European Commission

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 f...	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

Air flow reduction at low loads for split units (with inverter compressor and fans)
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.

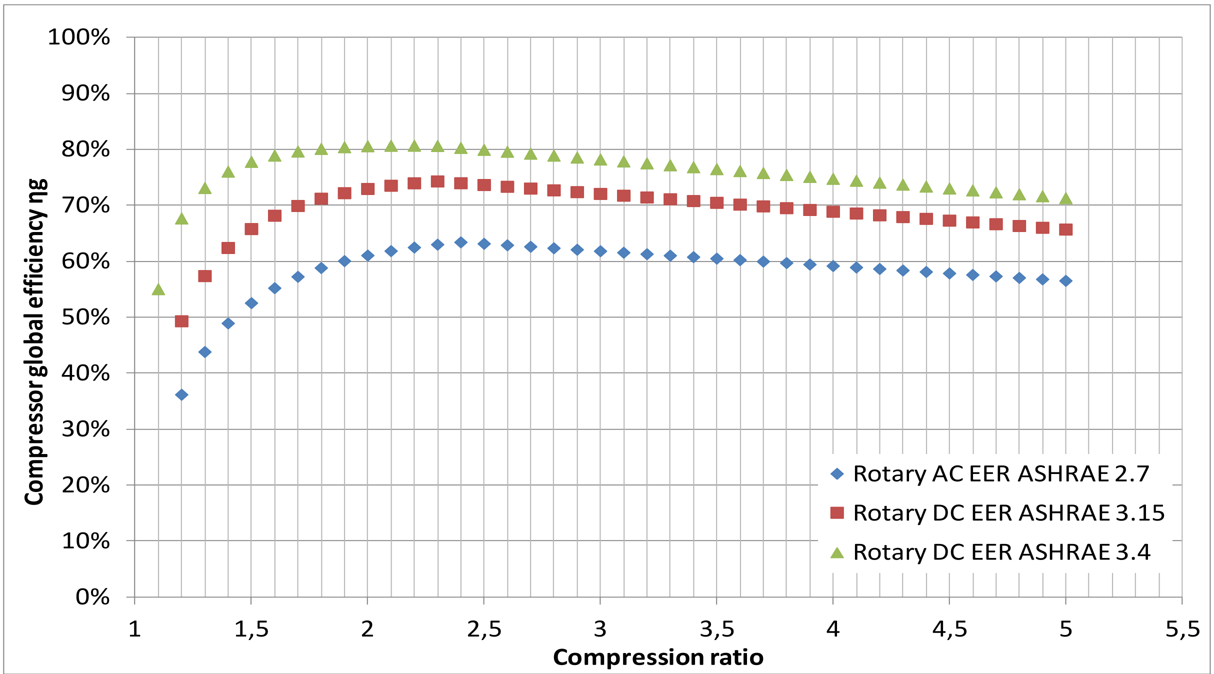

Figure 1: Compressor efficiency curve as a function of the compression ratio for the different compressor options

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).

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[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.

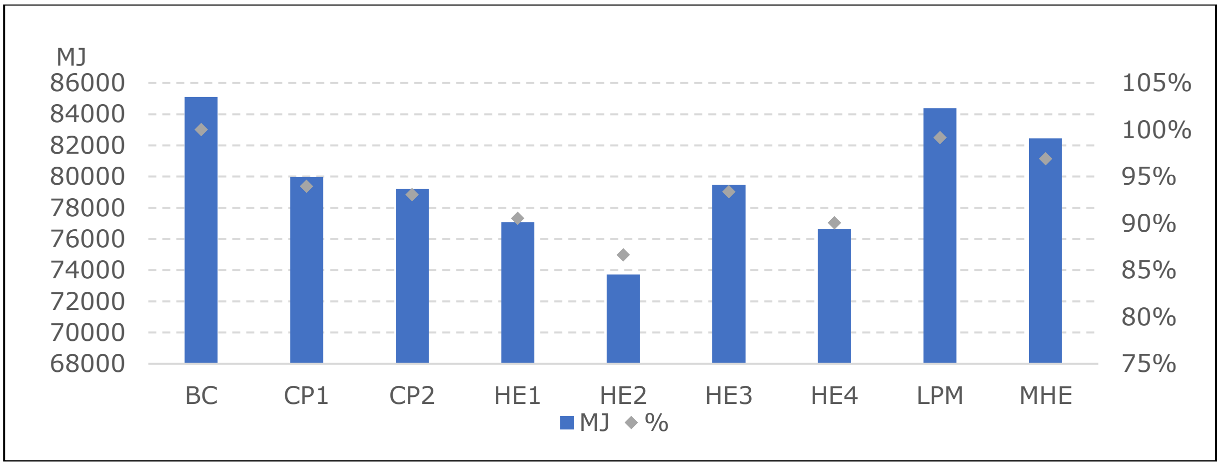

Figure 2: Total energy consumption of the base case and the different improvement options – for BC 1 (split 3.5 kW)

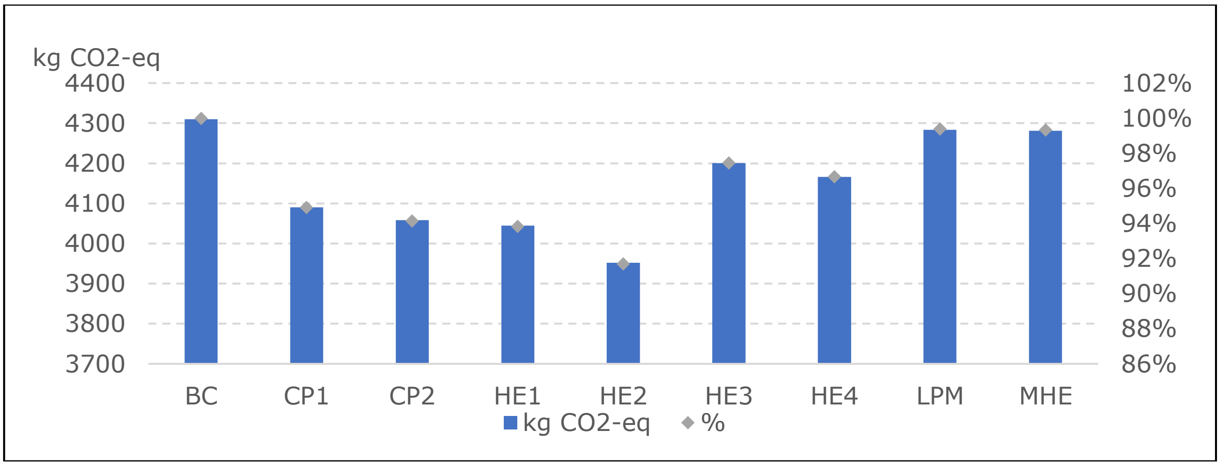

Figure 3: Emission of CO_2 (kg CO_2-eq) of the base case and the different improvement options – for BC 1 (split 3.5 kW)

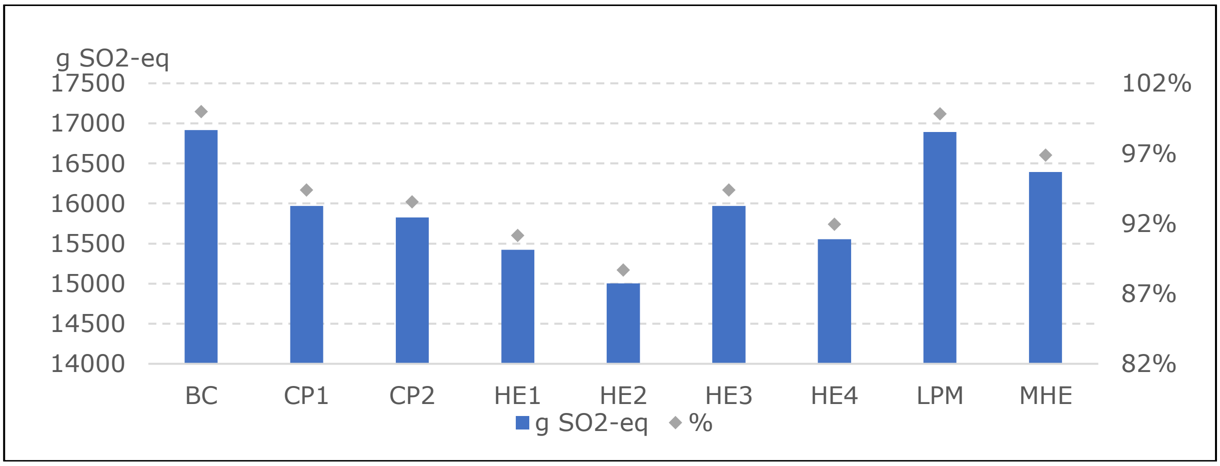

Figure 4: Emission of acidifying agents (g SO_2-eq) of the base case and the different improvement options – for BC 1 (split 3.5 kW)

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.

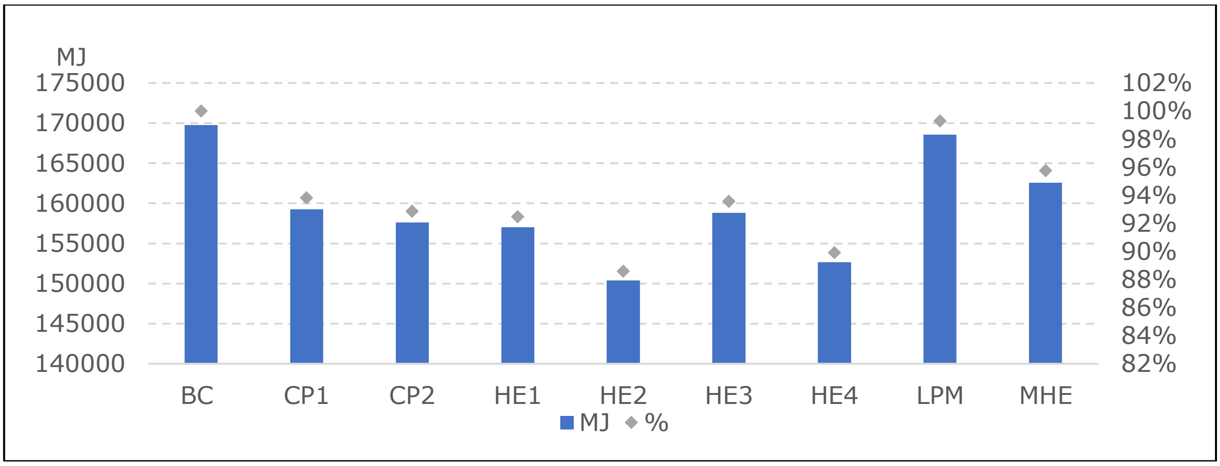

Figure 5: Total energy consumption of the base case and the different improvement options – for BC 2 (split 7.1 kW)

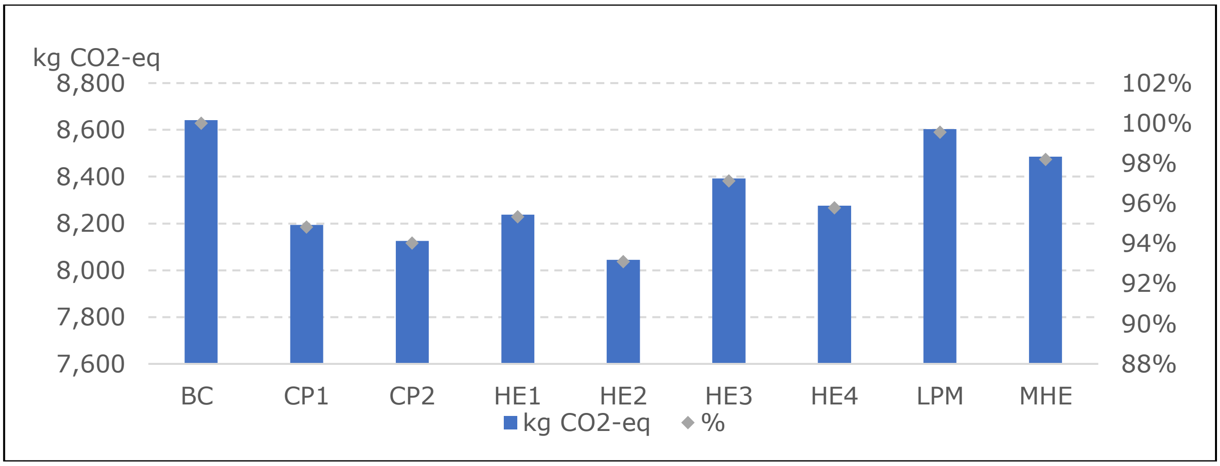

Figure 6: Emission of CO_2 (kg CO_2-eq) of the base case and the different improvement options – for BC 2 (split 7.1 kW)

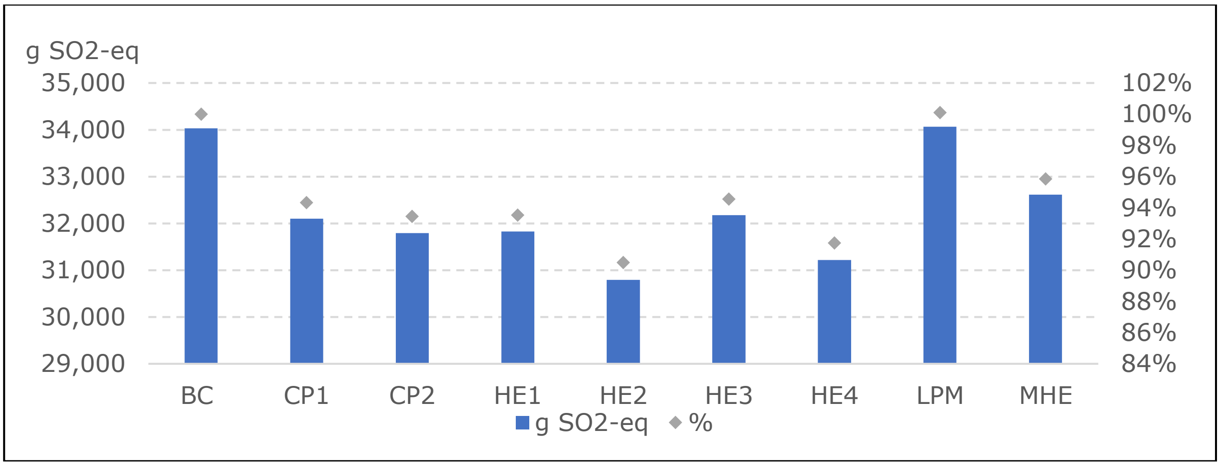

Figure 7: Emission of acidifying agents (g SO_2-eq) of the base case and the different improvement options – for BC 2 (split 7.1 kW)

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.

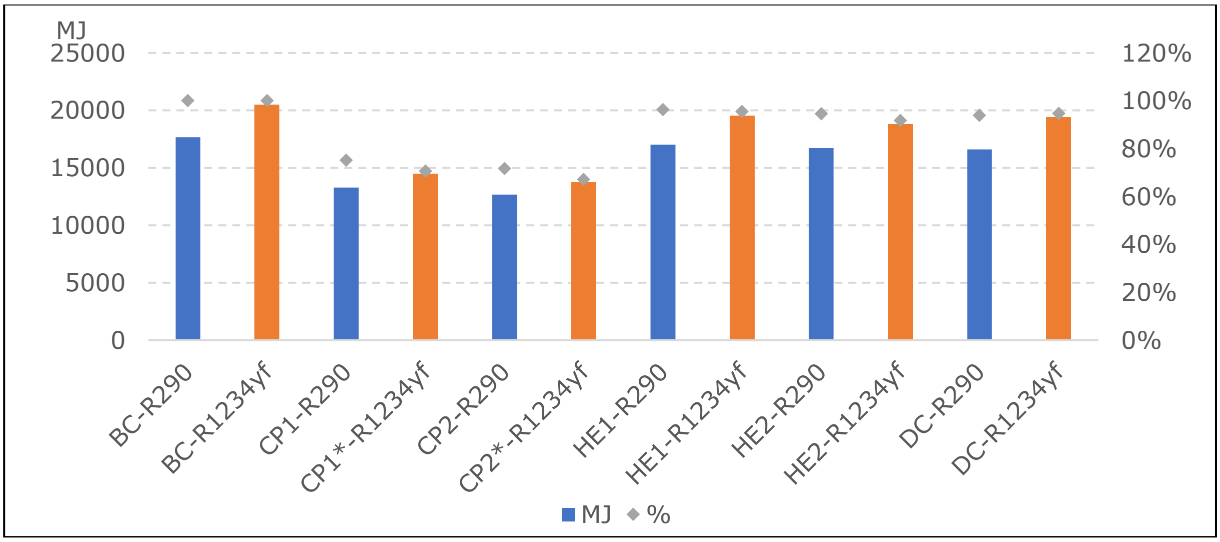

Figure 8: Total energy consumption of the base case and the different improvement options – for BC 3 (single duct 2.6 kW – R290 and R1234yf)

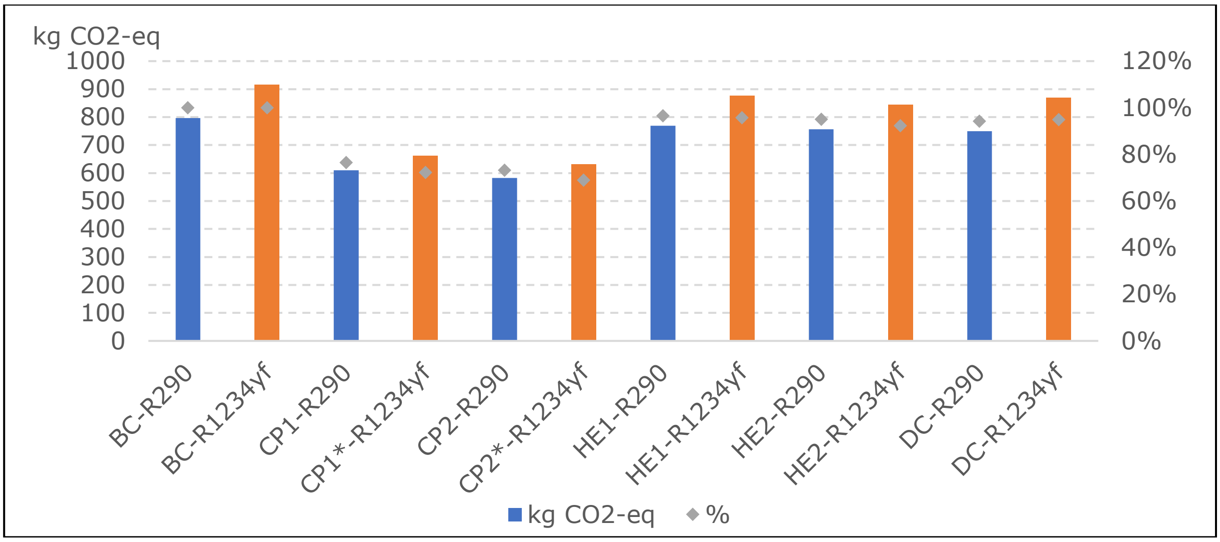

Figure 9: Emission of CO_2 (kg CO_2-eq) of the base case and the different improvement options – for BC 3 (single duct 2.6 kW– R290 and R1234yf)

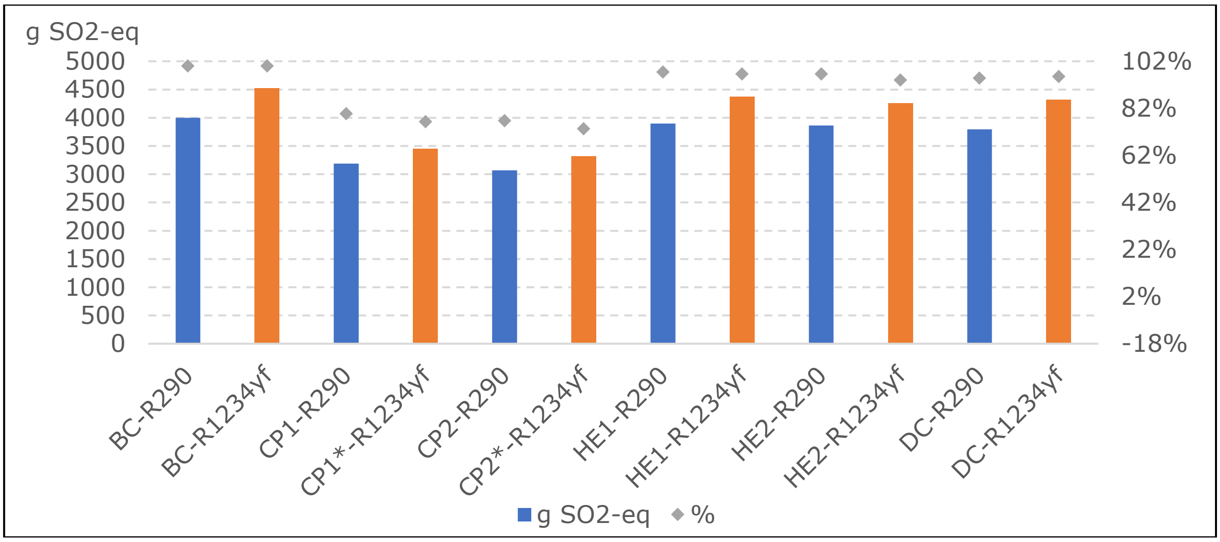

Figure 10: Emission of acidifying agents (g SO_2-eq) of the base case and the different improvement options – for BC 3 (single duct 2.6 kW– R290 and R1234yf)

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.

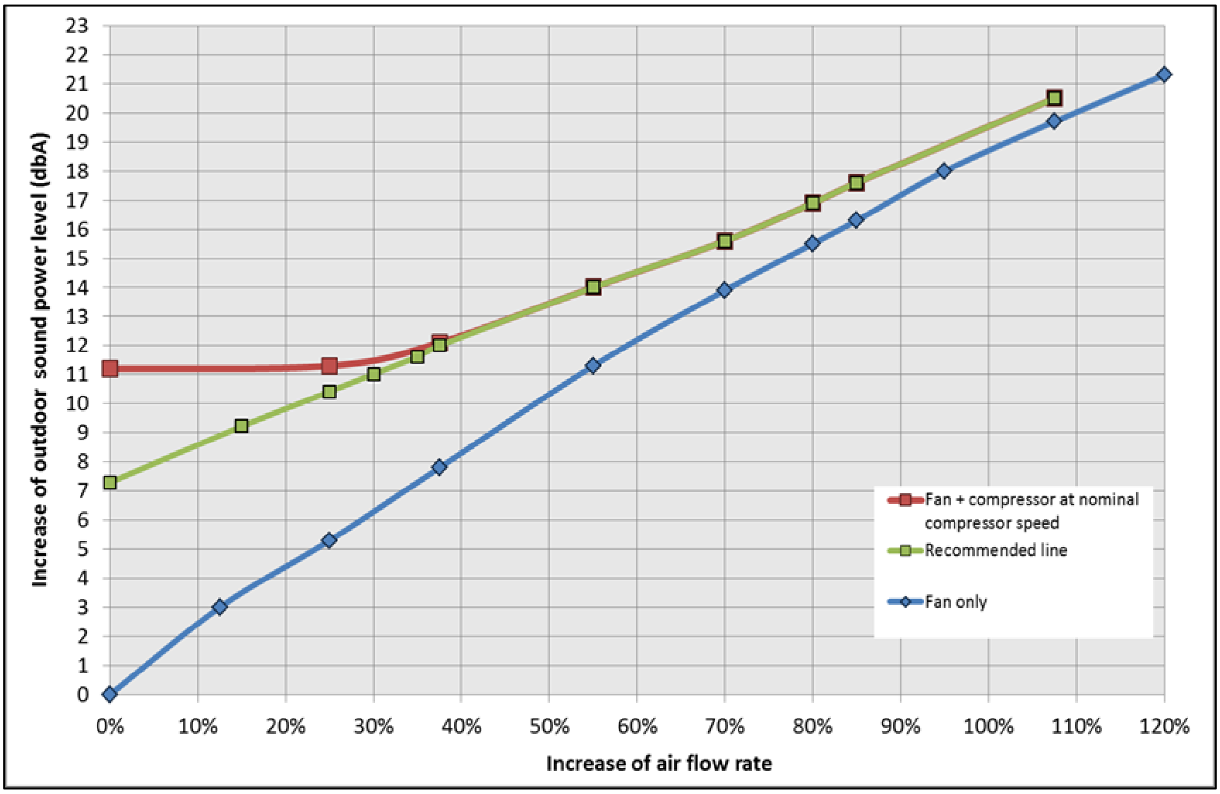

Figure 11: increase of sound power vs increase of airflow rate[15]

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

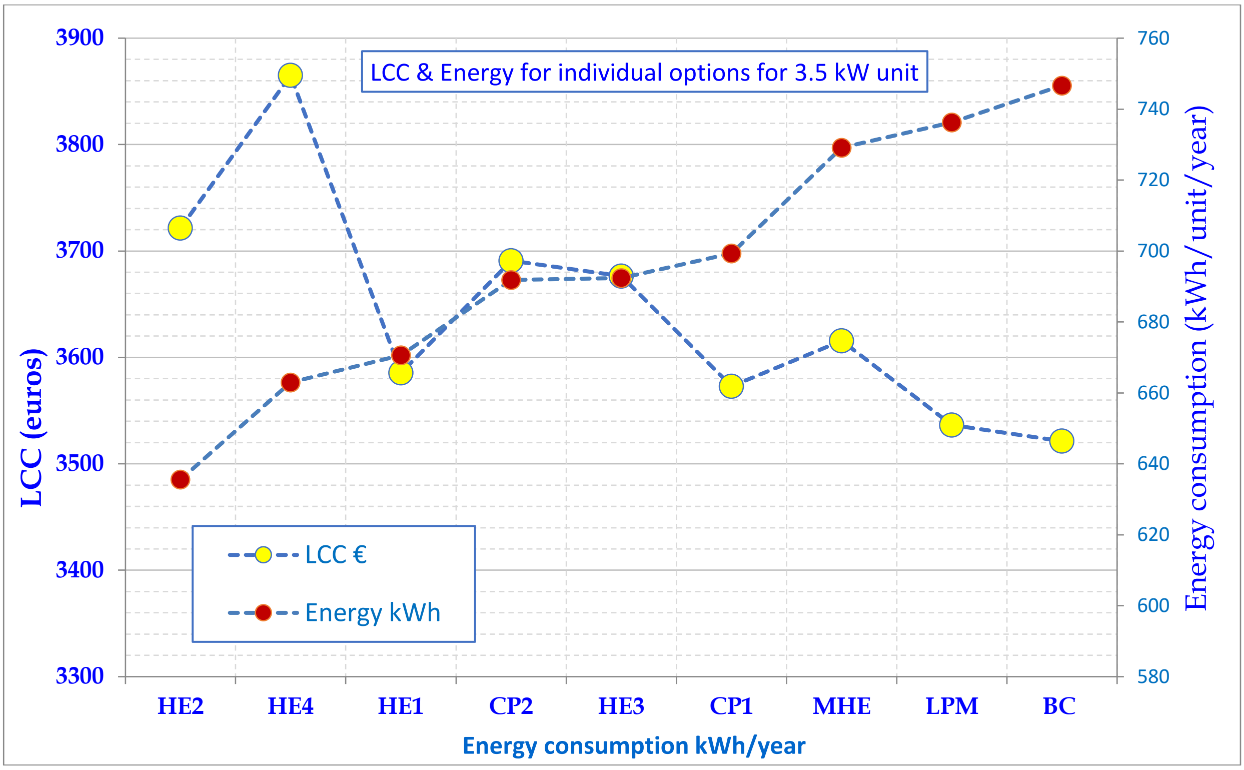

Figure 12: LCC and Energy consumption for split 3.5 kW unit, ranking by decreasing energy consummation

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

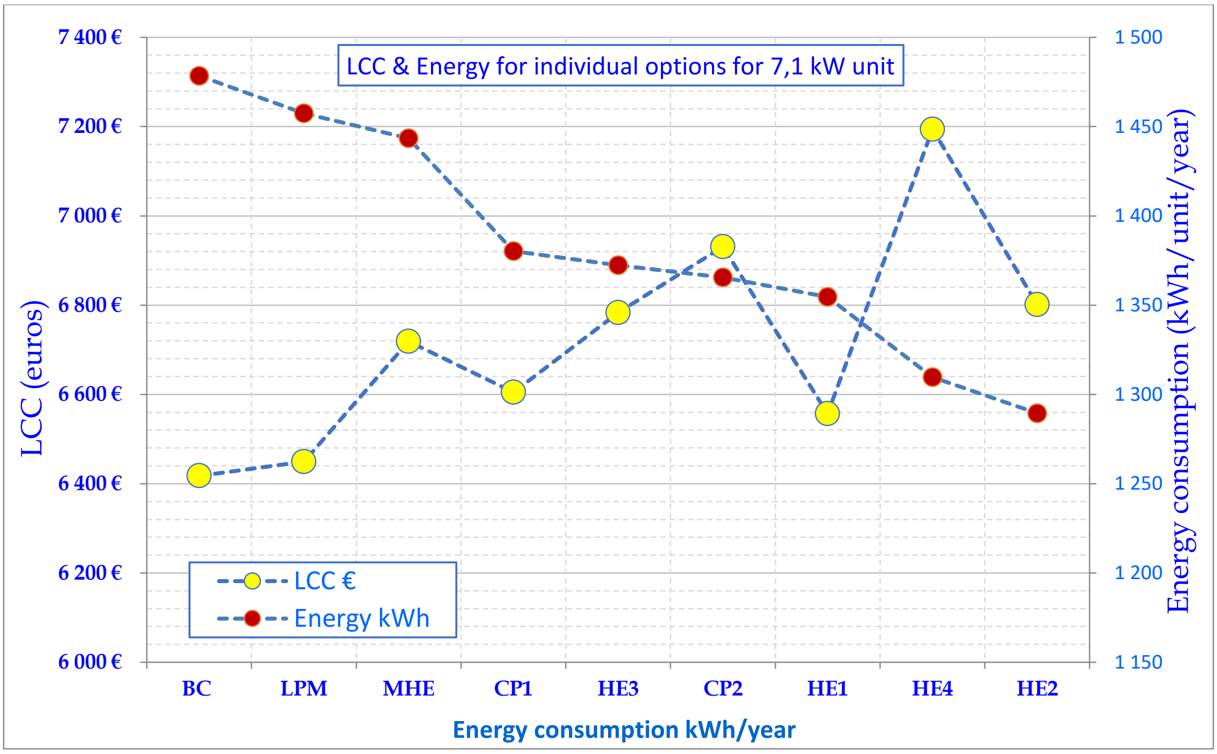

Figure 13: LCC and energy consumption for split 7.1 kW unit, ranking by decreasing energy consumption

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)	Purchasin g 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

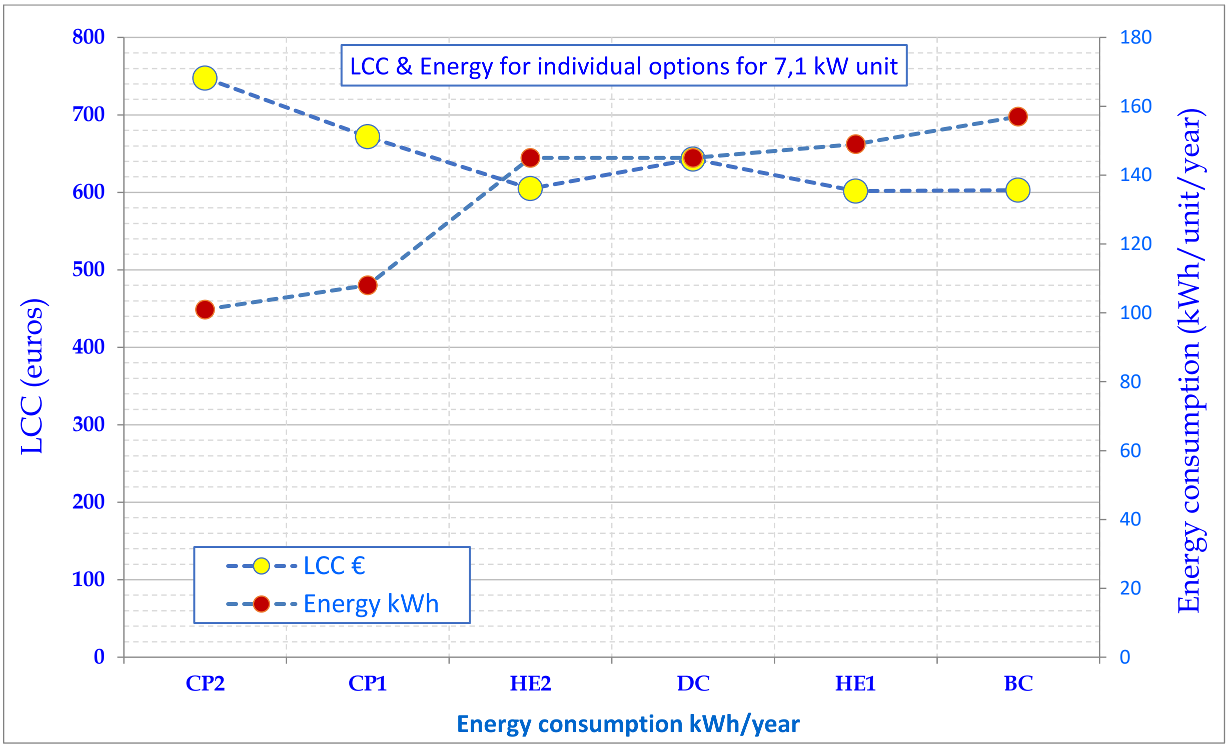

Figure 14 : LCC and energy consumption for single duct 2.6 kW unit (only cooling), R290

Table 21: Ranking of individual options by simple payback time, single duct 2.6 kW unit, R1234yf

	EER	SEER	Energy Cons (kWh)	Purchasin g 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

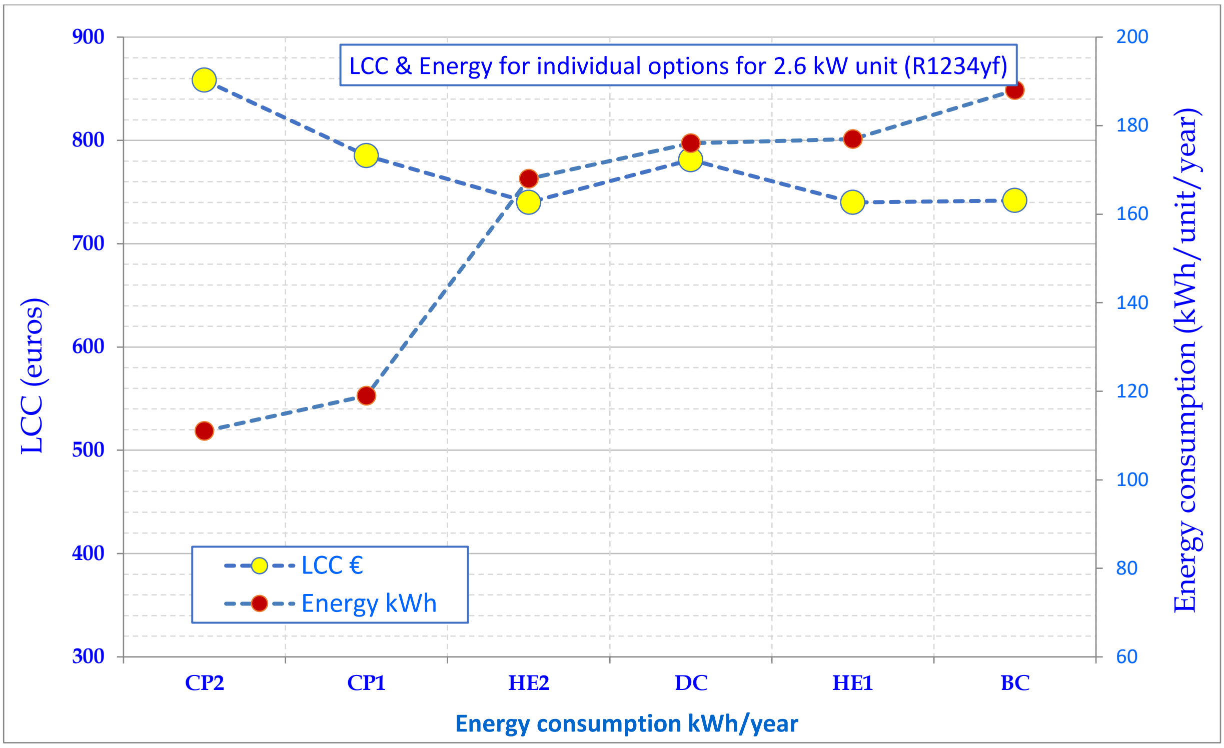

Figure 15 : LCC and energy consumption for single duct 2.6 kW unit (only cooling), R1234yf

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

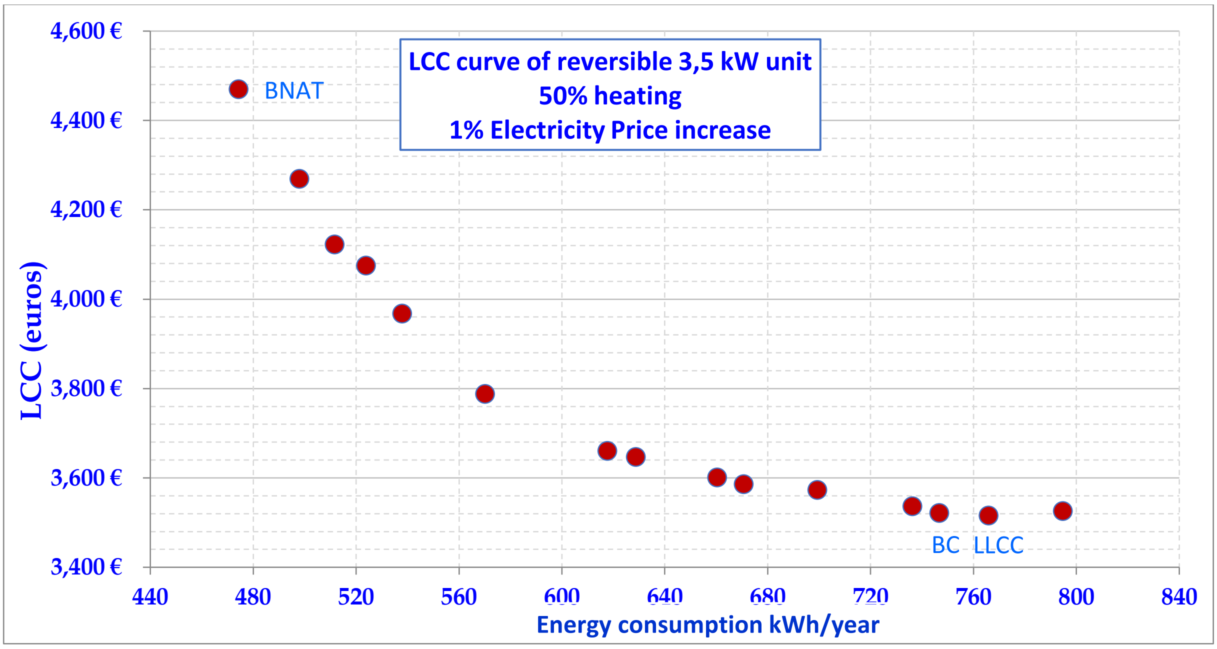

Figure 16: LCC curve of reversible 3.5 kW unit (50% heating hours and 1% electricity price increase)

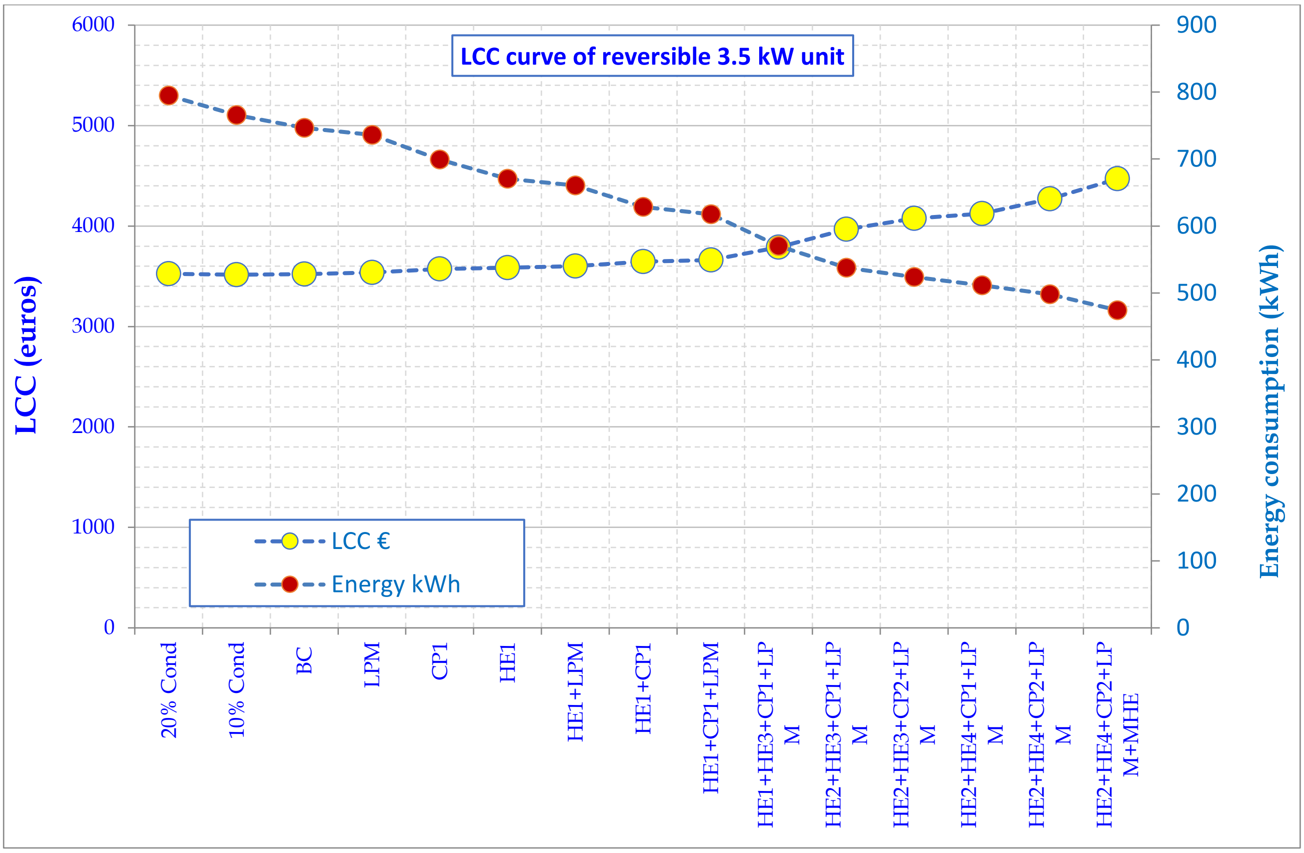

Figure 17: LCC & Energy consumption of reversible 3.5 kW unit (50% heating hours and 1% electricity price increase)

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.

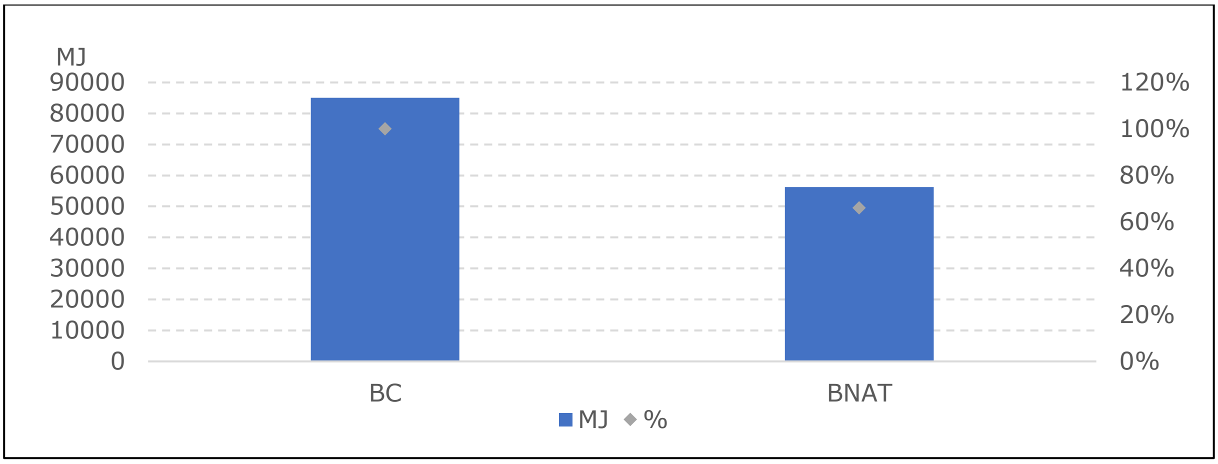

Figure 18: Total energy consumption of the base case, LLCC and BNAT – for BC 1 (split 3.5 kW)

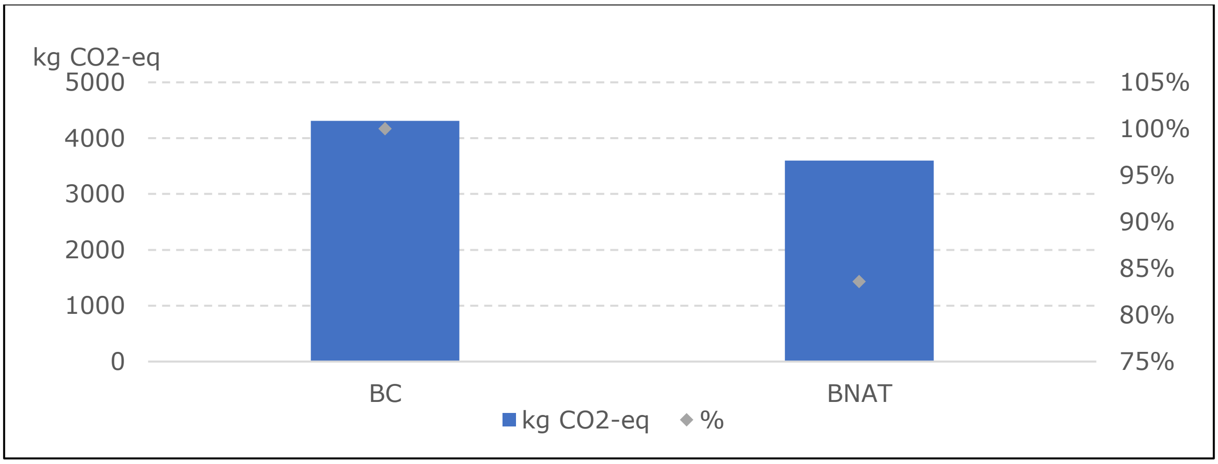

Figure 19: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 1 (split 3.5 kW)

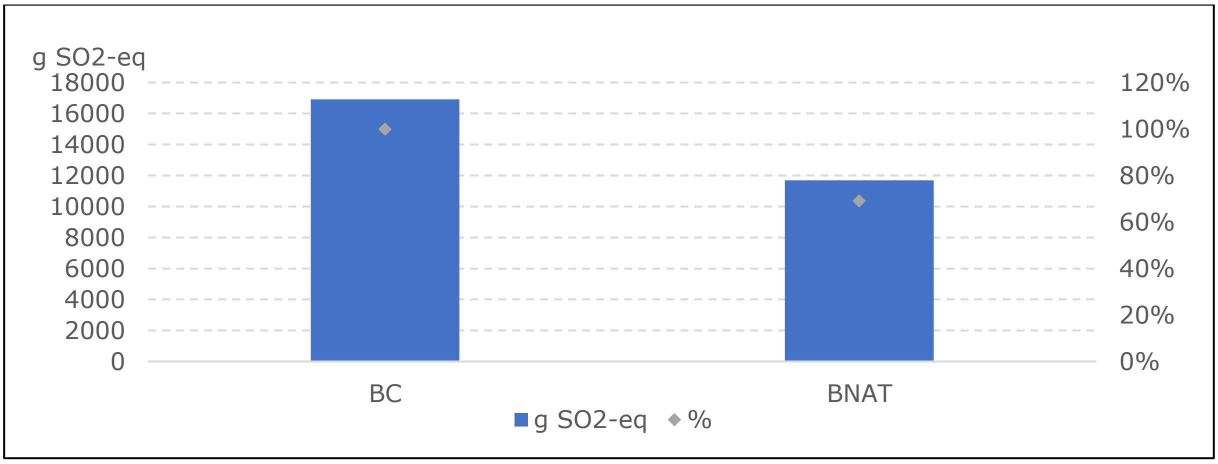

Figure 20: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 1 (split 3.5 kW)

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	Maintenance	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

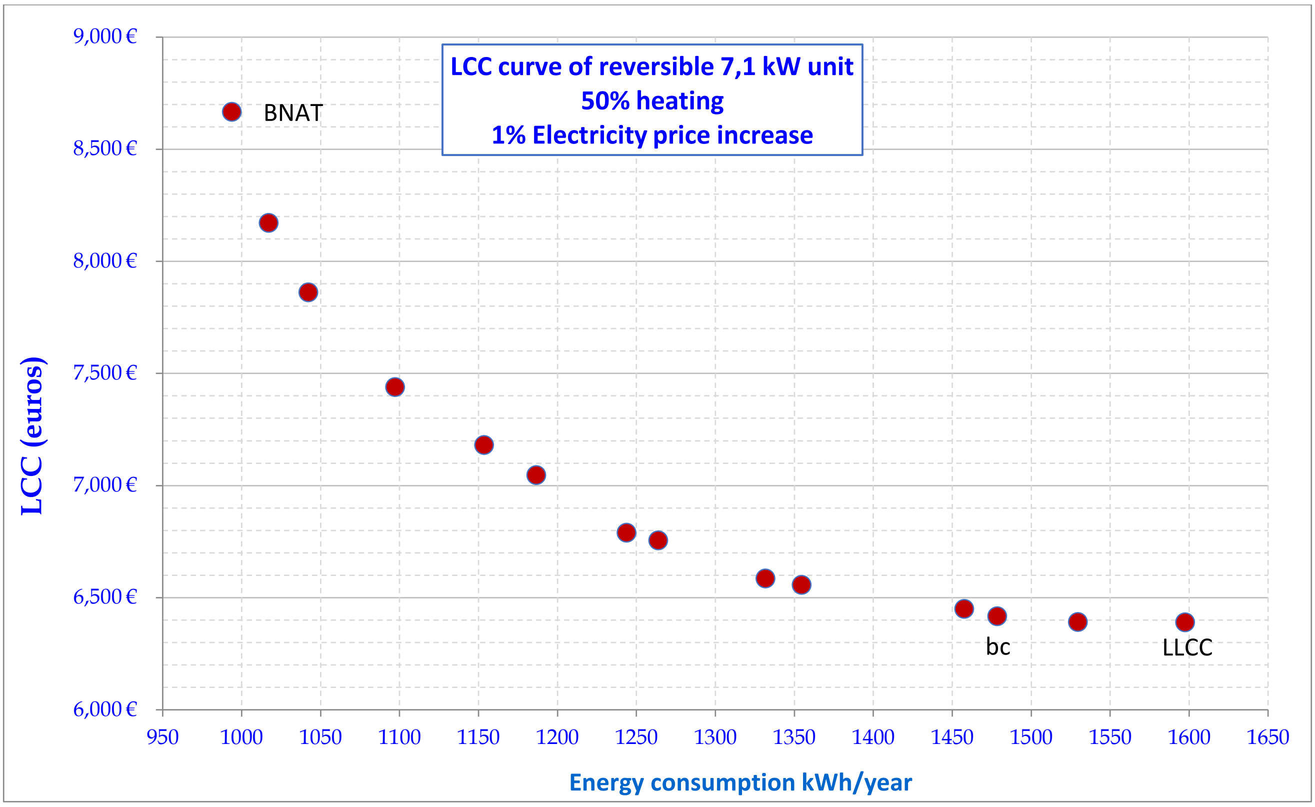

Figure 21: LCC curve of reversible 7.1 kW unit (50% heating hours and 1% electricity price increase)

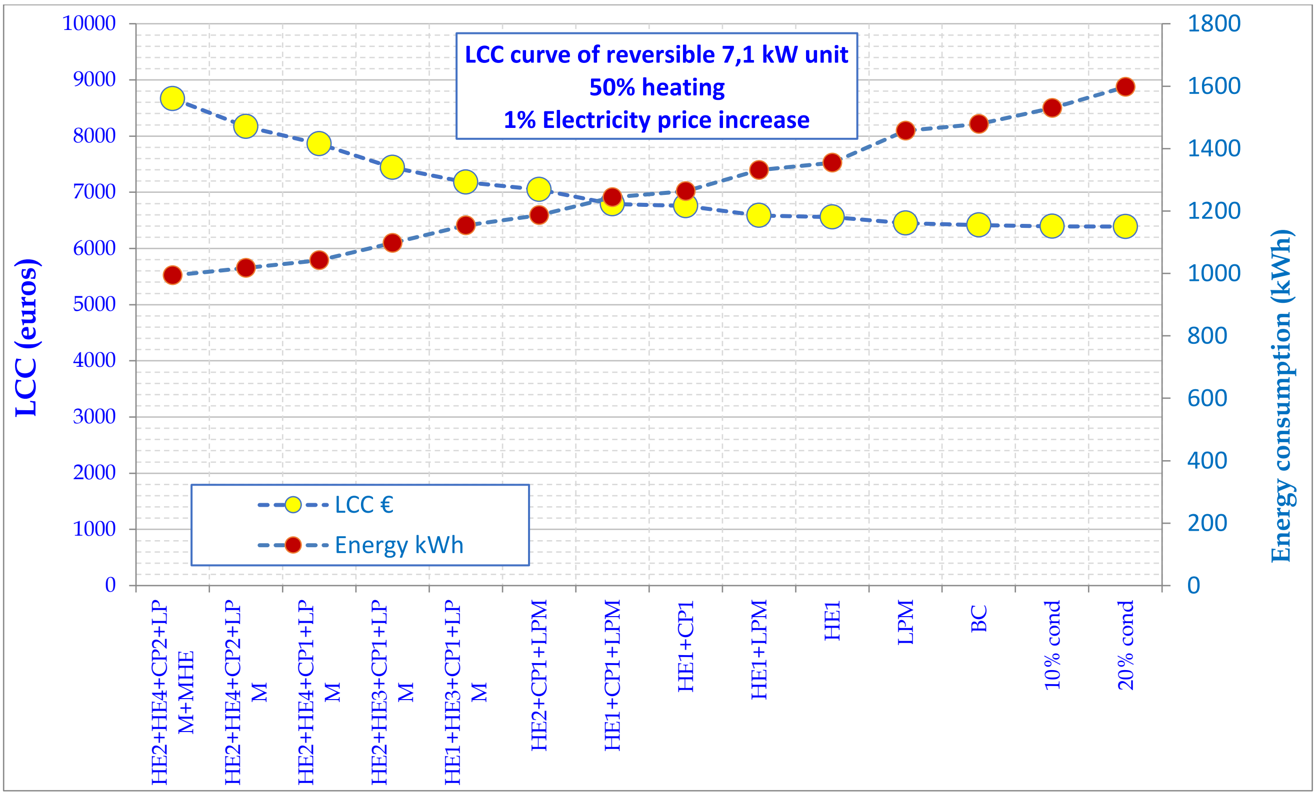

Figure 22: LCC & Energy consumption of reversible 7.1 kW unit (50% heating hours and 1% electricity price increase)

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.

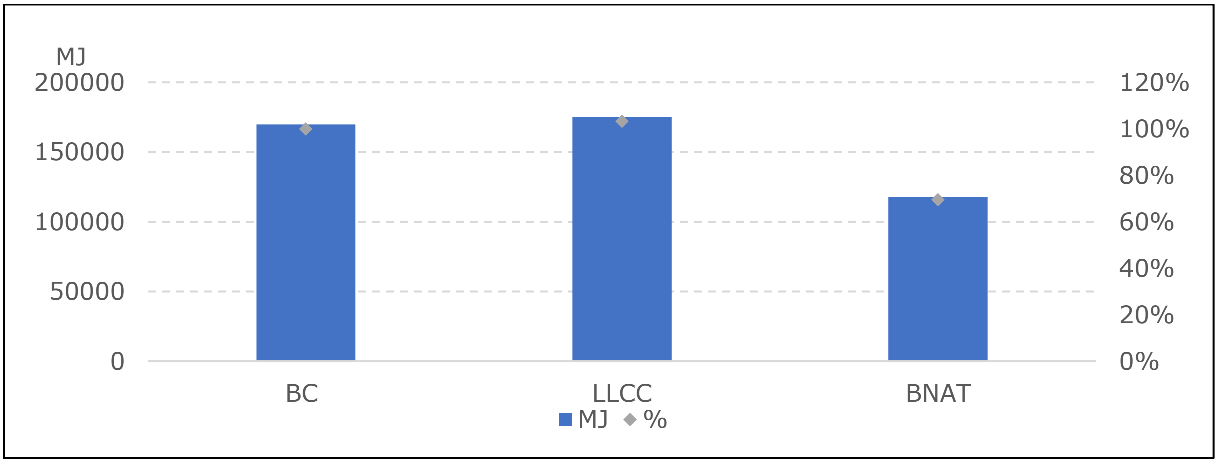

Figure 23: Total energy consumption of the base case, LLCC and BNAT – for BC 2 (split 7.1 kW)

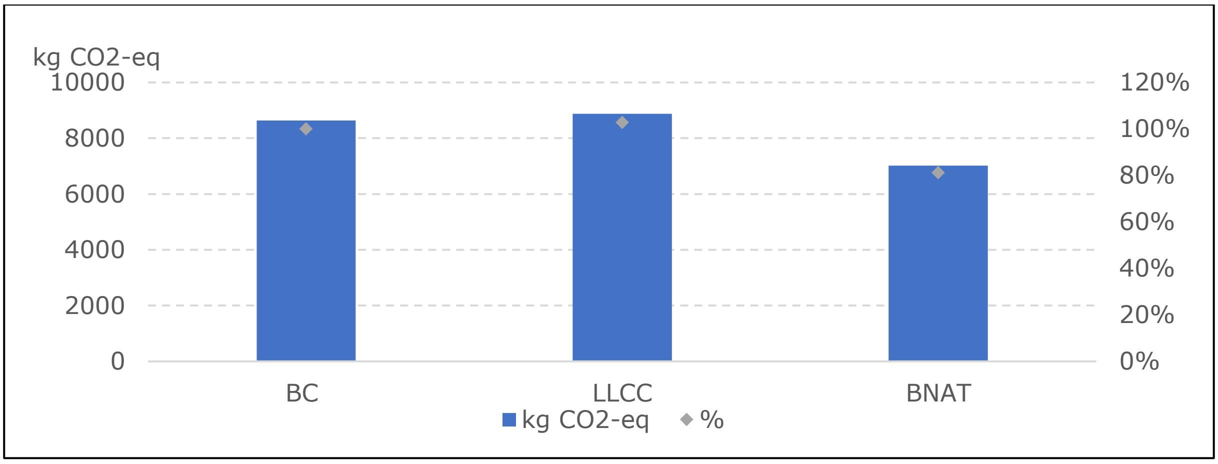

Figure 24: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 2 (split 7.1 kW)

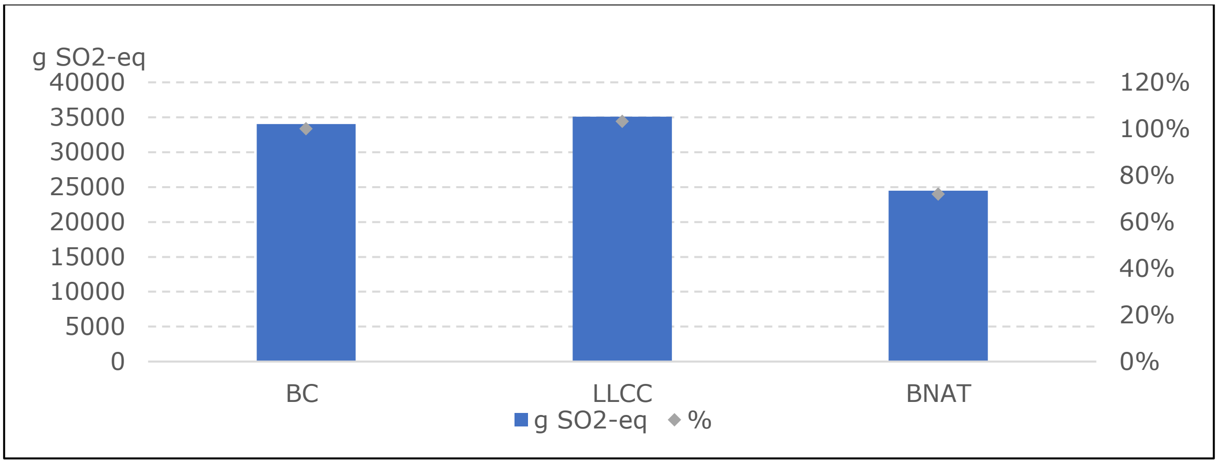

Figure 25: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 2 (split 7.1 kW)

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

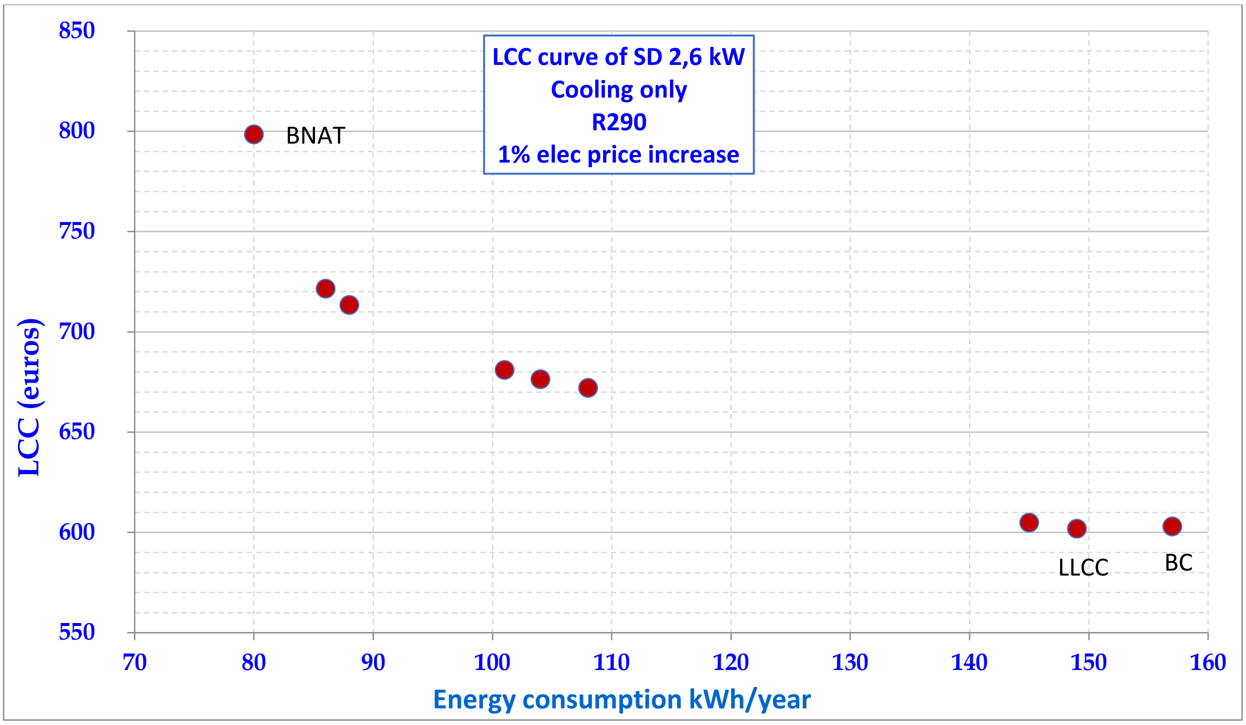

Figure 26: LCC curve of single duct 2.6 kW unit (cooling only, 1% electricity price increase), R290

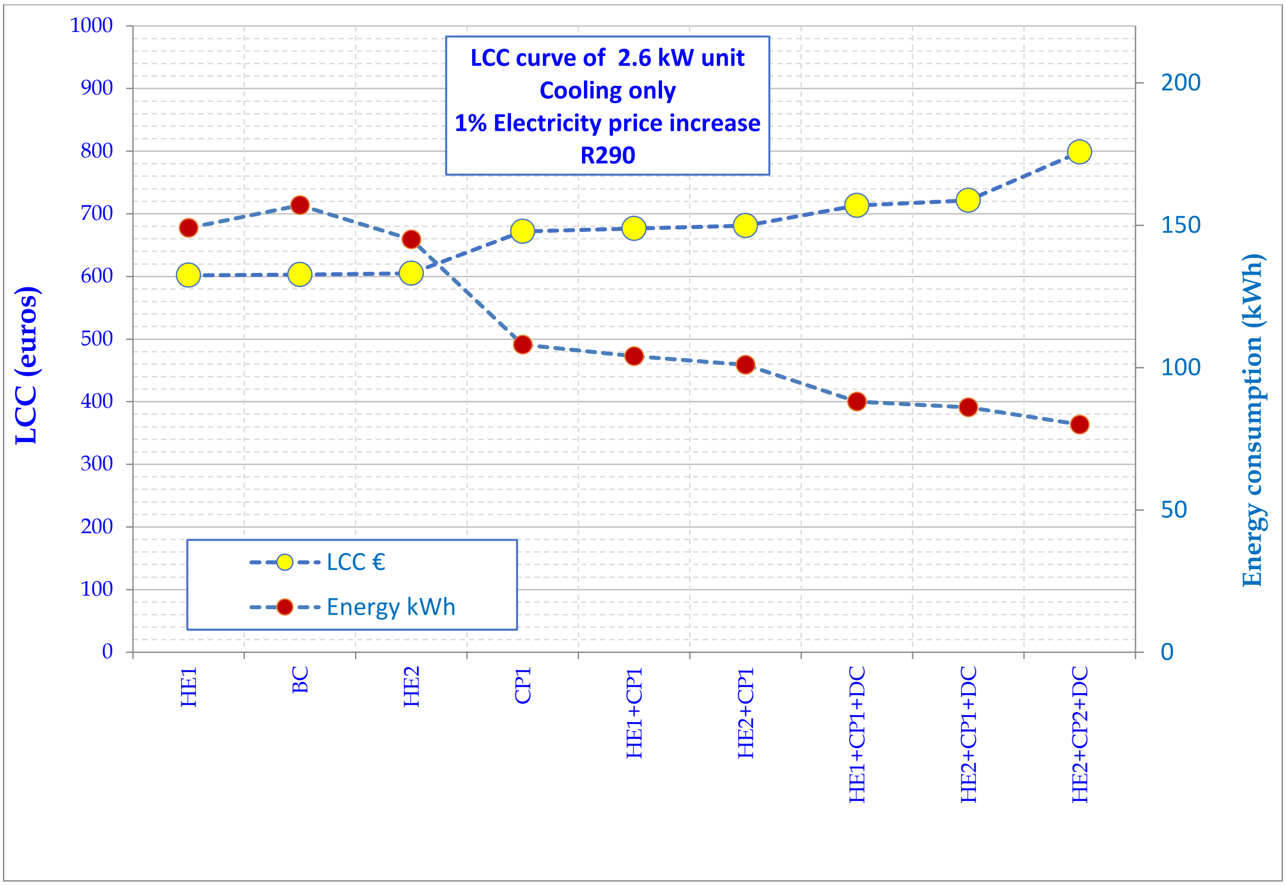

*Figure 27: LCC & Energy consumption of single duct 2.6 kW unit (*cooling only, 1% electricity price increase*), R290*

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

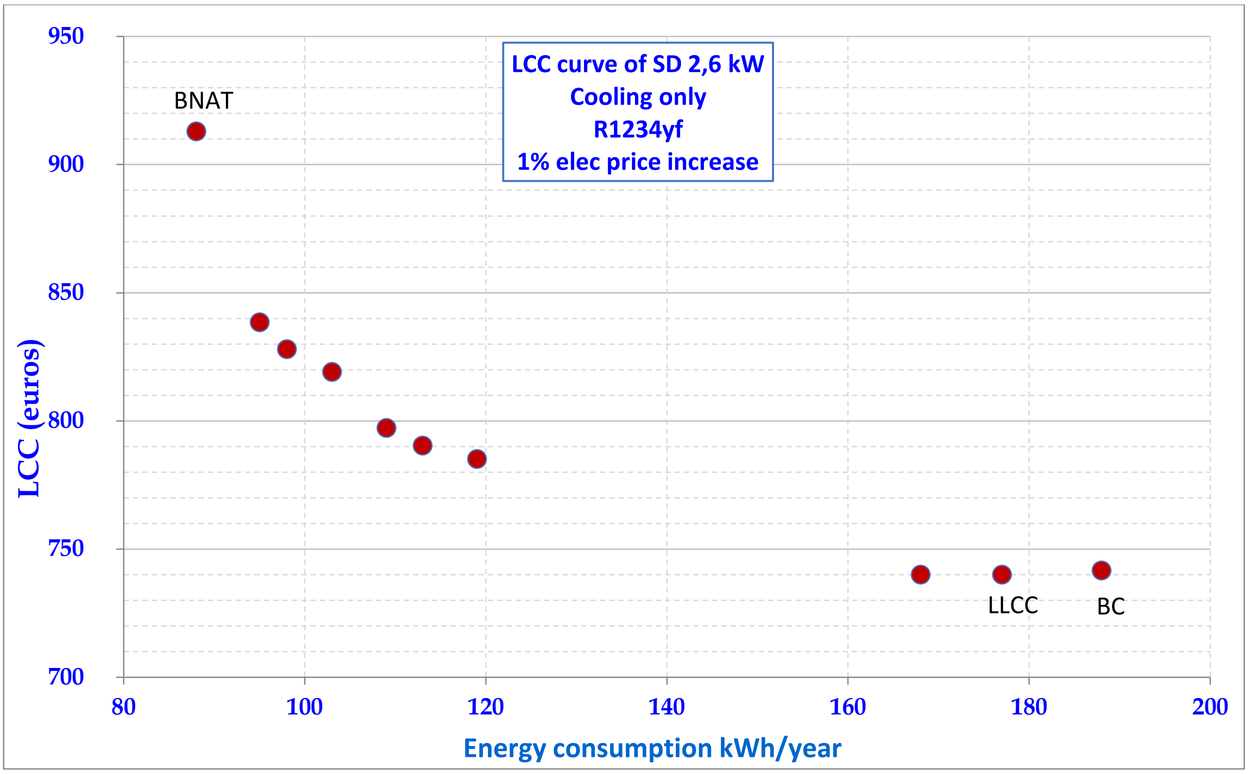

Figure 28: LCC curve of single duct 2.6 kW unit (cooling only, 1% electricity price increase), R1234YF

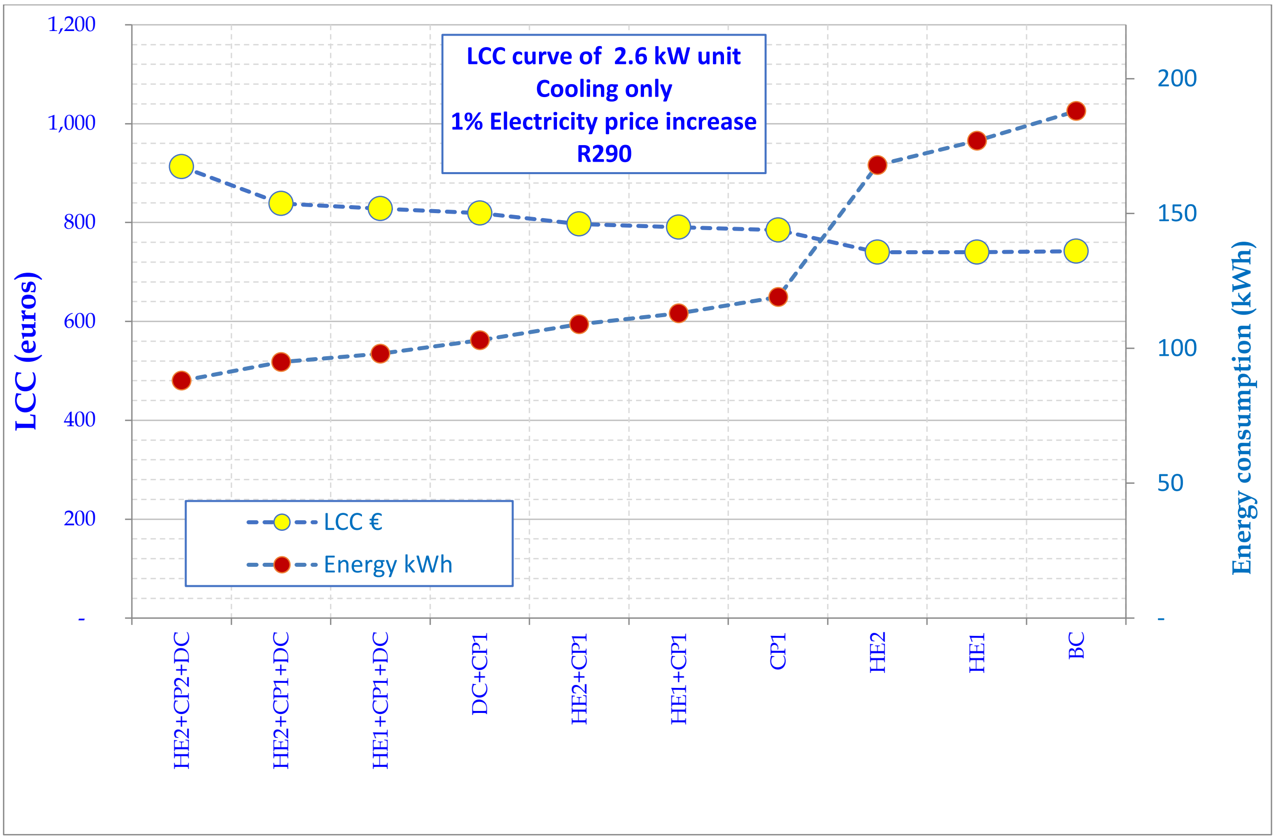

Figure 29: LCC & Energy consumption of single duct 2.6 kW unit (cooling only, 1% electricity price increase), R1234YF

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.

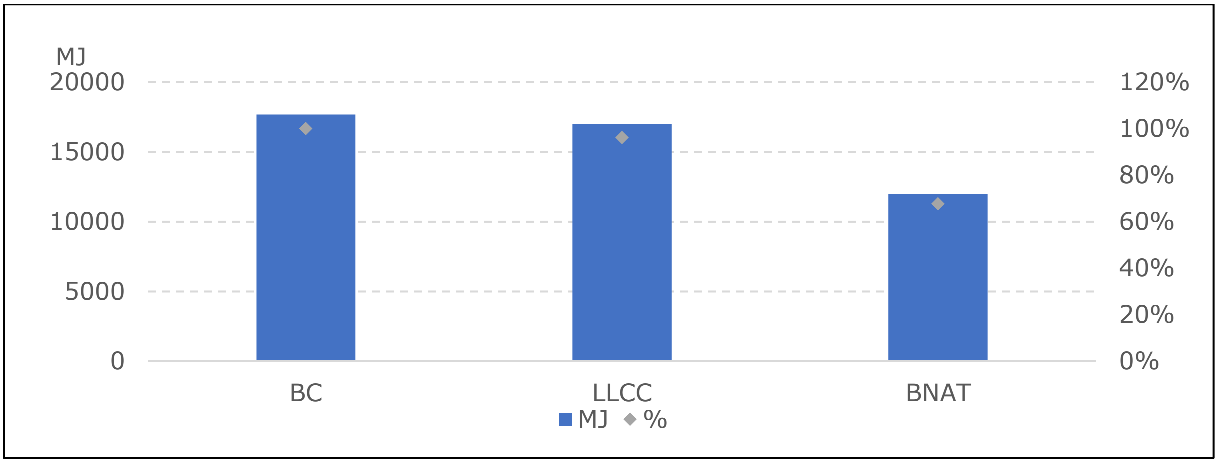

Figure 30: Total energy consumption of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R290)

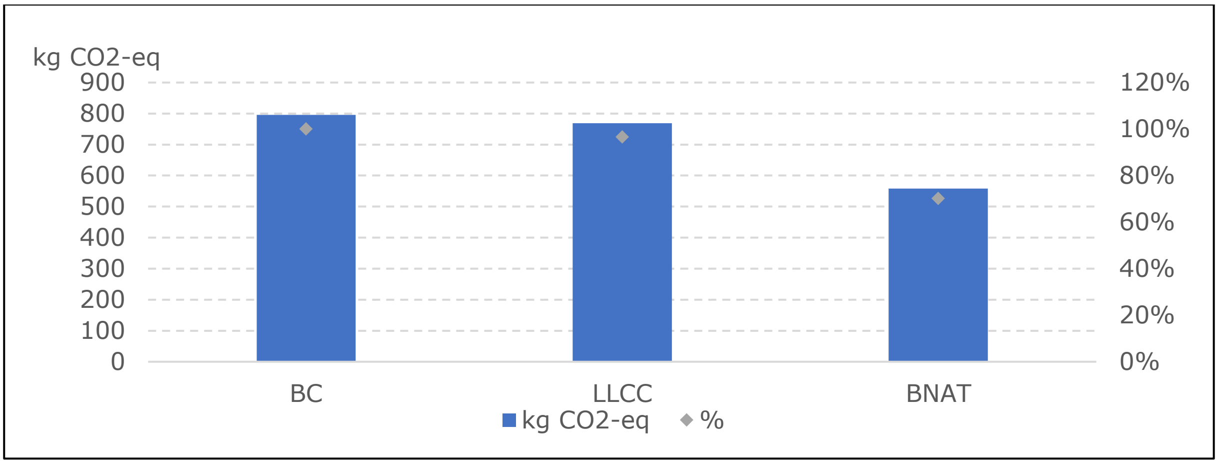

Figure 31: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R290)

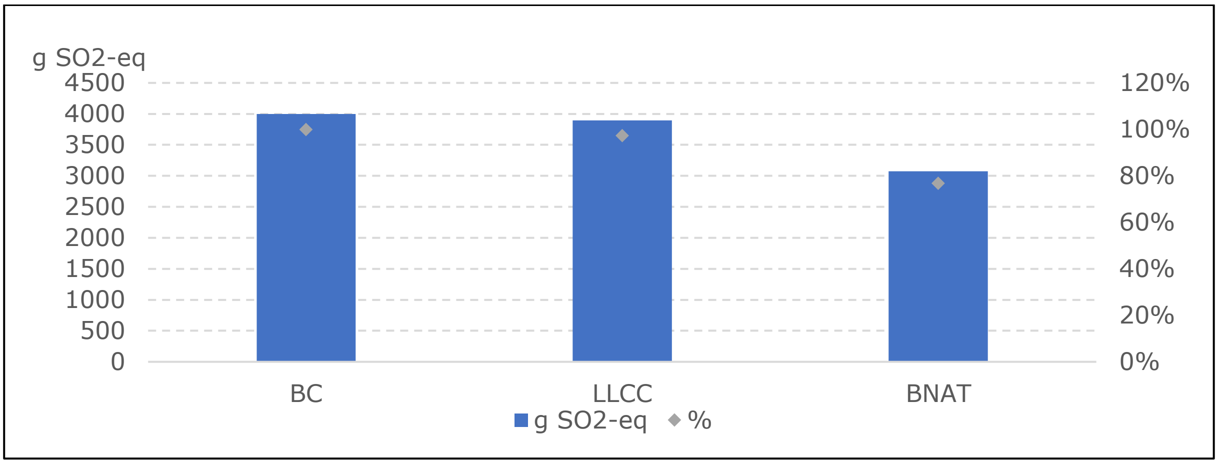

Figure 32: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R290)

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.

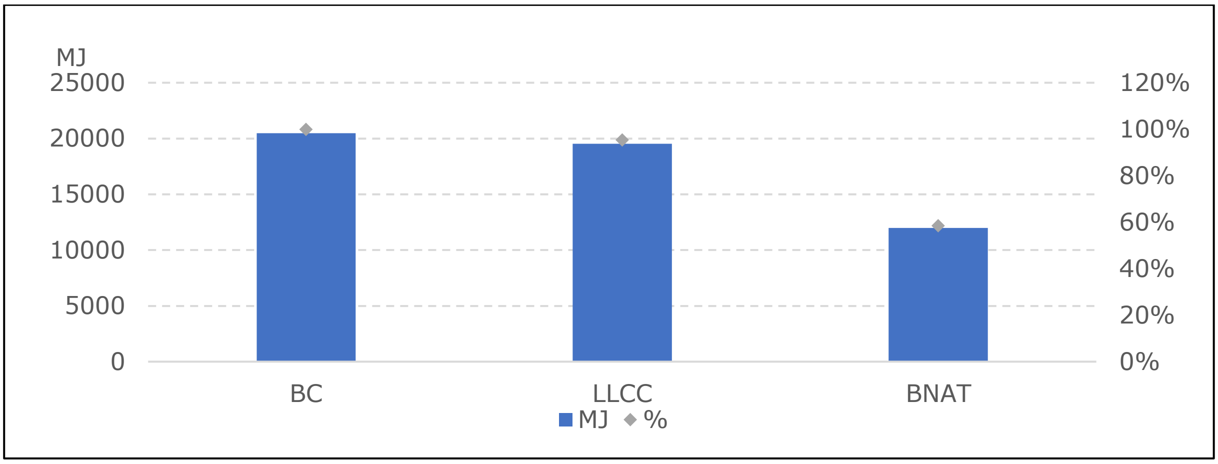

Figure 33: Total energy consumption of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R1234yf)

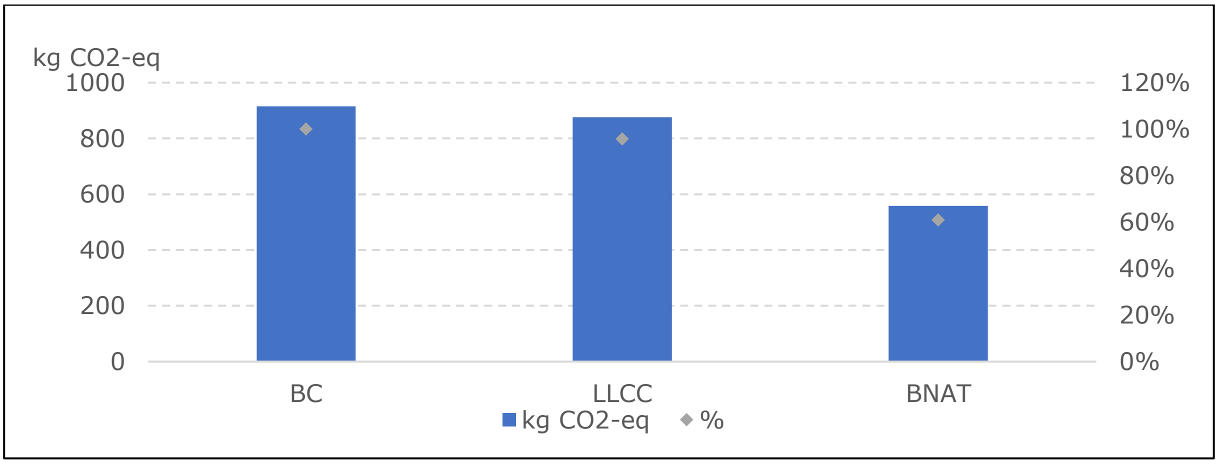

Figure 34: Emission of CO_2 (kg CO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R1234yf)

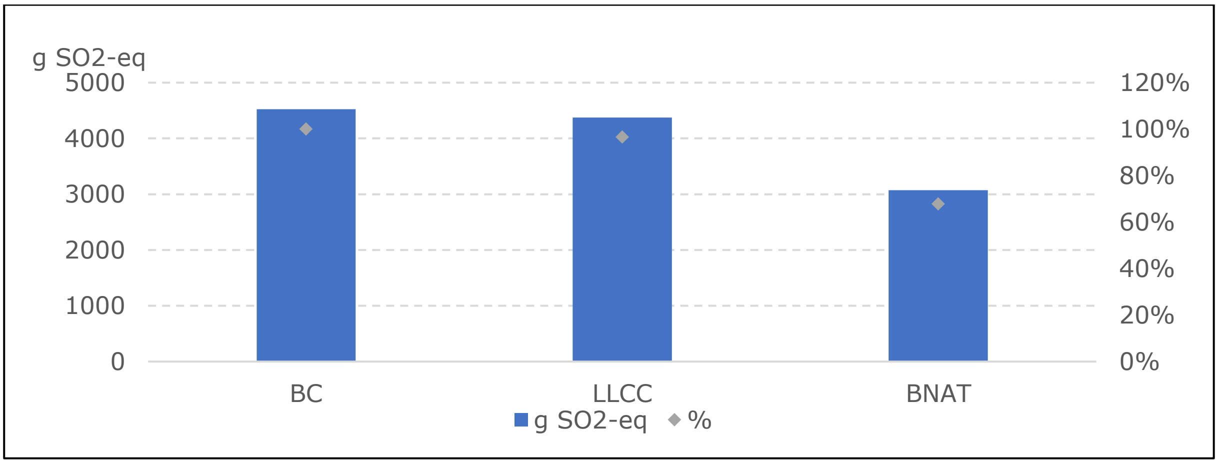

Figure 35: Emission of acidifying agents (g SO_2-eq) of the base case, LLCC and BNAT – for BC 3 (single duct 2.6 kW – R1234yf)

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

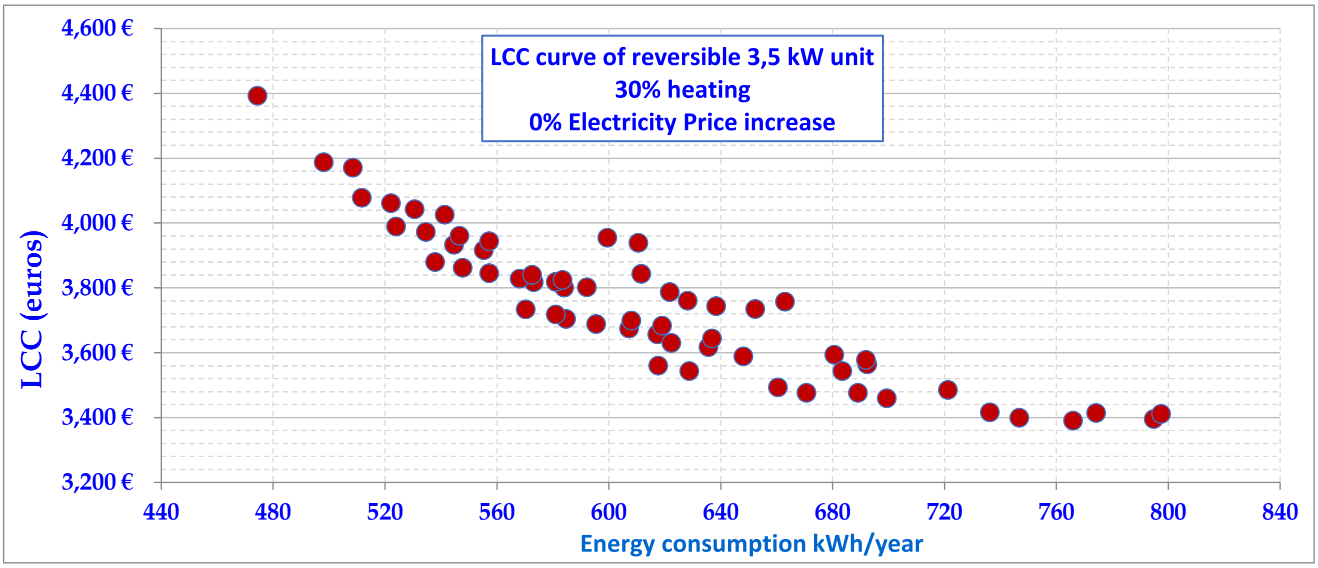

Figure 36 BC 1: 30% heating/ 0% electricity price increase

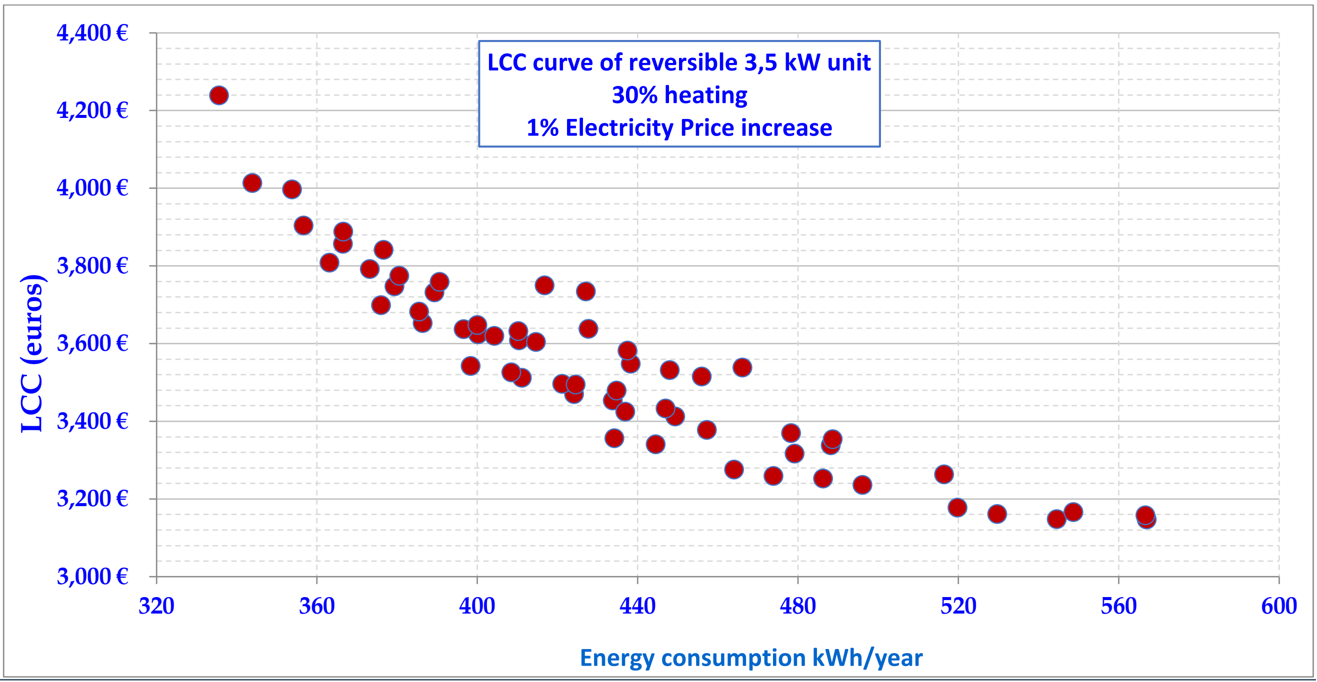

Figure 37 BC 1: 30% heating/ 1% electricity price increase

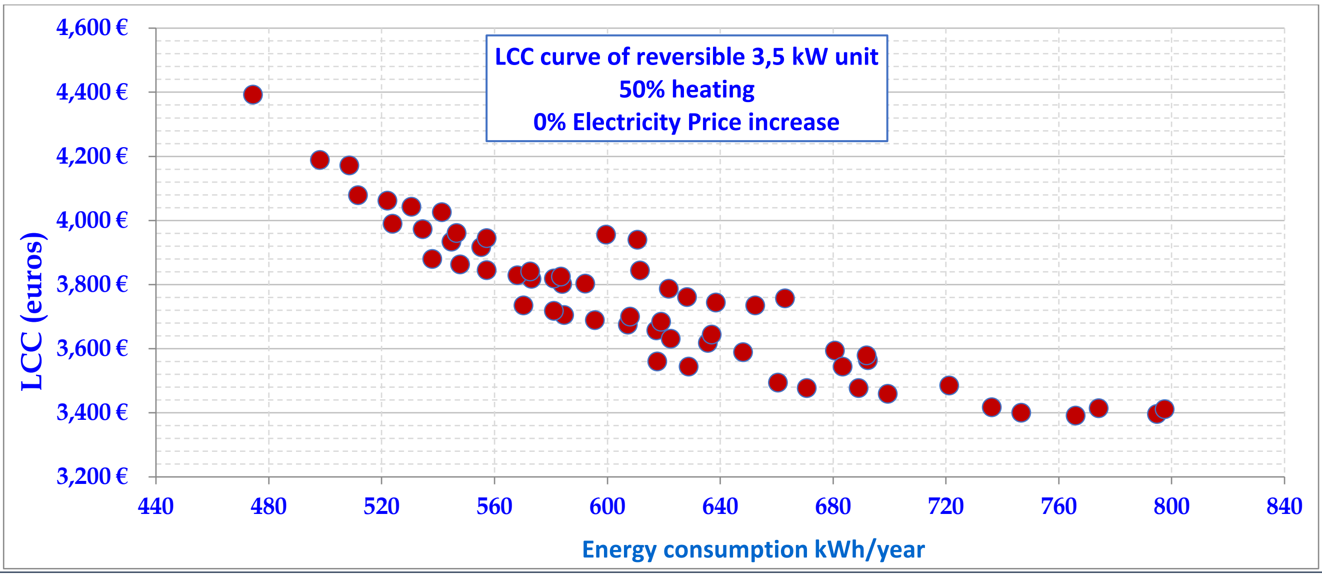

Figure 38 BC 1 : 50% heating/ 0% electricity price increase

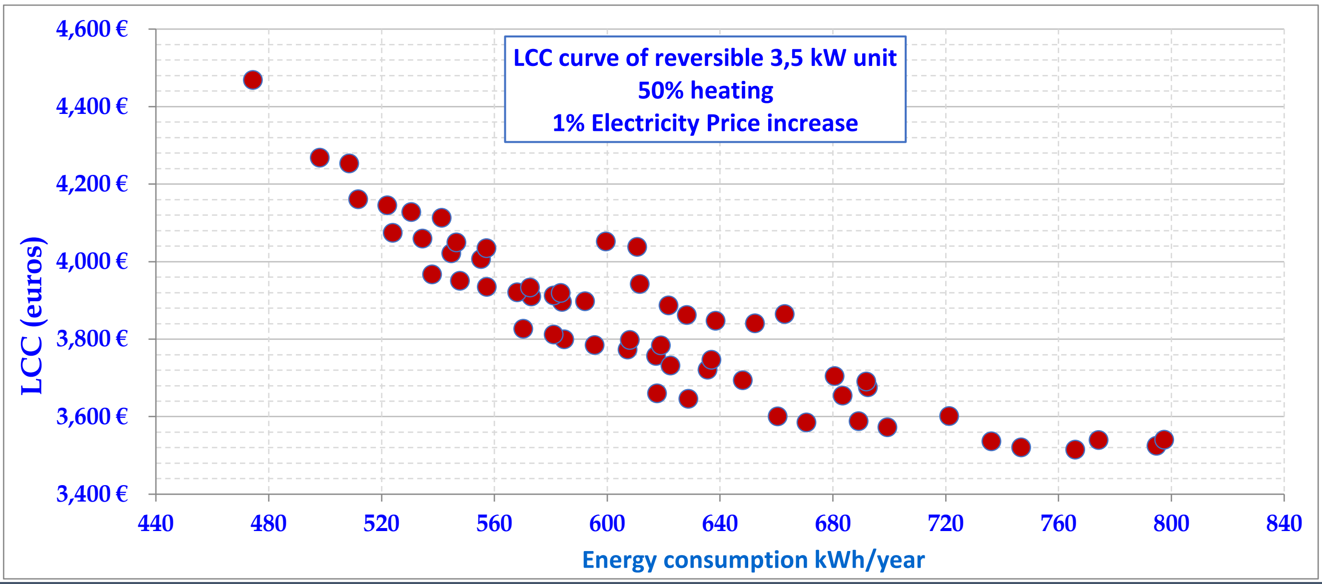

Figure 39 BC 1 : 50% heating/ 1% electricity price increase

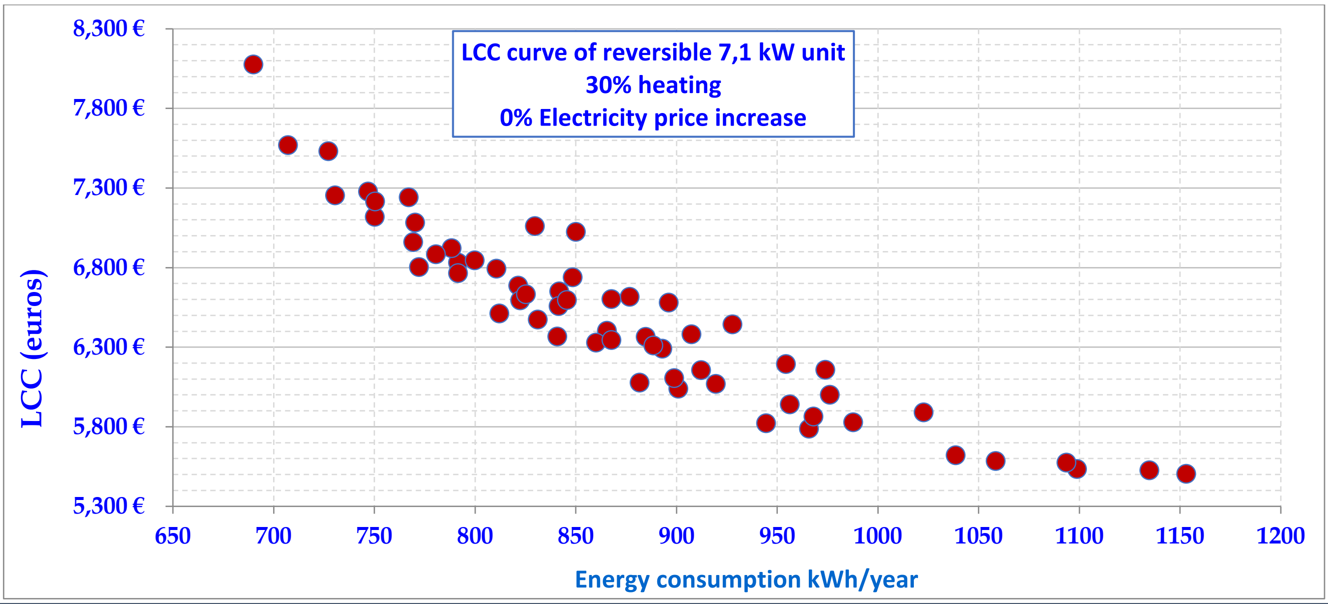

Figure 40 BC 2 : 30% heating/ 0% electricity price increase

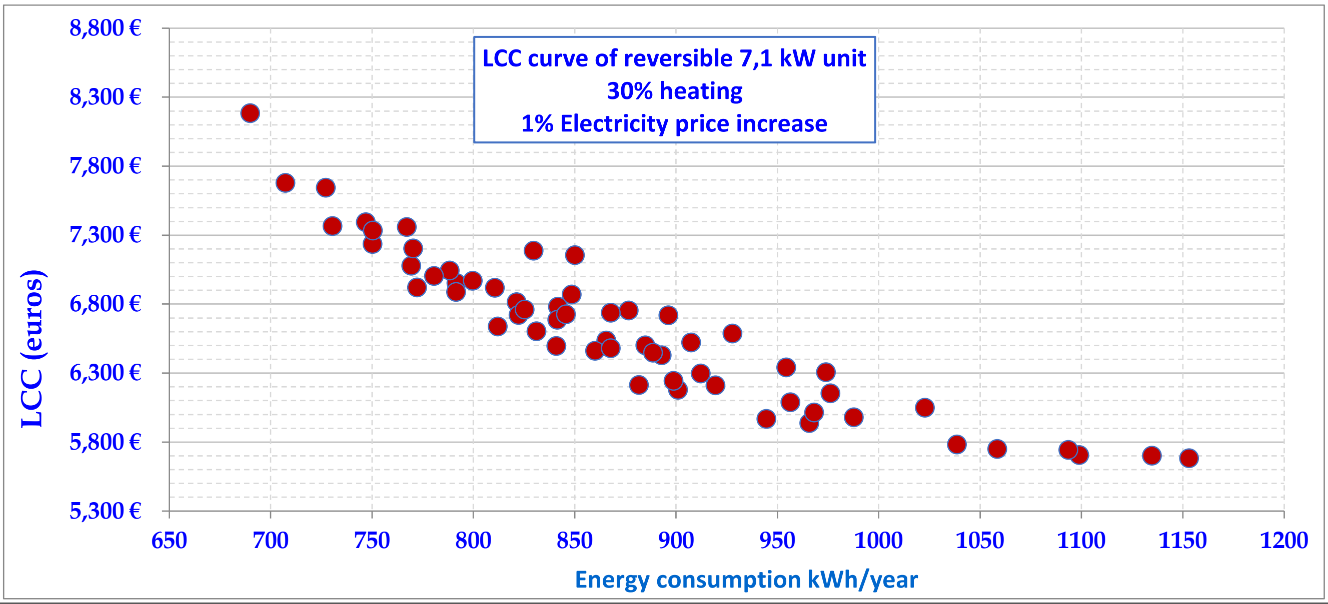

Figure 41 BC 2 : 30% heating/ 1% electricity price increase

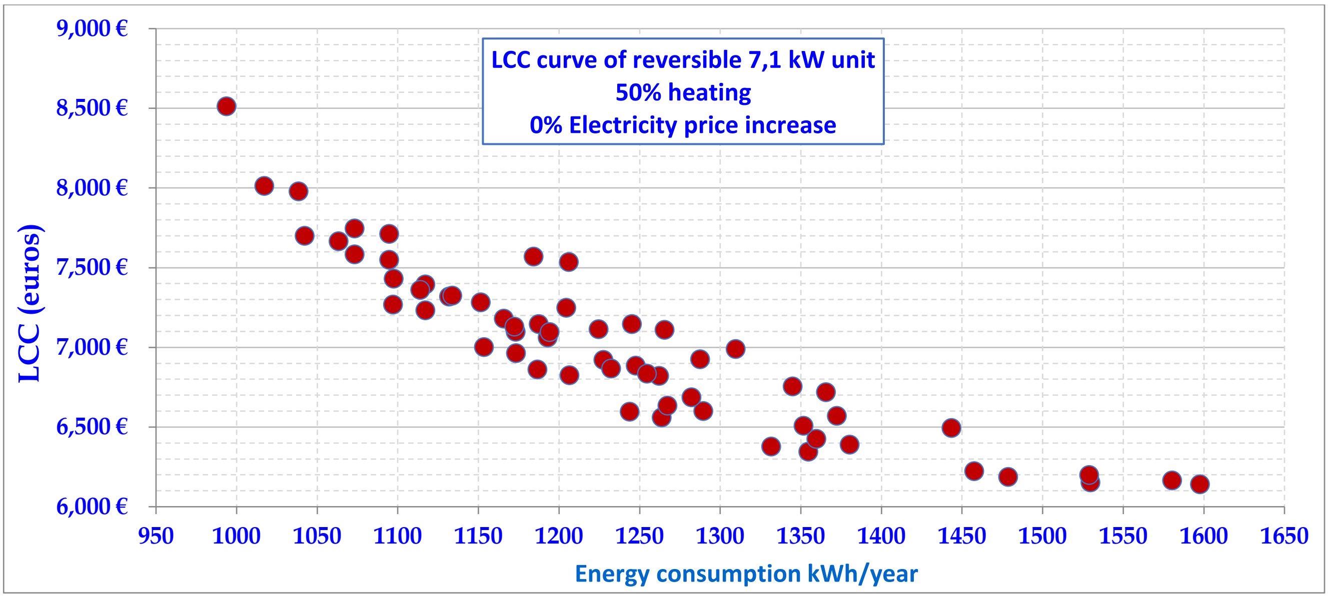

Figure 42 BC 2 : 50% heating/ 0% electricity price increase

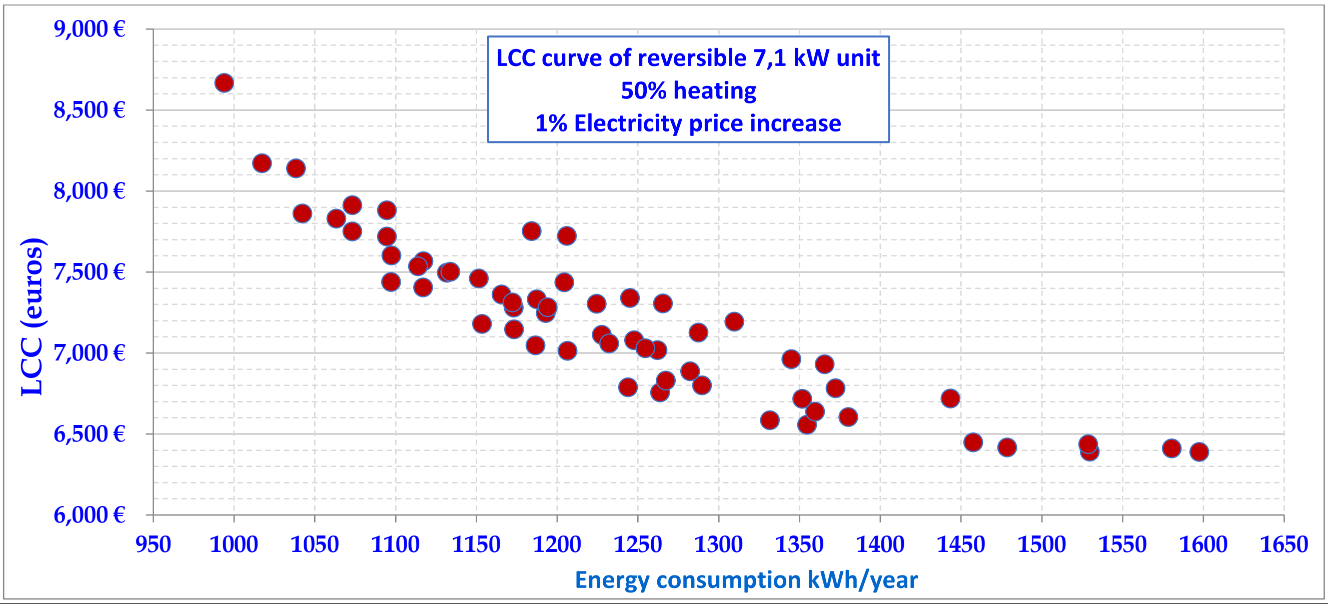

Figure 43 BC 2 : 50% heating/ 1% electricity price increase

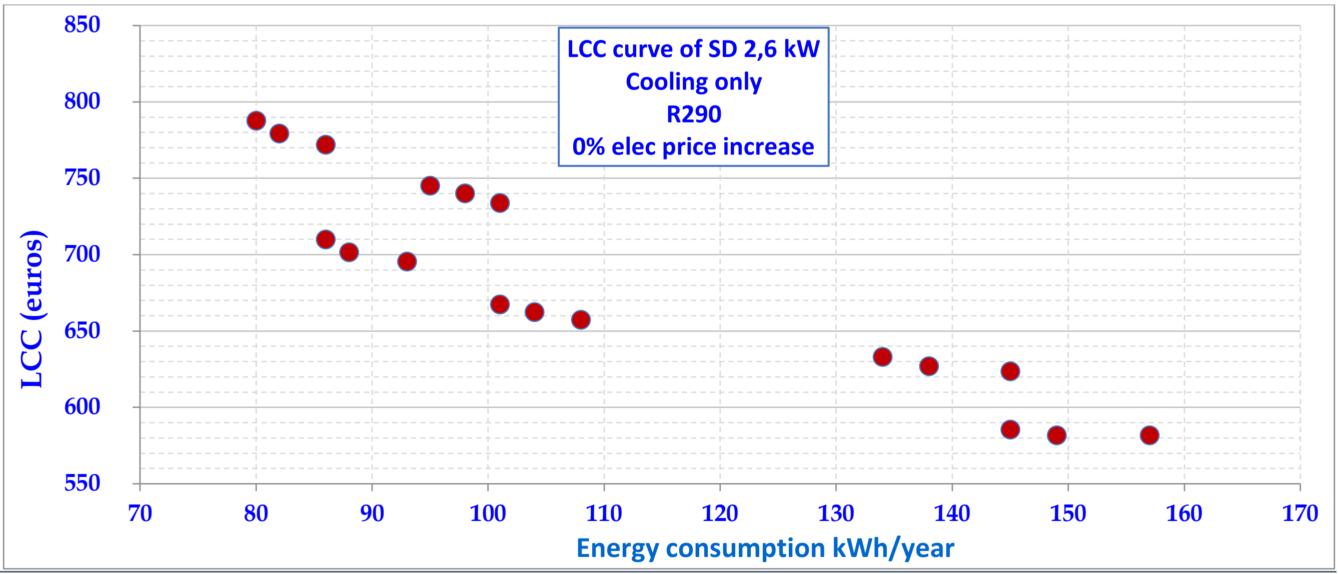

Figure 44 BC 3 : R290/ 0% electricity price increase

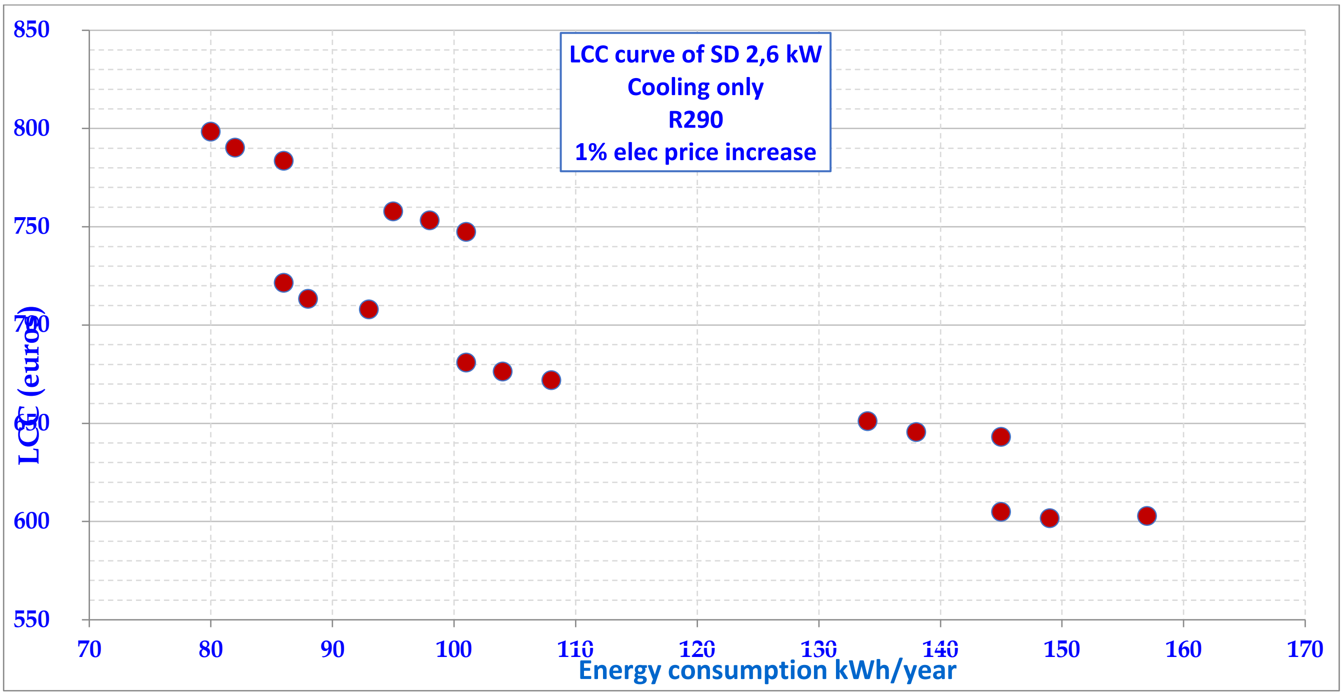

Figure 45 BC 3 : R290/ 1% electricity price increase

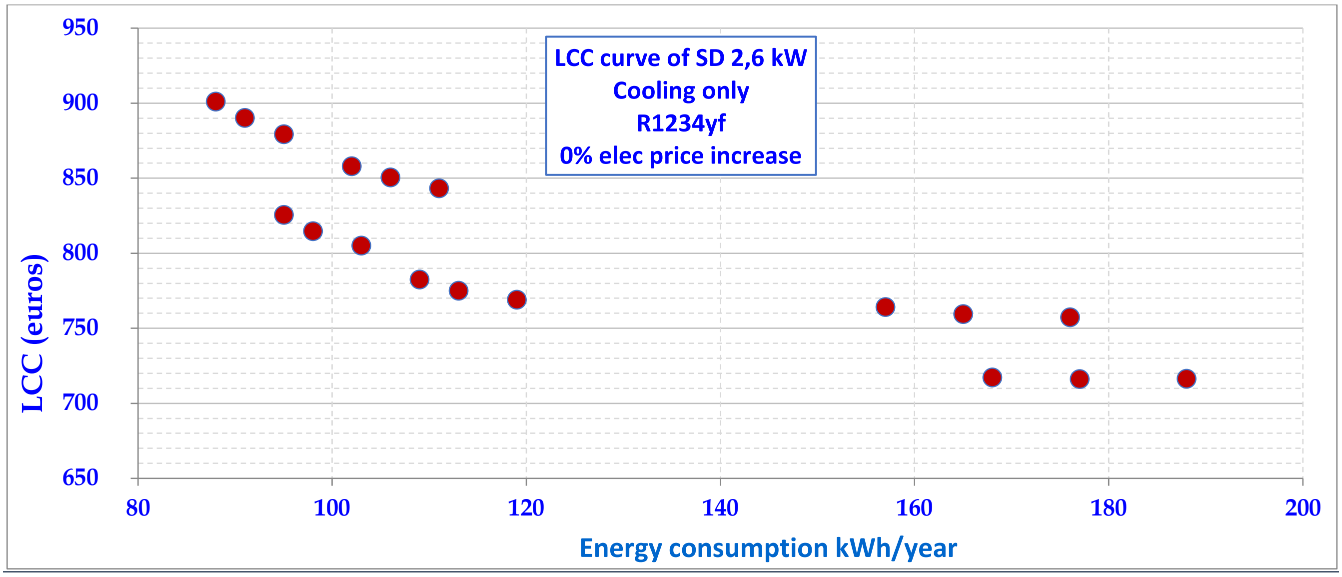

Figure 46 BC 3: R1234yf/ 0% electricity price increase

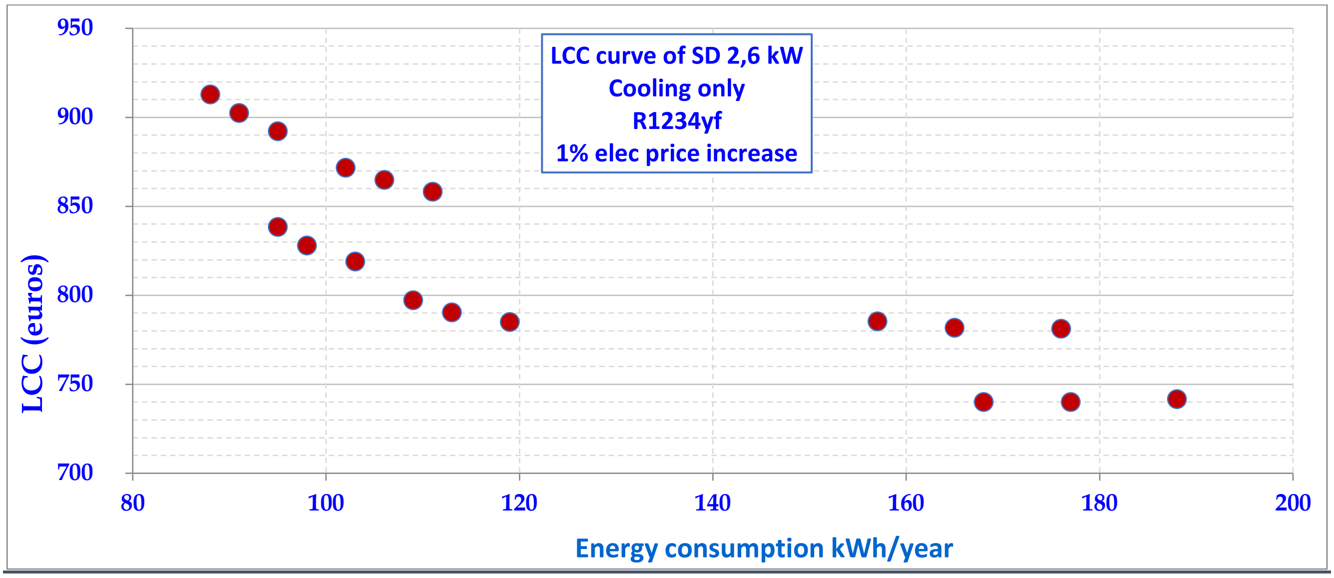

Figure 47 BC 3: R1234yf/ 1% electricity price increase