCC value for single duct 2.6 kW unit, with R290 corresponds to:

- LLCC: SEER 2.30 (HE1)

The BAT level of EER is of 3.6
The BNAT corresponds to: SEER 4.29 (with the options: HE2+DC+CP2)

To summarize:

- LLCC: SEER 2.30
- BAT: EER 3.6 (35°/35°)/ SEER 2.82
- BNAT: SEER 4.29

For the BC 3, the LLCC chosen should be the one with the lowest LCC from both refrigerants.

6.4.3.3.2 Base case 2.6 kW: R1234YF

Table 30: Ranking of combined options by simple payback time, single duct 2.6 kW, R1234yf

	SEER	Elec total (kwh)	Purchasing price €	Energy Cost €	Payback time (years)	LCC
BC	1.83	188	482	26	-	742
HE1	1.95	177	496	24	9	740
HE2	2.05	168	508	23	9	740
CP1	2.89	119	621	16	15	785
DC+CP1	3.33	103	677	14	17	819
HE1+CP1	3.03	113	634	16	15	790
HE1+CP1+DC	3.52	98	693	14	17	828
HE2+CP1	3.15	109	647	15	15	797
HE2+CP1+DC	3.64	95	707	13	18	838
HE2+CP2+DC	3.92	88	791	12	22	913

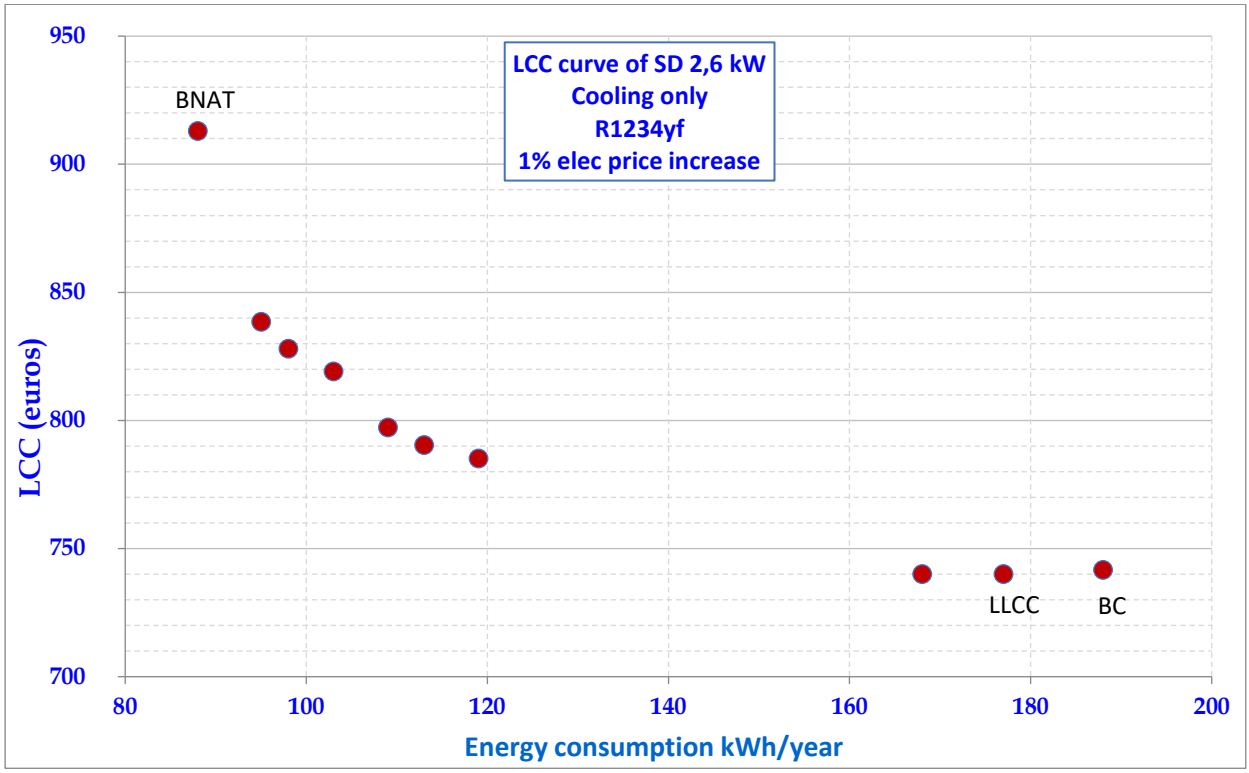

Figure 28: LCC curve of single duct 2.6 kW unit (cooling only, 1% electricity price increase), R1234YF

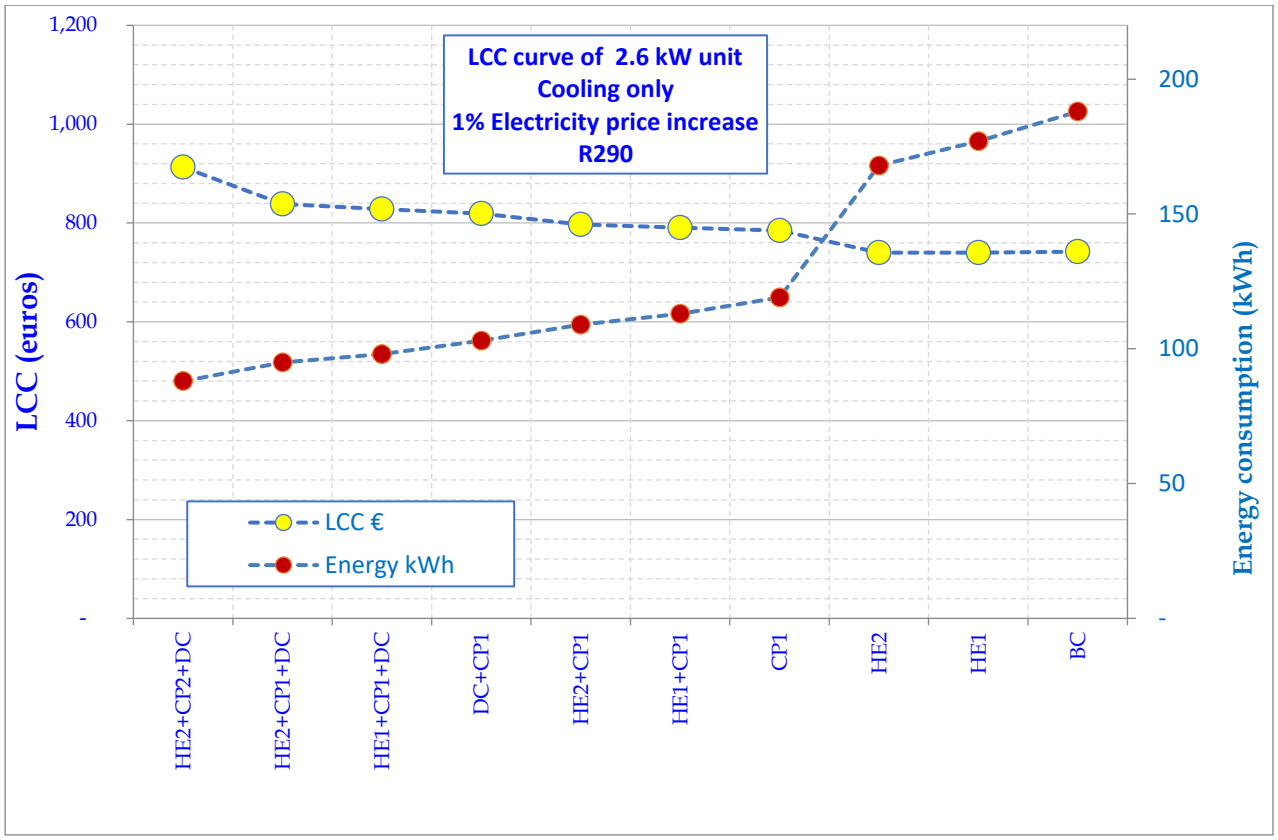

Figure 29: LCC & Energy consumption of single duct 2.6 kW unit (cooling only, 1% electricity price increase), R1234YF

The LLCC value for single duct 2.6 kW unit, with R1234yf corresponds to:

- LLCC1: SEER 1.95 (HE1)
- LLCC2: SEER 2.05 (HE2)

The BAT level of EER is of 3.6 (35°C/35°C) and SEER of 2.82.
The BNAT corresponds to: SEER 3.92 (with the options: HE2+DC+CP2)

To summarize:

- LLCC1: SEER 1.95 and SEER 2.05
- BAT: SEER 2.82
- BNAT: SEER 3.92

For the BC 3, the LLCC chosen should be the one with the lowest LCC from both refrigerants, so the option HE1 with R290 is the LLCC chosen for this base case since the LCC is lower than the LLCC option with R1234yf.

Environmental impacts of the LLCC and BNAT – R290

The impacts of the base case, LLCC and the BNAT for single duct 2.6 kW – R290 are presented in Figure 30, Figure 31 and Figure 32. The presented impact categories are the energy consumption, emission of CO_2-eq and emission of SO_2-eq.

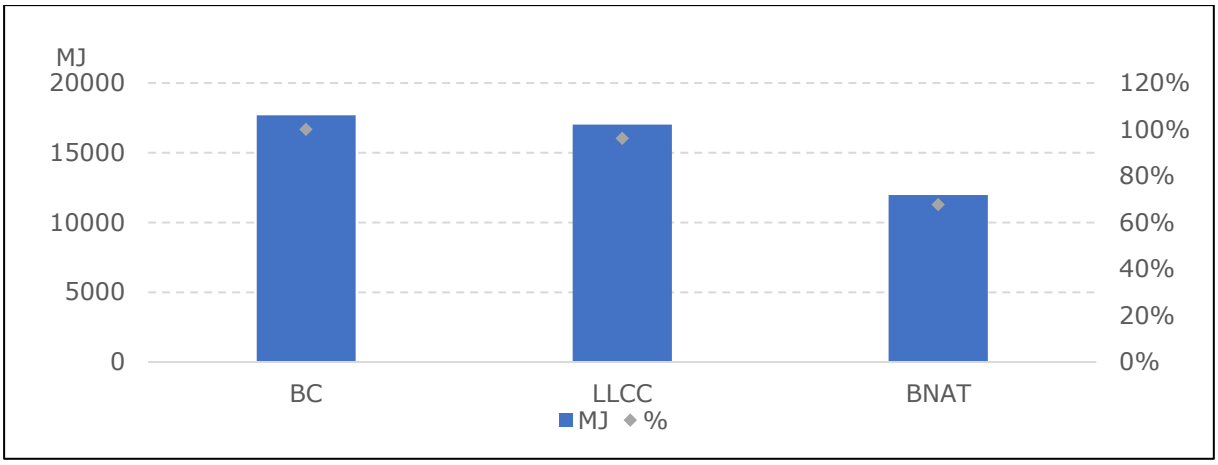

Figure 30: Total energy consumption of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R290)

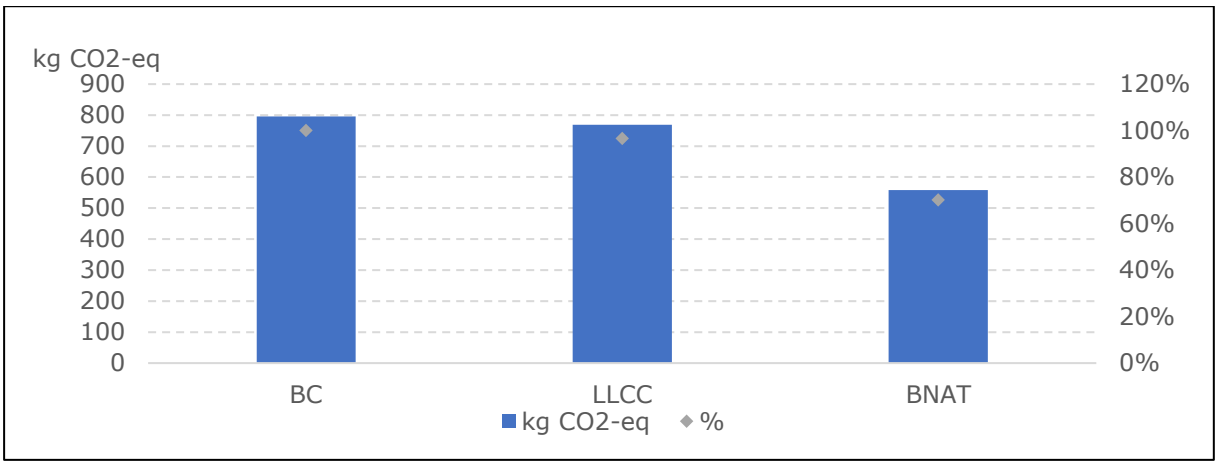

Figure 31: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R290)

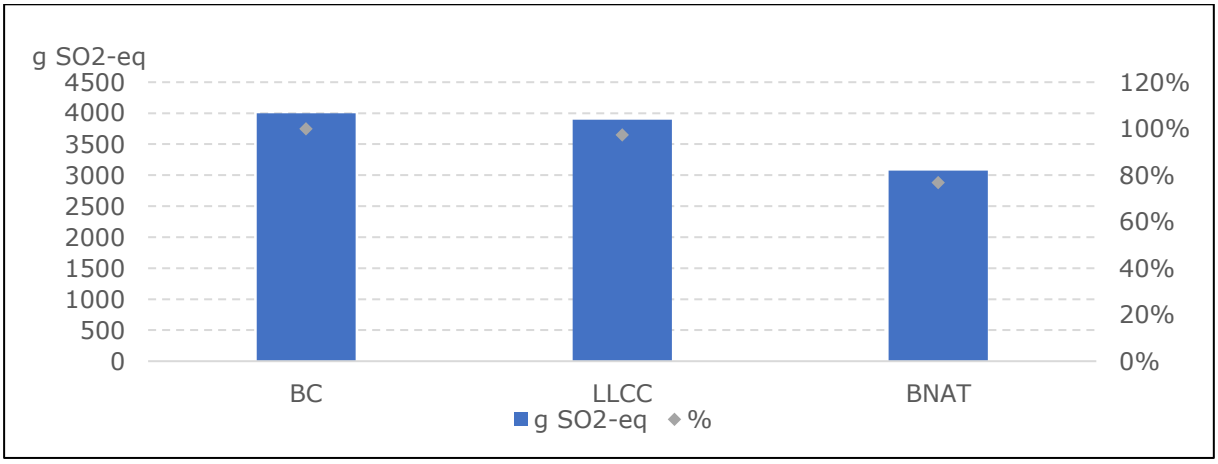

Figure 32: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R290)

Both the LLCC and BNAT have significant environmental improvements in all categories compared with the base cases. The increased material composition and increased refrigerant have only limited impact. The increase in refrigerant has less impact for portable air conditioners as the leakage rate and charge are low and the GWP of R290 is very low.

Environmental impacts of the LLCC and BNAT – SEER metrics

The impacts of the base case, LLCC and the BNAT for single duct 2.6 kW – R1234yf are presented in Figure 33, Figure 34 and Figure 35. The presented impact categories are the energy consumption, emission of CO_2-eq and emission of SO_2-eq.

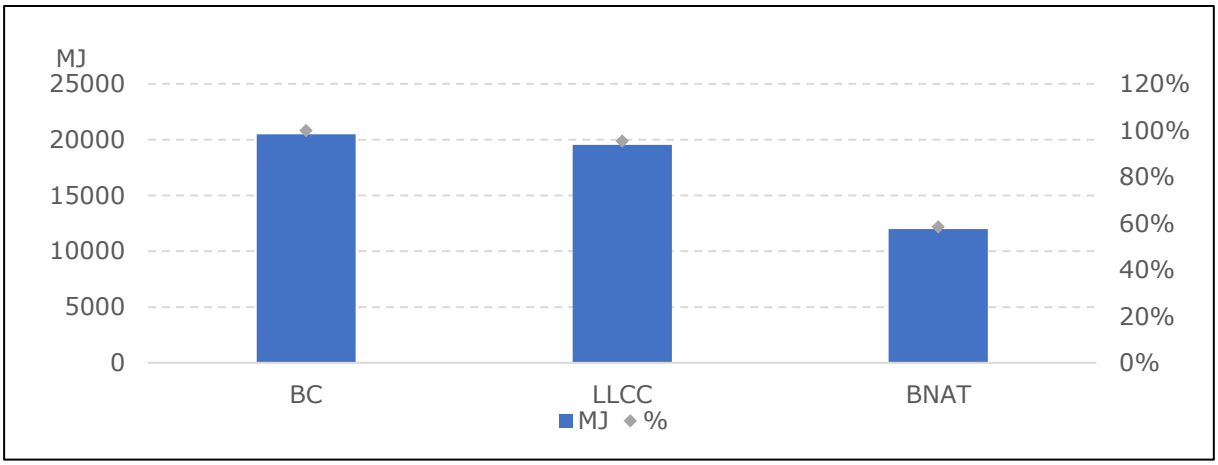

Figure 33: Total energy consumption of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R1234yf)

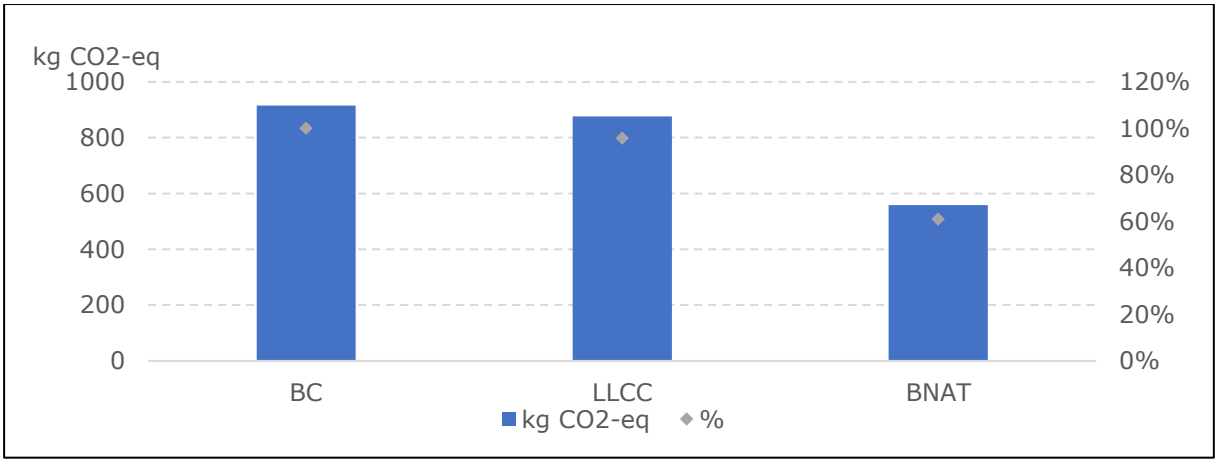

Figure 34: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R1234yf)

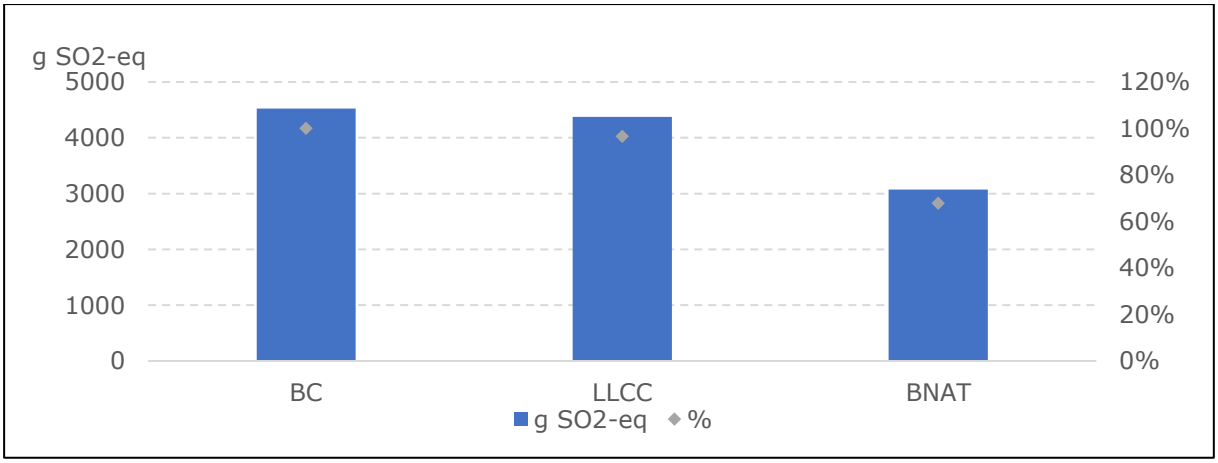

Figure 35: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R1234yf)

Both the LLCC and BNAT have significant environmental improvements in all categories compared with the base cases. The increased material composition and increased refrigerant have only limited impact. The increase in refrigerant has less impact for portable air conditioners as the leakage rate and charge are low and the GWP of R1234yf is very low.

6.5 Prices uncertainties

As mentioned in Task 2, prices for split units are derived with uncertainties, despite relatively complete information available. Regarding single duct, above price uncertainty, the coming ban for refrigerant fluids with GWP above 150 according to Regulation (EU) 517/2014 will lead to change fluid by 2020 and there is not yet a clear replacement fluid for R410A for these products. It is then useful to perform a sensitivity study on prices for these units.

This sensitivity study would best occur at the time of the impact assessment study when the direction of revised regulation becomes clearer and the data can be updated. This would allow some time to account for the market evolution of single ducts and also of single split systems. For these systems, the products offered at the end of 2017 are already more efficient than the products offered at the end of 2016. Since October 2017, it is for instance difficult to find A+ (Energy label class) products in the 3.5 kW range or A product in the 7.1 kW range, while their respective share was significant in 2015 and 2016 sales (Task 2).

6.6 Long-term targets

There is no indication presented to the study team to project what could become the efficiency of air conditioners on the long-term. If thermodynamics give Carnot ideal efficiency as a final limit, this is of little use to fix future potential efficiency limits for real life (as it cannot be reached).

Looking at the history of best available products also give limited information because of the recent metrics change. This is even more complicated because of the introduction of the sound power limitations. So, it does not seem feasible to make meaningful projections above BNAT levels.

Alternative technologies being studied are potential competitors to vapour compression cycles (see Task 4) but at the moment it can only be predicted that best of them only will have similar efficiency levels and that even if some of them - as magnetocaloric cooling - could be more efficient, there is a long way for these technologies to become commercially available.

6.7 Conclusions and recommendations

In this section, the conclusions and recommendation that stem from the environmental impacts and LCC assessments above of individual improvement options and combinations are presented.

Individual improvement options
For BC 1 and BC 2, 50% heating hours scenario is used for the individual option comparison.

The individual improvement options for BC 1 of 3.5 kW split unit have all a simple payback period higher than the lifetime.

For BC 2 of 7.1 kW split unit, also all individual options have larger than 12 years payback time values, which may not be attractive to consumers.

For BC 3 of portable 2.6 single duct unit, only the HE1 for R290 and HE1&HE2 have a reasonable payback period (below the lifetime period), while all other individual options have a payback period below 10 years.

LLCC and BNAT

The individual improvement options, combinations of options and the combination of all options have been compared together to arrive LLCC and BNAT for each base case. For base case 1 and 2, the results are based on 50% of the full load heating hours.

For **BC 1 of 3.5 kW split unit**, the LLCC option (-10% UA_cond option, UA value of condenser heat exchanger decreased by 10 %) is below the base case, however the difference in LCC of the LLCC option and the base case is very small, therefore the base case is chosen to represent the LLCC option. The BNAT which arrived by combining all options has a SEER of 11.4.

In terms of environmental impacts, the BNAT are lower in energy consumption, $CO_{2\text{-eq}}$ and $SO_{2\text{-eq}}$ compared with the base cases. The increased material composition has only limited impact, but the increased charge of refrigerants is visible in the emission of $CO_{2\text{-eq}}$ as the reductions are lower compared to the other categories.

The LLCC and BAT options for 0 – 6 kW air conditioners can be summarized as below:

- Base case 1: SEER= 6.00, SCOP = 4.0, LCC = 3521 €
- LLCC: base case / SEER= 6.00, SCOP = 4.0, LCC = 3521 €
- BAT: SEER 10.5, SCOP 6.2
- BNAT (all options): SEER= 11.4, SCOP = 5.9, LCC= 4469 €, 25 years of payback time

For **BC 2 of 7.1 kW split unit**, the LLCC option is below the base case. The BNAT which arrived by combining all options has a SEER of 10.6

In terms of environmental impacts, the BNAT are lower in energy consumption, $CO_{2\text{-eq}}$ and $SO_{2\text{-eq}}$ compared with the base cases. The increased material composition has only limited impact, but the increased charge of refrigerants is visible in the emission of $CO_{2\text{-eq}}$ as the reductions are lower compared to the other categories. The LLCC is worse than the base case regarding the impact categories assessed. With the conversion from R-32 the impacts due to refrigerants are lowered and the BNAT option will perform even better.

The LLCC and BNAT options for 6 – 12 kW air conditioners can be summarized as below:

- Base case 2: SEER= 5. 8, SCOP = 4.0, LCC = 6418 €
- LLCC (-10% UA_cond option, UA value of condenser heat exchanger decreased by 10 %): SEER= 5.5, SCOP= 3.9, LCC = 6391€, Energy consumption increase is about 7.5 % below the base case.
- BNAT (all options): SEER= 10.6, SCOP = 5.5, LCC= 8660 €, 32 years of payback time

For **BC 3 portable single duct unit**, LLCC option with R290 is achieved with the individual option HE1 (UA value of evaporator heat exchanger increased by 10 %, BNAT achieves a SEER of 4.29. And with R1234yf the LLCC is achieved with the 2 individual options HE1 and HE2, BNAT achieves a SEER of 3.92.

The LLCC, BAT, BNAT options for portable air conditioners can be summarized as below:

- Base case 3:
  - With refrigerant R410A: EER= 2.65 (35°/35°), SEER= 2.09
  - With refrigerant R290: EER= 2.79 (35°/35°), SEER= 2.20
  - With refrigerant R1234yf: EER= 2.32 (35°/35°), SEER= 1.83
- LLCC:
  - With refrigerant R290: (HE1): EER= 2.93 (35°/35°), SEER= 2.30, electricity consumption 149 kWh, LCC of 602 €
  - With refrigerant R1234YF, two LLCC points found:
    (HE1): EER= 2.47 (35°/35°), SEER= 1.95, electricity consumption 177 kWh, LCC of 740 €
    (HE2): EER= 2.60 (35°/35°), SEER= 2.05, electricity consumption 168 kWh, LCC of 740 €
- BAT: EER= 3.6 (35°/35°), SEER= 2.82, electricity consumption 122 kWh, as found currently on the market
- BNAT:
  - With refrigerant R290: EER= 4.83 (35 °C/35 °C), SEER= 4.29, electricity consumption 80 kWh
  - With refrigerant R1234yf: EER= 4.15 (35 °C/35 °C), SEER= 3.92, electricity consumption 88 kWh

For the BC 3, the LLCC chosen should be the one with the lowest LCC from both refrigerants, so the option HE1 with R290 is the LLCC chosen for this base case since the LCC is lower than the LLCC option with R1234yf.

However, it is possible in real life, the LLCC and BNAT values would be lower even these improvement options have been applied, due to a potential new metrics (seasonable performance) and the change of refrigerant fluid (alternative fluid to the F-gas ban). Conversely, the inclusion of standby mode and thermostat-off mode options could slightly decrease the energy consumption.

In terms of environmental impacts, LLCC and BNAT have significant improvement compared with the base case. With the shift of refrigerant, the BNAT can be significant better than the base case.

Sound power levels

Reducing sound power levels and increasing energy efficiency are potentially contradictory goals that air conditioner designers have to balance. To reach higher efficiency levels, close to BAT levels, it is not possible to decrease sound power maximum requirements for single duct nor for the 0-6 kW range. Regarding the 6 - 12 kW range, there is a margin for reducing outdoor sound power of the 7.1 kW unit, but this is due to the fact that the 6-12 kW range of current requirement has taken into account of the bigger units with larger air flows and hence sound power emissions. In order to further reduce sound power levels, it would probably require revising the requirements by making the sound power limits

proportional to the cooling capacity of the products. This would need a more in-depth analysis to develop.

Annex 1 – Sensitivity analysis on heating and electricity prices

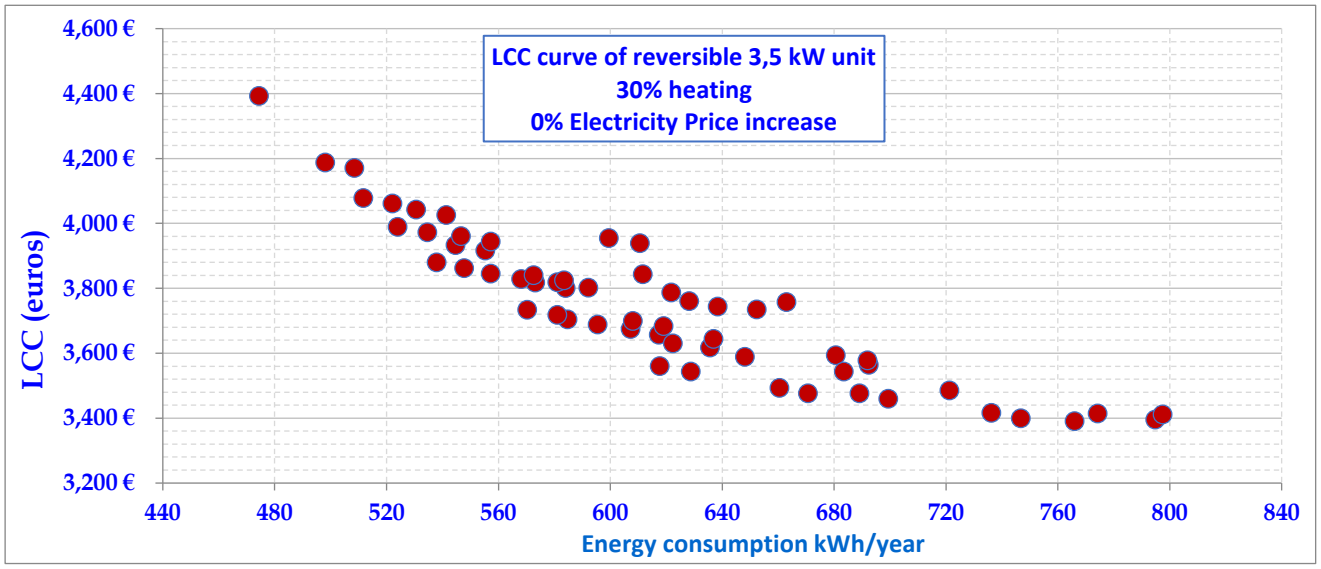

Figure 36 BC 1: 30% heating/ 0% electricity price increase

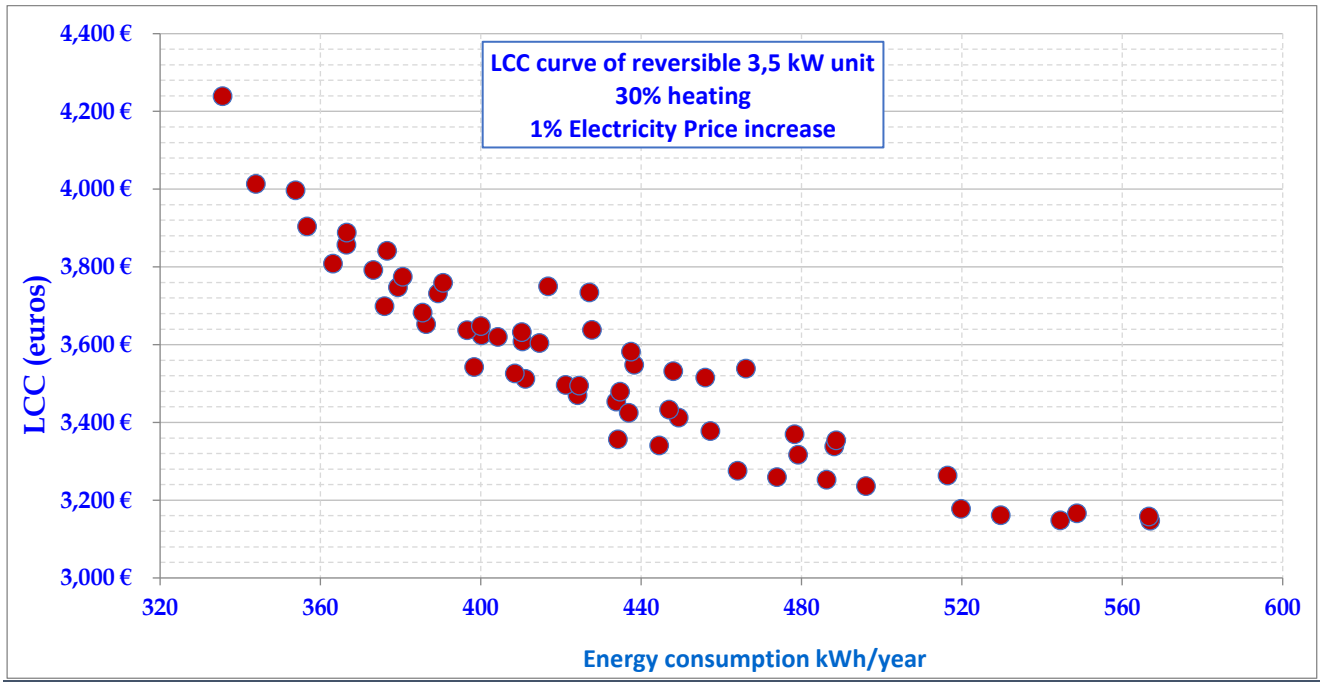

Figure 37 BC 1: 30% heating/ 1% electricity price increase

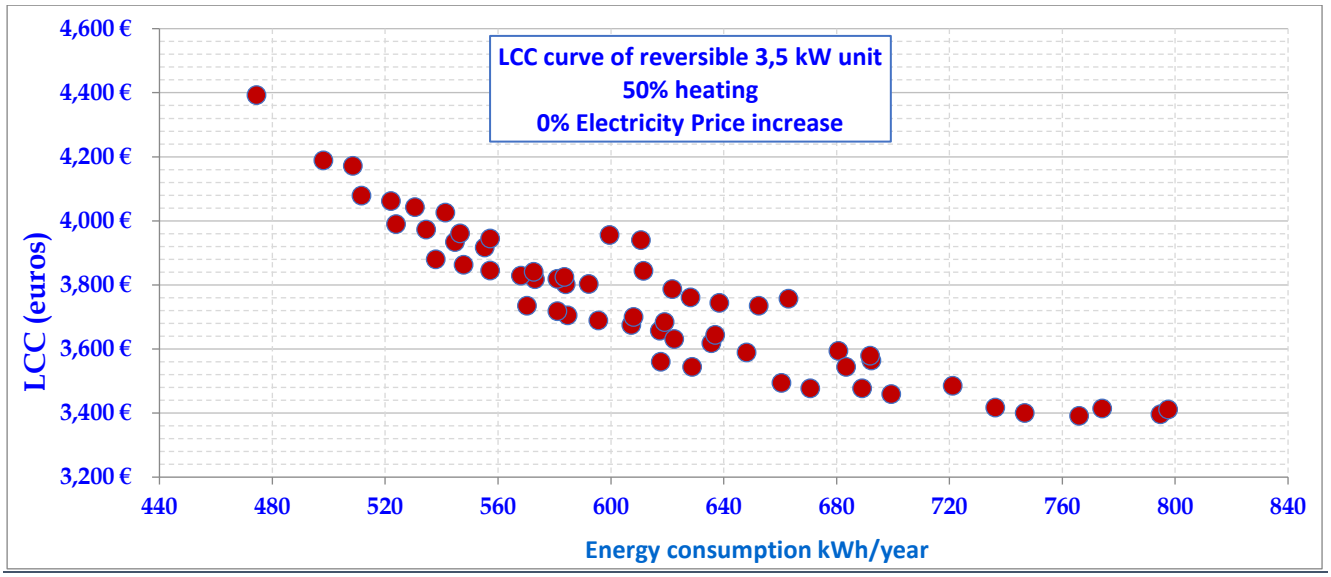

Figure 38 BC 1 : 50% heating/ 0% electricity price increase

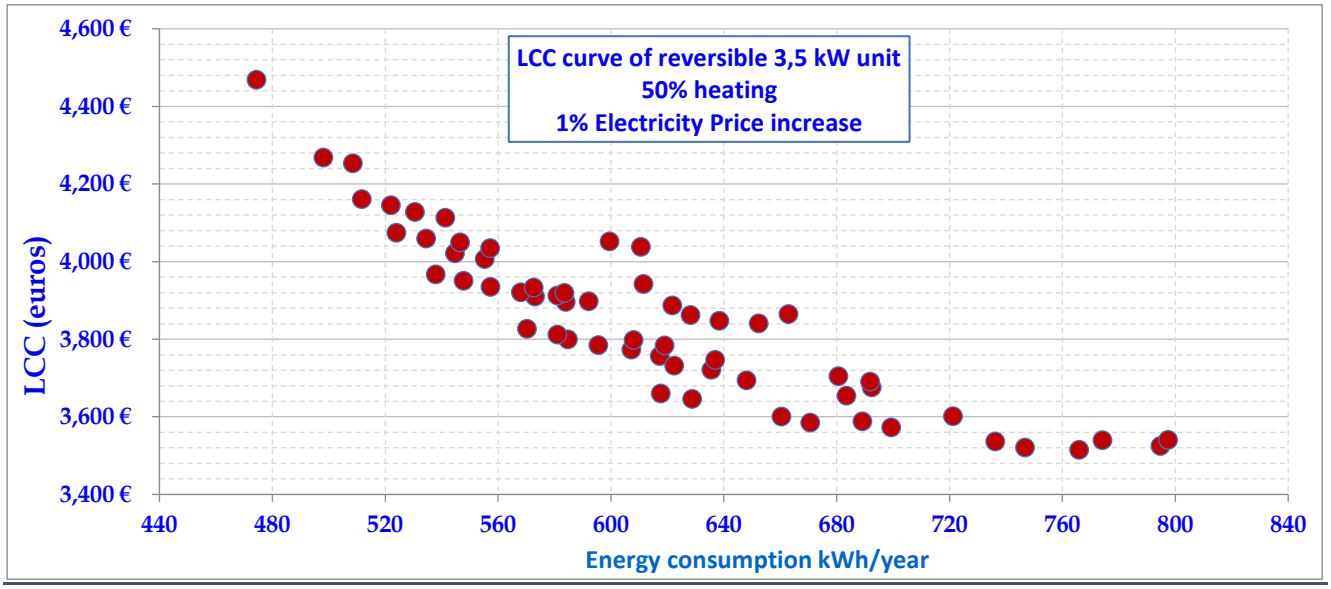

Figure 39 BC 1 : 50% heating/ 1% electricity price increase

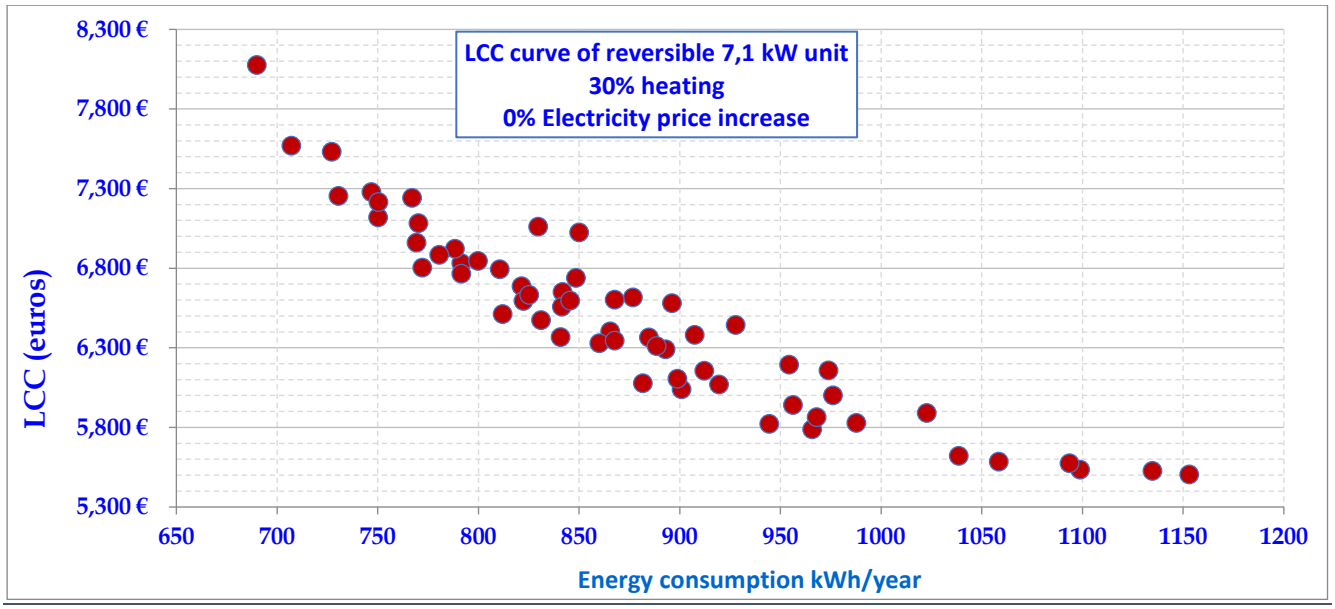

Figure 40 BC 2 : 30% heating/ 0% electricity price increase

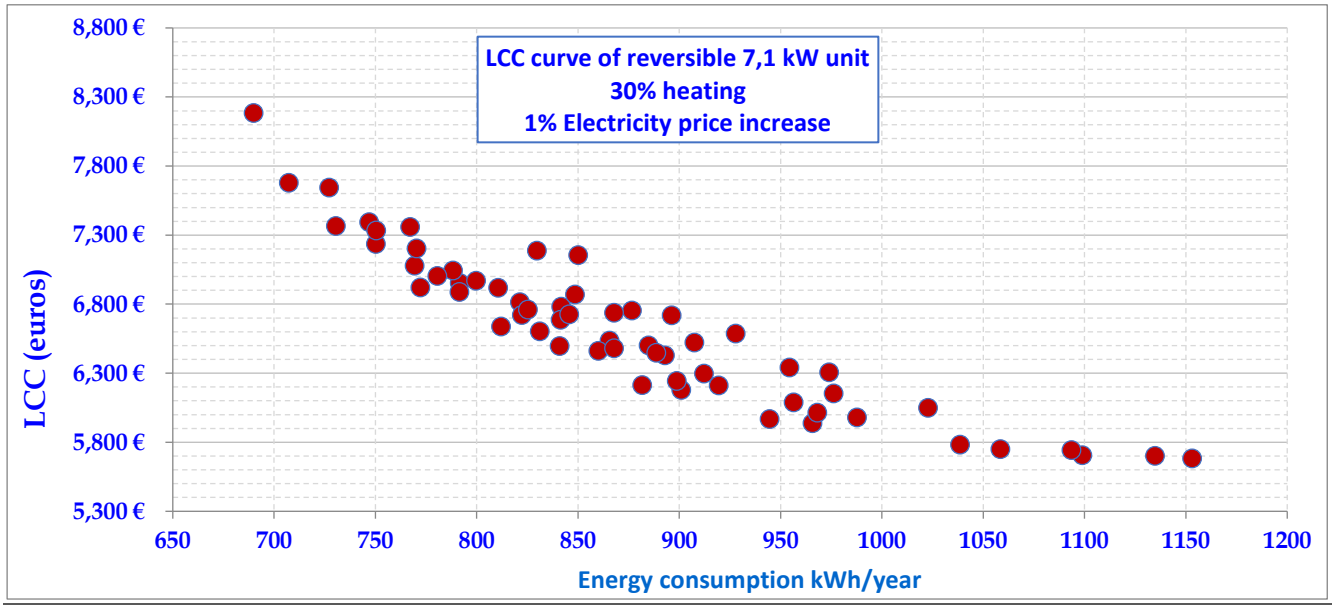

Figure 41 BC 2 : 30% heating/ 1% electricity price increase

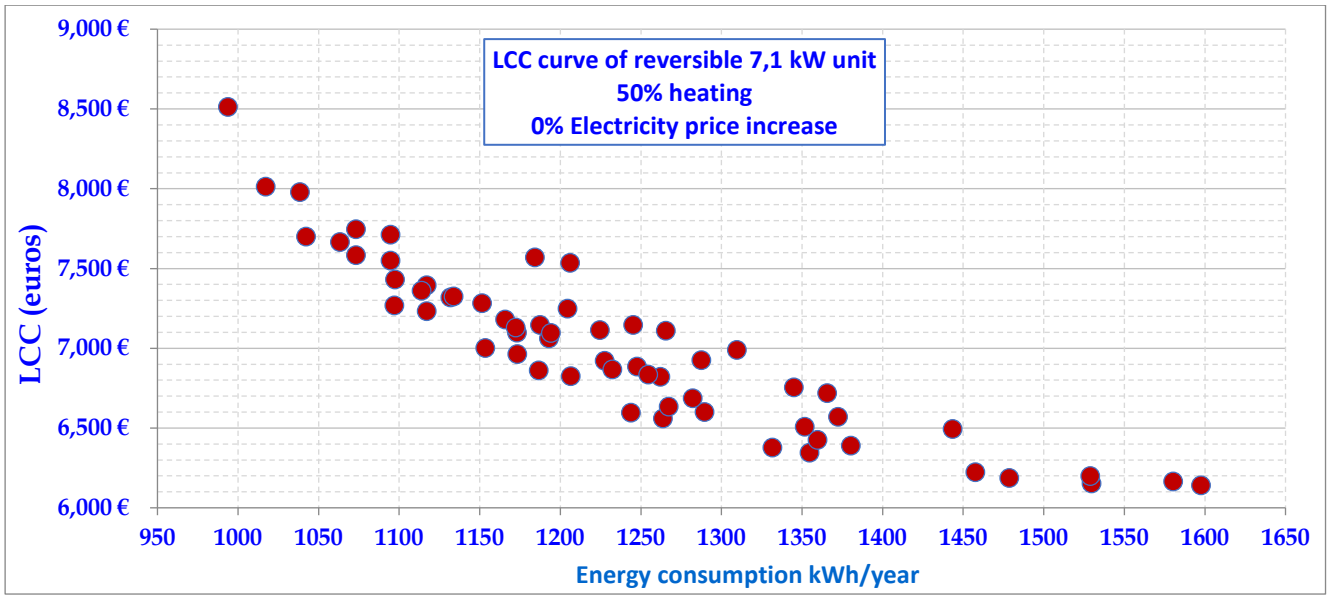

Figure 42 BC 2 : 50% heating/ 0% electricity price increase

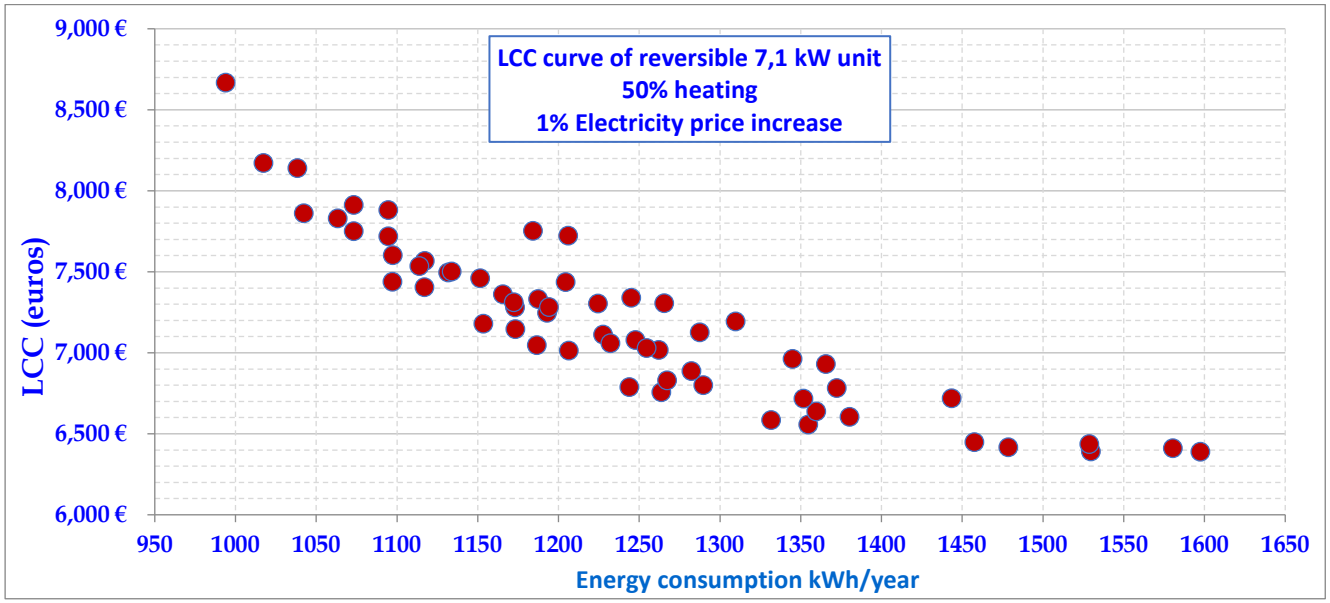

Figure 43 BC 2 : 50% heating/ 1% electricity price increase

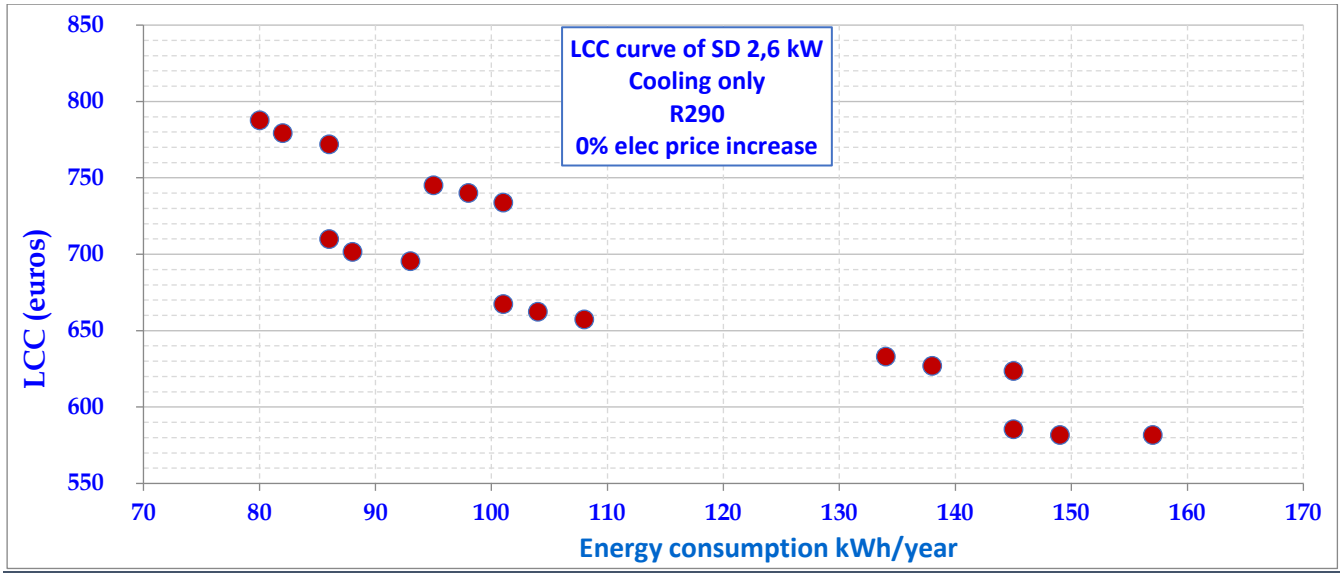

Figure 44 BC 3 : R290/ 0% electricity price increase

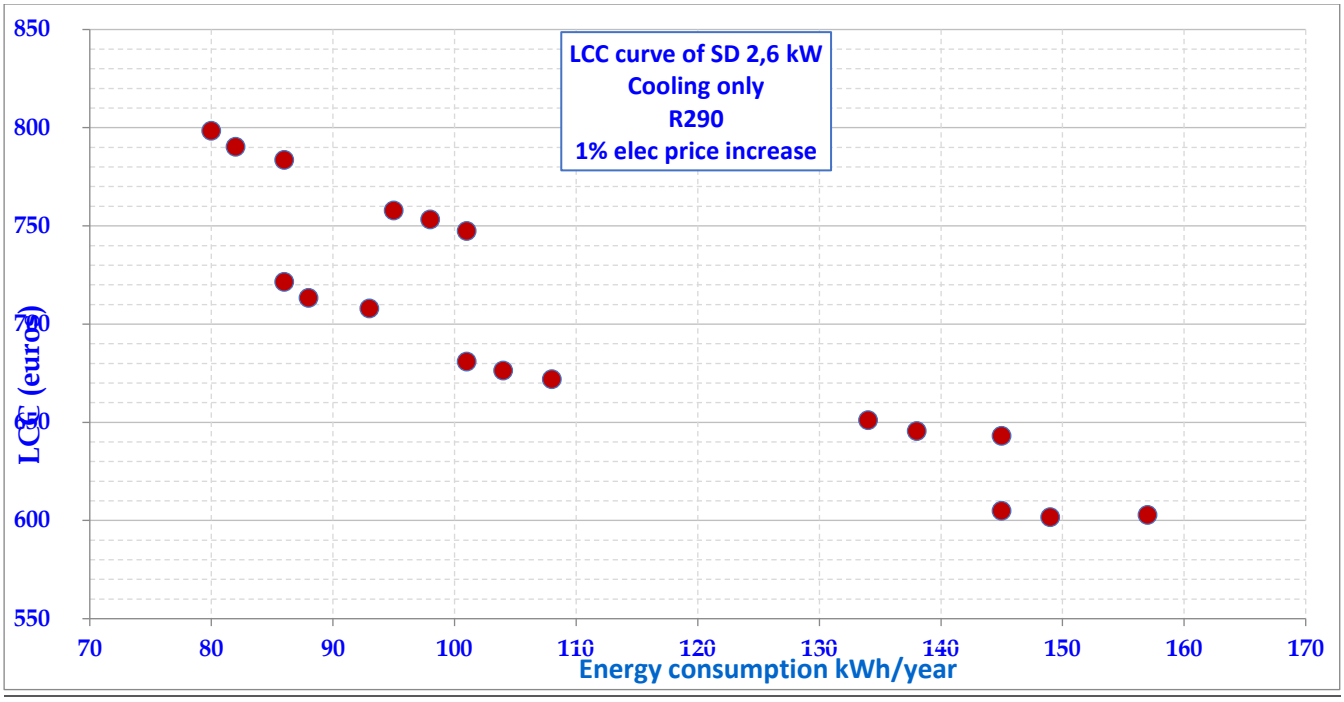

Figure 45 BC 3 : R290/ 1% electricity price increase

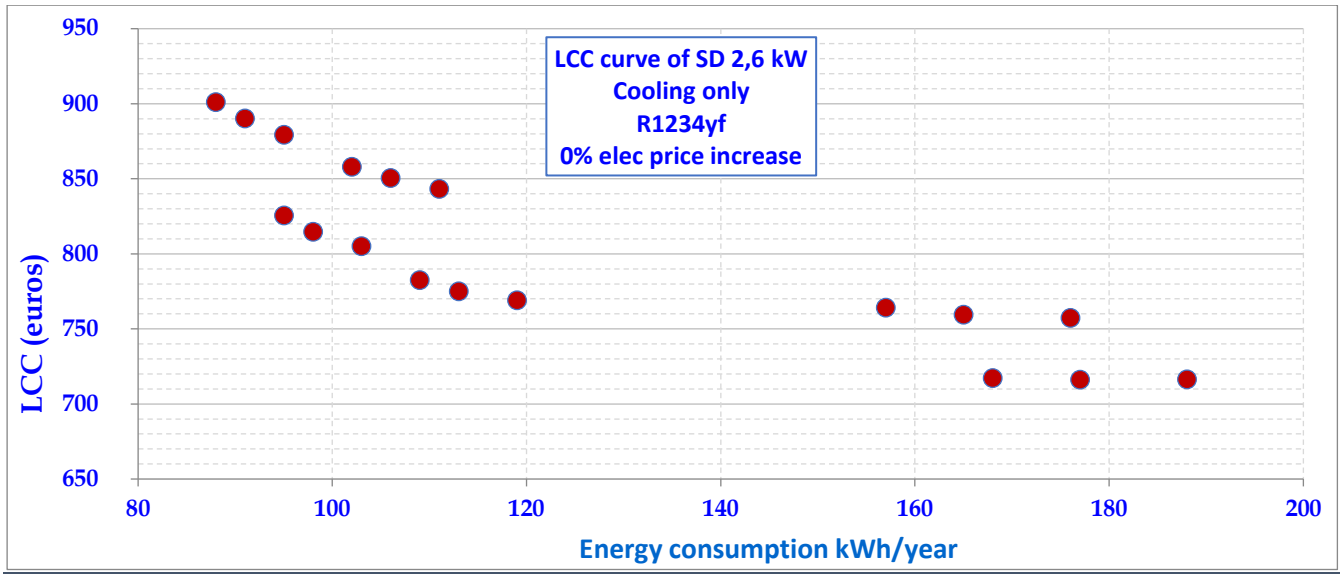

Figure 46 BC 3: R1234yf/ 0% electricity price increase

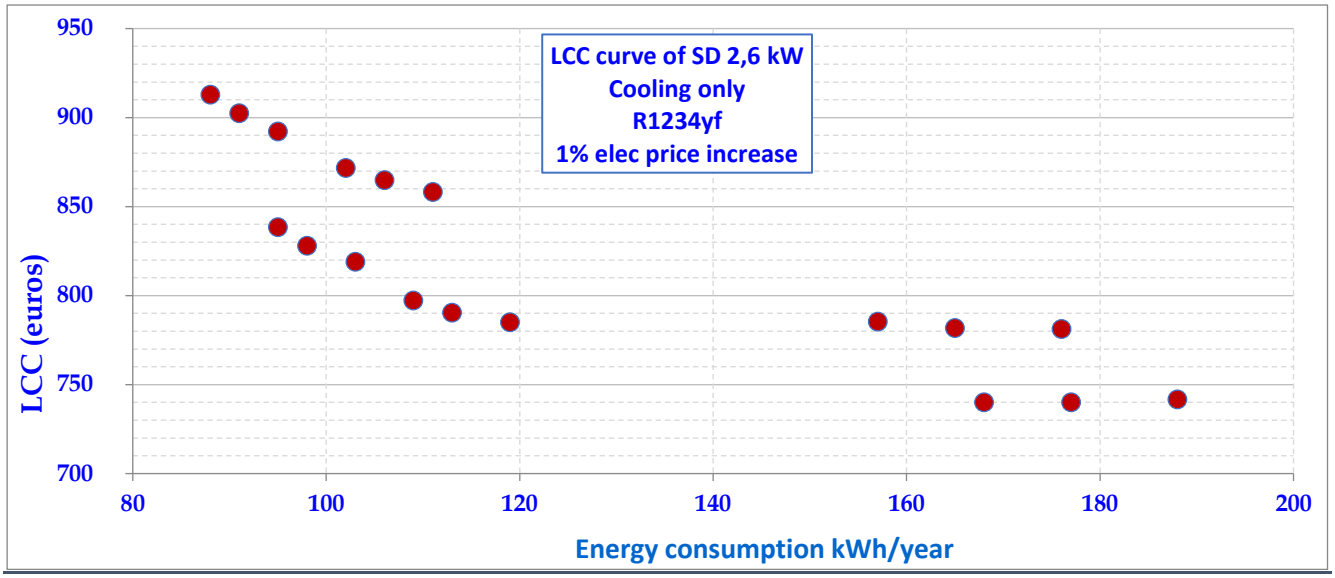

Figure 47 BC 3: R1234yf/ 1% electricity price increase

Review of Regulation 206/2012 and 626/2011

Air conditioners and comfort fans

Task 7 report

SCENARIOS

Final version

Date: May 2018

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Abbreviations

BAT	Best Available Technology
BAU	Business as Usual
BC	Base cases
BEP	Break-Even Point
BNAT	Best Not yet Available Technology
COP	Coefficient of Performance for air conditioners in heating mode
ECC	Eurovent Certita Certification
$\eta_{s,c}$	Greek letter eta, denoted by s,c, means primary seasonal space cooling efficiency
$\eta_{s,h}$	Greek letter eta, denoted by s,h, means primary seasonal space heating efficiency
EER	Energy Efficiency Ratio for air conditioners in cooling mode
GWP	Global warming potential
LLCC	Least Life Cycle Cost
RRT	Round Robin Test
SEER	Seasonal Energy Efficiency Ratio for air conditioners, cooling mode
SCOP	Seasonal Coefficient of Performance for air conditioners, heating mode

Introduction to the task reports

This is the introduction to the Review of Regulation 206/2012 and 626/2011 for air conditioners and comfort fans. The report has been split into seven 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.

7 Introduction to Task 7

In task 7, a number of policy scenarios will be established based on the analyses and stakeholder consultations. Task 7 presents the ecodesign and energy labelling requirements, both for energy efficiency and for material efficiency. The focus will be on updating the existing regulations in terms of updating requirements and possible new requirements, e.g. energy efficiency, the use of low-GWP refrigerants, etc. Moreover, feasibility of policy options that address durability, reparability, disassembly and recyclability is analysed.

The scenarios together with a Business-As-Usual scenario is modelled for the period from 2015 until 2030, including sensitivity analyses.

The task is concluded with a summary of the work undertaken in Task 7, with an overview of both positive and negative impacts related to each policy scenario as well as a set of recommendations.

This task report includes the following:

1. Overview of the barriers and opportunities for the suggested policy measures, focusing on ecodesign energy requirements and energy labelling.
2. Definition of proposed scope for ecodesign and energy labelling requirements.
3. Definition of policy measures for energy requirements, including timing and target levels.
4. Definition of material efficiency requirements, including the rationale for defining these requirements.
5. Scenario analyses presenting the effect of implementing the energy requirements.
6. Sensitivity analyses of the main parameters in the scenario analysis.

7.1 Policy analysis

According to MEErP and based on the results of the policy analysis, a (package of) policy instrument(s) should be selected and the impacts of the policy scenario(s) should be assessed on the energy system, the end-user and on industry in comparison with the impacts of the BAU scenario.

7.1.1 Stakeholder consultation

Stakeholders have been contacted and consulted from the very beginning of the study. Various industry stakeholders have supplied technical specifications of current average products, best available product on the market and best available technology (BAT). Consultation on material efficiency has also been carried out to assess the feasibility and needs for ecodesign policy interventions. Detailed market data and prices have been purchased from market intelligence company such as GfK[1] and BSRIA[2], and much of the analysis regarding efficiencies, sound power level, other technical parameters are based on the datasets from Eurovent Certita Certification (ECC[3]). The analysis of efficiencies is

[1] www.gfk.com
[2] https://www.bsria.co.uk
[3] 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

updated with datasets received from industry stakeholders after the second stakeholder meeting to make sure the result is based on sales weighted data to be more representative of the market.

After two stakeholder meetings, many industry stakeholders, NGOs, member states and consumer organisations have submitted comments and suggestions to the study, most of which have been taken into consideration or incorporated.

7.1.2 Barriers and opportunities for improvements

This subsection describes briefly the barriers and opportunities for improvements environmental impact, as well as opportunities for a revised Ecodesign measure.

Task 1 – 4 has shown that the current ecodesign and energy labelling regulations on air conditioners and comfort fans can be improved.

Scope coverage of current regulations for certain product group is blurry and to avoid loophole and ensure consistency with other regulations, the scope is recommended to extend to cover ventilation exhaust air conditioners and air to air heat pumps.

Low power modes power consumption and hours have been reviewed and it is shown that there is improvement potential to achieve lower power consumption in standby/off modes, thermostat-off mode and crankcase heater mode. The potential has not been realised by the industry due to the limited impact the consumption in each mode has on the overall efficiency calculation for SEER and SCOP. An opportunity for revised ecodesign measure is to propose to revise the weighting of the low power modes in the metrics, in order to create a greater incentive for manufacturers to reduce the power consumption. This is also identified as one of the improvement options to achieve higher efficiency in Task 6.

Assessment of existing average product and best available technology (BAT) shows that there is still potential for higher efficiency of heating and cooling for fixed air conditioners and of cooling by portable air conditioners. Least Life Cycle Cost (LLCC) assessment revealed that the LLCC option is close to the base case, as the LCC of a few different options are quite close to each other and the largest saving potential has already been achieved with current regulation due to the technology of inverter. The BNAT option shows the long-term potential, which is significant in comparison with LLCC option, although with the current cost for improvement, it is not the most economical option. However, this shows the level of achievable technology that could be used to set as a goal or a pulling force in the form of energy class scale.

To balance the energy efficiency and sound power level is crucial, for fixed air conditioners in the range of 6 – 12 kW capacity, there is a slight potential to lower the maximum sound power level requirement, whereas other air conditioners have no margin to achieve lower sound power at the same time achieve a higher minimum efficiency requirement as proposed.

To be able to better compare single and double duct air conditioners with others, it is suggested to split double duct air conditioners in two distinct categories, fix and portable products; indeed, fix double duct air conditioners in fact compete with split air conditioners, while portable double duct compete with single duct air conditioners. In addition, for portable air conditioners and heat pumps, there should be a seasonal performance metrics,

2016); representativeness is believed to be high: about 80 % of products sold in Europe according to the Preparatory study.

and there should be a test method that includes the infiltration air flow in the measurement. This would ensure better consumer understanding of the energy label which does not make a distinction between single/double duct air conditioners and others, and reports a more realistic performance at the same discourage consumers to use thermodynamic heating with single duct products. More details in section 7.1.5.

7.1.3 Policy options

There are several product policy instruments available, which could be used to regulate air conditioners and comfort fans. Given that there are already ecodesign and energy labelling regulation for these products, the focus of policy options is easily identified. The basic types of policy instruments as presented below:

1) **No action option – Business as usual (BAU)**, the current regulations are to be retained as they are. The first overall decision to be made is whether there is a need for further EU intervention. This BAU scenario will be used as reference for comparison with other policy scenarios.
2) **Ecodesign requirements** (under the Ecodesign Directive (2009/125/EC)): This means mandatory minimum requirements would be introduced for a set of parameters, the manufacturers would bear the responsibility for their products to be compliant when placed on the market and the Member States would verify compliance via market surveillance activities. This acts as a "push" instrument for products to achieve better performance because all appliances will have a minimum level of energy efficiency performance regulated by the implementing measure. Since there is already Ecodesign regulation No 206/2012 for air conditioners and comfort fans, this policy option will be analysed in one or more scenarios with newly proposed requirements in this review study.
3) **Energy labelling** (under the Energy Labelling Regulation (2017/1369/EU)[4]): This implies mandatory labelling of the product for a set of parameters. Manufacturers are responsible for labelling their products and it is also enforced by Member State market surveillance. This acts as a "pull" instrument because the consumers will choose the products they want to purchase which can pull the market towards higher energy performance. Since there is already Energy Labelling regulation No 626/2011, this policy option will be analysed in one or more scenarios with newly proposed requirements and energy class scale.
4) **Self-regulation** as an alternative to Ecodesign requirements: The Ecodesign Directive (2009/125/EC) recognizes self-regulation by industry as an alternative to binding legislation. Self-regulation, which can be based on voluntary agreements, is a valid alternative as long as it delivers the policy objectives set out in the legislation faster and in a less costly manner than mandatory requirements. The directive gives specific requirements for self-regulative measures. This option was already discarded since preparatory study as there have been established ecodesign and energy labelling regulations since.
5) **Voluntary labelling** implies manufacturers can choose whether to label their products. In the case of ENERGY STAR[5] and Ecolabel[6], the specifications are established through regulations, ensuring that the labelled product belongs to the

[4] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU
[5] Regulation (EC) No 106/2008 of the European Parliament and of the Council of 15 January 2008 on a Community energy-efficiency labelling programme for office equipment (recast version)
[6] Regulation (EC) No 66/2010 of the European Parliament and of the Council of 25 November 2009 on the EU Ecolabel

upper segment of the market in terms of energy consumption and other environmental aspects. Member States are responsible for market surveillance. The US ENERGY STAR covers air conditioners, but it is not in scope of the EU-US ENERGY STAR agreement (covers only office equipment). However, EU Regulation 66/2010/EC[7] for EU Ecolabel already covers air conditioners under heat pumps[8], therefore this policy option will not be further analysed in detail.

In conclusion, policy options 1, 2 and 3 will be analysed further in the later sections of this task.

7.1.4 Recommended policy measures

In this section, policy measures assessed in previous section as feasible options are selected for further analysis, including timing and target levels. In the following subsection, the discussions include whether there should be revised ecodesign requirements, such as minimum (or maximum) requirements, and whether it should be complemented with revised energy labelling schemes, needs for new standards to be developed as well as the existing measurement standards that could be used and lastly possibility of setting material efficiency requirements and information requirements on installation of the product or other user information.

7.1.4.1 Ecodesign requirements

LLCC identified in the Task 6 and used for setting the immediate minimum requirement for ecodesign.

For portable air conditioners, it is also recommended to set minimum ecodesign requirements based on seasonal performance metrics (SEER and SCOP) for portable air conditioners as well using the proposed metrics as transitional method.

It is proposed the following ecodesign requirements and timing:

- Tier 1: from 2021, minimum efficiency requirement with one tier based on BC:
  - LLCC for BC 1 (BC): SEER= 6.0, SCOP= 4.0, LCC = 3521€
  - LLCC for BC 2 ((10% UA cond): SEER= 5.5, SCOP= 3.9, LCC = 6391€
  - LLCC for BC 3 (HE1): SEER= 2.3, LCC = 602€, 9 years of payback time

See proposed ecodesign minimum efficiency requirements summarised in the table below.

Table 1: Proposed minimum efficiency requirements for air conditioners in a potential revised ecodesign regulation

	Tier 1, January 2023	
	SEER	SCOP
Other than portable, < 6 kW	6	4
Other than portable, 6 – 12 kW	5.5	3.9
Portable	2.3	-

As seen in the table, it is the opinion of the study team that no SCOP minimum requirement should be proposed for single and double duct air conditioners at this time. It is proposed to start the development of a new standard in line with EN14825 plus infiltrations (with default values if required). With this potential new standard in place, double duct products will have to be improved to stay on the market to compete with performance of other products. It is proposed that the single ducts would not be allowed to operate in

[7] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:027:0001:0019:en:PDF
[8] http://ec.europa.eu/environment/ecolabel/eu-ecolabel-products-and-services.html

thermodynamic heating mode. Once performances of new double duct products for new standard are known, then it can be evaluated how far their performances should be increased.

It is however proposed to add ecodesign information requirement of SCOP derived using the proposed metrics if the single and double duct air conditioners have heating function. This means that existing requirements in the current regulation No 206/2012 for COP should still apply beside the added information requirement.

Lastly, infiltration measurement should be proposed in the future mandate for standards.

Requirements for minimum energy efficiency

	Air conditioners, except double and single duct air conditioners		Double duct air conditioners		Single duct air conditioners	
	SEER	SCOP (heating season: Average)	EER_{rated}	COP_{rated}	EER_{rated}	COP_{rated}
If GWP of refrigerant > 150 for < 6 kW	4,60	3,80	2,60	2,60	2,60	2,04
If GWP of refrigerant ≤ 150 for < 6 kW	4,14	3,42	2,34	2,34	2,34	1,84
If GWP of refrigerant > 150 for 6-12 kW	4,30	3,80	2,60	2,60	2,60	2,04
If GWP of refrigerant ≤ 150 for 6-12 kW	3,87	3,42	2,34	2,34	2,34	1,84

Figure 1: Current minimum efficiency requirement set by Regulation 206/2012

As a comparison with current requirement shown in figure above, the proposed SEER requirement for air conditioners other than portables is quite much more ambitious, while the proposed SCOP requirement is not increased significantly from the current requirement level, in order to ensure competitiveness with other heating products. For portable air conditioners, the minimum requirement set for SEER of 2.3 is equal to EER of 2.93 (35°/35°).

7.1.4.2 Energy labelling requirements

BAT and BNAT identified in Task 6 are used for proposing energy efficiency classes, with BNAT as the top level at energy class A. BNAT for different base case is derived with simulation of improvement options, it could mean that it has higher performance than the best available product (BAT) on the market. In light of how quickly air conditioners have populated the current A+++ even though it is not yet introduced by the regulation, it is proposed that Energy Class A should have a relatively high threshold level. This is however in line with the Commission's goal with the revised energy labelling scheme that the upper class (A) shall be empty at the time when the regulation comes into force, therefore the best available product on the market when the revised regulation is adopted should only be able to achieve energy class B.

It is proposed that the following efficiency levels are used for the top energy efficiency class of a revised energy labelling regulation:

- BNAT for BC 1 (all improvement options): SEER= 11.4, SCOP = 5.9, LCC= 4469 €, 25 years of payback time
- BNAT for BC 2 (all improvement options): SEER= 10.6, SCOP = 5.5, LCC= 8667, 32 years of payback time
- BNAT for BC 3 (all improvement options with R290): SEER= 4.3, LCC= 798€, 28 years of payback time

Energy efficiency classes for air conditioners, except double ducts and single ducts

Energy Efficiency Class	SEER	SCOP
A+++	SEER ≥ 8,50	SCOP ≥ 5,10
A++	6,10 ≤ SEER < 8,50	4,60 ≤ SCOP < 5,10
A+	5,60 ≤ SEER < 6,10	4,00 ≤ SCOP < 4,60
A	5,10 ≤ SEER < 5,60	3,40 ≤ SCOP < 4,00
B	4,60 ≤ SEER < 5,10	3,10 ≤ SCOP < 3,40
C	4,10 ≤ SEER < 4,60	2,80 ≤ SCOP < 3,10
D	3,60 ≤ SEER < 4,10	2,50 ≤ SCOP < 2,80
E	3,10 ≤ SEER < 3,60	2,20 ≤ SCOP < 2,50
F	2,60 ≤ SEER < 3,10	1,90 ≤ SCOP < 2,20
G	SEER < 2,60	SCOP < 1,90

Figure 2 Current energy efficiency classes for air conditioners other than single and double ducts set by Regulation 626/2011

As a comparison with current energy efficiency class (Figure 2), the current class A+++ for air conditioners other than portables would be the proposed class C for SEER and SCOP. The requirements are different for double duct air conditioners, depending on whether it is portable or fixed. For portable air conditioners, the current class A+++(Figure 3) for EER of 4.1 and above would be in the proposed class B.

Energy efficiency classes for double ducts and single ducts

Energy Efficiency Class	Double ducts		Single ducts	
	EER_{rated}	COP_{rated}	EER_{rated}	COP_{rated}
A+++	≥ 4,10	≥ 4,60	≥ 4,10	≥ 3,60
A++	3,60 ≤ EER < 4,10	4,10 ≤ COP < 4,60	3,60 ≤ EER < 4,10	3,10 ≤ COP < 3,60
A+	3,10 ≤ EER < 3,60	3,60 ≤ COP < 4,10	3,10 ≤ EER < 3,60	2,60 ≤ COP < 3,10
A	2,60 ≤ EER < 3,10	3,10 ≤ COP < 3,60	2,60 ≤ EER < 3,10	2,30 ≤ COP < 2,60
B	2,40 ≤ EER < 2,60	2,60 ≤ COP < 3,10	2,40 ≤ EER < 2,60	2,00 ≤ COP < 2,30
C	2,10 ≤ EER < 2,40	2,40 ≤ COP < 2,60	2,10 ≤ EER < 2,40	1,80 ≤ COP < 2,00
D	1,80 ≤ EER < 2,10	2,00 ≤ COP < 2,40	1,80 ≤ EER < 2,10	1,60 ≤ COP < 1,80
E	1,60 ≤ EER < 1,80	1,80 ≤ COP < 2,00	1,60 ≤ EER < 1,80	1,40 ≤ COP < 1,60
F	1,40 ≤ EER < 1,60	1,60 ≤ COP < 1,80	1,40 ≤ EER < 1,60	1,20 ≤ COP < 1,40
G	< 1,40	< 1,60	< 1,40	< 1,20

Figure 3: Current energy efficiency classes for single and double ducts set by Regulation 626/2011

The proposed energy efficiency class is summarised in Table 2 and Table 3. Since the current energy labelling does not distinguish the scale for 0 – 6 kW range and 6 – 12 kW range, it is proposed to keep this approach and set the same scale for fixed air conditioners and there is no technical reason for why larger air conditioners cannot achieve the same BNAT levels for 0 – 6 kW range.

The class length is regular with 15 % increase for each class. This is a minimum value so that class width is superior to maximum uncertainties implied by present version of EN14825 standard (2016). In parallel, the study team aims at gathering stakeholders view on the feasibility to lower these tolerances. See more about proposed tolerances and uncertainties in section 7.1.6.

Given the extension of SCOP performances for split air conditioners, this leads to not using F and G classes.

Table 2: Proposed new label schemes for SEER

Label scheme	Other than portable air conditioners	Portable air conditioners
A	SEER ≥ 11.5	SEER ≥ 4
B	9.7 ≤ SEER < 11.5	3.5 ≤ SEER < 4
C	8.1 ≤ SEER < 9.7	3.0 ≤ SEER < 3.5
D	6.8 ≤ SEER < 8.1	2.6 ≤ SEER < 3.0
E	5.7 ≤ SEER < 6.8	2.3 ≤ SEER < 2.6
F	4.8 ≤ SEER < 5.7	SEER < 2.3
G	SEER < 4.8	

Table 3: Proposed new label scheme for SCOP

Label scheme	Other than portable air conditioners
A	SCOP ≥ 6.2
B	5.5 ≤ SCOP < 6.2
C	4.9 ≤ SCOP < 5.5
D	4.3 ≤ SCOP < 4.9
E	4.9 ≤ SCOP < 4.3
F	SCOP < 3.8
G	NA

Currently, consumers are not aware of the difference in energy efficiency when comparing fixed and portable air conditioners as the current energy labels for both types are largely the same. To enable better comparison, it is proposed that requirements should be set using seasonal performance metrics for both, proposed metrics with default infiltration values described in section 7.1.5 can be used as transitional method. However, it is the opinion of the study team that an energy class should only be proposed for portable air conditioners (single and double ducts) in cooling mode using proposed SEER metrics. SCOP is to be declared on the energy label but no energy class is proposed; see an example of visual presentation for proposed energy label in Figure 4 below. When seasonal performance (that accounts for infiltration) of these products is widely known, an energy class scale for SCOP can be then proposed.

Lastly, infiltration measurement should be proposed in the future mandate for standards.

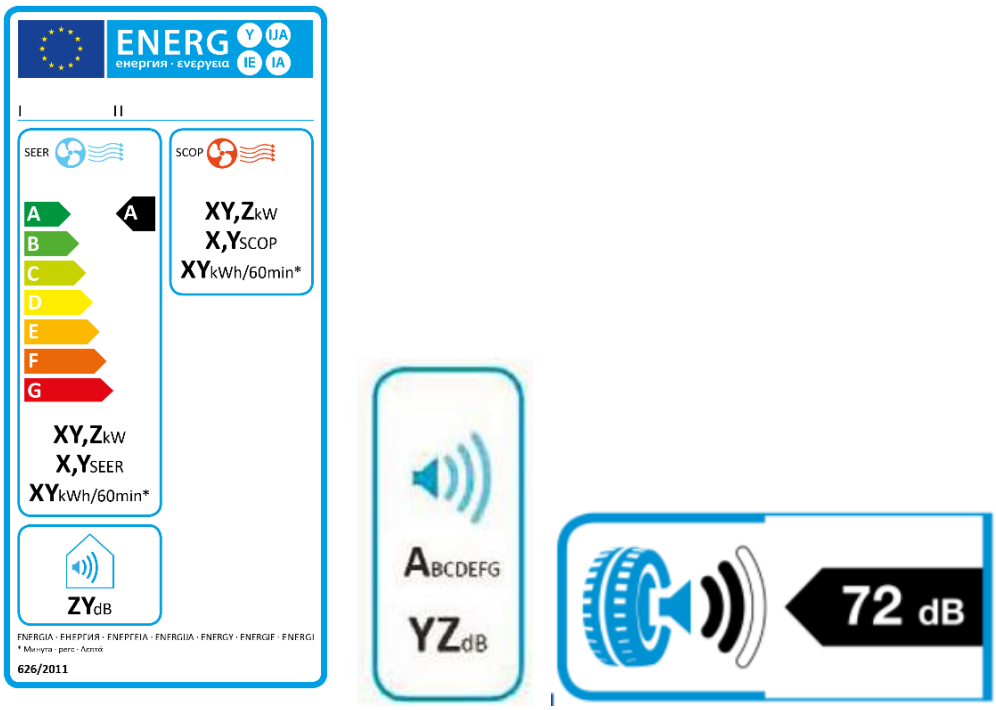

Figure 4: Example of proposed energy label for portable single and double duct units (not final revised label), example of expressing sound power level in a scale of A-G (middle), and example of sound power level expressed by pictograms of sound waves used by tyre labels (left).

Furthermore, some stakeholders[9] have suggested to establish a sound power level scale for all heat pumps and add it on the energy label. Since the noise is an increasing concern of the consumers, the energy label should indicate the sound power levels in a scale of A–G or the loudness should be indicated by pictograms the sound waves already used in the icon, tyre label can be of inspiration, see Figure 4.

Combined label scheme

For better comparison between fixed and portable air conditioners, a combined label scheme is suggested based on primary seasonal space heating and cooling efficiency ($\eta_{s,h}$ and $\eta_{s,c}$). A combined label scheme may influence positively the effect of the label, as the class length proposed above is elongated due to the efficiency development and it is too difficult and costly to improve the product to a better class. Another challenge is the difference in the SCOP and SEER calculations which means that the products not are 100 % comparable. The benefit of a combined label based on primary seasonal space heating and cooling efficiency ($\eta_{s,h}$ and $\eta_{s,c}$) is the better comparison of products, so the consumers can see the differences in efficiency of the different technologies.

Primary seasonal space heating and cooling efficiency is also used in e.g. Regulation (EU) No 811/2013 for space heaters, combination heaters and Regulation (EU) No 2015/1187 for solid fuel boilers etc. Ideally, the use of $\eta_{s,h}$ should be aligned with all relevant regulations so all heating products can be compared.

Table 4 represents a suggestion on how the classes could be defined in a combined label scheme. Note that SEER and SCOP are replaced with $\eta_{s,c}$ and $\eta_{s,h}$. $\eta_{s,c}$ is calculated as the SEER value divided by the primary energy factor[10] and $\eta_{s,h}$ is calculated as the SCOP value divided with the primary energy factor.

Table 4: Proposed new label schemes for a combined label

Label scheme	$\eta_{s,c}$	$\eta_{s,h}$
A	$\eta_{s,c} \geq 4.6$	$\eta_{s,h} \geq 2.5$
B	$3.3 \leq \eta_{s,c} < 4.6$	$2 \leq \eta_{s,h} < 2.5$
C	$2.4 \leq \eta_{s,c} < 3.3$	$1.6 \leq \eta_{s,h} < 2$
D	$1.8 \leq \eta_{s,c} < 2.4$	$1.3 \leq \eta_{s,h} < 1.6$
E	$1.3 \leq \eta_{s,c} < 1.8$	$1 \leq \eta_{s,h} < 1.3$
F	$0.9 \leq \eta_{s,c} < 1.3$	$0.8 \leq \eta_{s,h} < 1$
G	$\eta_{s,c} < 0.9$	$\eta_{s,h} < 0.8$

7.1.4.3 Comfort fans

Regarding comfort fans the same challenges still exist (since the preparatory study) and it is further elaborated in Annex 1. Based on the findings of this assessment there are options which are:

- Setting minimum energy efficiency requirements on comfort fans with the proposed requirements (from the preparatory study) with the risk of banning many comfort fans in the European market (expected savings in the preparatory study was slightly below 1 TWh).

[9] NGOs such as ANEC and BEUC, Member states such as Germany and EEA country Norway
[10] Primary energy factor is assumed 2.5 until the European Commission published a new value.

- Enforcing better market surveillance on the current information requirement and gathering accurate information on comfort fan efficiency and test methods through a complementary study/efficiency tests with corresponding costs.

7.1.4.4 Material efficiency requirement

Material efficiency requirements are very difficult to model, as the material efficiency is dependent on the waste handling system. This system can change due to commodity prices which potentially can change the business model of shredders. If the commodity prices are subject to a significant increase the recycling may be improved due to improved economic incentive and vice versa. As long as the preferred recycling option is shredding all suggestions regarding improved disassembly are not reasonable regarding improvement in recycling rates. The affordability of repair could be improved due to design for disassembly, but manufactures have indicated that they already are targeting to improve the reparability so they do not believe that there is a need to include these requirements. This was supported by exploded views of appliances where it was visible that the assembly was proportionate simple and parts like the PCBs was easily reachable, see Table 5 for more detail. Furthermore, air conditioners already have to comply with the requirements in the WEEE directive, but the transposition of the directive is different in Member state.

Another challenge is the End-of-Life shredding if air conditioners are mixed with other types of appliances (E.g. refrigerators). Then the impact of material requirements (e.g. requirements of the type of plastic used for the casing) will be reduced as air conditioners are mixed with other products containing different materials and the risk of contamination will increase. To improve the recycling rate of air conditioners the best solution is to make horizontal requirements of product families so products that are recycled together consist of compatible materials. Another solution is to improve the recycling facilities by investing in improved sorting technologies or new technologies such as carbon capture technologies[11]. Carbon capture technologies can in the future use CO_2 (e.g. from combustion of plastic) as a feedstock for polymers.

Opportunities for setting material efficiency requirements in ecodesign exist, however without the appropriate assessment tool the impacts of any requirements cannot be properly assessed. EcoReport tool can assess the impacts of the amount of raw materials used, the percentage of mass fraction at end of life is reused, recycled or utilised for heat recovery. Nevertheless, the EcoReport tool focuses mainly on energy and CO2-related indicators, with the significant use phase energy consumption, any impacts of potential material efficiency requirement are in comparison very small, in Task 5 it was also concluded that the use phase related to the highest impacts due to the high energy consumption. In addition, the environmental impacts of improving material efficiency cannot be properly assessed as it is expected to have greater influence on other environmental indicators not included in EcoReport Tool such as abiotic depletion.

Industry stakeholder implied that material efficiency requirements would have very little impact as air conditioners are assembled and designed with repair and maintenance in mind, and unlikely to affect the recycling process for air conditioners, as most of the household appliances are shredded. In the sensitivity analyses in section 7.4, the potential impacts of increasing the recycling rate to maximum are calculated and the results shows little significance.

[11] https://setis.ec.europa.eu/setis-reports/setis-magazine/carbon-capture-utilisation-and-storage/co2-feedstock-polymers

Table 5: Discussion on material efficiency improvements options presented in Task 4.

Difficulties	Ecodesign opportunities	Current situation[12]
Many consumer products are facing reduction in their useful life. This means an increased resource consumption for production of new materials.	Requirements of availability of spare parts (selected parts)	Consulted European manufactures are providing spare parts as a service in the range of 7-12 year which seems reasonable as inefficient/old air conditioners should be replaced at some point. Though, this may not be always true for the lower end of the market.
To avoid premature disposal of efficient air conditioners the cost of repair should be reduced so more air conditioners are repaired. This will minimise the resource consumption of raw materials.	Requirements of exploded views[13] and instructions for disassembly	Exploded views are already available from the largest manufacturers for repair (not for disassembly as the products are shredded[14] anyways). Stakeholders have suggested that manufactures have a genuine interest in informing the professional installers about the detailed design of each product to make the repair as easy as possible. It seems reasonable not to provide these information for regular customers due to safety risks (inappropriate disassemble and repair). End-of-Life the products are most likely shredded and instructions for disassembly would be redundant for recyclers but may prove useful for reparation and refurbishment of appliances[15].
Regarding repair and recycling efficiency it is beneficial if certain components are easy to repair or remove End-of-Life. Especially PCBs are of interest regarding repair (among the most sold spare parts) and End-of-Life treatment (critical raw materials).	Requirements regarding the number of operation to remove targeted components (e.g. printed circuit boards greater than 10 square centimetres)	Consulted European manufacturers have stated that most air conditioners already are designed for fast and easy access and exchange of parts for repair, therefore they assumed that recyclers easily can remove the PCBs before shredding if desired.
Most refrigerants today have an GWP above 2000 and pose a serious threat to the environment.	Requirements of pump-down systems to minimise leakage of refrigerants End-of-Life	According to stakeholders the pump-down function is only useful if the End-of-Life at the site is planned. If the End-of-Life is caused by malfunctions the installer would anyways recover the refrigerant. Furthermore, the amount of leakage during decommissioning is difficult to quantify and the F-gas regulation will limit the impact. In addition, it is assumed that most air conditioners are equipped with a pump down function.

However, if material efficiency requirements are aligned across several regulations as mentioned above, the impact may be much greater and it ensures regulatory consistency within ecodesign framework. In Table 6, different material efficiency requirements in other regulations are presented.

[12] Based on inputs from EPEE
[13] A technical drawing of the appliance showing position of each components inside
[14] Currently, due to economic constraints most household appliances are shredded at recyclers and then e.g. the printed circuit boards are removed by eddy-current separation of sink/float separation.
[15] Confirmed by former operator on AVERHOFF, Tom Ellegaard

Table 6: Alignment with other regulations

	1. Information requirements for refrigeration gases	2. Requirements for dismantling for the purpose of avoiding pollution, and for material recovery and recycling	3. Spare part availability	4. Spare part maximum delivery time	5. 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[16]. 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[17]. Though these requirements are difficult to quantify with the current methodology, a study from Deloitte[18] suggest that the following options might have a positive effect on the environment:

- Measures to ensure provision of information to consumers on possibilities to repair the product (corresponds to requirement 5 in Table 6)
- Measures to ensure provision of technical information to facilitate repair to professionals (corresponds to requirement 1, 2 and 5 in Table 6)
- Measures to enable an easier dismantling of products (corresponds to requirement 2 in Table 6)

[16] 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.
[17] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.
[18] Deloitte (2016) Study on Socioeconomic impacts of increased reparability – Final Report. Prepared for the European Commission, DG ENV.

- 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 (corresponds to requirement 3 and 4 in Table 6)
- Different combination of the above-mentioned options

It is therefore recommended to consider aligning with material efficiency requirements regulations for dishwashers, washing machines or domestic refrigerators and freezers.

7.1.5 Metrics changes

Impact of infiltration for single duct and double duct air conditioners

A mandate to CEN should be delivered to develop a test procedure to measure infiltration air flow (i.e. condenser air flow when the unit is operated in cooling mode) for single duct air conditioner. Different methods may be possible; for each of them, uncertainties for these different methods need to be characterized.

7.1.5.1 Portable air conditioners: change in standard rated conditions in cooling mode

To account for infiltration impact on performances, it is necessary to measure single duct unit capacity and efficiency at test condition 27 °C indoor (wet bulb 19°C) / 27 °C outdoor (wet bulb 19°C). This point should be used to define the rated capacity instead of 35 (24) / 35 (24).

For portable double duct units, a supplementary test point, that defines the product rated capacity, is to be done at 27 °C (and 19 °C wet bulb temperature) outdoor inlet air temperature / 27 °C (and 19 °C wet bulb temperature) indoor air inlet conditions.

7.1.5.2 Portable air conditioners: cooling mode metrics

To account for infiltration impact on cooling capacity and performance, the following air flow (AF) should be considered for single duct in absence of test to measure the infiltration air flow: 200 m3/h/kW rated cooling capacity

To compute **seasonal efficiency** in cooling mode:

$$SEER = \frac{Qce}{\frac{Qce}{SEER_{on}} + H_{TO} \times P_{TO} + H_{SB} \times P_{SB}}$$

with

$$Qce = 10/24 \times \sum_{1}^{n} hj \times Pc_corr(Tj)$$

and

$$SEER_{on} = \frac{\sum_{j=1}^{n} hj \times Pc_corr(Tj)}{\sum_{j=1}^{n} hj \times \left(\frac{Pc_corr(Tj)}{EER_{bin}(Tj)}\right)}$$

Where,

- *Tj = the bin temperature*
- *j = the bin number*

- *n = the amount of bins*
- Qce: cooling energy supplied by the unit over a season
- SEER: the seasonal energy efficiency ratio in cooling mode
- SEERon: the seasonal energy efficiency ratio in cooling mode without accounting standby and thermostat-off electricity consumption
- *Pc_corr(Tj) = below equilibrium point: the cooling demand of the building for the corresponding temperature Tj; above the equilibrium point: the capacity of the unit for the corresponding temperature Tj*
- *hj = the number of bin hours occurring at the corresponding temperature Tj*
- *$EER_{bin}(Tj)$ = the EER values of the unit for the corresponding temperature Tj.*
- *H_{TO}, H_{SB}: the number of hours the unit is considered to work in thermostat-off mode*
- *P_{TO}, P_{SB}: the electricity consumption during thermostat-off mode*

<u>Calculation of *Pc_corr(Tj)* and *$EER_{bin}(Tj)$* for single duct air conditioners</u>

The rated capacity Qc(Tj) for temperature of bin j should be computed as follows.

$$Qc(Tj) = Qc(27)\ (Eq\ 1)$$

Where:

- *Qc(27): rated capacity at 27(19) indoor and outdoor*

Capacity should then be corrected for infiltration as follows:

$$Qc_corr(Tj) = Qc(Tj) + Q_{INF}(Tj)\ (Eq\ 2)$$

Where:

- Qc_corr(Tj): maximum capacity of the unit corrected with infiltration
- Qc(Tj): maximum capacity in bin Tj without accounting for infiltration

The infiltration impact is calculated with the following formulas:

$$If\ Tj < 27, Q_{INF}(T_j) = \frac{27 - T_j}{27 - 20} \times \left[AF \times \left(rho_{air_{27}} \times h_{27} - rho_{air_{20}} \times h_{20}\right)\right]$$

$$If\ Tj > 27, Q_{INF}(T_j) = \frac{27 - T_j}{35 - 27} \times \left[AF \times \left(rho_{air_{35}} \times h_{35} - rho_{air_{27}} \times h_{27}\right)\right] = \frac{27 - T_j}{35 - 27} \times INF$$

Where:

- *$Q_{INF}(T_j)$: Heat loss by infiltration (W)*
- *Tj: outdoor temperature of bin j*
- *AF: infiltration air flow (m^3/s)*
- *$rho_{air_{20}}$ = 1.20 kg / m3, density of dry air at 20 °C (1 atm)*
- *$rho_{air_{27}}$ = 1.17 kg / m3, density of dry air at 27 °C (1 atm)*
- *$rho_{air_{35}}$ = 1.15 kg / m3, density of dry air at 35 °C (1 atm)*
- *h_{20} = 42.2 kJ/kg_{da} specific enthalpy of infiltration air at 20 °C dry bulb and 15 °C wet bulb temperature per kg of dry air*
- *h_{27} = 54.2 kJ/kg_{da} specific enthalpy of infiltration air at 27 °C dry bulb and 19 °C wet bulb temperature per kg of dry air*

- h_{35} = *72.5 kJ/kg$_{da}$ specific enthalpy of infiltration air at 35 °C dry bulb and 24 °C wet bulb temperature per kg of dry air*
- *INF = infiltration in kW (cooling capacity loss - negative capacity value due to infiltration)*

Equilibrium temperature, which is the intersection between building load curve (Eq 3) and capacity corrected with infiltration (Eq 2) is determined and noted Teq.

$$Qc_corr(Tj) = Qc(27) + \frac{27 - T_j}{35 - 27} \times INF \ (Eq\ 2)$$

$$BL(Tj) = Qc(27) \times (T_j - 23) \ / \ (35 - 23) \ (Eq\ 3)$$

$$T_{eq} = \frac{Qc(27) + \frac{27}{35 - 27} \times INF + \frac{23}{(35 - 23)} \times Qc(27)}{\frac{Qc(27)}{35 - 23} + \frac{INF}{(35 - 27)}} \ (Eq\ 4)$$

Pc_corr(Tj) is then computed as follows:

$$If\ Tj \leq Teq: Pc_corr(Tj) = BL(Tj)$$
$$If\ Tj > Teq: Pc_corr(Tj) = Qc_corr(Tj)$$

To compute EERbin(Tj), two cases may occur. In both cases, the capacity ratio should be computed as follows:

$$CR(Tj) = min\ (1\ ;\ Pc_corr(Tj) \ / \ BL(Tj))$$

Case 1: on-off unit

$$If\ CR(Tj) < 1;\ EERbin(Tj) = EERrated\ x\ (1 - Cdc\ x\ (1 - CR(Tj)))$$

With Cdc cycling coefficient with a value 0.25 by default.

Case 2: inverter unit

A supplementary test should be made at 27 (19) / 27 (19) temperature conditions and at 33 % capacity ratio. The part load coefficient of EER variation noted PLc should be computed as follows:

$$PLc = \frac{\frac{EER(27;33\%) - EER(27;100\%)}{EER(27;100\%)}}{\frac{Qc(27;100\%) - Qc(27;33\%)}{Qc(27;100\%)}} \ (\text{Eq } 5)$$

And EERbin(Tj) should be computed as follows:

$$If\ CR(Tj) \geq 0.33;\ EERbin(Tj) = EERrated\ x\ (1 + PLc\ x\ (1 - CR(Tj)))$$

$$If\ CR(Tj) < 0.33;\ EERbin(Tj) = EERrated\ x\ \big(1 + PLc\ x\ (1 - 0.33)\big) x \big(1 - 0.25\ x\ (1 - CR(Tj)/0.33)\big)$$

<u>Calculation of *Pc_corr(Tj)* and *EER$_{bin}$(Tj)* for double duct air conditioners</u>

$$Qc(Tj) = Qc(27) + (Qc(35) - Qc(27))/8\ x\ (Tj - 27)\ (Eq\ 1bis)$$

Where:

- *Qc(27): rated capacity at 27(19) indoor and outdoor*
- *Qc(35): rated capacity at 27(19) indoor and 35(24) outdoor*

Capacity should then be corrected for infiltration as follows:

$$Qc_corr(Tj) = Qc(Tj)\ (Eq\ 2bis)$$

Equilibrium temperature, which is the intersection between building load curve (Eq 3) and capacity corrected with infiltration (Eq 2) is determined and noted Teq.

$$Qc_corr(Tj) = Qc(27) + (Qc(35) - Qc(27))/8\ x\ (Tj - 27)\ (Eq\ 2bis)$$

$$BL(Tj) = Qc(27) \times (T_j - 23) / (35 - 23)\ (Eq\ 3)$$

$$T_{eq} = \frac{Qc(27) - 27 \times \frac{Qc(35) - Qc(27)}{8} + 23 \times \frac{Qc(27)}{(35 - 23)}}{\frac{Qc(27)}{35 - 23} - \frac{Qc(35) - Qc(27)}{(35 - 27)}}\ (Eq\ 4)$$

Pc_corr(Tj) is then computed as follows:

$$If\ Tj \leq Teq: Pc_corr(Tj) = BL(Tj)$$

$$If\ Tj > Teq: Pc_corr(Tj) = Qc_corr(Tj)$$

To compute EERbin(Tj), two cases may occur. In both cases, the capacity ratio (CR(Tj)) should be computed as follows:

$$CR(Tj) = min\ (1\ ;\ Pc_corr(Tj) / BL(Tj))$$

For double duct units, the efficiency at maximum capacity should be computed as follows:

$$EER(Tj) = EER(27) + (EER(35) - EER(27))/8\ x\ (Tj - 27)$$

Where:

- *EER(27): rated EER at 27(19) indoor and outdoor*
- *EER(35): rated EER at 27(19) indoor and 35(24) outdoor*

Case 1: on-off unit

$$If\ CR(Tj) < 1;\ EERbin(Tj) = EER(Tj)\ x\ (1 - Cdc\ x\ (1 - CR(Tj)))$$

With Cdc cycling coefficient with a value 0.25 by default.

Case 2: inverter unit

A supplementary test should be made at 27 (19) / 27 (19) temperature conditions and at 33 % capacity ratio. The part load coefficient of EER variation noted PLc should be computed as follows:

$$PLc = \frac{\frac{EER(27;33\%) - EER(27;100\%)}{EER(27;100\%)}}{\frac{Qc(27;100\%) - Qc(27;33\%)}{Qc((27;100\%)}} (Eq\ 5)$$

And EERbin(Tj) should be computed as follows:

$$If\ CR(Tj) \geq 0.33;\ EERbin(Tj) = EERrated\ x\ (1 + PLc\ x\ (1 - CR(Tj)))$$

$$If\ CR(Tj) < 0.33;\ EERbin(Tj) = EERrated\ x\ \big(1 + PLc\ x\ (1 - 0.33)\big) x \big(1 - 0.25\ x\ (1 - CR(Tj)/0.33)\big)$$

7.1.5.3 Metrics change for double duct products (fix and portable) in heating mode

The intent is to use the same methodology for double duct as for split air conditioners in heating mode following EN14825 standard. There is in fact no difference to be made as infiltrations are already included in the tests done for double duct units.

Because of the effect of infiltration, bivalent temperature points should be set higher than for products without infiltration. Bivalent temperatures used in Regulation EU no 206/2012 can be used for double duct heat pumps.

Changes in metrics for fixed air conditioners and heat pumps
Crankcase hours should be adjusted.

7.1.6 Proposed tolerances and uncertainties

Present tolerance levels in Regulation (EU) No 206/2012

Tolerances are defined as follows:

- EER of single duct and double duct appliances: 10 %
- SEER and SCOP of split air conditioners: 8 %

Tolerance and uncertainty: background

Fixing tolerance is a political decision. CEN/CENELEC Eco-design Coordination Group[19] defines the general policy for Ecodesign measures on how to choose appropriate tolerance levels. This should be based upon the expanded measurement uncertainty which includes the repeatability and reproducibility components. Repeatability refers to measurement uncertainty of the same unit tested several times in the same laboratory. Reproducibility refers to variations between laboratories. This leaves to manufacturers the charge of the variations due to manufacturing.

Expanded measurement uncertainties should be based upon the results of Round Robin tests (RRT), if available. According to CEN/CENELEC Eco-design Coordination Group, "the expanded uncertainty is taken as the product of (a) a coverage factor (usually equal to 2) that yields an interval of values within which the true value lies with a level of

[19] http://ecostandard.org/wp-content/uploads/ECO-CGN0195-Recommendations-for-establishing-verification-tolerance-considering-measurement-uncertainty.pdf

confidence of approximately 95 %, and (b) the standard deviation of the results divided by the square root of the number of results".

It is thus strongly advised to lead Round Robin tests for both SEER of portable air conditioners and SEER and SCOP of fixed air conditioners. However, at the time this report is written, such results are not available. For portable air conditioners, a preliminary report on a still on-going Round Robin test reported by UBA[20] could allow to compute EER expanded uncertainties: reproducibility standard deviation was determined to be of 1 % (test in 2 different laboratories) and the repeatability standard deviation was not greater than 0.6 % in each test laboratory (with 4 tests by laboratory). Further results from additional laboratories are expected by mid-2018 to deliver statistically valid reproducibility value. Applying Eco-design coordination group methodology to present results (an approximation is used here as individual test results have not been supplied) would lead to expanded uncertainties below 3 % ($2 \times \sqrt{(0.01^2+0.006^2)} = 2.3$ %). This seems very low as compared to present tolerances of 10 % on EER for single duct air conditioners in Regulation (EU) n° 206/2012 so it seems better to wait for the complete RRT to be completed and final report to become available.

In absence of Round Robin test indications, existing standard EN14825:2016 includes maximum measurement expanded uncertainties (including both repeatability and reproducibility) for capacity and electricity values so that it is possible to calculate maximum expanded measurement uncertainty for seasonal performance indicators. These expanded measurement uncertainties are also used for portable air conditioners here because the same measurement method as for split air conditioners (calorimetric room) is also used for these products. A supplementary measurement is required for single duct air conditioners, this is the condenser air flow, which measurement expanded uncertainty is 5 % according to EN14511-3:2013.

To calculate the expanded uncertainty, as measurement uncertainties indicated in EN14825:2016 are expanded measurement uncertainties, it is enough to propagate the uncertainties to compute seasonal performance metrics expanded uncertainties of measurement from these values.

We then use this method to determine the maximum expanded uncertainties from available standard information for a number of representative units. Calculation of SEER and SCOP uncertainties are done using the software EES[21], which allows to prevent uncertainty propagation uprate due to derivative calculation simplifications or errors. Discussion with test laboratories on this subject show there might be a need for a CEN TC 113 guidance on how to calculate measurement uncertainties for SEER / SCOP as the calculation by hand is quite complex and time consuming (and then may lead to significant errors).

Individual measurement uncertainties

Expanded individual measurement uncertainties are defined as:

- (EN14825:2016) Regarding thermal capacities: 15 % below 1 kW, 10% between 1 and 2 kW, 5 % above 2 kW and 10 % (or 15 % if capacity is less than 1 kW) in non-stationary conditions - i.e. for test points including frost/defrost cycles.

[20] UBA and BAM, Comments received February 6 2018.
[21] Klein, S.A., EES – Engineering Equation Solver, Version 10.039, 2016, F-Chart Software, http://fchart.com

- (EN14825:2016) Regarding electric power: 1 % with a minimum value of 0.1 W below 10 W (useful for auxiliary power mode measurement[22])
- (EN14511:3, 2016) For infiltration measurement of single duct air conditioners, 5% on the air flow rate.

Best possible values achievable by the time of the measures have been discussed with test laboratories:

- Regarding thermal capacities: 10 % below 2 kW, 5 % above 2 kW and 5 % (or 10 % if capacity is less than 1 kW) in non-stationary conditions - i.e. for test points including frost/defrost cycles.
- Regarding electric power: 1 % with a minimum value of 0.1 W below 10 W
- For infiltration air flow measurement of single duct air conditioners, 5%.

Note that for infiltration air flow of single duct air conditioners, manufacturers indicated that the air flow test is to be done in realistic operating conditions because the air flow decreases when the quantity of condensates increases in the condenser air flow (most single duct units indeed recirculate the condensates from the evaporator to the condenser so that they may be evaporated). The impact of a higher uncertainty level of 10 % is thus tested hereafter.

EU test laboratories have indicated that to further decrease expanded measurement uncertainties for thermal capacities, which are the major components in the final repeatability uncertainty of SEER and SCOP value, it would be necessary that EU test laboratories build new calorimetric room chambers of smaller size, which, even if they had the money to invest in, could not be realistically ready at the time revised air conditioner regulations enter into force. Basing upon the example of measurement uncertainty in other economies, manufacturers believe it is still possible to go lower by forcing all test laboratories to standardize some of the measurement methods between the laboratories.

Expanded uncertainty calculation for split air conditioners

Six different unit types are considered. For these units, all parameters required to compute SEER / SCOP are available. For all these units, as explained before in Task 4, the building load required at D point condition cannot be reached. This tends to reduce the measurement uncertainty for lower capacity units as measurement uncertainties presently increases with decreasing capacity. Consequently, it is supposed in what follows that the same efficiency at D point can be obtained without cycling but by adjusting the capacity to the required building load. This gives an idea of the uncertainty increase for machines that can reach such low capacity levels. This tend to increase SEER/SCOP expanded uncertainty between 0.5 % (smaller units) to 0.3 % (larger units).

Calculation results are shown in Table 7 for both present uncertainty levels and the improved scenario described above.

[22] Note this value is to be increased to 0.3 W in the next revision of EN14825:2016, but this has a negligible impact on SEER and SCOP uncertainty values.

Table 7: Measurement uncertainty calculation results for 6 split units of different sizes.

Expanded uncertainty				
Products Cooling capacity (kW)	**SEER**	**SCOP**	**Unc_SEER %**	**Unc_SCOP %**
1.5	5.7	4.0	7.1%	8.4%
2.5	7.8	4.6	5.3%	6.5%
3.5	8.5	4.7	4.8%	5.8%
5	6.1	4.2	3.2%	5.9%
7	7.1	4.0	3.1%	5.8%
10.5	6.1	4.0	2.8%	5.8%
Expanded uncertainty				
Products Cooling capacity (kW)	**SEER**	**SCOP**	**Unc_SEER %**	**Unc_SCOP %**
1.5	5.7	4.0	5.1%	5.6%
2.5	7.8	4.6	4.9%	5.7%
3.5	8.5	4.7	4.3%	5.6%
5	6.1	4.2	3.2%	3.6%
7	7.1	4.0	3.1%	3.6%
10.5	6.1	4.0	2.8%	3.0%

Tolerance in Regulations (EU) n°206/2012 and 626/2011 should be set close to the expanded uncertainty levels. The 8 % tolerance in these regulations is compatible for all units except in heating mode for less than 2 kW unit for which expanded measurement uncertainty is 8.4 %. However, the D point capacity in real life cannot be reached and so the expanded uncertainty is close to 8 %.

With present expanded measurement uncertainties in EN14825:2016, tolerance could already be reduced for the higher capacity range. In the present situation, the following maximum expanded uncertainties could be used to set tolerances as follows:

- SEER tolerance: 8 % below 2 kW cooling capacity, 6 % between 2 and 6 kW and 4 % between 6 and 12 kW.
- SCOP tolerance: 8 % below 2 kW cooling capacity, 7 % between 2 and 6 kW and 6 % between 6 and 12 kW.

With the improved accuracy in the second scenario, (expanded uncertainties and so) tolerances could be reduced to 6 % below 6 kW cooling capacity and 4 % between 6 and 12 kW for both SEER and SCOP.

Expanded uncertainty calculation for portable air conditioners

For portable air conditioners, the base case single duct appliance is used, part load control is either on/off cycling or with compressor inverter; in that later case, it is supposed the test point capacity at 33 % can be reached by reducing the frequency (this maximize capacity measurement uncertainty at low load). Two values regarding air flow measurement uncertainties are considered given that the measurement methodology is not yet fixed, 5 % and 10 %.

Calculation results are shown in Table 8 below.

Table 8: Measurement uncertainty calculation results for 2 single duct units of different sizes

Existing individual uncertainty							
Products Cooling capacity (kW)	**Unc_Air flow rate %**	**SEER**	**T_eq**	**P[T_eq]**	**Unc_SEER %**	**Unc_Teq %**	**Unc_P[T_eq] %**
2.44 kW (27) ON/OFF	5%	2.1	30.0	1.42	5.8%	0.4%	6.5%
2.44 kW (27) ON/OFF	10%	2.1	30.0	1.42	5.9%	0.7%	6.9%
2.44 kW (27) Inverter	5%	2.9	30.0	1.42	7.5%	0.4%	6.5%
2.44 kW (27) Inverter	10%	2.9	30.0	1.42	7.6%	0.7%	6.9%
1.90 kW (27) ON/OFF	5%	2.1	30.0	1.10	11.3%	0.7%	12.7%
1.90 kW (27) ON/OFF	10%	2.1	30.0	1.10	11.4%	0.9%	13.0%
1.90 kW (27) Inverter	5%	2.9	30.0	1.10	10.0%	0.7%	12.7%
1.90 kW (27) Inverter	10%	2.9	30.0	1.10	10.1%	0.9%	13.0%
With reduced individual uncertainties - Repeatability only							
Products Cooling capacity (kW)	**Unc_Air flow rate %**	**SEER**	**T_eq**	**P[T_eq]**	**Unc_SEER %**	**Unc_Teq %**	**Unc_P[T_eq] %**
2.44 kW (27) ON/OFF	5%	2.1	30.0	1.42	5.8%	0.4%	6.5%
2.44 kW (27) ON/OFF	10%	2.1	30.0	1.42	5.9%	0.7%	6.9%
2.44 kW (27) Inverter	5%	2.9	30.0	1.42	5.8%	0.4%	6.5%
2.44 kW (27) Inverter	10%	2.9	30.0	1.42	6.0%	0.7%	6.9%
1.90 kW (27) ON/OFF	5%	2.1	30.0	1.10	11.3%	0.7%	12.7%
1.90 kW (27) ON/OFF	10%	2.1	30.0	1.10	11.4%	0.9%	13.0%
1.90 kW (27) Inverter	5%	2.9	30.0	1.10	8.8%	0.7%	12.7%
1.90 kW (27) Inverter	10%	2.9	30.0	1.10	8.9%	0.9%	13.0%

Air flow measurement uncertainty has a very limited influence on the performance parameters. Although no smaller than 2 kW (capacity @ 27/27) unit could be identified in today EU market, if such a unit was available, tolerances should be much higher than for higher than 2 kW units. If inverter units become available on the EU market, the uncertainties and tolerances need to be higher.

In the present situation, the following maximum expanded uncertainties could be used to set tolerances as follows:

- SEER: 6 % for on/off and 8 % for inverter (12 % for lower than 2 kW @ 27/27 units)
- Pc(Teq): 7 % (13 % for lower than 2 kW @ 27/27 units)
- Teq: 0.3 K (0.4 K for lower than 2 kW @ 27/27 units)

The improved accuracy scenario would allow to lower the SEER uncertainty as follows:

- SEER: 6 % (12 % for lower than 2 kW @ 27/27 units)

Conclusion: proposal regarding tolerances of performance parameters

According to previous definitions, tolerances should be higher than the repeatability measurement uncertainty alone and lower or equal to the expanded uncertainty. In absence of RRT, tolerance values should be fixed to the maximum possible value, i.e. to the level of the maximum expanded uncertainties.

With present measurement uncertainties, tolerance levels can be set as follows:

- split air conditioners:
    - SEER tolerance: 8 % below 2 kW cooling capacity, 6 % between 2 and 6 kW and 4 % between 6 and 12 kW.
    - SCOP tolerance: 8 % below 2 kW cooling capacity, 7 % between 2 and 6 kW and 6 % between 6 and 12 kW.
- portable air conditioners:
    - SEER: 6 % for on/off and 8 % for inverter (12 % for lower than 2 kW @ 27/27 units)
    - Pc(Teq): 7 % (13 % for lower than 2 kW @ 27/27 units)
    - Teq: 0.3 K (0.4 K for lower than 2 kW @ 27/27 units)

SEER and SCOP tolerance levels in Regulations (EU) No 206/2012 and 626/2011 need to be revised.

With improved measurement accuracy, tolerances could be reduced to the following levels:

- split air conditioners:
    - SEER: 6 % below 6 kW cooling capacity and 4 % between 6 and 12 kW
    - SCOP: 6 % below 6 kW cooling capacity and 4 % between 6 and 12 kW
- portable air conditioners:
    - SEER: 6 % (12 % for lower than 2 kW @ 27/27 units)

Further discussions with test laboratories and manufacturers are required about the conditions of feasibility and timing of this improved scenario.

These proposed air conditioner performance indicators should be the subject of regular Round Robin Tests amongst EU laboratories. These RRT should be used to calculate the expanded measurement uncertainties from test results and to lower tolerances depending on the RRT results. Individual measurement uncertainties on capacity should also be adjusted depending on the results of such campaigns.

A RRT campaign is on-going for portable air conditioners and could be used to reduce the expanded uncertainty on EER measurements and thus also on the performance parameters indicated here.

7.2 Scenario analysis

The scenario analysis investigates the impact of the current regulation and revised regulation regarding reduction in energy consumption and emission of CO_2-eq. The impact of changes to material composition are not included as the impacts are very limited due to changes in the material composition. Nor are suggestions towards improved material efficiency included due to the limited impact (industry have already improved due to a focus on reparability) and to the difficulties with quantifying the improvement potential.

The options investigated are all related to improved energy efficiency and sound power level. The investigated options are:

- Option 0 and 1: BAU scenario (before and after current regulation)
- Option 2: Revised Ecodesign requirement
- Option 3: Revised Energy labelling
- Option 4: Combination of revised Ecodesign and Energy labelling

These options are all modelled according to the assumed effect on the proposed requirements and are used to model different scenarios. These scenarios are dependent on the different potential improvement options presented in Task 6. The modelled scenarios and the correlation with the improvement options presented in Task 6 are shortly described in the table below.

Table 9: Summary of policy scenarios and brief descriptions

Policy scenario	Description
Scenario 0 (0 BAU)	BAU before EU regulation – In general low yearly improvements. The only improvement included is the use of inverter technology
Scenario 1 (1 BAU)	BAU scenario (current regulation) – The impact of the current regulation with only limited incentive to improve products beyond the A+++ label
Scenario 2 (1 tier eco)	Ecodesign minimum efficiency requirement with one tier based on LLCC (BC 1 for BC 1, -10%Ua_cond for BC 2 and HE1with R290for BC 3)
Scenario 3 (lbl)	Energy class A as BNAT (combining the different improvement for each of the base cases)
Scenario 4 (eco+lbl)	Ecodesign and Energy labelling scenario 2 + scenario 3

The impacts of the different scenarios are calculated based on the stock and the annual sales. Furthermore, all scenarios are built on different assumptions from Task 5 and Task 6 and are presented in Annex 1.

The development of SEER and SCOP in the different scenarios are presented below in the different scenarios.

7.2.1 Before EU regulation – 0 scenario

The before EU regulation scenario is used as a baseline to show how effective the EU intervention has been so far. Though, this is difficult since the regulation in countries outside of the EU also have an effect on the European market. The assumptions made to model the improvements on SEER and SCOP are mainly focusing on the shift to inverter technology which supposedly also would have happened without any intervention from EU. The assumed average SEER and SCOP development for air conditioners sold are presented in Table 10.

Table 10: Development of SEER and SCOP of air conditioners sold - with no EU regulation

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
SEER										
BC1	2.18	2.30	2.76	3.22	3.68	4.14	4.59	5.05	5.51	5.65
BC2	1.88	1.99	2.41	2.84	3.26	3.68	4.11	4.53	4.95	5.08
BC3	1.22	1.28	1.34	1.39	1.44	1.50	1.55	1.60	1.66	1.68
SCOP										
BC1	1.85	1.93	2.21	2.48	2.76	3.03	3.31	3.58	3.86	3.96
BC2	1.60	1.67	1.93	2.18	2.44	2.70	2.95	3.21	3.47	3.56
BC3	-	-	-	-	-	-	-	-	-	-

Without the EU regulation the SEER and SCOP levels in 2040 are not even on par with the current situation in 2017. So, the regulation has accelerated the development significantly. The energy and emission of CO_2 are calculated based on these values in Table 11. Note that the hours in heating mode and cooling mode are the same in all scenarios to make the impacts in the different scenarios comparable.

Table 11: The annual energy consumption and emission of CO_2-eq in scenario 0 (no intervention from EU)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Electricity consumption (TWh)										
BC1	4.5	13.2	26.7	37.9	38.7	36.4	42.6	52.2	62.7	75.3
BC2	2.4	6.7	12.8	19.6	22.7	22.4	25.3	29.3	33.7	38.7
BC3	0.4	0.9	1.1	1.2	1.1	1.0	1.0	1.0	1.0	1.0
Total	**7.3**	**20.8**	**40.6**	**58.6**	**62.6**	**59.8**	**69.0**	**82.6**	**97.4**	**115.0**
mt CO_2-eq										
BC1	2.6	6.6	12.9	17.4	17.6	16.5	18.7	22.2	26.3	31.5
BC2	1.3	3.3	6.2	9.0	10.4	10.2	11.2	12.5	14.2	16.2
BC3	0.2	0.4	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5
Total	**4.1**	**10.3**	**19.7**	**27.1**	**28.6**	**27.2**	**30.4**	**35.2**	**40.9**	**48.2**

Sound power level

Before the regulation the sound power level varied a lot for the different air conditioners from quieter to more noisy air conditioners than today. It should be noted that it is difficult to link air flow and sound power level. Though, air flow is clearly one of the main factors in determining the sound power levels, and it is challenging to increase efficiency while reducing sound power level further. The sound power level of air conditioners is presented in Figure 5 and Figure 6.

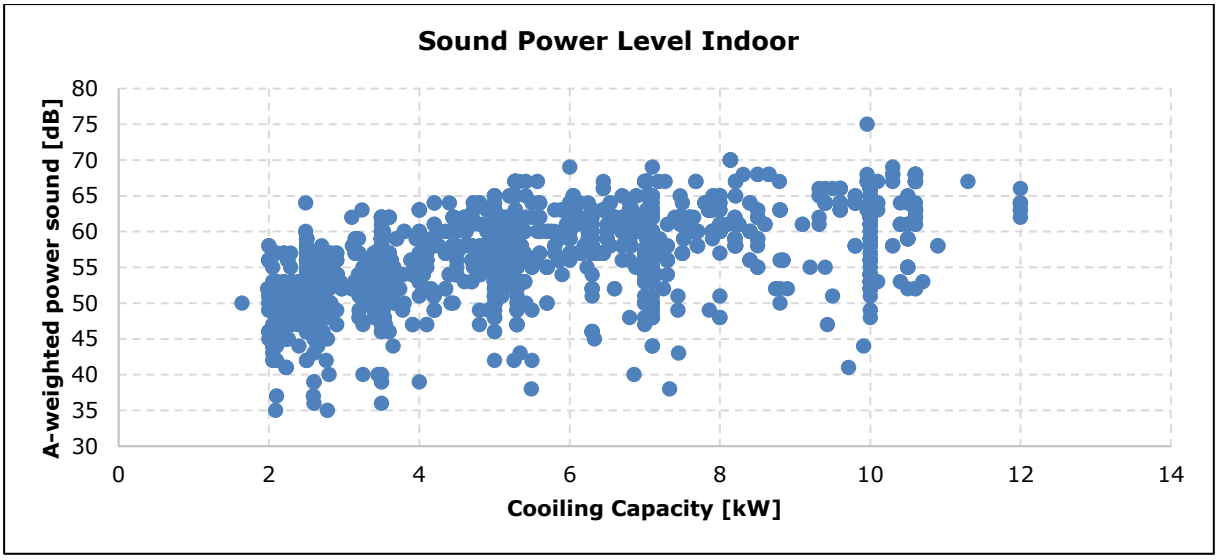

Figure 5: ECC directory 2006, air conditioners below 12 kW, sound power level of indoor unit in cooling mode

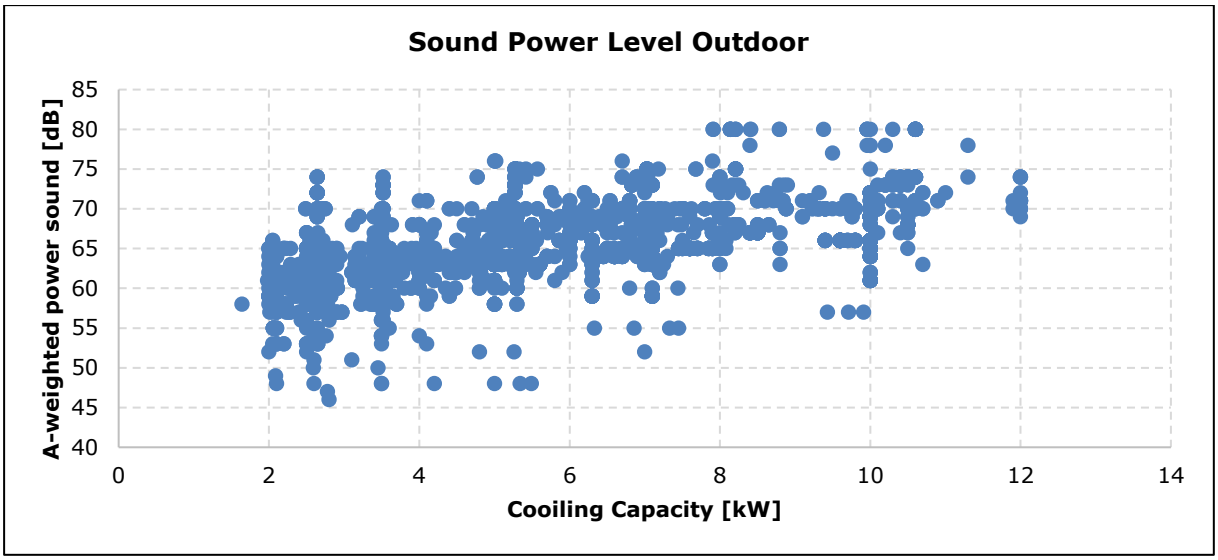

Figure 6: ECC directory 2006, air conditioners below 12 kW, sound power level of outdoor unit in cooling mode

These figures show the sound power level of air conditioners before the current EU regulation.

7.2.2 Business-as-Usual (BAU) - scenario 1

The business-as-usual scenario quantifies the effect of the current regulation (Ecodesign Regulation 206/2012 and Energy Labelling 626/2011) so far and estimate the development until 2040. By comparing scenario 0 and scenario 1 it is possible to calculate the saved energy and emission of CO_2-eq due to the current regulation.

The SEER and SCOP values are based on the current development until today and with no other enforcement for improvement it is estimated that BAT levels (from the preparatory study) first will be reached in 2050. The assumed SEER, SCOP are presented in Table 12.

Table 12: Development of SEER and SCOP with the current regulation

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
SEER										
BC1	2.18	2.44	3.63	4.81	6.00	6.36	6.71	7.07	7.43	7.79
BC2	1.88	2.15	3.37	4.58	5.80	6.01	6.23	6.44	6.66	6.87
BC3	1.22	1.31	1.48	1.65	1.83	1.87	1.91	1.96	2.00	2.05
SCOP										
BC1	1.85	2.01	2.67	3.34	4.00	4.09	4.17	4.26	4.34	4.43
BC2	1.60	1.77	2.51	3.26	4.00	4.04	4.09	4.13	4.17	4.21
BC3	-	-	-	-	-	-	-	-	-	-

Just by comparing the improvement in SEER and SCOP it is visible that the current regulation has had a significant impact for fixed air conditioners. The improvements are approximately 50 % for SEER and SCOP in 2020. This development in SCOP are properly also one of the main reasons for the increased use of fixed air conditioners in heating mode. Air conditioners are replacing inefficient electric radiators as the savings are increasing due to the improved performance of air conditioners. The replacement of inefficient heaters will lead to even larger savings which not are accounted in the presented values below. The smallest increase in efficiency is for portable air conditioners. The SEER has improved from 1.50 in scenario 0 to 1.87 in scenario 1 (2020).

The annual energy consumption and emission of CO_2-eq of scenario 1 are calculated compared to scenario 0 in the presented figures below.

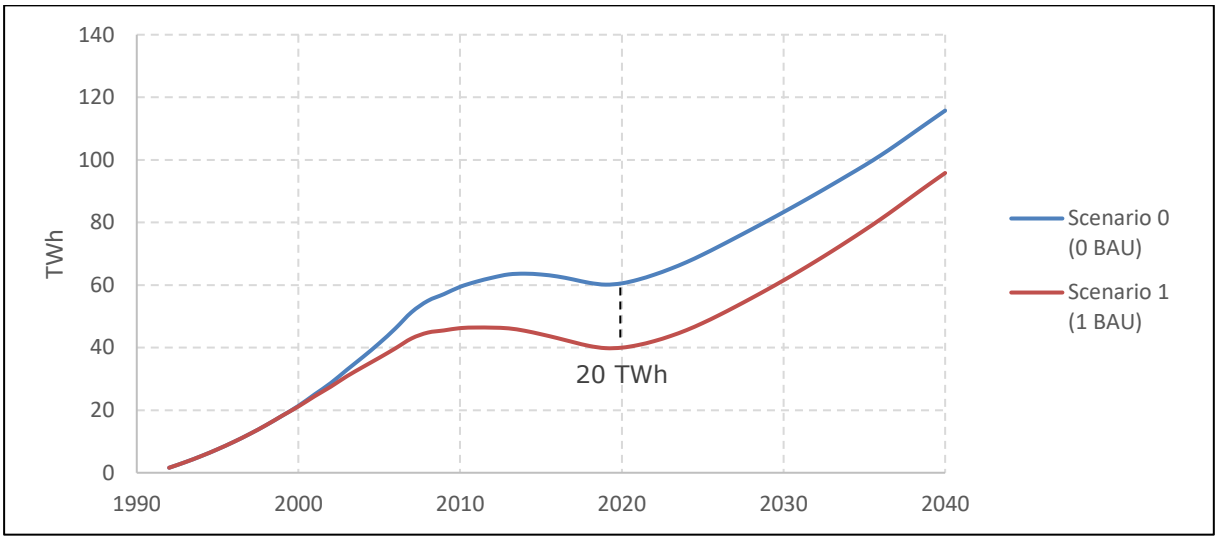

Figure 7: Comparison of the annual energy consumption of scenario 0 and scenario 1.

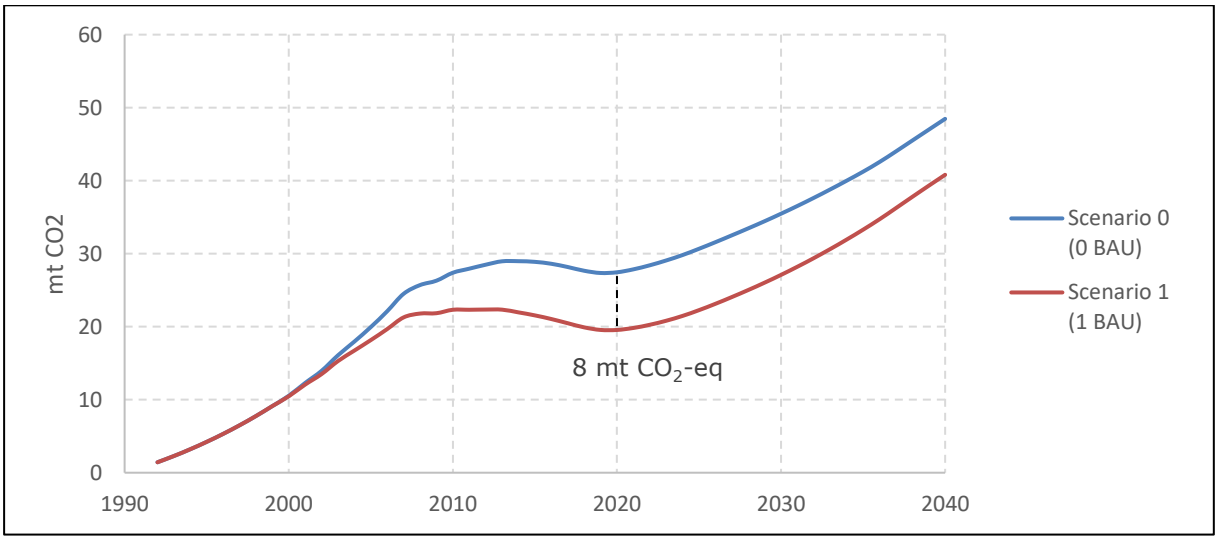

Figure 8: Comparison of the annual emission of CO_2-eq in scenario 0 and scenario 1.

It is visible that both the energy consumption and emission of CO_2-eq have been reduced significantly due to the current regulation. The annual savings of energy and CO_2-emission is approximately 20 TWh and 8 mt CO_2-eq. In Table 13, the annual electricity consumption and emission of CO_2-eq for each of the base cases are presented and the annual saving compared to scenario 0 (before regulation).

Table 13: The annual energy consumption and emission of CO_2-eq in scenario 1 (current regulation)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Electricity consumption (TWh)										
BC1	4.5	13.1	24.0	30.4	28.4	25.3	30.7	40.2	51.2	64.1
BC2	2.4	6.6	11.3	14.7	15.1	14.0	16.6	20.8	25.7	31.1
BC3	0.4	0.9	1.0	1.0	0.9	0.8	0.8	0.8	0.8	0.8
Total	**7.3**	**20.6**	**36.3**	**46.2**	**44.5**	**40.2**	**48.1**	**61.8**	**77.7**	**96.0**
mt CO_2-eq										
BC1	2.6	6.5	11.9	14.6	13.6	12.2	14.2	17.6	21.9	27.2
BC2	1.3	3.3	5.6	7.1	7.5	7.0	7.8	9.2	11.1	13.3
BC3	0.2	0.4	0.5	0.6	0.5	0.4	0.4	0.4	0.4	0.4
Total	**4.1**	**10.2**	**18.0**	**22.3**	**21.6**	**19.6**	**22.4**	**27.2**	**33.4**	**40.9**
Annual energy and mt CO_2-eq savings compared with 0 BAU										
Electricity consumption (TWh)										
BC1	0	0.10	2.71	7.42	10.32	11.04	11.89	12.04	11.48	11.24
BC2	0	0.06	1.58	4.88	7.60	8.35	8.78	8.56	8.04	7.64
BC3	0	0.00	0.04	0.12	0.18	0.20	0.21	0.19	0.18	0.18
Total	**0**	**0.17**	**4.33**	**12.43**	**18.10**	**19.59**	**20.87**	**20.79**	**19.70**	**19.06**
mt CO_2-eq										
BC1	0	0.04	1.04	2.85	3.96	4.24	4.57	4.62	4.41	4.32
BC2	0	0.02	0.61	1.88	2.92	3.21	3.37	3.29	3.09	2.94
BC3	0	0.00	0.02	0.05	0.07	0.08	0.08	0.07	0.07	0.07
Total	**0**	**0.06**	**1.66**	**4.77**	**6.95**	**7.53**	**8.02**	**7.99**	**7.57**	**7.32**

The majority of the saving are originating from small fixed air conditioners due to their high improvements in SEER and SCOP and the large stock.

In the table below is the combined accumulated savings in energy and emission of CO_2-eq presented.

Table 14: The accumulated savings in energy and emission of CO_2-eq in scenario 1 (effect of current regulation) compared to scenario 0

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
TWh	0	0	11	58	138	234	336	441	542	638
Mt CO_2-eq	0	0	4	22	53	90	129	169	208	245

The current regulation has by 2015 saved more than 138 TWh electricity and avoided more than 53 mt CO_2-eq. These accumulated saving are only increasing in the future.

Scenario 1 are used as the current baseline in the policy scenarios.

Sound power level

The sound power level in 2016 shows the sound power levels of air conditioners after the enforcement of the regulation, see figures below.

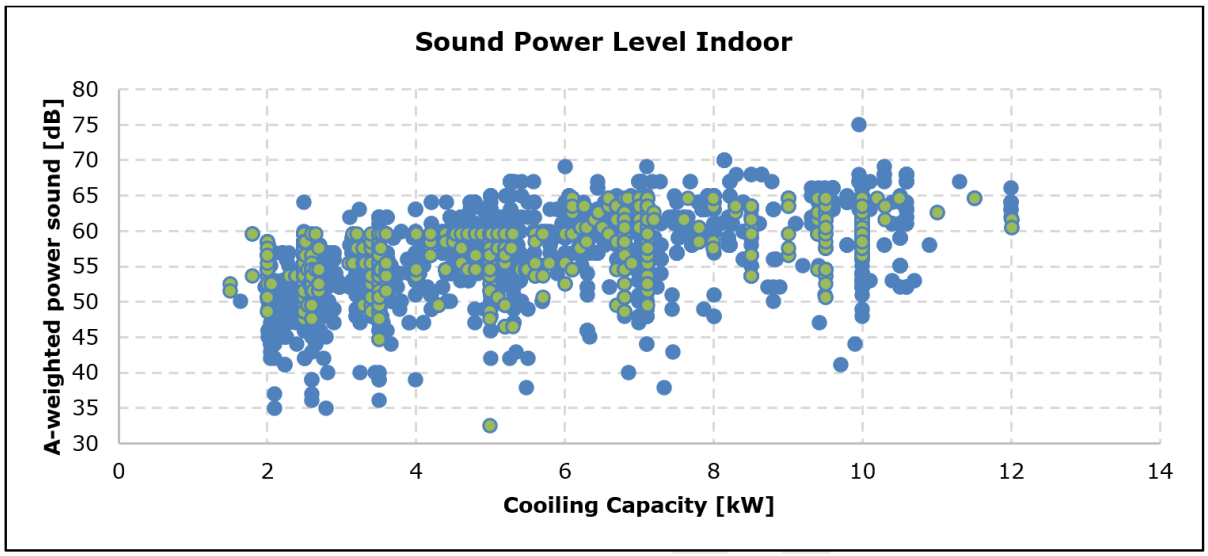

Figure 9: Comparison of the indoor sound power level in 2006 (blue dots and) and 2016 (Green dots)

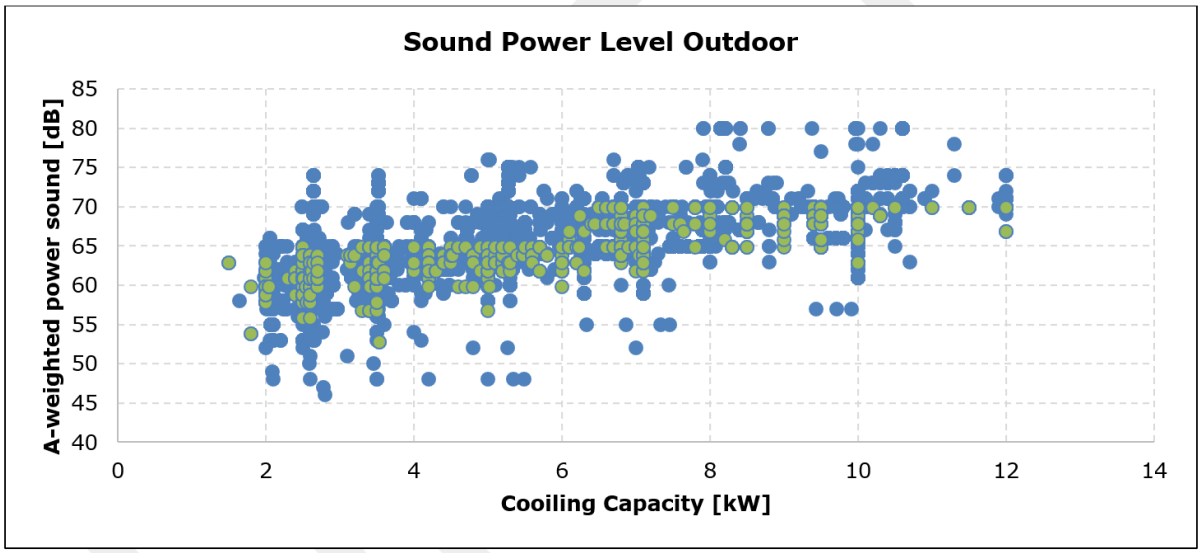

Figure 10: Comparison of the outdoor sound power level in 2006 (blue dots and) and 2016 (Green dots)

It is visible that the current regulation has been effective since the noisiest air conditioners are removed from the market. It is also visible that many air conditioners are close to the current requirements and without sound power level requirements the air conditioners would have had higher values. Today the average indoor sound power level of fixed split air conditioners (≤6 kW) is 56.3 dB(A) while the average outdoor sound power level is 62.3 dB(A). For larger air conditioners (>6 kW) the average indoor sound power level is 61 dB(A) while the average outdoor sound power level is 67.6 dB(A).

As discussed in Task 6, there is little to none margin for sound power level improvement while increasing energy efficiency of 0 – 6 kW capacity air conditioners as well as portable air conditioners. Although there is slightly more room for improvement for 6 – 12 kW range, it may require a more precise requirement of sound power level proportional to the capacities.

7.2.3 Policy scenarios

The policy scenarios show the potential for future requirements. Other countries around the world are also progressively strengthening their requirements and EU should not lag behind in this positive development. Both USA and Japan have currently more ambitious requirements that will benefit the environment.

Based on the LLCC and BAT technologies in Task 6 it is possible to determine a new set of requirements and a new label scheme. These are presented in Table 2 and Table 3 above. Based on the new requirements it is possible to model the future evolution on SEER and SCOP. The predicted evolution is presented in the table below:

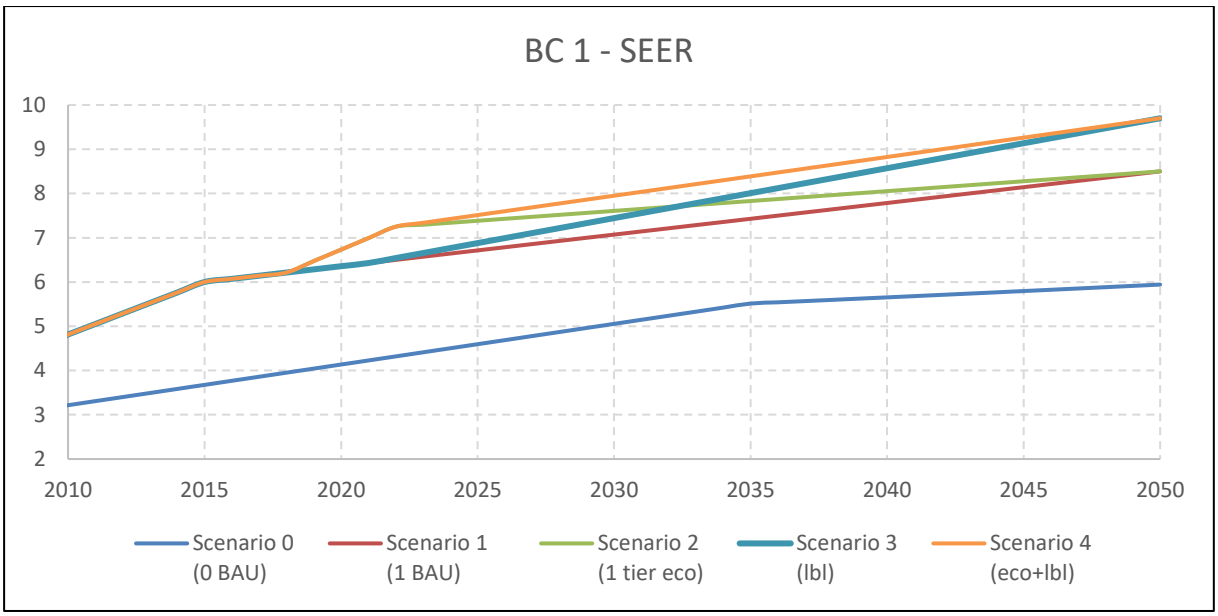

Figure 11: Comparison of the SEER development for BC1 in all scenarios

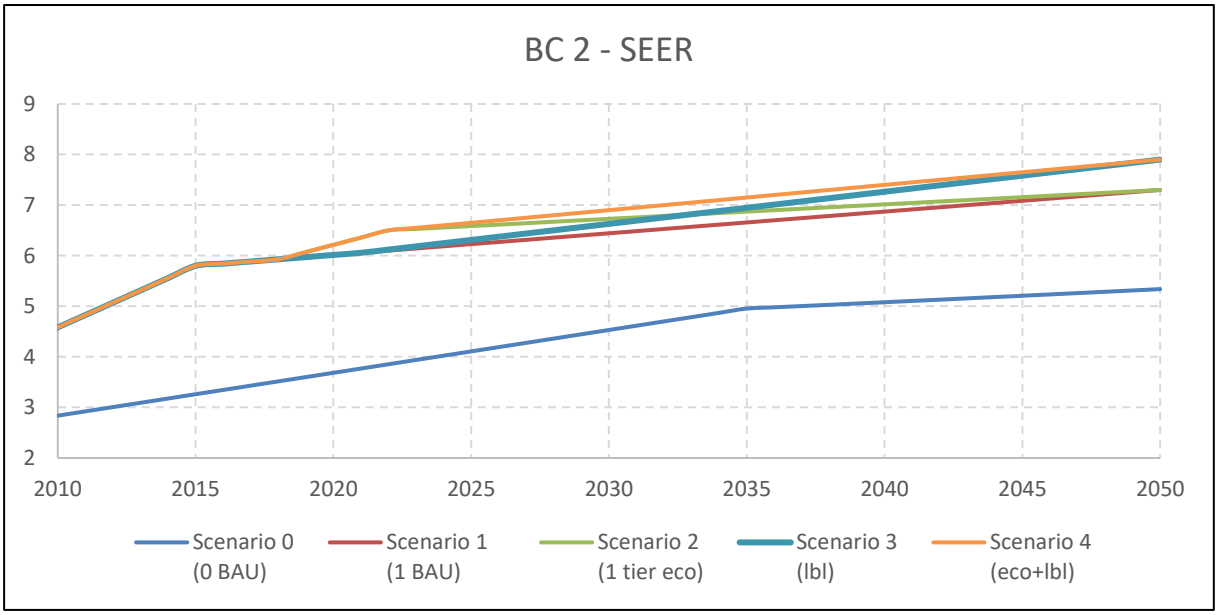

Figure 12: Comparison of the SEER development for B2 in all scenarios

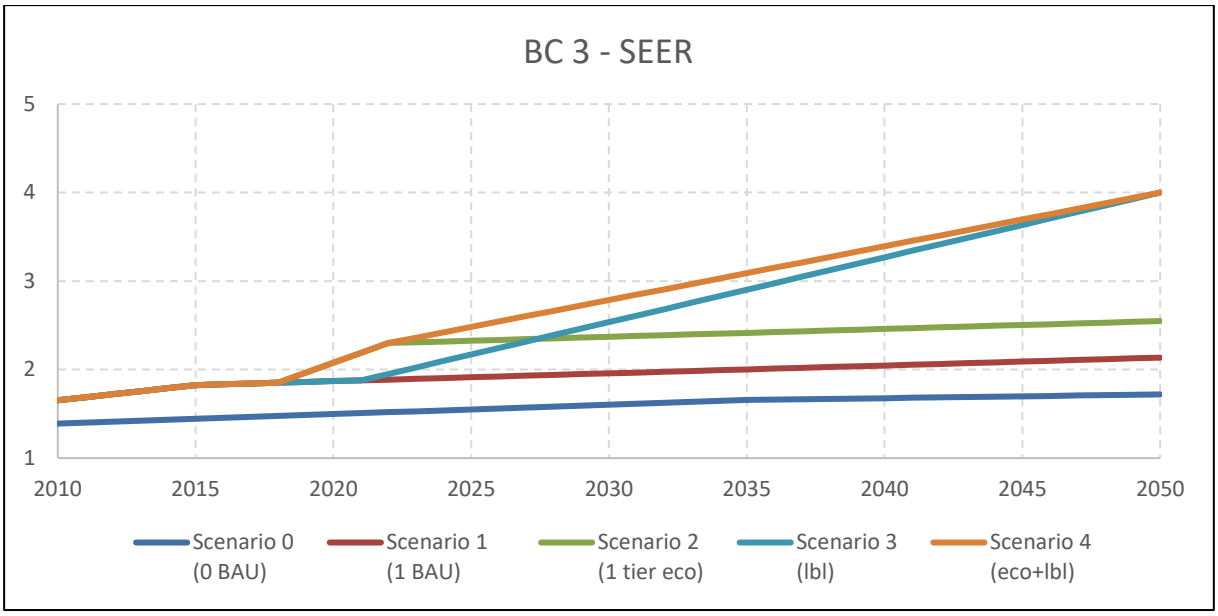

Figure 13: Comparison of the SEER development for BC3 in all scenarios

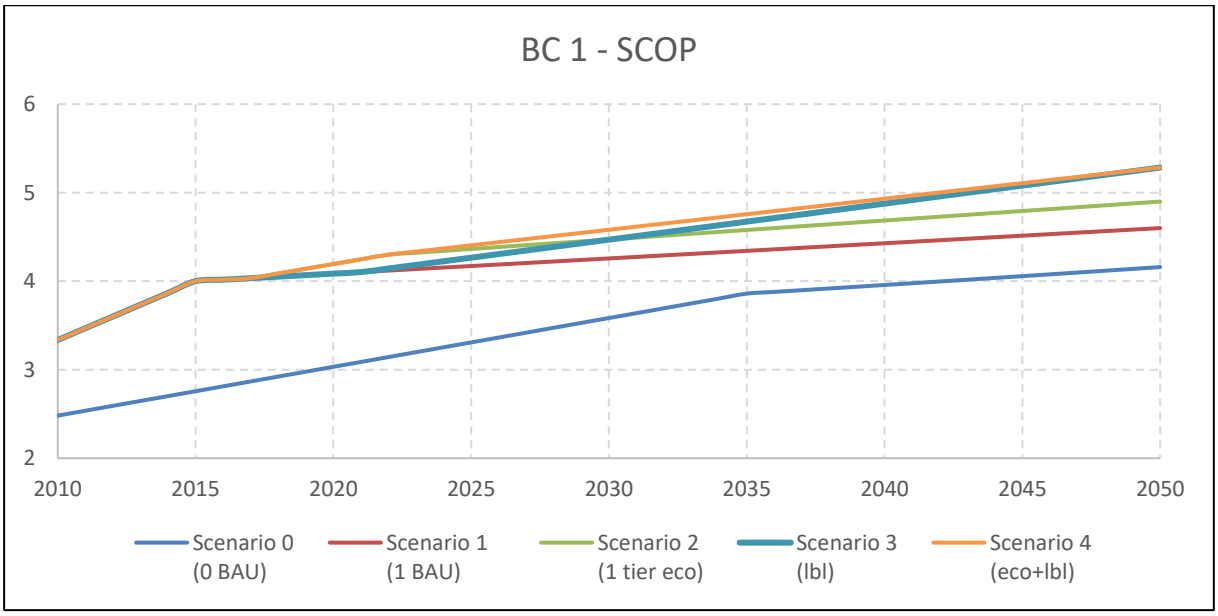

Figure 14: Comparison of the SCOP development for BC1 in all scenarios

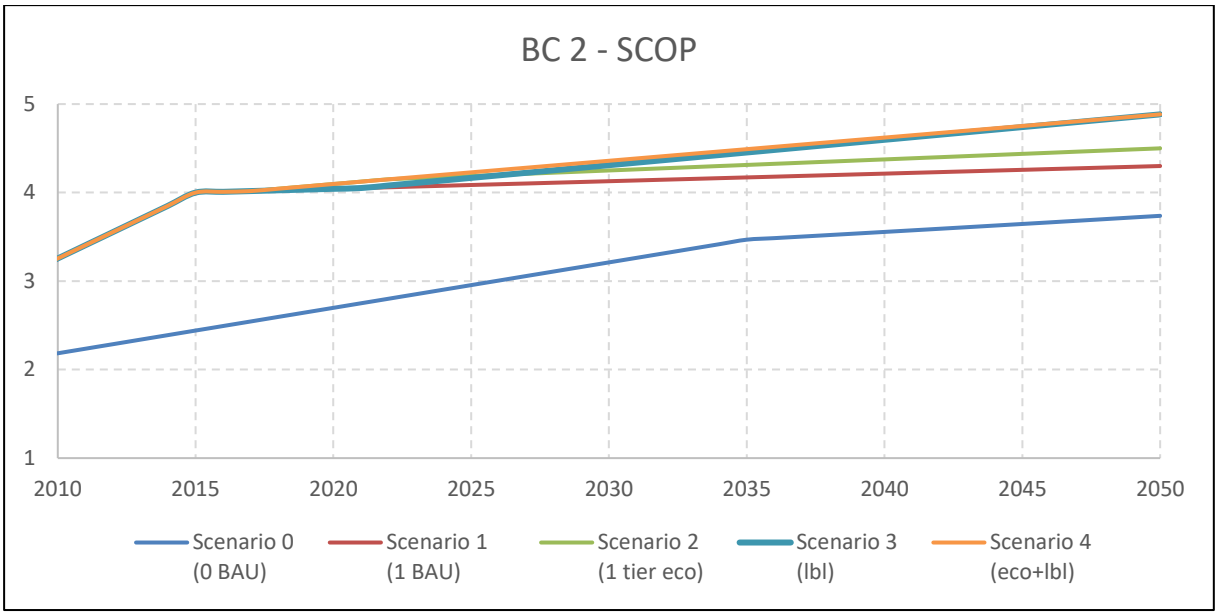

Figure 15: Comparison of the SCOP development for BC2 in all scenarios

From the figures it is visible that air conditioners still have the technological potential for further improvement in efficiency for both heating and cooling. These assumptions are based on the different improvement options in Task 6. With a new and stricter Ecodesign requirements the development can be boosted in the coming years as less efficient products are banned from the market. After this boost in efficiency the improvements are assumed to flatten. If only the labelling scheme are adopted a steady improvement are assumed until BNAT levels are reached in 2050.

Comparing the different base cases, it is visible that fixed air conditioners have the highest improvement potential compared to scenario 1. Currently portable air conditioners have not improved at the same pace as fixed air conditioners.

The annual energy consumption and emission of CO_2-eq are calculated for all the scenarios and presented figures below. All values are also presented in Table 33 to Table 37 in Annex 3 where the values per base cases are presented. Primary energy consumption is also presented in these tables in Annex 3.

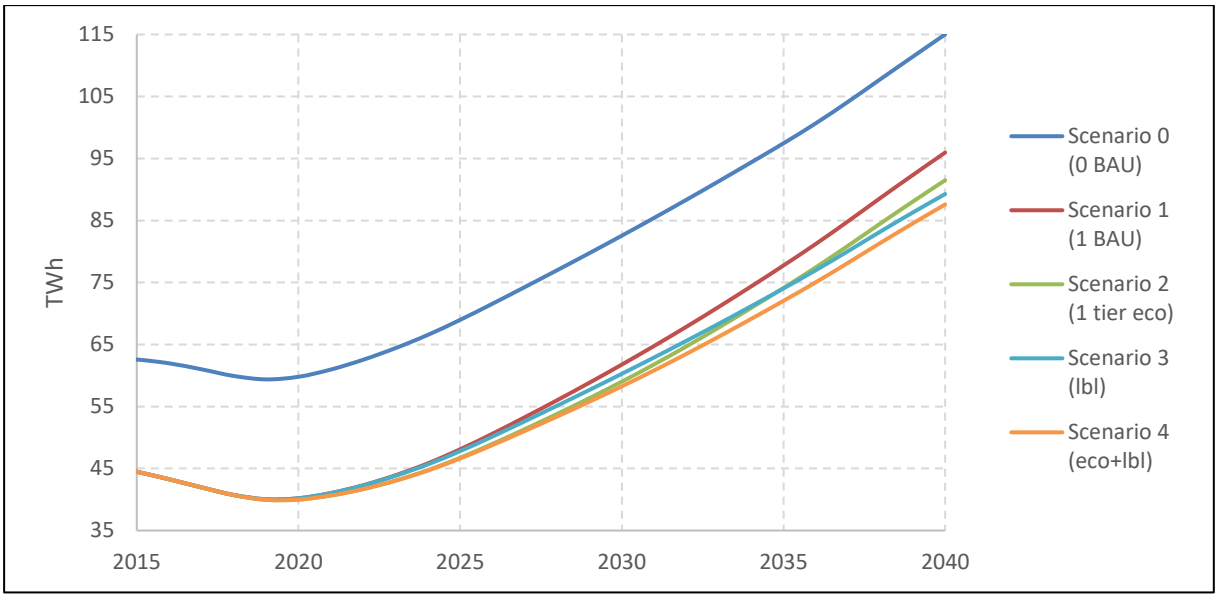

Figure 16: Comparison of the annual energy consumption of three base cases in all scenarios

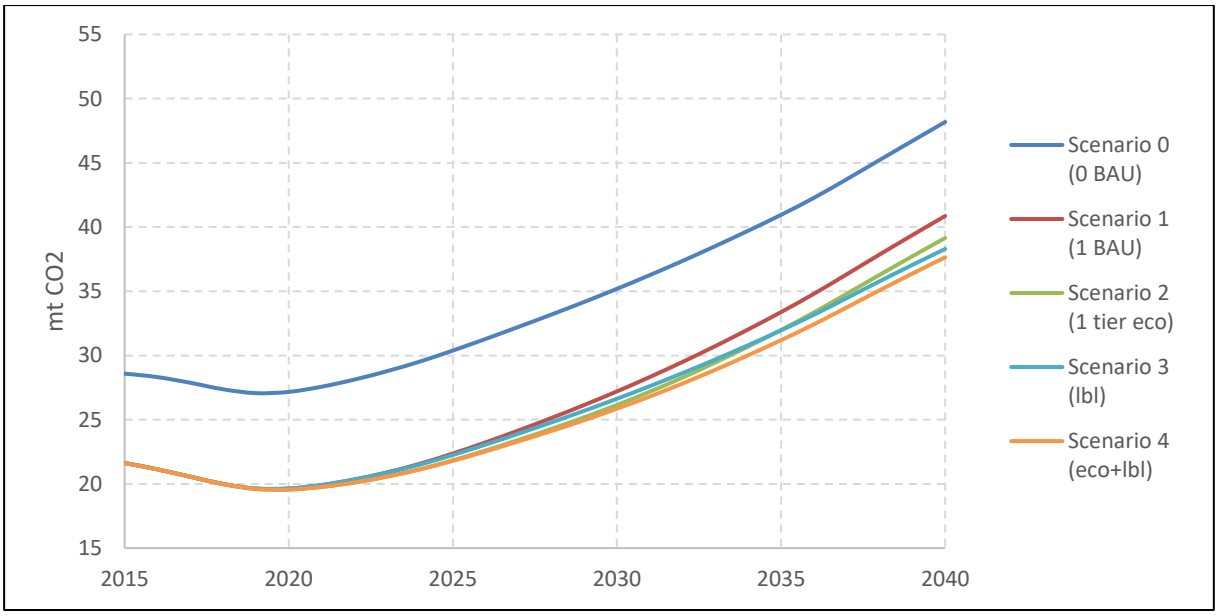

Figure 17: Comparison of the annual emission of CO_2-eq of three base cases in all scenarios

From the figure it is visible that the annual saving is the highest for scenario 4a with annual saving of 3.5 TWh and 1.4 mt CO_2-eq in 2030 (compared to scenario 1). From the figures it is not possible to see how the scenarios effect each of the base case. The annual savings compared to scenario 1 (current regulation) for electricity, primary energy and emission of CO_2-eq for each of the base cases are presented in the tables below. In Annex 3 the annual energy consumption for different policy scenarios are presented.

Table 15: Impacts of scenario 2 (1 tier eco) – Annual savings compared to scenario 1 (current regulation) in TWh, Primary energy and CO_2-eq

		2010	2015	2020	2025	2030	2035	2040
Scenario 2 (1 tier eco)								
TWh (Electricity)	BC1	0	0	0.16	0.99	2.00	2.67	3.31
	BC2	0	0	0.05	0.29	0.60	0.81	1.01
	BC3	0	0	0.01	0.09	0.14	0.15	0.14
	Total	**0**	**0**	**0.21**	**1.37**	**2.75**	**3.63**	**4.46**
PJ (Primary energy)	BC1	0	0	1.40	8.88	18.04	24.02	29.77
	BC2	0	0	0.41	2.65	5.41	7.29	9.11
	BC3	0	0	0.12	0.79	1.30	1.31	1.30
	Total	**0**	**0**	**1.92**	**12.32**	**24.75**	**32.63**	**40.18**
Mt CO_2-eq	BC1	0	0	0.06	0.38	0.77	1.03	1.27
	BC2	0	0	0.02	0.11	0.23	0.31	0.39
	BC3	0	0	0.01	0.03	0.06	0.06	0.06
	Total	**0**	**0**	**0.08**	**0.53**	**1.06**	**1.39**	**1.72**

Table 16: Impacts of scenario 3 (lbl) - Annual savings compared to scenario 1 (current regulation) in TWh, Primary energy and CO_2-eq

		2010	2015	2020	2025	2030	2035	2040
Scenario 3 (lbl)								
TWh (Electricity)	BC1	0	0	0	0.19	0.98	2.48	4.57
	BC2	0	0	0	0.08	0.40	1.02	1.85
	BC3	0	0	0	0.03	0.11	0.20	0.27
	Total	**0**	**0**	**0**	**0.30**	**1.49**	**3.70**	**6.69**
PJ (Primary energy)	BC1	0	0	0	1.71	8.79	22.33	41.09
	BC2	0	0	0	0.70	3.61	9.18	16.67
	BC3	0	0	0	0.24	0.98	1.79	2.42
	Total	**0**	**0**	**0**	**2.66**	**13.39**	**33.30**	**60.18**
Mt CO_2-eq	BC1	0	0	0	0.07	0.38	0.95	1.75
	BC2	0	0	0	0.03	0.15	0.39	0.71
	BC3	0	0	0	0.01	0.04	0.08	0.10
	Total	**0**	**0**	**0**	**0.11**	**0.57**	**1.42**	**2.57**

Table 17: Impacts of scenario 4 (eco+lbl) - Annual savings compared to scenario 1 (current regulation) in TWh, Primary energy and CO_2-eq

		2010	2015	2020	2025	2030	2035	2040
Scenario 4a (eco+lbl)								
TWh (Electricity)	BC1	0	0	0.16	1.06	2.48	4.01	5.87
	BC2	0	0	0.05	0.33	0.83	1.44	2.20
	BC3	0	0	0.01	0.10	0.20	0.26	0.30
	Total	**0**	**0**	**0.21**	**1.48**	**3.51**	**5.70**	**8.38**
PJ (Primary energy)	BC1	0	0	1.40	9.52	22.36	36.06	52.83
	BC2	0	0	0.41	2.95	7.45	12.96	19.83
	BC3	0	0	0.12	0.88	1.76	2.30	2.72
	Total	**0**	**0**	**1.92**	**13.34**	**31.57**	**51.32**	**75.38**
Mt CO_2-eq	BC1	0	0	0.06	0.41	0.95	1.54	2.26
	BC2	0	0	0.02	0.13	0.32	0.55	0.85
	BC3	0	0	0.01	0.04	0.08	0.10	0.12
	Total	**0**	**0**	**0.08**	**0.57**	**1.35**	**2.19**	**3.22**

The highest savings are all connected with small air conditioners as they have higher annual sales and because of their high improvement potential. For portable air conditioners the savings are smaller.

The accumulated savings of the different policy options are compared to current regulation (scenario 1) and presented in the figures below.

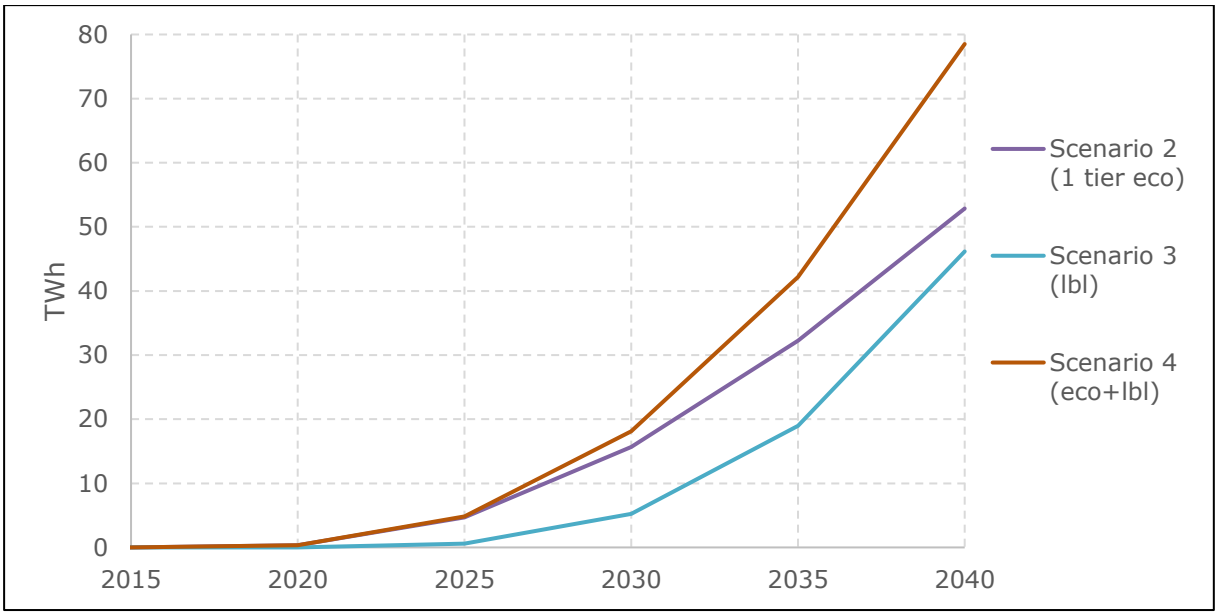

Figure 18: The accumulated savings in electricity (TWh) and emission of CO_2-eq of the policy options compared to the current regulation (scenario 1)

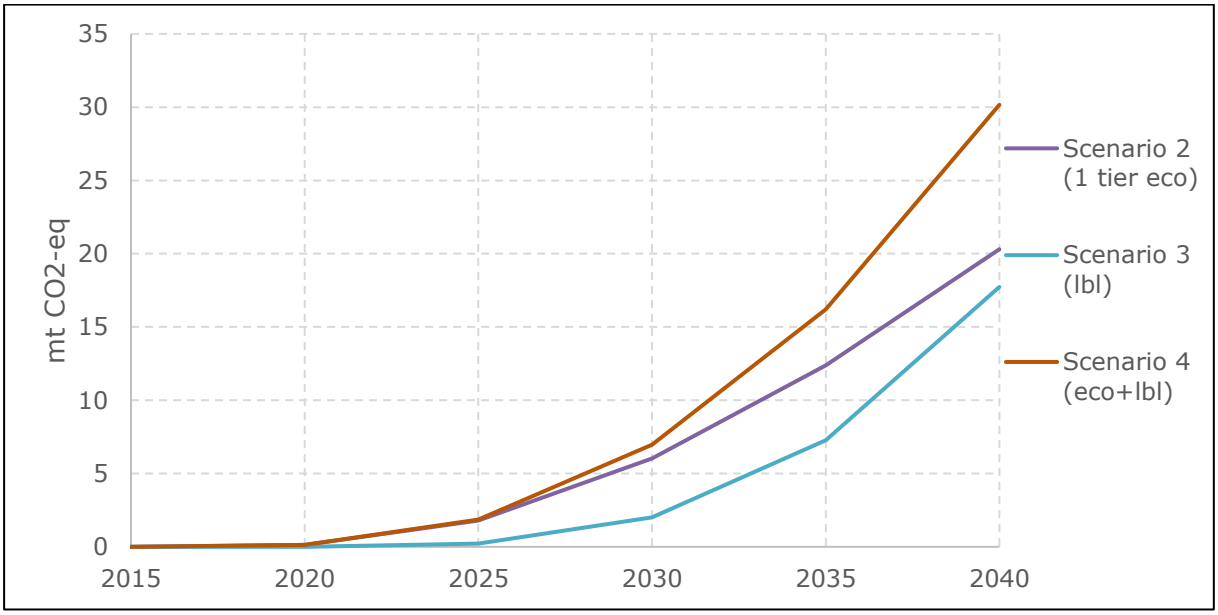

Figure 19: The accumulated savings in emissions of CO_2-eq of the policy options compared to the current regulation (scenario 1)

By applying both Ecodesign requirements and a new energy label scheme the accumulated savings in 2040 are almost 80TWh and above 30 mt CO_2-eq compared to scenario 1 (current regulation). Improving the current regulation will definitely have a positive and significant impact on the environment.

7.3 Impact analysis for consumers and industry

7.3.1 Consumer impacts

The consumer impacts are related to the electricity consumption and the purchase price of the equipment. The maintenance price and installation costs are assumed to be almost unchanged from the different scenarios, so they are only calculated based on a fixed rate and the annual sales.

The purchase price of the unit is dependent on the technological development in SEER, and an annual product price decrease by 2 % which is according to MEErP[23]. The correlation between SEER for the different base cases are calculated based on the different improvement options presented in Task 6. In all options there seems to be a correlation between SEER and then the product price. The correlation for the different base cases are:

- BC1 – 138 EUR/SEER point increase
- BC2 – 355 EUR/SEER point increase
- BC3 – 168 EUR/SEER point increase

This correlation and an annual price decrease are used to calculate the development in purchase price. The assumed development in purchase price are calculated and presented in Table 39 in Annex 3.

In most scenarios the price of air conditioners is expected to increase and especially the most ambitious scenarios. The price increase is present in the scenarios including Ecodesign requirements as the improvements are accelerated. In scenario 3 (only labelling scheme) the annual cost reduction of 2 % exceeds the increase in price due to voluntary efficiency improvements resulting in lower prices. The expected purchase price is used to calculate the annual consumer expenditures in Figure 20. The annual consumer expenditures are calculated based on the expected purchase price and expected annual sales, see exact values for the base cases in Table 40 in Annex 3.

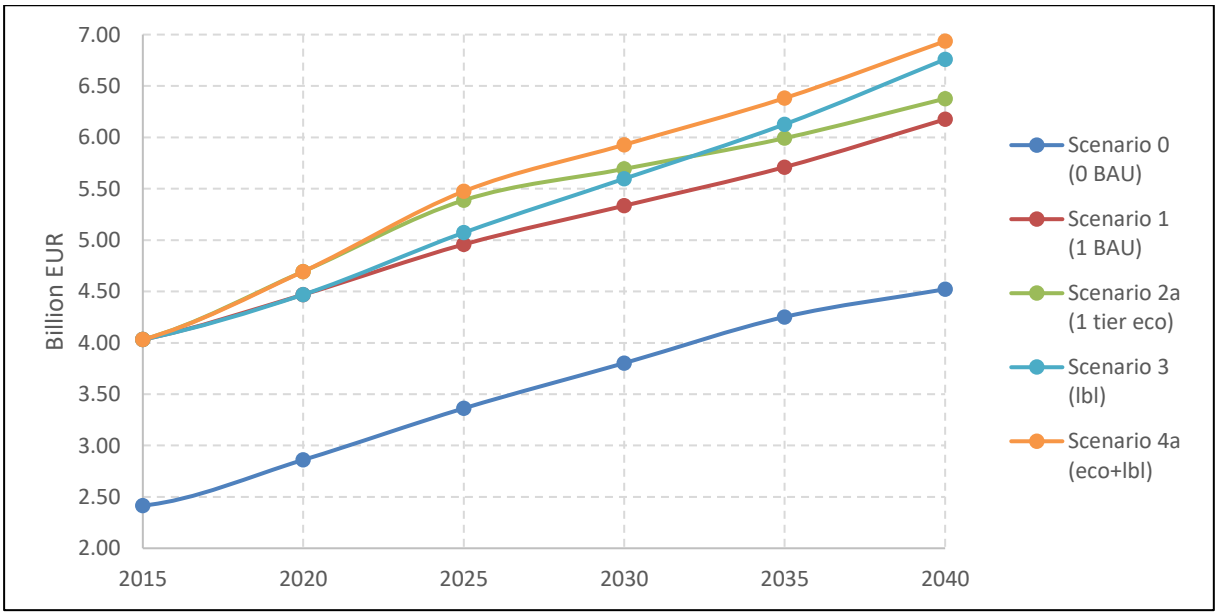

Figure 20: Annual consumer purchase costs of air conditioners in absolute values

The electricity price is expected to increase by 1 % per year. The assumed expected annual energy consumption and the stock model is used for modelling the consumer expenditures for the electricity presented in the Figure 21, see exact values of electricity costs for the base cases in Table 41 in Annex 3.

[23] VHK(2011), MEErP 2011 METHODOLOGY PART 1.

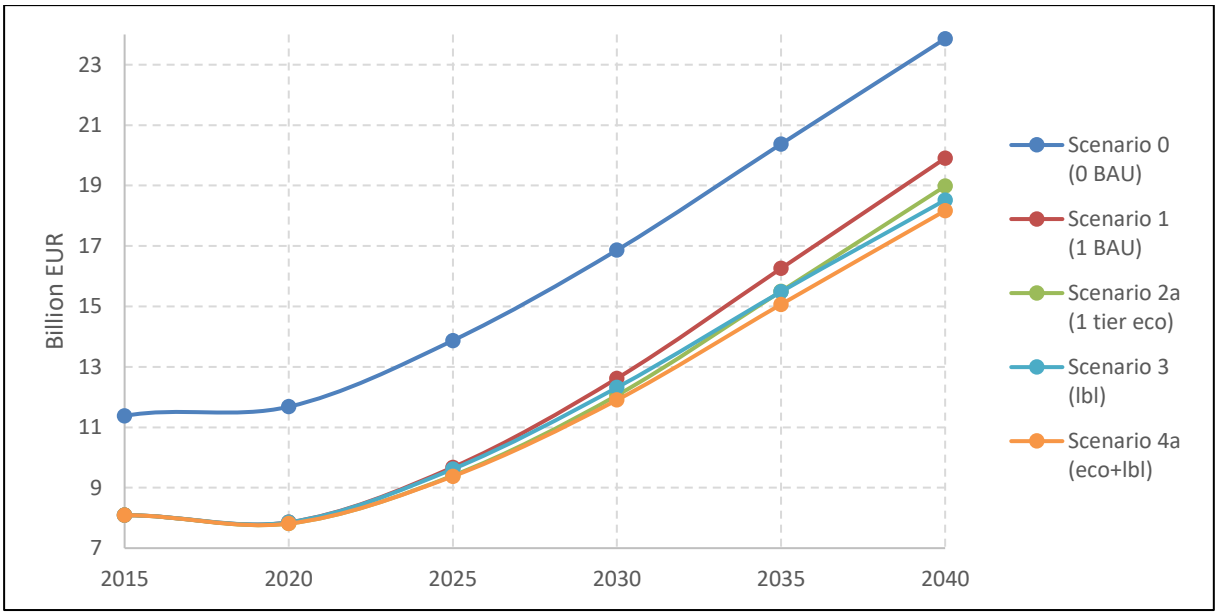

Figure 21: Annual consumer electricity costs in absolute values

The annual consumer expenditures for installation and maintenance are assumed negligible and therefore are equal in all scenarios. For comparison with the other costs, the exact installation and maintenance costs for each scenario are presented in Table 42 in Annex.

Total annual consumer expenditure is calculated as the sum of purchase cost, electricity costs and annual installation and maintenance costs. The total annual consumer expenditures are presented Figure 22 , and the annual consumer savings compared with 1 BAU current regulation in different policy options are presented in Table 18.

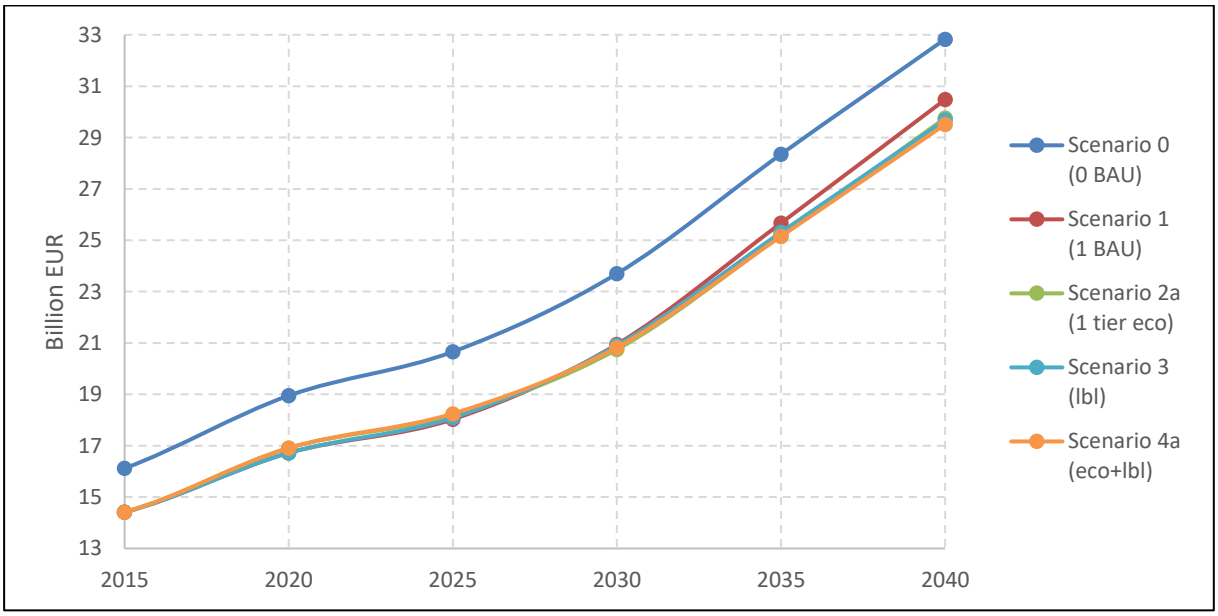

Figure 22: Total annual consumer expenditures in absolute values

Table 18: Total annual consumer expenditures in absolute values and annual savings compared with 1 BAU current regulation

	2010	2015	2020	2025	2030	2035	2040
Total annual consumer expenditures (billion EUR)							
Scenario 0 (before regulation)	14.23	16.12	18.95	20.66	23.7	28.35	32.83
Scenario 1 (current regulation)	13.51	14.42	16.72	18.03	20.95	25.67	30.48
Scenario 2 (1 tier eco)	13.51	14.42	16.91	18.19	20.75	25.19	29.76
Scenario 3 (lbl)	13.51	14.42	16.72	18.09	20.91	25.31	29.68
Scenario 4a (eco+lbl)	13.51	14.42	16.91	18.25	20.83	25.15	29.51
Annual consumer expenditure saving compared with 1BAU							
Scenario 2 (1 tier eco)	0	0	-0.18	-0.15	0.20	0.48	0.72
Scenario 3 (lbl)	0	0	0	-0.06	0.04	0.36	0.80
Scenario 4a (eco+lbl)	0	0	-0.18	-0.22	0.12	0.52	0.98

As the figures show that the annual consumer expenditures are similar in all policy options but in the long term the scenarios with both Ecodesign requirements and labelling scheme are the most advantageous for the consumers.

7.3.2 Industry impacts

The impacts for the industry are based on a number of assumptions from task 2 and from MEErP. The assumptions are presented in the table below:

Table 19: Assumptions to model to industry impacts.

Impact	Value	Source
Fixed Manufacturer Selling Price as fraction of Product Price [%]	45%	From task 2 markup 2.2
Portable Manufacturer Selling Price as fraction of Product Price [%]	59%	From task 2 markup 1.7
Margin Wholesaler [% on msp]	30%	MEErP
Margin Retailer on product [% on wholesale price]	20%	MEErP
Manufacturer turnover per employee [mln €/ a]	0.00035	Sector turnover 2109 mln euro / 6099 employed persons[24]
OEM personnel as fraction of manufacturer personnel [-]	1.2	MEErP
Wholesaler turnover per employee [mln €/ a]	0.00051	the entire wholesale sector turnover 5.3 trillion Euro10.4 million employees[25]
Fraction of OEM personnel outside EU [% of OEM jobs]	80 %	

[24] Stakeholder input, January 2018
[25] http://www.eurocommerce.eu/commerce-in-europe/facts-and-figures.aspx

The markups presented are average numbers covering both retail and wholesale. Portable air conditioners (not installation), are mainly sold directly by retailers. Only about 5 % are surely sold via installers according to BSRIA leading to a mark of 1.7[26].

For split air conditioners, the proportions of the different routes are more balanced, and comparing with GfK total B2C sales, it can be assessed this share is larger than just the retailer share in BSRIA statistics on first point of sales, higher than 40 %. According to BSRIA it should also be lower than about 60 % (as installers and contractors represent about 60 % of the total). Assuming a 50/50 sharing between final B2C retail and sales via installers, this leads to a total markup of 2.2[27].

Based on these assumptions the industry impacts are calculated for the different scenarios in the figures below.

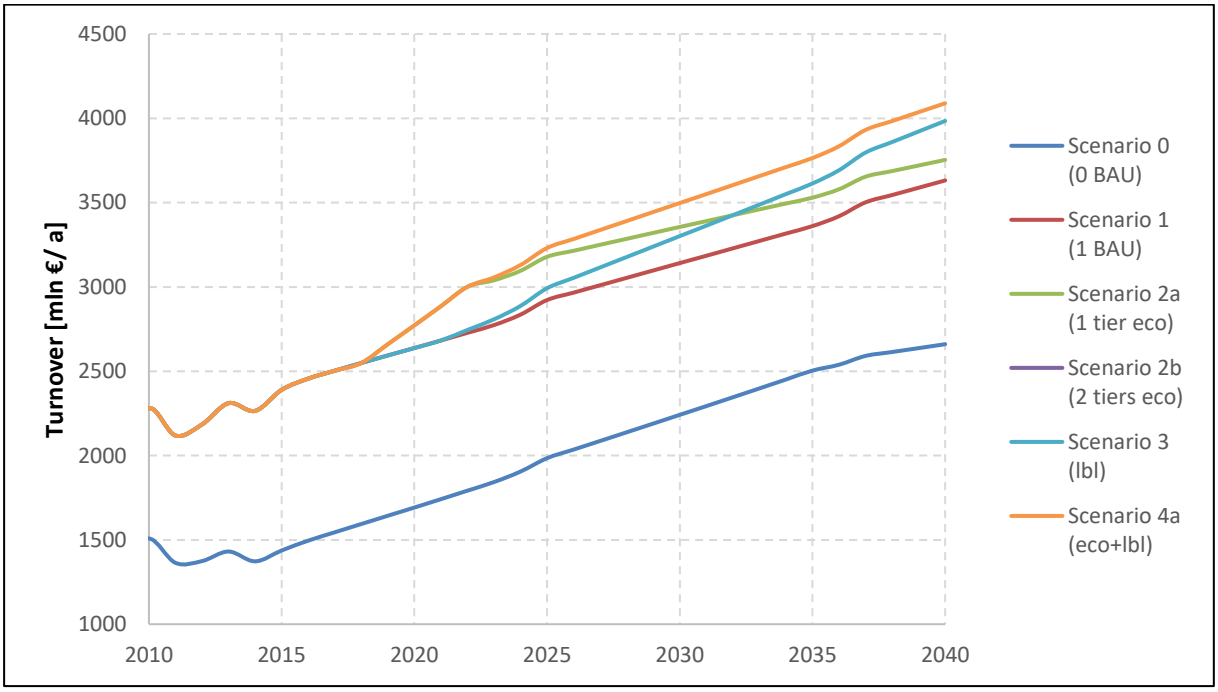

Figure 23: Industry turnover per year for different policy scenarios

[26] The markup value for portable air conditioners are explained and calculated in Task 2
[27] The markup value for fixed air conditioners are explained and calculated in Task 2

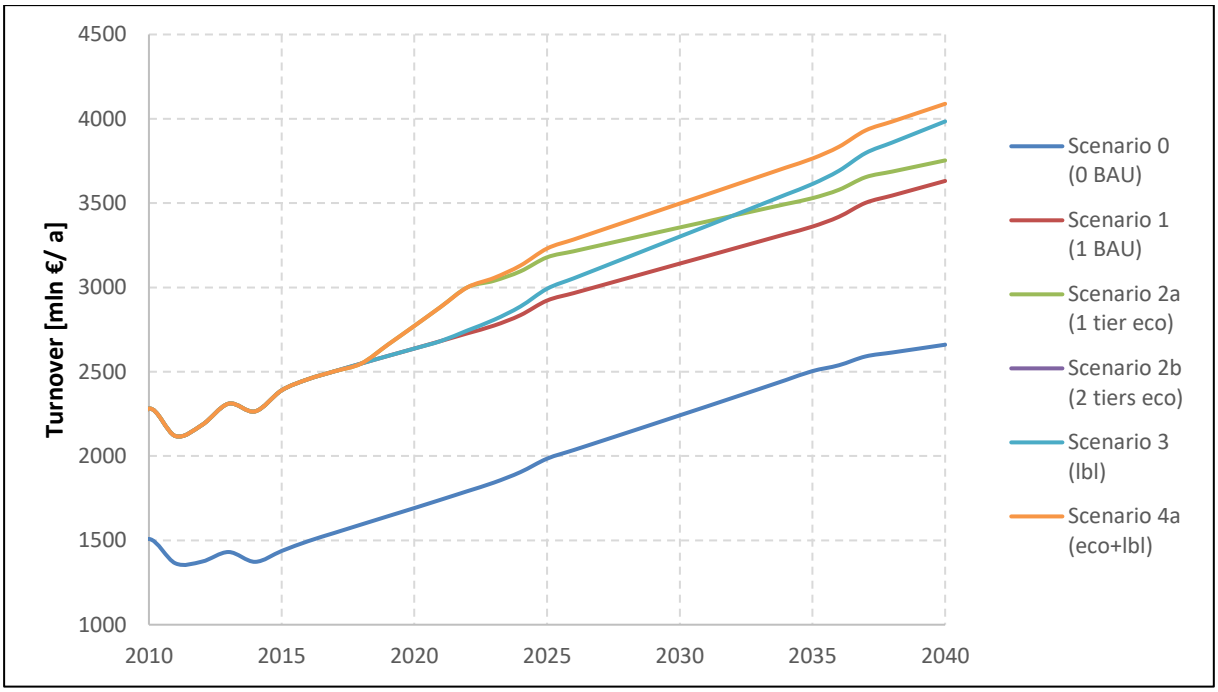

Figure 24: Number of personnel in air conditioner industry for different policy scenarios

From the above figures it is also visible that the most ambitious options also are the most beneficial for the manufactures as their turnover will increase and more workers will be employed in the sector. The values presented in the above figures are also presented in tables and divided into categories (manufacturer turnover, manufacture total personnel, OEM total personnel, OEM total personnel (EU), wholesaler turnover and wholesaler total personnel) in Annex 3 – Tables.

7.4 Sensitivity analysis

The sensitivity analysis is focusing on the leakage of refrigerant and the material composition of the air conditioner. These analyses are made for scenario 5 as these factors have a higher impact in this scenario due to the reduced energy consumption. Regarding the sensitivity analysis the following adjustments are made:

- Sensitivity of the material composition
  - 95 % recycling
- Sensitivity of the leakage of refrigerant
  - Double the leakage rate

The impact of these changes is calculated as the difference in CO_2-eq as this measure can be used in both analyses.

Table 20: The calculated impacts of higher levels of recycling and the effect of higher leakage.

		2010	2015	2020	2025	2030	2035	2040
Sensitivity (95% recycling) – Reduction in emission								
Mt CO_2-eq	BC1	0.10	0.09	0.11	0.16	0.33	0.69	1.19
	BC2	0.06	0.06	0.07	0.09	0.18	0.34	0.57
	BC3	0.02	0.01	0.01	0.02	0.03	0.05	0.07
	Total	**0.18**	**0.16**	**0.19**	**0.26**	**0.54**	**1.08**	**1.83**
Sensitivity (Double leakage) – Increase in emission								
Mt CO_2-eq	BC1	2.92	2.84	2.34	1.92	1.44	1.29	1.47
	BC2	1.47	1.64	1.44	1.17	0.83	0.71	0.78
	BC3	0.05	0.05	0.04	0.02	0.00	0.00	0.00
	Total	**4.43**	**4.53**	**3.82**	**3.10**	**2.26**	**1.99**	**2.25**

Note that in Table 20, for 95% recycling rate, the figures are the reduction in emission, for double leakage rate, the figures are the increase in emission

The sensitivity analysis show that increased recycling can reduce the annual emission of CO_2-eq with approximately 0.2 mt, but the recycling rates in this scenario are very optimistic and may not be obtainable in the near future. If the leakage is higher (e.g. twice as high) than assumed, then the emission of CO_2-eq be 3.8 mt higher in 2020. Due to the f-gas regulation this impact is reduced to 2.3 mt CO_2-eq in 2040 and the impact of leakage is reduced. These tables are also presented in absolute values in Table 49 in Annex 3.

It is also proposed that sensitivity analysis to be carried out for product prices and overcosts in the impact assessment.

7.5 Comparison of air-to-air heat pumps and other heating products

Air-to-air heat pump, despite being a specific product group and having presently its own Ecodesign and Labelling regulations (No. 206/2012 and 626/2011), are competing with other heating means. This includes, direct electric heating, larger than 12 kW air-to-air heat pumps, but also water-based heating solutions.

From an end-user point of view, it would be easier if all these products competing on the heating function could be compared directly, for instance using the same energy label or energy class scale.

Above national differences, it should also be avoided that minimum performance requirements and or different labelling scale lead to distort the heating market in a wrong direction (i.e. leading to more energy consumption or CO2 emissions). For instance, to excessively increase minimum efficiency requirement for air-to-air heat pumps could significantly increase their price making those units less affordable. It could thus affect their sales and make direct electric heating more economical for buildings with average to low heat loads. The same might be true for consumers who consider replacing fossil fuel boiler with air-to-air heat pumps at the time when heating system and generator need to be replaced.

Ecodesign and Energy Labelling Directive only require impact assessment including environmental impacts, costs and competitiveness within the same product group. As competition exists between this various product groups that all have the same "space heating" function, it is advised to include a supplementary dimension in the impact assessment of future or revised Ecodesign and labelling regulations or to conduct a dedicated study on the comparison of the proposed and existing regulations across the different product groups that offer space heating.

7.6 Conclusions and recommendations

Policy options

Based on the assessment, the following policy options are chosen for further analysis:

- No action option – Business as usual (BAU), the current regulations are to be retained as they are. This BAU scenario will be used as reference for comparison with other policy scenarios.

- Ecodesign requirements (under the Ecodesign Directive (2009/125/EC)): Including revised mandatory minimum requirements acting as a "push" instrument for products to achieve better performance.
- Energy labelling (under the Energy Labelling Regulation (2017/1369/EU)[28]): This implies a revised scale for mandatory labelling of the products' efficiency.

Based in these policy options, six scenarios are modelled and are presented in Table 21.

Table 21: Summary of policy scenarios and brief descriptions

Policy scenario	Description
Scenario 0 (0 BAU)	BAU before EU regulation – In general low yearly improvements. The only improvement included is the use of inverter technology
Scenario 1 (1 BAU)	BAU scenario (current regulation) – The impact of the current regulation with only limited incentive to improve products beyond the A+++ label
Scenario 2 (1 tier eco)	Ecodesign minimum efficiency requirement with one tier based on LLCC (BC 1 for BC 1, -10%Ua_cond for BC 2 and HE1with R290for BC 3)
Scenario 3 (lbl)	Energy class A as BNAT (combining the different improvement for each of the base cases)
Scenario 4 (eco+lbl)	Ecodesign and Energy labelling scenario 2 + scenario 3

Ecodesign requirements

The LLCC identified in the Task 6 is used for setting the immediate minimum requirement for fixed air conditioners in ecodesign scenario 2. The BNAT level specify the energy class A for energy labelling, only revised energy labelling regulation without revising ecodesign, this is simulated in scenario 3. Scenario 4 represents the combination of the Ecodesign requirements (scenario 2) and the Energy labelling (scenario 3).

The proposed ecodesign requirements and timing are presented in Table 22.

Table 22: Proposed minimum efficiency requirements for air conditioners in a potential revised ecodesign regulation

	Tier 1, January 2023	
	SEER	SCOP
Other than portable, < 6 kW	6	4
Other than portable, 6 – 12 kW	5.5	3.9
Portable	2.3	-

No SCOP minimum requirement is proposed for portable air conditioners. However, it is proposed that ecodesign should include information requirement of SCOP using the proposed metrics for portable on top of the existing minimum requirement on COP from current regulation. It is also proposed to start the development of a new standard in line with EN14825 plus infiltrations. With this potential new standard in place, portable products will have to be adjusted to stay on the market. It is proposed that the portable would not be allowed to operate in thermodynamic heating mode. Once performances of new double duct products for new standard are known, then it can be evaluated how far their performances should be increased.

[28] Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU

For portable air conditioners in general, it is recommended to have seasonal performance metrics (SEER and SCOP) for setting requirements in the future.

Ecodesign requirement for comfort fans

Regarding comfort fans the same challenges still exist (since the preparatory study) and it is further elaborated in Annex 1. Based on the findings of this assessment there are two options which are:

- Setting minimum energy efficiency requirements on comfort fans with the proposed requirements (from the preparatory study) with the risk of banning many comfort fans in the European market (expected savings in the preparatory study was slightly below 1 TWh).
- Enforcing better market surveillance on the current information requirement and gathering accurate information on comfort fan efficiency and test methods through a complementary study/efficiency tests with corresponding costs.

Energy Labelling requirements

The proposed new label schemes are presented in Table 23 and Table 24. The label scheme is based on the BNAT levels identified in Task 6 as the top level at energy class A. This means that the best product currently available on the market only are able to achieve the B class. This however does not apply to portable air conditioners, as products with alternative refrigerants (as R410A will be banned after 2020) are not widely available and it is difficult predict the refrigerant that will be used.

Table 23: Proposed new label schemes for SEER

Label scheme	Other than portable air conditioners	Portable air conditioners
A	SEER ≥ 11.5	SEER ≥ 4
B	9.7 ≤ SEER < 11.5	3.5 ≤ SEER < 4
C	8.1 ≤ SEER < 9.7	3.0 ≤ SEER < 3.5
D	6.8 ≤ SEER < 8.1	2.6 ≤ SEER < 3.0
E	5.7 ≤ SEER < 6.8	2.3 ≤ SEER < 2.6
F	4.8 ≤ SEER < 5.7	SEER < 2.3
G	SEER < 4.8	

Table 24: Proposed new label scheme for SCOP

Label scheme	Other than portable air conditioners
A	SCOP ≥ 6.2
B	5.5 ≤ SCOP < 6.2
C	4.9 ≤ SCOP < 5.5
D	4.3 ≤ SCOP < 4.9
E	4.9 ≤ SCOP < 4.3
F	SCOP < 3.8
G	NA

It is the opinion of the study team that an energy class should only be proposed for portable air conditioners in cooling mode using proposed SEER metrics in section 7.1.5. SCOP is to be declared on the energy label but no energy class scale is proposed. When seasonal performance (that accounts for infiltration) of these products is widely known, an energy

class scale for SCOP can be then proposed. A combined label is also being considered so consumers can compare fixed and portable air conditioners.

A combined label can be based $\eta_{s,c}$ and $\eta_{s,h}$ and have the following classes presented in Table 25. Ideally the label for heating should be aligned with other regulations so all products/heaters can be compared.

Table 25: Proposed new label schemes for a combined label

Label scheme	$\eta_{s,c}$	$\eta_{s,h}$
A	$\eta_{s,c} \geq 4.6$	$\eta_{s,h} \geq 2.5$
B	$3.3 \leq \eta_{s,c} < 4.6$	$2 \leq \eta_{s,h} < 2.5$
C	$2.4 \leq \eta_{s,c} < 3.3$	$1.6 \leq \eta_{s,h} < 2$
D	$1.8 \leq \eta_{s,c} < 2.4$	$1.3 \leq \eta_{s,h} < 1.6$
E	$1.3 \leq \eta_{s,c} < 1.8$	$1 \leq \eta_{s,h} < 1.3$
F	$0.9 \leq \eta_{s,c} < 1.3$	$0.8 \leq \eta_{s,h} < 1$
G	$\eta_{s,c} < 0.9$	$\eta_{s,h} < 0.8$

Finally, infiltration measurement should be proposed in the future mandate for standards.

Tolerances and uncertainties have been assessed in earlier Tasks and two approaches have been proposed to adjust tolerances. According to the previous definitions, the tolerances should be higher than the repeatability measurement uncertainty alone and lower or equal to the expanded uncertainty. In absence of Round Robin Tests, tolerance values should be fixed to the maximum possible value, i.e. to the level of the maximum expanded uncertainties.

With present measurement uncertainties, tolerance levels can be set as follows:

- split air conditioners:
    - SEER tolerance: 8 % below 2 kW cooling capacity, 6 % between 2 and 6 kW and 4 % between 6 and 12 kW.
    - SCOP tolerance: 8 % below 2 kW cooling capacity, 7 % between 2 and 6 kW and 6 % between 6 and 12 kW.
- portable air conditioners:
    - SEER: 6 % for on/off and 8 % for inverter (12 % for lower than 2 kW @ 27/27 units)
    - Pc(Teq): 7 % (13 % for lower than 2 kW @ 27/27 units)
    - Teq: 0.3 K (0.4 K for lower than 2 kW @ 27/27 units)

SEER and SCOP tolerance levels in Regulations (EU) No 206/2012 and 626/2011 need to be revised accordingly.

With improved measurement accuracy, tolerances could be reduced to the following levels:

- split air conditioners:
    - SEER: 6 % below 6 kW cooling capacity and 4 % between 6 and 12 kW
    - SCOP: 6 % below 6 kW cooling capacity and 4 % between 6 and 12 kW

- portable air conditioners:
    - SEER: 6 % (12 % for lower than 2 kW @ 27/27 units)

Before EU regulations and BAU

Scenario 0 (before EU regulation) and scenario 1 (current BAU with EU regulations) show that the current regulations have been effective and efficient, it is estimated that current regulations (Ecodesign Regulation 206/2012 and Energy Labelling 626/2011) have accumulatively by 2015 saved more than 138 TWh electricity and avoided more than 53 mt CO2-eq. It is expected that annual savings in period 2015 - 2020 is around 20 TWh compared with consumptions before EU ecodesign and energy labelling regulations.

Sound power levels have also shown that the regulations have been effective, as the sound power levels reported are kept below the maximum allowed levels when comparing data from 2006 with the data from 2016. However, it is identified very limited further improvement potential for sound power level if energy efficiency is to be continuously increased.

Scenario analyses

Based on the newly proposed ecodesign requirements and labelling scheme, the impacts of the different scenarios are modelled. The assessed impacts are electricity consumption, primary energy and emission of CO_2-eq. The annual impacts of the different scenarios in 2030 are presented in Table 26.

Table 26: The annual electricity consumption, emission of CO_2-eq and associated savings in 2030

Scenario	Electricity (TWh)	Savings from 1 BAU (TWh)	Emission of CO_2-eq (mt)	Savings from 1 BAU (mt CO_2-eq)
Scenario 0 (0 BAU)	83.3	-	35.2	-
Scenario 1 (1 BAU)	61.8	-	27.2	-
Scenario 2 (1 tier eco)	59.0	2.8	26.1	1.1
Scenario 3 (lbl)	60.3	1.5	26.6	0.6
Scenario 4a (eco+lbl)	58.3	3.5	25.9	1.3

From the scenarios is it is visible that the largest savings are the combination of both ecodesign requirements and the energy label with annual electricity saving of 3.5 TWh in 2030. The energy label alone has smaller impacts than the Ecodesign requirements in the presented values, but for future reduction in the impacts the labelling scheme are important to push for further improvements beyond 2030.

Table 27 shows the savings in 2040, as the revised regulations will have long-lasting effects due to the continuous change of stock air conditioners to efficient new air conditioners, the savings in 2040 are greater than those in 2030. Scenario 4 which combines ecodesign and energy labelling is expected to yield 8 TWh electricity savings per year.

Table 27: The annual electricity consumption, emission of CO2-eq and associated savings in 2040

Scenario	Electricity (TWh)	Savings from 1 BAU (TWh)	Emission of CO_2-eq (mt)	Savings from 1 BAU (mt CO_2-eq)
Scenario 0 (0 BAU)	115	-	48.2	-
Scenario 1 (1 BAU)	96	-	40.9	-
Scenario 2 (1 tier eco)	91.5	4.5	39.1	1.7
Scenario 3 (lbl)	89.3	6.7	38.3	2.6
Scenario 4a (eco+lbl)	87.6	8.4	37.6	3.2

The presented savings are supposedly even larger than the presented values as the replacement of inefficient heaters due to more and more end-users operate reversible air conditioners in heating mode are not accounted.

The sensitivity analysis showed that an improved recycling of the materials only will have a limited impact regarding emission of CO_2-eq, but this impact may not be a proper measure for the material efficiency impacts. The leakage of refrigerant is important and could pose a threat, but the f-gas regulation is already limiting the potential negative impacts.

Due to the progressive development in efficiency to comply with ecodesign requirement and energy labelling, the product price is expected to increase in the coming years, but the extra costs will slowly reduce again over time. Overall, the consumer net expenditures decrease in the scenarios with the highest efficiency, as energy costs savings offset the increase in product price. In the future, the energy costs are even more important for the consumers as the electricity prices are expected to increase.

The improved energy efficiency is not only beneficial for the consumers and the environment but also for the industry. The industry is expected to grow and improve their annual turnover and more persons are expected to work in air conditioner industry.

Material efficiency

Based on the assessment on possible material efficiency requirements for air conditioners, as well as other studies for different product groups where possible material efficiency requirements have been assessed, the following general conclusions are drawn:

- Ecodesign opportunity for material efficiency requirement for air conditioners exists but the impact of such requirements is anticipated to be minimal without addressing the issue at system level.
- EcoReport tool although has been revised in 2014, but it is not adequate for properly assessing environmental impacts of material efficiency.
- Possible material efficiency requirements – even if they contribute to as high as 95% of recycling rate, the results from EcoReport Tool show that material efficiency has only small impact in terms of the product's entire LCA, this is due to that the focus and the environmental indicators of the EcoReport Tool are mainly on energy, for proper assessment, other environmental indicators should be included.

- There could be synergies with DG Environment's development of Product Environmental Footprint (PEF). The methodology can be simplified and applied in Ecodesign to assess other environmental impacts.
- Material efficiency of electrical and electronic products requires a system approach within which the recycling processes, methods and facilities are addressed together with product design. However, system approach of recycling processes, methods and facilities is rather in the scope of WEEE directive than ecodesign.
- Furthermore, material efficiency is an issue that should be addressed at a horizontal level, as per product group, the associated saving potential is low, but horizontally across all electrical and electronic products, large savings potential can be achieved. Therefore it may prove effective to align material efficiency requirements with other regulations (such as for dishwasher, washing machines and domestic refrigerators and freezers).
- Looking prospectively, to address the issue at a horizontal level, voluntary labelling of recycled materials and minimum percentage used in product could be considered as a policy model. FSC labelling approach from the European Union Timber Regulation(EUTR) could be of inspiration.
- Unpredictable consequences and barriers exist for ecodesign requirements on material efficiency that encourages reuse, as it is currently unclear who should take on the ownership of a refurbished product and responsibility of the product's safety.

Summary of suggestions

This section summarises the suggestions from Task 1 to Task 6.

- **Ventilation exhaust air-to-air heat pumps and air conditioners ≤ 12 kW**
  It is advised to include these products in the scope of Regulation (EU) No 206/2012 and 626/2011 when their thermal power is below or equal to 12 kW and to specify SEER and SCOP rating conditions and also to better specify which air is used indoor and outdoor for air conditioners and heat pumps in Regulation (EU) No 206/2012.
  Test conditions proposed for SEER and SCOP determination of exhaust air-to-outdoor air heat pumps and air conditioners are described in Task 1, Annex 1. However, the latest update in April 2018 of this issue is that according to CEN TC 113 WG 7, it is not possible to develop a SEER/SCOP for these units. Without SEER/SCOP, it is difficult to include these products in scope. The reason is that these units are ventilation units where heat recovery is made by the heat pump instead of being done by a heat recovery heat exchanger. The fact that these units have two functions would make SCOP / SEER results not directly comparable to the ones of other heat pumps. In other words they indeed supply capacity but part of it might be supplied at an indoor temperature below 20 °C so capacity related to heating (and so to Pdesignh declaration) is only a part of measured capacity.

- **Definition of a heat pump and air-to-air heat pump**
  The definition of a heat pump and air-to-air heat pump will also be added to the regulation. The definitions will be adapted from Regulation (EU) No 2016/2281 and are described above in section 1.1.1.2.

- **Residential fan heaters**
  It is recommended to include information requirement on the "air movement" function of residential fan heaters in Regulation (EU) No 2015/1188 (similar to the information requirement for comfort fans in Regulation 206/2012).

- **Noise standards - EN 12102:2013**
  A draft version of this standard (prEN12102-2016) has been submitted for approval with no major change identified. According to convenor of CEN TC 113 / WG8, this standard could include rating conditions in the future. In order to link SCOP value and sound power measurement in heating mode, it is planned to use the point C in heating mode (outdoor air 7 °C / indoor air 20 °C / capacity 50 %) in order to rate the sound power level of air conditioners in heating mode. This is to be taken into account in any future regulation.

- **EU Regulation 206/2012/EU - Ecodesign Requirements for air conditioners and comfort fans**
  Regarding the calculation method, following input from test laboratories reported in the description of standard EN14825 in Task 1 section 1.2.2, it is advised not to allow performance tests to measure cycling performance degradation coefficients Cdc and Cdh, but to use the default value 0.25 instead as there is no proof the value can be measured satisfactorily for inverter units. However, in a possible mandate to CEN for the revised regulation could emphasize the need to define properly cycling tests for inverter units.
  In the future, SEER and SCOP values should be replaced by primary energy efficiency ratio in cooling and in heating mode following the example of more recent regulations (e.g. Regulation (EU) No 2281/2016).
  For heating only air-to-air heat pumps, it is also suggested that the test conditions to measure sound power level in heating mode are specified. The planned test conditions are heating mode point C in EN14825:2016 (outdoor air temperature + 7°C / declared capacity 50 %).
  Finally, the crankcase hours should be changed from 2672 to 2363.

- **Backup heater capacity**
  It is suggested to indicate the necessary additional backup heater capacity required to reach Pdesignh even if it is not included in the unit. So it is proposed to require the following additional information requirement under the naming "backup heater":
  - Required additional backup heater capacity: 3 values in kW to be supplied for warm / average/cold climates; this corresponds to the difference between Pdesignh for a specific climate and unit capacity of the unit at Tdesignh;
  - Backup heater included in the unit: Yes or No (3 values for the 3 different climates).

- **EU Regulation 1275/2008/EU - Ecodesign Requirements for standby and off mode, and networked standby, electric power consumption of electrical and electronic household and office equipment**
  It should be noted that air conditioners are not included in the standby regulation but the requirements for standby in Regulation 206/2012 (with and without a display) and off mode are in line with the standby regulation. Stakeholders have

raised the question whether air conditioners also should comply with the requirements of networked standby and HiNA equipment. The standby consumption is already included in the SEER calculation and leaves more room for development for manufacturers. It is suggested that if the air conditioners are networked by default, the networked standby consumption should be included in the efficiency calculation instead of standby consumption, present standby hours can be used.

- **Low power mode hours**
  Low power mode hours have been reviewed. In the EN 14825:2016, the crankcase heater consumption is measured in test condition D in both heating and cooling mode, it means that for the average climate, there are two values for P_{CK}, and thus potentially also for P_{TO}, P_{SB} and P_{OFF}.
  It is proposed to require two distinct **crankcase power values** for reversible units, respectively for cooling mode - measured at 20 °C - and for heating mode - measured at 12 °C. Cooling (or heating) only unit crankcase power measurement should be done at 20 °C (12 °C), as already written in standard EN14825:2016. Minor adjustments of **crankcase hours** are proposed, see above.

- **Measurement of blown air temperature**
  It is proposed, for units in the scope of this study, to complete the data supplied in test report of EN14511-3 with a measurement of the blown air temperature in heating mode and blown air temperature and humidity in cooling mode. These temperatures are normally measured during tests but not published. They should be available in the technical documentation of the products for data collection purpose. These values are to be reviewed at the time of the next revision of Regulation 206/2012 and 626/2011 and evaluate the possible impacts and the required changes in the standard and the regulation to ensure that SEER and SCOP remain representative of real life. More details in Task 3, section 3.1.7.

- **In situ continuous performance measurement**
  On-board measurement and others similar methods for in-situ continuous performance measurement could be generalized and used by all manufacturers, some of the manufacturers are already developing these methods themselves. However, it is important to carry out standardization work to ensure their reliability. This should 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. This is an important topic to improve further the efficiency and to reduce real life consumption of air conditioners, as well as to ensure that test standards are aligned with real life operating conditions as regards sizing, equivalent full load hours and other operating hours.

- **Additional information to end-user to reduce real life consumption**
  Another suggestion to cut real life energy consumption is to ensure continuous monitoring. It is proposed to include the electricity consumption measurement in the standardisation work to be done regarding in-situ continuous performance measurement mentioned above. It is necessary to fix a certain number of requirements (e.g. maximum uncertainty, minimum acquisition and averaging times, test of the functionality in the unit based on standard tests).

- **Testing information for set-up in technical documentation**

It is thus proposed that testing information required to set up the machine to reach claimed values be indicated in the technical documentation of the product, instead of being provided upon request or to include it in the EU energy labelling database (where it can only be accessed by market surveillance authorities). To make it mandatory in the product information would also help the development of competitive surveillance systems where manufacturers can check the claims of their competitors.

Annex 1 – Comfort fans assessment

Sales

The sales of comfort fans in the preparatory study was based on data from PRODCOM. The PRODCOM statistics are the official source for product data on the EU market. It is based on product definitions that are standardised across the EU thus guaranteeing comparability between Member States. Data are reported by Member States to Eurostat.

The PRODCOM statistics have some limitations given the complexities in the market and so are they not always as detailed as necessary to support decision making within ecodesign preparatory studies (e.g. data for air conditioners).

Within this study, the PRODCOM statistics are used to compare against product data sourced from other data sources and expert assumptions in order to provide a higher degree of confidence in the final product dataset. The product data sourced was used to establish annual sales for product categories in scope, and subsequently for establishing the installed base in the EU (i.e. stock).

PRODCOM EU sales and trade (i.e. the EU consumption) is derived by using the following formula based on data from PRODCOM:

$$EU\ sales\ and\ trading = production + import - export$$

For and comfort fans, the following PRODCOM categories have been used in the preparatory study and the current study.

Table 28: Prodcom categories covering products relevant for this study.

PRODCOM code	PRODCOM Nomenclature
27.51.15.30	Table, floor, wall, window, ceiling or roof fans, with a self-contained electric motor of an output <= 125 W

Figure 25 illustrate the EU-28 production, import and export quantity according to the current PRODCOM data for comfort fans below 125 W and Figure 26 shows the calculated EU sales and trading for comfort fans below 125 W.

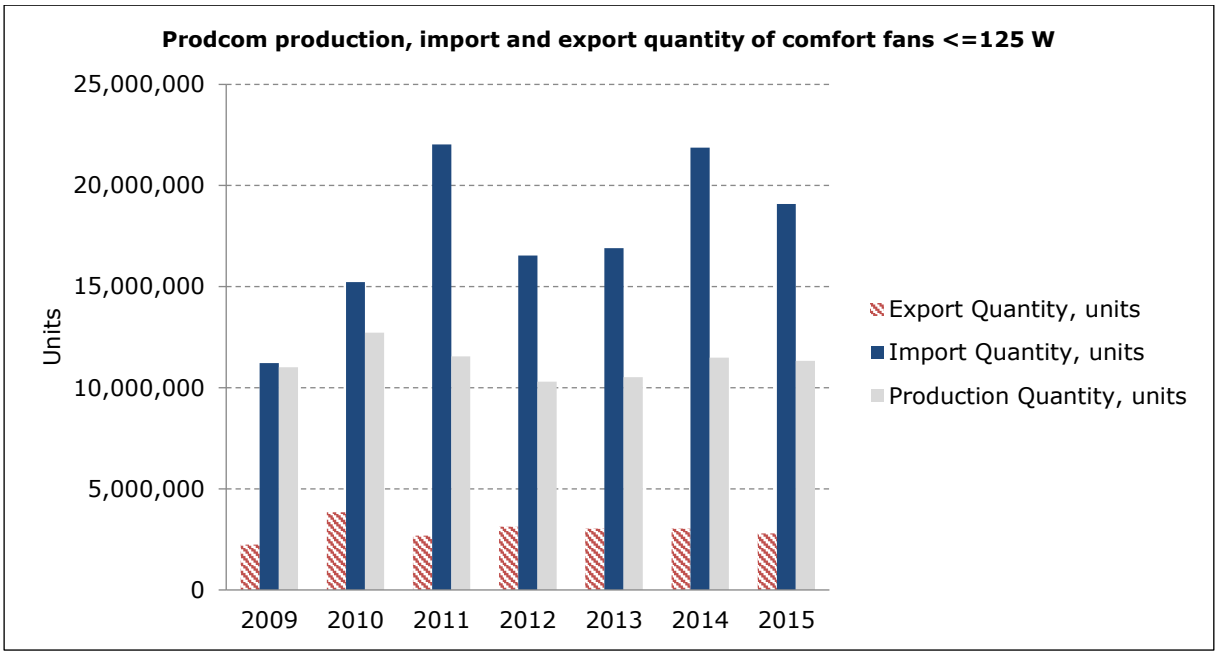

Figure 25: Total production, import and export quantity of comfort fans below 125 W 2009-2015. PRODCOM assessed April 2017.

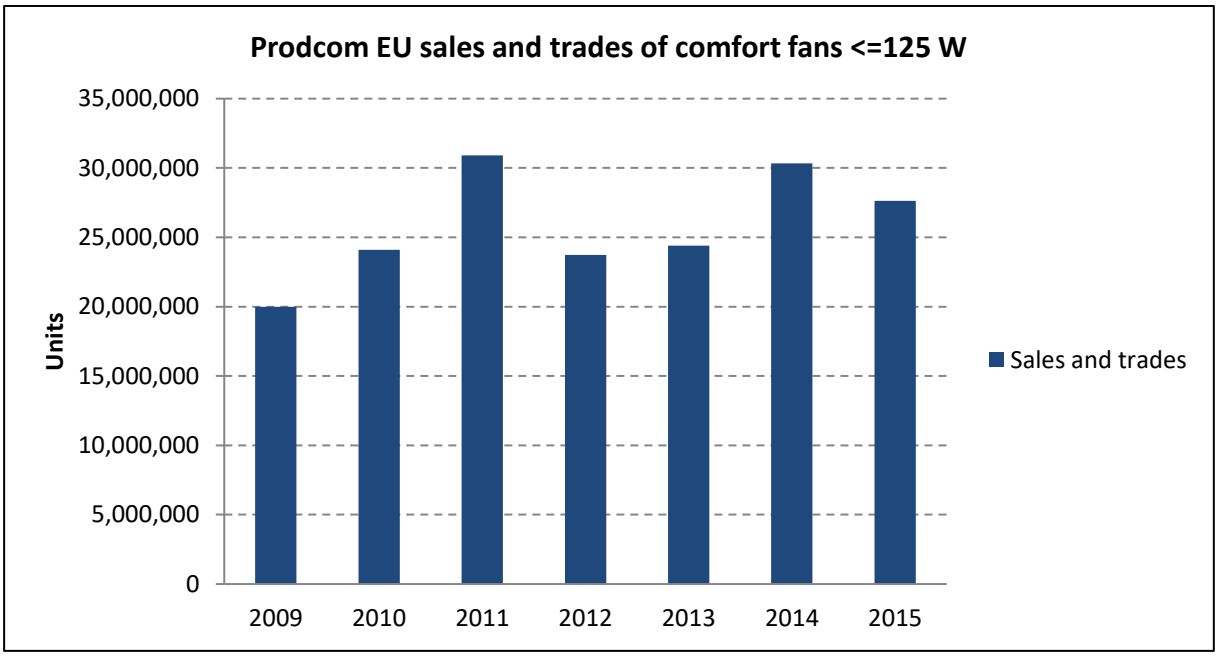

Figure 26: Total EU sales and trading of comfort fans below 125 W 2009-2015. PRODCOM assessed April 2017.

From the current PRODCOM data the general tendency is a slight increase in the period from 2009 to 2015. The sales and trading are expected to be highly connected with the weather in the year concerned, so over a period of time one must expect some fluctuation in the sales and trading. Since 2012 the EU sales and trading of comfort fans has increased with an average increase of 5 % per year. This increase is highly connected with the increase in import. The production and export of comfort fans only have minor fluctuation over the years with an almost flat trend.

Since no other data has been available for comfort fans, PRODCOM data is used still used in the current assessment. The assumptions made in the preparatory study assumed a decrease in the annual sales. Current PRODCOM data presented in Figure 26 shows an

increasing trend, but by expanding the timeframe it is possible to see a falling trend in the current data as well. In Figure 27 the assumptions on EU sales and trading of comfort fans in the preparatory study are compared with current PRODCOM data.

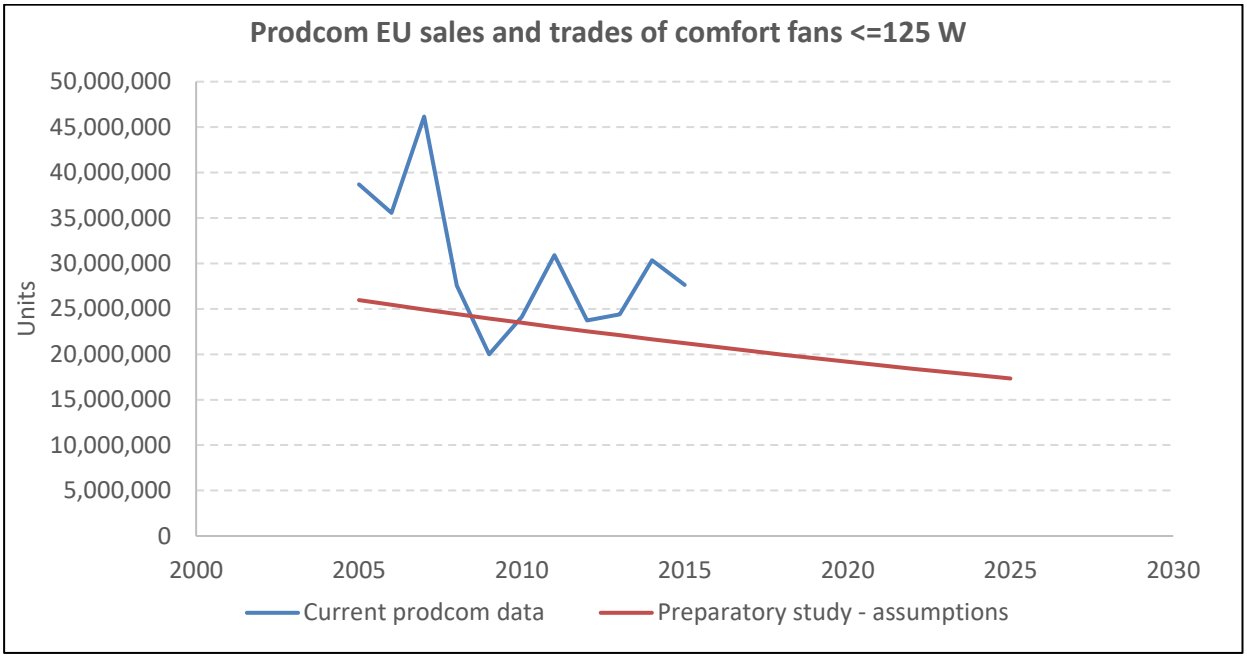

Figure 27: Comparison of EU sales and trading of comfort fans below 125 W 2009-2015 of current PRODCOM data (assessed April 2017) and expected sales and trades from the preparatory study

From the figure it is visible that the sales of comfort fans were expected to progressively fall in the preparatory study (2 % per year due to the competition with air conditioners). In reality the sales are very much dependent on the weather but overall the sales are expected to fall. Based on the sales figures it is assumed that the data in the preparatory study still are representative to the current situation despite the expected large fluctuations. This means that the assumptions made on stock also is representative. The stock in the preparatory study is presented in Figure 28.

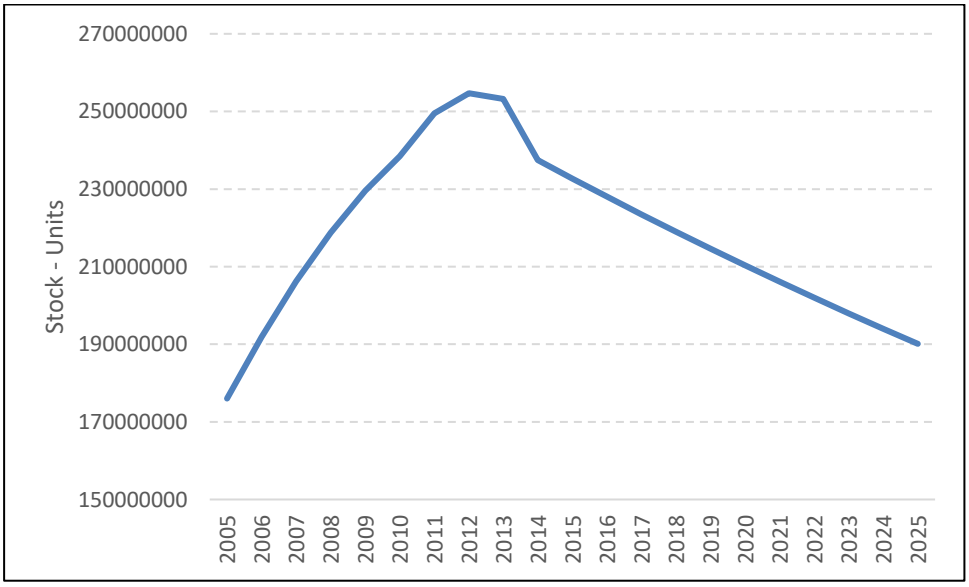

Figure 28: Assumed stock development - preparatory study

The PRODCOM data does not distinguish between the different types of comfort fans but this was also assessed in the preparatory study by internet and store surveys. The distribution of comfort fan types is presented in Figure 29.

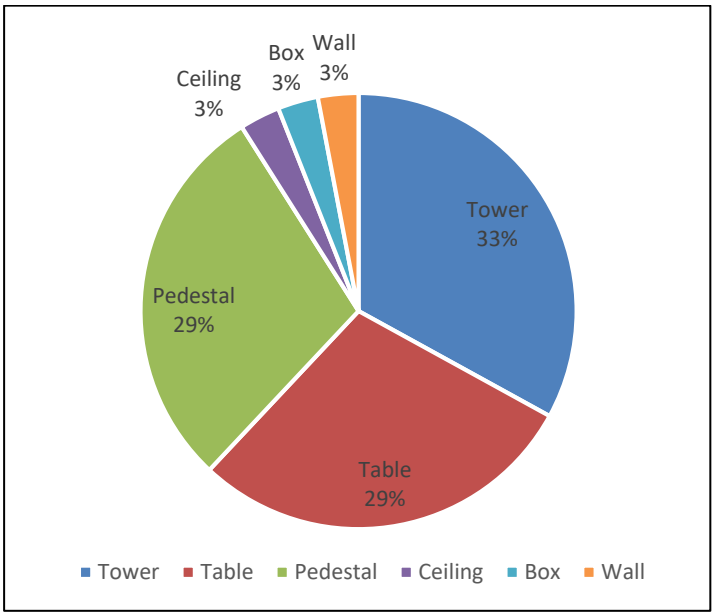

Figure 29: Types of comfort fans - assumption from the preparatory study

Tower fans, pedestal fans and table fans are the dominant type of fans based on the internet and store survey in the preparatory study. This distribution of fan types is still believed to be representative to the current situation.

Market overview

Based on data retrieved from topten[29] it is possible to assess the current efficiency of comfort fans on the European market. This data contained information on 158 models of comfort fans that are presently available on the market. topten[30] informed that the product declaration was very poor despite the current information requirements. Of the whole sample only 67 models declared sufficient information to assess the Service Value of the products. For 8 models, the information was available on the retailer's website. For the remaining 137 models, the information on the service value and maximum fans flow rate was not declared. This means that the consumers are buying comfort fans without the knowledge of potential energy consumption. This also means that the consumers cannot compare the different comfort fans regarding energy consumption.

The available data (75 comfort fans) are used to make the following figures. In Figure 30 is the distribution of wattage and service values presented and Figure 31 visualises the spread in service values of the different types of comfort fans.

[29] http://www.topten.eu/
[30] http://www.topten.eu/

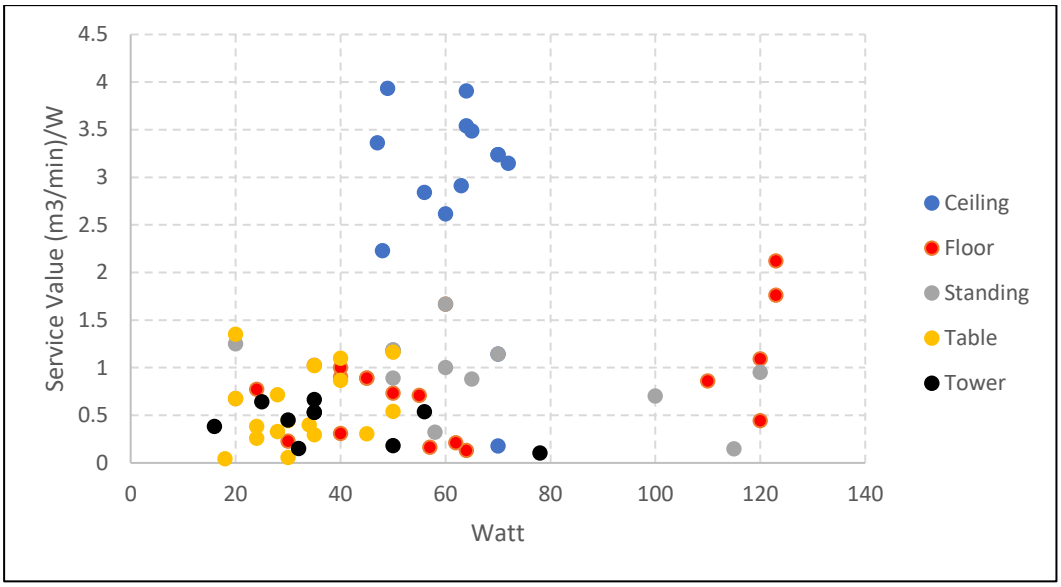

Figure 30: Spread in wattage and service values of comfort fans

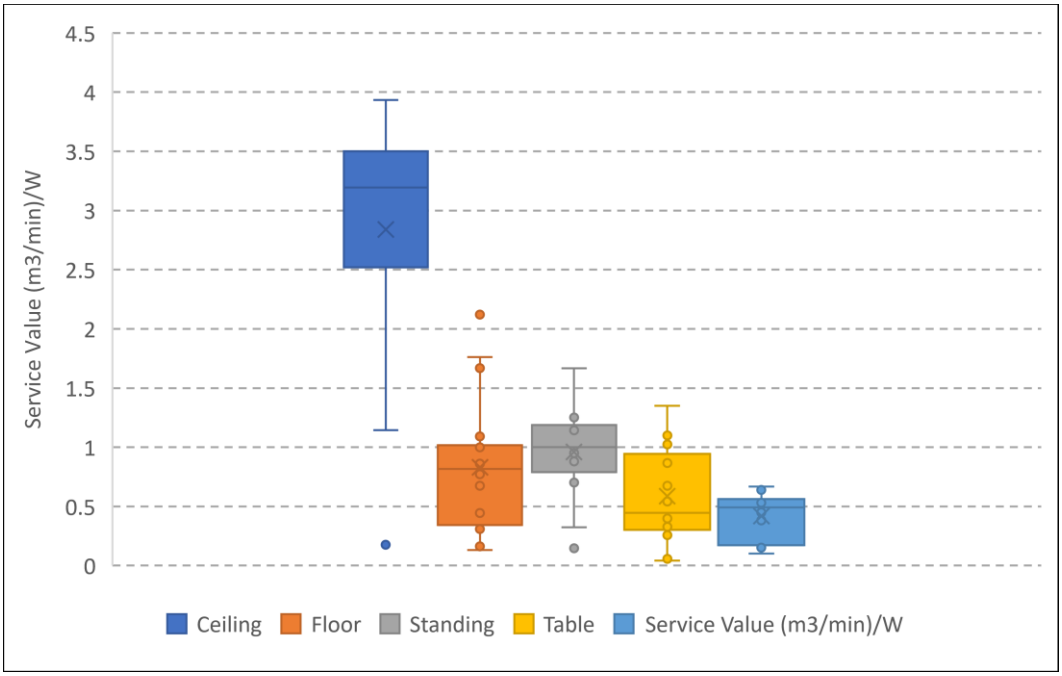

Figure 31: Spread in service values of the different types of comfort fans

From the figures it is visible that the service value of comfort fans is very widespread, and it is of special concern that very inefficient models are available on the European market. For all types of fans, the difference of the most and least efficient fans are more than (0.5 m^3/min)/W.

Despite the information requirements there is still a lack of data, which also was the case during the preparatory study. In the impact assessment the following is stated:

"As to comfort fans, the heart of the issue is the lack of robust data on the performance of fans sold in the EU. The preparatory study recognised this problem and proposed as possible solution the setting of minimum efficiency (and noise) requirements as applied in China and Taiwan. These values were thought to be attainable (since applied in the manufacturing country of origin for comfort fans) leading close to 1 TWh/a savings by 2020.

However, during the impact assessment study it became apparent that the results of fan efficiency established using IEC 60879 are not compatible with the Chinese requirements. Additional input from stakeholders and experts revealed that there is no certainty to what actual measurement standards are applied when the performance of fans is declared and whether the fans actually meet the Chinese requirements. This removed the basis for the proposal to introduce minimum efficiency requirements in line with the Chinese legislation. In the second Consultation Forum meeting three options were considered:

1) *Setting efficiency requirements at similar level as in China/Taiwan with risk of removing virtually all comfort fans from the EU market;*
2) *Setting requirements at lower levels than proposed in the preparatory study with loss of savings potential. However, the insufficiency of data and test results would result in 'blindly-set' requirements with corresponding risk of lost savings or banning of appliances;*
3) *Setting information requirements only for the indication of the measured efficiency of the appliance and the measurement method used. Savings would be postponed until the setting of minimum efficiency and/or labelling requirements, but the information requirements would help supporting national authorities in their market surveillance activities and provide sound basis for energy efficiency data for any future measures. Information requirements will not lead to any considerable administrative burden, as the efficiency tests will provide this information for each model anyway. While today appliances include information based on EER and COP, they will include information based on SEER and SCOP after the coming into force of requirements.*

The third option was chosen, as options 1 and 2 were considered unacceptably risky. As the setting of product information requirements is not estimated to differ significantly from the baseline scenario in terms of costs against the obvious benefits, this option is not further analysed."

The available standard is still IEC 60879 so there is a still a risk that service values not are comparable across borders. This makes it very difficult to suggest any reasonable requirements as the efficiency on the market is unknown. Furthermore, the standard does not include tower fans which are assumed to cover 33 % of the market.

By implementing the MEPS suggested in the preparatory study the concern was that comfort fans were banned from the market. The suggested minimum requirements in the preparatory study are presented in Table 29.

Table 29: Suggested minimum requirements in the preparatory study

Fan type	Fan diameter (cm)	Service value minimum acceptable ((m³/min)/W)	Maximum acceptable noise (dB(A))
Tower fans	0-20	0.54	59
All comfort fans except tower and ceiling	20-23	0.54	59
	23-25	0.64	60
	25-30	0.74	61
	30-35	0.81	63
	35-40	0.9	65
	40-45	1	67
	45-50	1.1	68
	50-60	1.13	70
	60+	1.3	73
Ceiling fans	0-60	0.54	62
	60-90	0.87	62
	90-120	1.15	65
	120-130	1.46	67
	130-140	1.45	70
	140-150	1.45	72
	150+	1.47	75

Whether these requirements still are assumed to ban comfort fans from the market is unknown. The available data is not divided in fan diameter and since there is a clear link between fan diameter and obtainable service value it is difficult to suggest new requirements based on data currently available.

Instead of assessing fans based on their fan diameter the requirements could be dependent on the type. This may mean that small comfort fans (small diameter) are banned from the market. These requirements could be based on the LLCC found in the preparatory study. The LLCC and BAT found in the preparatory study are presented in

Table 30: LLCC and BAT for different types of comfort fans - based on the preparatory study

	LLCC	BAT
Service Values for Table fans ((m³/min)/Watt)	1	1.77
Service Values for Pedestal fans ((m³/min)/Watt)	1	1.77
Service Values for Tower fans ((m³/min)/Watt)	1.5	2.2

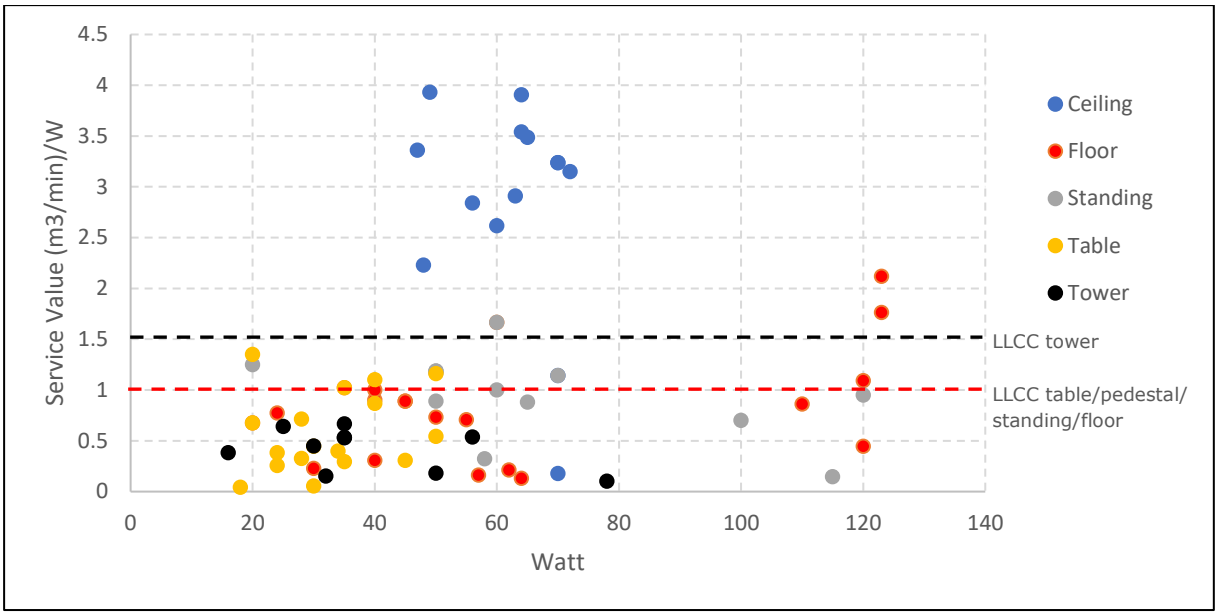

Figure 32: LLCC from the preparatory study and current service value.

From the figure it seems like the majority of the table fans currently not even are able to reach the LLCC level from the preparatory study. This means that there has been very little technological development on comfort fans in Europe. Most comfort fans are also low priced, so this may affect the possibilities for further improvement. The lack of improvement in Europe may also be due to the lack of requirements so all the inefficient comfort fans are shipped to Europe. Topten have informed that it seems like comfort fans in e.g. china are more efficient than in Europe.

Impact of requirements

If any minimum requirements are suggested it is unknown how this will affect the market due to the inconsistencies with standards (Europe/Asia) and also the lack of data. If the service value in Europe and Asia is comparable there is room for improvement. The most efficient comfort fans are present in China and India. This is based on the topten list requirements in Asia. The service value requirements to reach the topten list in China are presented in table

Construction type	Energy efficiency value (m^3/min/W)
Standing	≥ 1.31
Ceiling	≥ 3.08
Other	≥ 1.40

The presented threshold values in China are considered weak, but if these threshold values are adopted to Europe it seems difficult for topten to populate the list. Though, there is still the uncertainty regarding standards. So, it is unknown whether comfort fans in China are rated better due to differences in the standard or lack in control.

So overall the same challenges still exist regarding requirements for comfort fans and the following two options from the impact assessment is still valid to consider:

- Setting minimum energy efficiency requirements on comfort fans with the proposed requirements (from the preparatory study) with the risk of banning many comfort

fans in the European market (expected savings in the preparatory study was slightly below 1 TWh).

- Enforcing better market surveillance on the current information requirement and gathering accurate information on comfort fan efficiency and test methods through a complementary study/efficiency tests with corresponding costs.

Annex 2 – Policy scenarios assumptions

All scenarios consist of a set of assumptions that are fixed which are presented in the table below.

Table 31: Assumptions in all scenarios

	Cooling capacity kW	Cooling hours	Pdesignh (kW)	Leakage rate
BC 1	3.5	350	3	3%
BC 2	7.1	350	6.5	3%
BC 3	2.6			1%

All scenarios also consist of some values that are changing due to annual development. Though are these assumptions alike in all scenarios. These assumptions are:

- Assumptions for hours in heating:
  - 0 hours in 1992 to 700 hours in 2015 (linear regression until full load hours are reached in 2038 for new products)
- Assumptions for refrigerant:
  - R410 until ban, then R-32 for fixed and propane for portable. For fixed air conditioners there is a linear regression in the conversion from R410 until the ban. This means that the GWP will gradually decrease until the ban.

Annex 3 – Tables and figures

This annex presents additional tables and figures to support the analysis in this report.

Development of SEER and SCOP average sales values in the different policy options

The assumed SEER and SCOP development for the different policy options are presented in the table below.

Table 32: Development of SEER and SCOP average sales values in the different scenarios.

		2010	2015	2020	2025	2030	2035	2040
Scenario 2 (1 tier eco)								
SEER	BC1	4.81	6.00	6.73	7.38	7.61	7.83	8.05
	BC2	4.58	5.80	6.21	6.59	6.73	6.87	7.01
	BC3	1.65	1.83	2.08	2.33	2.37	2.42	2.46
SCOP	BC1	3.34	4.00	4.19	4.36	4.47	4.58	4.69
	BC2	3.26	4.00	4.10	4.19	4.25	4.31	4.38
	BC3	-	-	-	-	-	-	-
Scenario 3 (lbl)								
SEER	BC1	4.81	6.00	6.36	6.88	7.44	8.01	8.57
	BC2	4.58	5.80	6.01	6.31	6.63	6.95	7.26
	BC3	1.65	1.83	1.87	2.17	2.54	2.90	3.27
SCOP	BC1	3.34	4.00	4.09	4.27	4.47	4.67	4.88
	BC2	3.26	4.00	4.04	4.17	4.31	4.45	4.60
	BC3	-	-	-	-	-	-	-
Scenario 4 (eco+lbl)								
SEER	BC1	4.81	6.00	6.73	7.51	7.95	8.39	8.83
	BC2	4.58	5.80	6.21	6.65	6.90	7.15	7.40
	BC3	1.65	1.83	2.08	2.48	2.79	3.09	3.39
SCOP	BC1	3.34	4.00	4.19	4.41	4.58	4.76	4.93
	BC2	3.26	4.00	4.10	4.23	4.36	4.49	4.62
	BC3	-	-	-	-	-	-	-

Environmental impacts of the different scenarios for each of the base cases

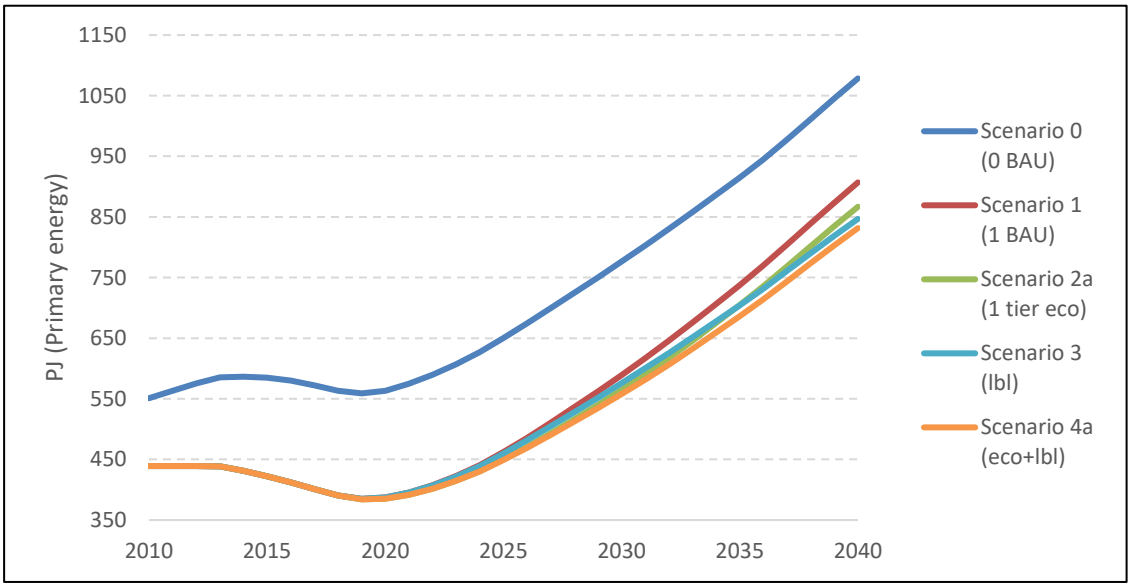

Figure 33: Comparison of impacts of the different scenarios – Primary energy (PJ) in absolute values

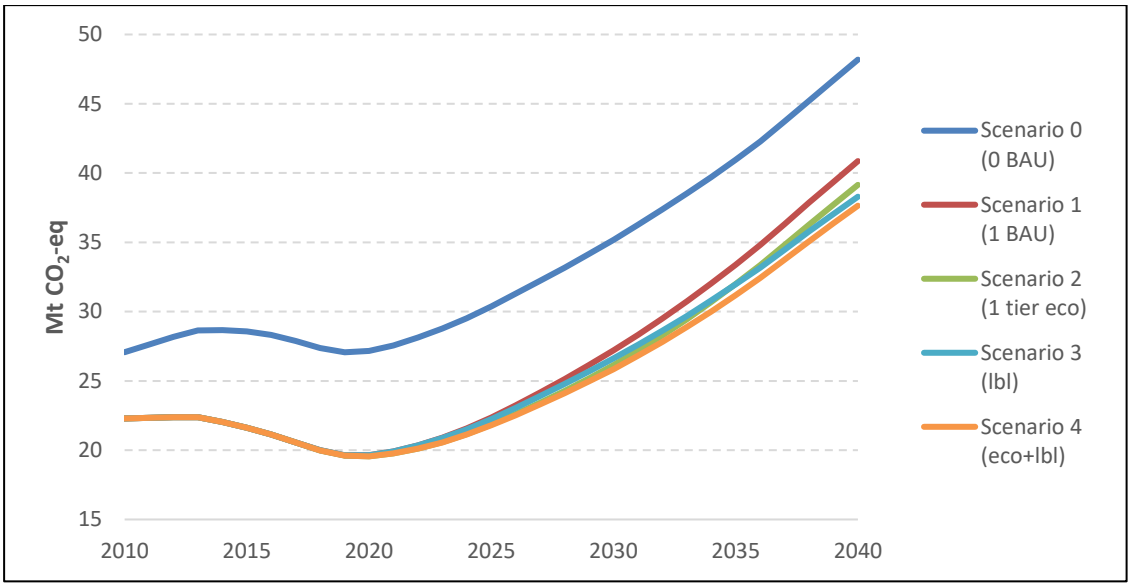

Figure 34: Comparison of impacts of the different scenarios – Emission of CO_2 (Mt) in absolute values

Table 33: Impacts of scenario 0 (before regulation) - TWh, Primary energy and CO_2-eq in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 0 (current regulation)								
TWh (Electricity)	BC1	37.9	38.7	36.4	42.6	52.2	62.7	75.3
	BC2	19.6	22.7	22.4	25.3	29.3	33.7	38.7
	BC3	1.2	1.1	1.0	1.0	1.0	1.0	1.0
	Total	**58.6**	**62.6**	**59.8**	**69.0**	**82.6**	**97.4**	**115.0**
PJ (Primary energy)	BC1	354.4	360.2	341.8	400.9	490.0	587.5	704.8
	BC2	184.0	213.0	210.7	238.4	275.5	316.4	362.7
	BC3	12.5	11.9	10.9	11.0	10.9	11.0	11.0
	Total	**551.0**	**585.1**	**563.4**	**650.2**	**776.4**	**914.9**	**1078.5**
Mt CO_2-eq	BC1	17.4	17.6	16.5	18.7	22.2	26.3	31.5
	BC2	9.0	10.4	10.2	11.2	12.5	14.2	16.2
	BC3	0.6	0.6	0.5	0.5	0.5	0.5	0.5
	Total	**27.1**	**28.6**	**27.2**	**30.4**	**35.2**	**40.9**	**48.2**

Table 34: Impacts of scenario 1 (current regulation) - TWh, Primary energy and CO_2-eq in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 1 (current regulation)								
TWh (Electricity)	BC1	30.4	28.4	25.3	30.7	40.2	51.2	64.1
	BC2	14.7	15.1	14.0	16.6	20.8	25.7	31.1
	BC3	1.0	0.9	0.8	0.8	0.8	0.8	0.8
	Total	**46.2**	**44.5**	**40.2**	**48.1**	**61.8**	**77.7**	**96.0**
PJ (Primary energy)	BC1	287.6	267.4	242.5	293.9	381.7	484.2	603.6
	BC2	140.0	144.5	135.5	159.4	198.4	244.1	293.9
	BC3	11.4	10.3	9.1	9.1	9.2	9.3	9.4
	Total	**439.1**	**422.2**	**387.1**	**462.4**	**589.3**	**737.5**	**906.9**
Mt CO_2-eq	BC1	14.6	13.6	12.2	14.2	17.6	21.9	27.2
	BC2	7.1	7.5	7.0	7.8	9.2	11.1	13.3
	BC3	0.6	0.5	0.4	0.4	0.4	0.4	0.4
	Total	**22.3**	**21.6**	**19.6**	**22.4**	**27.2**	**33.4**	**40.9**

Table 35: Impacts of scenario 2 (1 tier eco) - TWh, Primary energy and CO_2-eq in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 2 (1 tier eco)								
TWh (Electricity)	BC1	30.4	28.4	25.2	29.7	38.2	48.6	60.7
	BC2	14.7	15.1	14.0	16.3	20.2	24.9	30.0
	BC3	1.0	0.9	0.8	0.7	0.7	0.7	0.7
	Total	**46.2**	**44.5**	**40.0**	**46.7**	**59.0**	**74.1**	**91.5**
PJ (Primary energy)	BC1	287.6	267.4	241.1	285.0	363.6	460.1	573.9
	BC2	140.0	144.5	135.1	156.7	193.0	236.8	284.8
	BC3	11.4	10.3	9.0	8.3	7.9	8.0	8.1
	Total	**439.1**	**422.2**	**385.2**	**450.1**	**564.5**	**704.9**	**866.8**
Mt CO_2-eq	BC1	14.6	13.6	12.2	13.8	16.8	20.9	25.9
	BC2	7.1	7.5	6.9	7.7	9.0	10.8	12.9
	BC3	0.6	0.5	0.4	0.4	0.4	0.4	0.4
	Total	**22.3**	**21.6**	**19.6**	**21.8**	**26.1**	**32.0**	**39.1**

Table 36: Impacts of scenario 3 (lbl) - TWh, Primary energy and CO_2-eq in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 3 (lbl)								
TWh (Electricity)	BC1	30.4	28.4	25.3	30.5	39.2	48.7	59.5
	BC2	14.7	15.1	14.0	16.5	20.3	24.7	29.2
	BC3	1.0	0.9	0.8	0.8	0.7	0.6	0.6
	Total	**46.2**	**44.5**	**40.2**	**47.8**	**60.3**	**74.0**	**89.3**
PJ (Primary energy)	BC1	287.6	267.4	242.5	292.2	372.9	461.8	562.5
	BC2	140.0	144.5	135.5	158.7	194.8	234.9	277.2
	BC3	11.4	10.3	9.1	8.9	8.2	7.5	7.0
	Total	**439.1**	**422.2**	**387.1**	**459.7**	**575.9**	**704.2**	**846.8**
Mt CO_2-eq	BC1	14.6	13.6	12.2	14.1	17.2	20.9	25.4
	BC2	7.1	7.5	7.0	7.8	9.1	10.7	12.6
	BC3	0.6	0.5	0.4	0.4	0.4	0.3	0.3
	Total	**22.3**	**21.6**	**19.6**	**22.3**	**26.6**	**32.0**	**38.3**

Table 37: Impacts of scenario 4 (eco+lbl) - TWh, Primary energy and CO_2-eq in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 4a (eco+lbl)								
TWh (Electricity)	BC1	30.4	28.4	25.2	29.7	37.7	47.2	58.2
	BC2	14.7	15.1	14.0	16.2	19.9	24.2	28.9
	BC3	1.0	0.9	0.8	0.7	0.6	0.6	0.5
	Total	**46.2**	**44.5**	**40.0**	**46.6**	**58.3**	**72.0**	**87.6**
PJ (Primary energy)	BC1	287.6	267.4	241.1	284.4	359.3	448.1	550.8
	BC2	140.0	144.5	135.1	156.4	191.0	231.1	274.1
	BC3	11.4	10.3	9.0	8.2	7.4	7.0	6.7
	Total	**439.1**	**422.2**	**385.2**	**449.0**	**557.7**	**686.2**	**831.6**
Mt CO_2-eq	BC1	14.6	13.6	12.2	13.8	16.6	20.3	24.9
	BC2	7.1	7.5	6.9	7.7	8.9	10.5	12.4
	BC3	0.6	0.5	0.4	0.4	0.3	0.3	0.3
	Total	**22.3**	**21.6**	**19.6**	**21.8**	**25.9**	**31.2**	**37.6**

The accumulated savings

The accumulated energy savings compared to scenario 1 (the current regulation) are presented in the table below.

Table 38: The accumulated savings in energy and emission of CO_2-eq of the policy options compared to the current regulation (scenario 1)

	1995	2000	2005	2010	2015	2020	2025	2030	2035	2040
Electricity consumption (TWh)										
Scenario 2 (1 tier eco)	0	0	0	0	0	0	5	16	32	53
Scenario 3 (lbl)	0	0	0	0	0	0	1	5	19	46
Scenario 4a (eco+lbl)	0	0	0	0	0	0	5	18	42	79
Primary energy consumption (PJ)										
Scenario 2 (1 tier eco)	0	0	0	0	0	0	5	47	171	415
Scenario 3 (lbl)	0	0	0	0	0	3	44	163	380	707
Scenario 4 (eco+lbl)	0	0	0	0	0	0	5	47	171	415
mt CO_2-eq										
Scenario 2 (1 tier eco)	0	0	0	0	0	0	2	6	12	20
Scenario 3 (lbl)	0	0	0	0	0	0	0	2	7	18
Scenario 4 (eco+lbl)	0	0	0	0	0	0	2	7	16	30

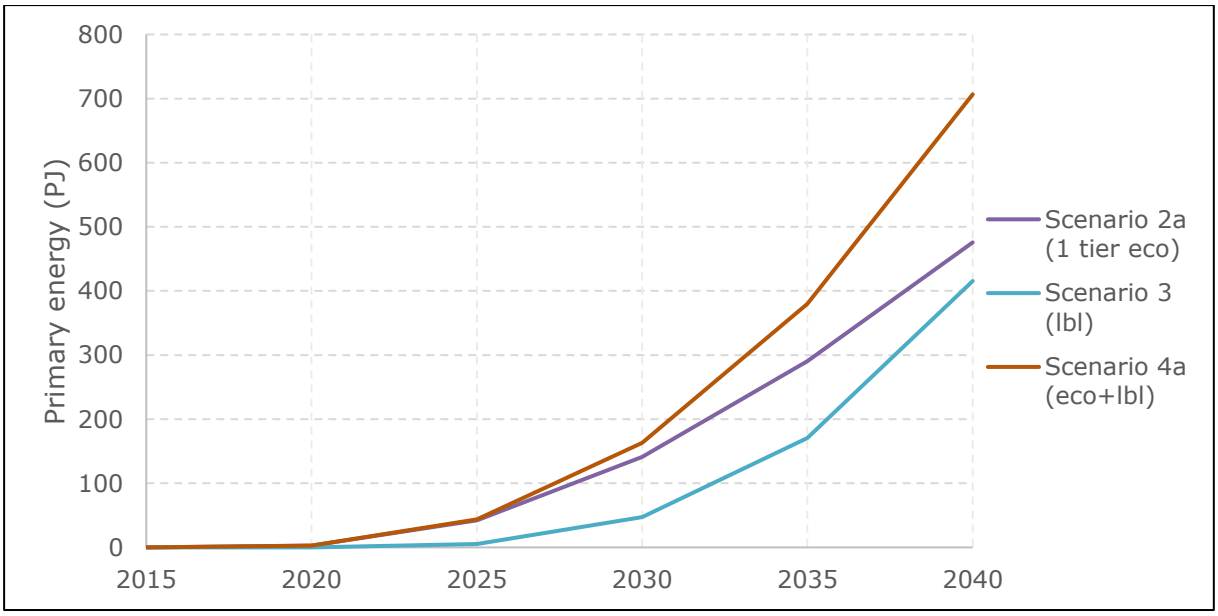

Figure 35: The accumulated savings in primary energy (PJ)of the policy options compared to the current regulation (scenario 1)

Development of purchase price per unit in different policy options

Table 39: Development in purchase price per unit in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 0 (before regulation)								
EUR	BC1	492	509	517	520	517	509	472
	BC2	1114	1157	1182	1191	1188	1174	1088
	BC3	259	243	228	213	199	186	170
Scenario 1 (current regulation)								
EUR	BC1	737	830	795	759	723	686	650
	BC2	1799	2059	1929	1806	1689	1577	1472
	BC3	308	307	284	263	243	225	208
Scenario 2 (1 tier eco)								
EUR	BC1	737	830	842	835	777	723	673
	BC2	1799	2059	1994	1910	1764	1628	1502
	BC3	308	307	316	320	295	271	250
Scenario 3 (lbl)								
EUR	BC1	737	830	795	778	761	740	716
	BC2	1799	2059	1929	1830	1738	1646	1556
	BC3	308	307	284	298	315	326	332
Scenario 4a (eco+lbl)								
EUR	BC1	737	830	842	849	813	775	737
	BC2	1799	2059	1994	1928	1809	1694	1585
	BC3	308	307	316	341	346	347	344

Consumer impacts for each of the base cases in absolute values

Table 40: Annual consumer purchase costs of air conditioners in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 0 (before regulation)								
Billion EUR	BC1	1.53	1.32	1.69	2.04	2.34	2.66	2.89
	BC2	0.85	0.96	1.06	1.22	1.37	1.50	1.55
	BC3	0.15	0.14	0.10	0.10	0.09	0.09	0.09
	Total	**2.53**	**2.42**	**2.85**	**3.36**	**3.8**	**4.25**	**4.53**
Scenario 1 (current regulation)								
Billion EUR	BC1	2.29	2.16	2.60	2.99	3.27	3.58	3.98
	BC2	1.38	1.70	1.74	1.85	1.94	2.02	2.10
	BC3	0.18	0.17	0.13	0.12	0.12	0.11	0.10
	Total	**3.85**	**4.03**	**4.47**	**4.96**	**5.33**	**5.71**	**6.18**
Scenario 2 (1 tier eco)								
Billion EUR	BC1	2.29	2.16	2.76	3.28	3.52	3.77	4.11
	BC2	1.38	1.70	1.80	1.96	2.03	2.09	2.14
	BC3	0.18	0.17	0.14	0.15	0.14	0.13	0.13
	Total	**3.85**	**4.03**	**4.7**	**5.39**	**5.69**	**5.99**	**6.38**
Scenario 3 (lbl)								
Billion EUR	BC1	2.29	2.16	2.60	3.06	3.45	3.86	4.38
	BC2	1.38	1.70	1.74	1.88	2.00	2.11	2.22
	BC3	0.18	0.17	0.13	0.14	0.15	0.16	0.17
	Totals	**3.85**	**4.03**	**4.47**	**5.08**	**5.6**	**6.13**	**6.77**
Scenario 4a (eco+lbl)								
Billion EUR	BC1	2.29	2.16	2.76	3.34	3.68	4.04	4.51
	BC2	1.38	1.70	1.80	1.98	2.08	2.17	2.26
	BC3	0.18	0.17	0.14	0.16	0.16	0.17	0.17
	Totals	**3.85**	**4.03**	**4.7**	**5.48**	**5.92**	**6.38**	**6.94**

Table 41: Annual consumer electricity costs in absolute values

		2010	2015	2020	2025	2030	2035	2040
Scenario 0 (before regulation)								
Billion EUR	BC1	6.3	7.1	7.1	8.6	10.7	13.2	15.7
	BC2	3.2	4.1	4.3	5.1	5.9	7.0	8.0
	BC3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Total	**9.7**	**11.4**	**11.7**	**13.9**	**16.9**	**20.4**	**23.9**
Scenario 1 (current regulation)								
Billion EUR	BC1	5.1	5.2	5.0	6.2	8.3	10.8	13.4
	BC2	2.4	2.7	2.7	3.3	4.2	5.3	6.4
	BC3	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	Total	**7.7**	**8.1**	**7.9**	**9.7**	**12.6**	**16.3**	**19.9**
Scenario 2 (1 tier eco)								
Billion EUR	BC1	5.1	5.2	4.9	6.0	7.8	10.2	12.7
	BC2	2.4	2.7	2.7	3.2	4.1	5.2	6.2
	BC3	0.2	0.2	0.2	0.1	0.1	0.1	0.1
	Total	**7.7**	**8.1**	**7.8**	**9.4**	**12.1**	**15.5**	**19.0**
Scenario 3 (lbl)								
Billion EUR	BC1	5.1	5.2	5.1	6.1	8.2	10.2	12.5
	BC2	2.4	2.7	2.7	3.3	4.1	5.2	6.1
	BC3	0.2	0.2	0.2	0.2	0.1	0.1	0.1
	Totals	**7.7**	**8.1**	**7.9**	**9.6**	**12.4**	**15.5**	**18.7**
Scenario 4a (eco+lbl)								
Billion EUR	BC1	5.1	5.2	5.0	5.9	7.9	9.9	12.2
	BC2	2.4	2.7	2.7	3.2	4.0	5.1	6.1
	BC3	0.17	0.16	0.16	0.14	0.12	0.12	0.11
	Totals	**7.7**	**8.1**	**7.9**	**9.3**	**12.0**	**15.1**	**18.4**

Table 42: Annual installation and maintenance costs in absolute values

		2010	2015	2020	2025	2030	2035	2040
All scenarios – installation								
Billion EUR	BC1	1.5	1.8	3.3	2.5	2.1	2.6	3.1
	BC2	0.3	0.4	0.7	0.6	0.7	0.7	0.8
	BC3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total	**1.8**	**2.1**	**4.0**	**3.1**	**2.7**	**3.3**	**4.0**
All scenarios – maintenance								
Billion EUR	BC1	0.2	0.2	0.3	0.3	0.2	0.3	0.3
	BC2	0.0	0.0	0.1	0.1	0.1	0.1	0.1
	BC3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Totals	**0.2**	**0.2**	**0.4**	**0.3**	**0.3**	**0.4**	**0.4**

Industry impacts

The Industry impacts are presented in the table below.

Table 43: Industry impacts - Manufacturer turnover (Mln EUR)

	2010	2015	2020	2025	2030	2035	2040
	Manufacturer turnover (Mln EUR)						
Scenario 0 (0 BAU)	1160	1106	1301	1527	1724	1926	2046
Scenario 1 (1 BAU)	1755	1838	2029	2248	2417	2585	2794
Scenario 2 (1 tier eco)	1755	1838	2132	2445	2581	2715	2887
Scenario 3 (lbl)	1755	1838	2029	2302	2540	2779	3065
Scenario 4 (eco+lbl)	1755	1838	2132	2485	2690	2896	3145

Table 44: Industry impacts - Manufacture total personnel (Persons)

	2010	2015	2020	2025	2030	2035	2040
	Manufacture total personnel (Persons)						
Scenario 0 (0 BAU)	3356	3197	3764	4415	4986	5570	5918
Scenario 1 (1 BAU)	5075	5316	5867	6501	6988	7476	8079
Scenario 2 (1 tier eco)	5075	5316	6166	7071	7465	7851	8349
Scenario 3 (lbl)	5075	5316	5867	6656	7344	8038	8863
Scenario 4 (eco+lbl)	5075	5316	6166	7187	7780	8374	9096

Table 45: Industry impacts - OEM total personnel (Persons)

	2010	2015	2020	2025	2030	2035	2040
	OEM total personnel (Persons)						
Scenario 0 (0 BAU)	4027	3837	4516	5298	5984	6684	7102
Scenario 1 (1 BAU)	6090	6380	7041	7801	8386	8971	9694
Scenario 2 (1 tier eco)	6090	6380	7400	8485	8958	9421	10019
Scenario 3 (lbl)	6090	6380	7041	7988	8813	9646	10636
Scenario 4 (eco+lbl)	6090	6380	7400	8624	9337	10049	10916

Table 46: Industry impacts - OEM total personnel – EU (Persons)

	2010	2015	2020	2025	2030	2035	2040
	OEM total personnel – EU (Persons)						
Scenario 0 (0 BAU)	805	767	903	1060	1197	1337	1420
Scenario 1 (1 BAU)	1218	1276	1408	1560	1677	1794	1939
Scenario 2 (1 tier eco)	1218	1276	1480	1697	1792	1884	2004
Scenario 3 (lbl)	1218	1276	1408	1598	1763	1929	2127
Scenario 4 (eco+lbl)	1218	1276	1480	1725	1867	2010	2183

Table 47: Industry impacts - Wholesaler turnover (Mln EUR)

	2010	2015	2020	2025	2030	2035	2040
	Wholesaler turnover (Mln EUR)						
Scenario 0 (0 BAU)	348	332	390	458	517	578	614
Scenario 1 (1 BAU)	526	552	609	674	725	776	838
Scenario 2 (1 tier eco)	526	552	640	734	774	814	866
Scenario 3 (lbl)	526	552	609	691	762	834	919
Scenario 4a (eco+lbl)	526	552	640	746	807	869	944

Table 48: Industry impacts - Wholesaler total personnel (Persons)

	2010	2015	2020	2025	2030	2035	2040
	Wholesaler total personnel (Persons)						
Scenario 0 (0 BAU)	683	651	766	899	1015	1134	1205
Scenario 1 (1 BAU)	1033	1082	1194	1323	1423	1522	1644
Scenario 2 (1 tier eco)	1033	1082	1255	1439	1520	1598	1700
Scenario 3 (lbl)	1033	1082	1194	1355	1495	1636	1804
Scenario 4a (eco+lbl)	1033	1082	1255	1463	1584	1705	1852

Sensitivity analysis in absolute values

Table 49: The calculated impacts of higher levels of recycling and the effect of higher leakage in absolute values.

		2010	2015	2020	2025	2030	2035	2040
Scenario 4 (eco+lbl)								
Mt CO_2-eq	BC1	14.6	13.6	12.2	13.8	16.6	20.3	24.9
	BC2	7.1	7.5	6.9	7.7	8.9	10.5	12.4
	BC3	0.6	0.5	0.4	0.4	0.3	0.3	0.3
	Total	**22.3**	**21.6**	**19.6**	**21.8**	**25.9**	**31.2**	**37.6**
Sensitivity (95% recycling)								
Mt CO_2-eq	BC1	14.5	13.6	12.1	13.6	16.5	20.2	24.7
	BC2	7.1	7.4	6.9	7.6	8.8	10.4	12.3
	BC3	0.5	0.5	0.4	0.4	0.3	0.3	0.3
	Total	**22.1**	**21.5**	**19.4**	**21.6**	**25.6**	**30.9**	**37.3**
Sensitivity (Double leakage)								
Mt CO_2-eq	BC1	17.5	16.5	14.5	15.7	18.1	21.6	26.4
	BC2	8.6	9.1	8.4	8.8	9.7	11.2	13.2
	BC3	0.6	0.5	0.5	0.4	0.3	0.3	0.3
	Total	**26.7**	**26.2**	**23.4**	**24.9**	**28.1**	**33.2**	**39.9**