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Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation)

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Improvement Potential

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 DEFINITION OF PRODUCTS, STANDARDS AND LEGISLATION

Draft version of task 1 is available on the website study:
http://www.ecoaircon.eu

2 ECONOMIC AND MARKET ANALYSIS

Draft version of task 2 is available on the website study:
http://www.ecoaircon.eu

3 CONSUMER BEHAVIOUR AND LOCAL INFRASTRUCTURE

Draft version of task 3 is available on the website study:
http://www.ecoaircon.eu

4 TECHNICAL ANALYSIS OF EXISTING PRODUCTS

Draft version of task 4 is available on the website study:
http://www.ecoaircon.eu

5 DEFINITION OF BASE-CASE

Draft version of task 5 is available on the website study:
http://www.ecoaircon.eu

6 TECHNICAL ANALYSIS OF BAT

Draft version of task 6 is available on the website study:
http://www.ecoaircon.eu

7 IMPROVEMENT POTENTIAL

Introduction

The MEEuP methodology requires the following analysis:

Scope: *Identify design options, 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 Available Technology (BAT). The assessment of monetary Life Cycle Costs is relevant to indicate whether design solutions might negatively or positively impact the total EU consumer's expenditure over the total product life (purchase, running costs, etc.). The distance between the LLCC and the BAT indicates —in a case a LLCC solution is set as a minimum target— the remaining space for product-differentiation (competition). The BAT indicates a medium-term target that would probably more subject to promotion measures than restrictive action. The BNAT (subtask 6.5) indicates long-term possibilities and helps to define the exact scope and definition of possible measures.*

7.1 List of options

MEEuP methodology
"Identification and description of individual design options for environmental improvement."

The environmental impact of air conditioners was undertaken in task 4. It appeared that most important impact was energy. In addition, the TEWI analysis undertaken in task 6 has shown that it was possible to minimize CO2 emissions without entailing the energy efficiency (energy consumed being the major environmental impact of the product). Consequently, the individual ecoreporting of each option is not investigated here but only the energy consumed in each case.

7.1.1 Split air conditioners 3.5 kW reversible

Base case

Base case has an EER equal to 3.1 and a COP equal to 3.4, and heating capacity equal to 4. Main technical characteristics have been described in task 5.

Heating and cooling

Compressor

Starting from a 2.8 EER rotary compressor, nominal EER (at ARI conditions) can be increased by 7 % to 3.0, 14 % at 3.2 and by 21 % until 3.4, where it reaches the technological limit, by accepting (ECCJ, 2006) indications (maximum isentropic efficiencies of 0.82 and motor efficiencies up to 95 %) refer to the ARI standard conditions. In that latter case, it already includes most efficient DC motors and compressor improvement. Default performance curves for rotary compressors were extracted from (Shao, 2004) in order to simulate the compressor performance variations. However, the impact of frequency variation could differ from (Shao, 2004) for DC motors, with improved performances at low speed, as suggested in (Bensafi, 2004) and reported in Figure 7-1.

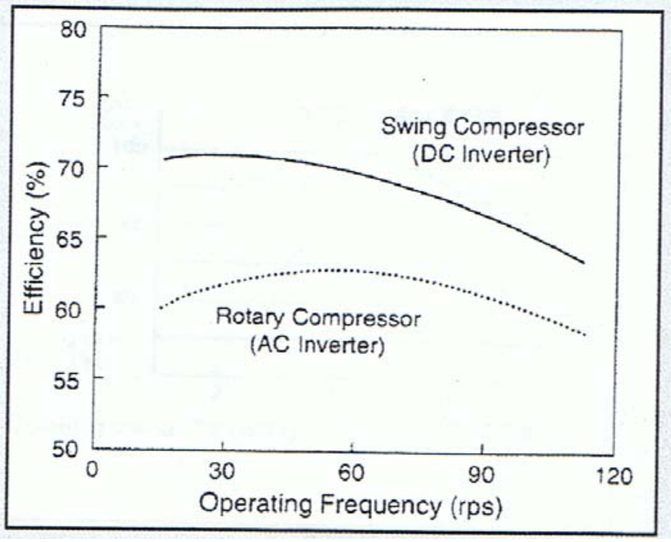


Figure 7-1: Comparison of total efficiency (including isentropic and motor) of "Swing" (Daikin®) and rotary compressor, from (Bensafi, 2006)

AC inverter, typically coupled with lower 2.8 and 3.0 EER compressors, would lead to a range of frequency variations from 25 Hz to 80 Hz.
DC inverter would enable to extend the frequency range of efficient operation to 10-120 Hz, with increased gain at part load operation because of the different compressor efficiency curve with compression ratio.

Supplementary gain can be obtained with inverter driven indoor and outdoor fan that enable to optimise the part load gain by limiting the air flow rate on both sides.
It would also be possible to get two compressors instead of one to achieve equivalent gains in cooling mode. However, the inverter enables to get higher heating capacities at –7 °C, while the overcost is lower according to information supplied by stakeholders.

Option CP1	3.0 EER compressor
Option CP2	3.2 EER compressor
Option CP3	3.4 EER compressor
Option INV AC	AC compressor variable speed drive, 25-80 Hz
Option INV DC	DC compressor variable speed drive, 10-120 Hz
Option ALL DC	DC compressor and fans

Heat exchanger

The power of the heat exchanger can simply be written as $Q = UA*DTLM$, where Q (W) is the capacity of the heat exchanger, U (W/m2/K) the heat transfer coefficient, air or refrigerant side, A(m2) the total heat exchange area, air or refrigerant side respectively and DTLM the logarithmic mean temperature difference between air and refrigerant.
Efficiency of the air conditioner in both modes is directly a function of the compression ratio, the pressure difference between the high and low pressure sides. The lower the difference the higher the efficiency. When reducing the refrigerant flow rate by 1/2, there is twice less capacity to exchange through the heat exchanger and the temperature difference between the air stream and the refrigerant fluid decreases. To get about this level of efficiency at rated capacity, global heat transfer coefficients at both heat exchangers (UA) have to be increased by a factor of 2. The simpler way to do it is to oversize both heat exchangers and to increase air flow rates consequently. Strategies developed by manufacturers vary depending on the technologies used to reach highest efficient EER and COP of 6 and above.

Concerning the refrigerant side, the base case already uses grooved tubes. The default coefficients kept to simulate the effect of the U coefficient improvement is about 2.4 for the evaporator and 2.2 for the condenser as referred to smooth tubes with a pressure loss increase of 1.5 (LNBL, 2001). Japanese manufacturers with innovative groove patterns say they can reach enhancement factors between 3 for evaporation and 3.5 in condensation on the refrigerant side. On the air side, improved louvered pattern levels lead to heat transfer enhancement of 2.5 as referred to plain fins while the slit fins have a 1.8 heat transfer rate enhancement in cooling mode and 1.6 in heating mode according to (LNBL, 2001). In both cases, the coil size can be undersized by 20 % to 30 % at equal air flow rate while reaching the same efficiency level.

Other options to reduce the coil size are to adopt lower tube diameters at the indoor or both air heat exchanger, tubes outside diameters vary between 5 and 7 mm, to reduce the fin pitch (depends on the fin design), to reduce the row and tube pitches. All these options require the adoption or more efficient fans in order not to loose by fan power consumption the gains on the compressor side. Compactness could be increased further with micro-channel heat exchangers but this option has not been commercialised yet to our knowledge in this capacity segment.

Both heat exchangers should be improved in order to keep comparable performances in both modes. For the purpose of this study, we consider symmetrical UA enhancement of both sides starting from the base case value. The analysis of (JRAIA, 2006) data suggests air flow rates at both sides are limited to twice the base case values to limit noise A-weighted pressure sound levels to around 45 dBA at rated ISO T1 and H1 capacity. We define 5 simple options that are to increase heat exchange area and indoor air flow rate simultaneously from 20 % to 100 %.

Option HE1	UA value of both heat exchanger increased by 20 %
Option HE2	UA value of both heat exchanger increased by 40 %
Option HE3	UA value of both heat exchanger increased by 60 %
Option HE4	UA value of both heat exchanger increased by 80 %
Option HE5	UA value of both heat exchanger increased by 100 %

Indoor unit fan

The indoor unit fan of the base case delivers 300 CFM (510 m3/h) for a 30 W power input, a service value of 0.25 m3/min/W in cooling mode. This is already a rather efficient solution if compared, for instance, with default Chinese model (LIN, 2008) whose default baseline unit has a service value of 0.15 m3/min/W. However, there is still a high potential for improvement. Best values are observed at 0.5 m3/min/W at rated speed and for similar coil configurations.

Improvement may be obtained by improving the motor fan efficiency, with a standard DC motor or improved DC motor with rare earth magnet and by using an aluminium random skew cross-flow fan instead. This enables also to lower the noise pressure level. The gain on the fan is mostly visible at part load when the fan power consumption has a larger weight over the total consumption of the unit.
A fan with a variable speed drive is supposed to be implemented at the same time that the variable speed drive for the compressor. It enables to optimise the ratings of the unit, with different rated speeds in cooling and in heating mode and optimised operation at low outdoor air ambient in cooling mode at part load. There is a double gain for variable speed fan on the indoor unit that can operate at about one half of the rated value in thermostat off mode. This option will only be considered in addition to inverter units.
Part of the fan power improvement is not linked to the fan, but to the air flow path to lower pressure losses. That is the reason why fan improvement are considered together with heat exchanger size increase in what follows.

Option IF1	Service value increases by 20 %
Option IF2	Service value increases by 40 %
Option IF3	Service value increases by 60 %
Option IF4	Service value increases by 80 %
Option IF5	Service value increases by 100 %

Outdoor unit fan

Default service value is 0.33, already about 15 % higher than for the default Chinese model (LIN, 2008). Best values at similar coil pattern are larger than 1. Improvement on the fan and on the motor are necessary to reach such performance levels. We will only consider motor efficiency improvement that enable to reach about 0.8 m3/min/W. From a standard 15 % for fan and motor efficiency, with motor efficiency of 40 % and fan efficiency of 38 %, the motor efficiency can be increased to 60 % using a standard DC motor fan and until 80 % for a more sophisticated DC motor (ECCJ, 2006). This enables to decrease the power consumption by 33 and 50 %. The variable speed option is also considered only with compressor inverter.
Part of the fan power improvement is not linked to the fan, but to the air flow path to lower pressure losses. That is the reason why fan improvement are considered together with heat exchanger size increase in what follows.

Option OF1	Service value increases by 20 %

Option OF2	Service value increases by 40 %
Option OF3	Service value increases by 60 %
Option OF4	Service value increases by 80 %
Option OF5	Service value increases by 100 %

Expansion valve

The base case is supplied with a capillary tube. Options for improvement are thermostatic expansion valve, and electronic expansion valve. With better superheat maintain, the efficiency can be improved by 1 to 5 % depending on the conditions. Gain is obtained at low ambient in cooling mode or high outdoor air temperature in heating mode.

The essential gain is linked to part load and is translated in the Cd cycling coefficient starting at 0.18 for capillary tubes, to 0.12 for thermostatic expansion valve and 0.06 for electronic expansion valves. Following results of (Lazzarin, 2008), gain at part load linked to the better control of superheat level at average load and temperature conditions has been estimated to be of 1.5 % for thermostatic expansion valve and 3 % for electronic expansion valve.

Option TXV	Superheat gain: 1.5 % in operation and Cd=0.12
Option EXV	Superheat gain: 3 % in operation and Cd=0.06

Frost and defrost

Default defrost modelling is a simple capacity loss of 10 % starting at 5 °C and decreasing to normal low outdoor operation at –7 °C. Compressor power input is not reduced. This is supposed to model control of defrost cycles by the temperature difference between outdoor air and refrigerant temperatures. Efficiency can be improved in several ways, by getting better information on the frost formation with several temperature sensors and triggering the defrost cycle at the optimal time for different operating conditions, e.g sooner; for inverter units, the same gain can be obtained by software optimisation without adding new temperature sensors.

Option DEF	Improved defrost control

Low temperature heating

Operation at low ambient can be improved and extended by vapor injection during the compression process. This application requires a scroll compressor or a rotary two stage compressor. (Ding, 2004) shows that heating capacity can be increased by 15 % at low ambient and that COP gain is about 5 %.

Option LT	Vapor injection

Standby

From data gathered in previous tasks it appears that 0.7 W is feasible and 1 W common at least in Japan for wall mounted split reversible split units up to 4 kW. In order to enable the control of the crankcase heater, a temperature sensor has to be maintained active in standby and off mode. The second function that is active is the reactivation sensor of the remote control. This means that the PCBs of the two units (outdoor and indoor) remain active in standby, while only the outdoor unit PCB remain active in off mode. Hence, it is simply a matter of cost: reducing the standby power can be done but by including dedicated supplementary PCBs to sense the remote controller and the required temperature(s) to control the crankcase.

According to EuP Lot 6 Task 7, standby could be reduced to 0.3 W for the indoor unit by switching off other than the reactivation function (the supply is inferior to 10 W) and for the outdoor unit it depends on the size of the crankcase heater. Whether the crankcase heater is of more than 45 W, 1.25 W could be reached while 0.4 W would be feasible under 45 W.
Other options are to reduce the power of the PCBs that also cut consumption in other modes, but the cost seems higher.

Option Sb	0.7 W standby with separation of reactivation and crankcase functions

Thermostat off

The thermostat off energy consumption, for the parameters identified in the previous tasks that define the hours of use, mainly depends on the indoor fan consumption whether it remains on during this time period so that the unit may sense indoor air conditions. Variable speed drive fans have then the possibility to fulfil this function with a power consumption of about one third of the rated power consumption for half flow rate but no specific option is considered regarding the time of operation in this mode.

Compressor oil heater for reversible units

In the base case, the crankcase heater has a value of 30 W for the 3.5 kW unit and 70 W for the 7.1 kW unit. Some units may have no positive temperature controller, or this can be to a higher temperature.
However, in the case of the standard base case, the crankcase heater is controlled for an outdoor air temperature of 10 °C.

Two levels of improvement are defined:
- electrified stator coil in the compressor give 10 W and 20 W respectively for the 3.5 kW and 7.1 kW units,
- control on the temperature difference and not only on the outdoor air temperature leads to 5 and 10 W in average.

In any case, there is double gain on the cycling losses and on the thermostat off energy consumption.

Option CK1	Electrified stator coil reduces crankcase heater to 10 W for 3.5 kW rated cooling capacity
Option CK2	Improved crankcase heater control enables to cut the operating time by two third

7.1.2 Other split units

Cooling only 3.5 kW air conditioner

The base case has an EER of 2.9. As compared to the reversible unit, UA values are decreased by 10 % both sides. There is simply less copper tubes and finned area in both heat exchanger with exactly the same design elsewhere to keep the benefit of manufacturing reversible units in large numbers. Consequently, a supplementary option HE0 is added that enables to recover the EER loss by increasing UA values of 10 %. Options applied are the same as for the reversible unit except that the options specific to the heating mode do not apply.

Reversible 7.1 kW air conditioner

The base case has an EER of 2.8 and a COP of 3.3. Performances are slightly more in favour of heating than in the case of the 3.5 kW unit.
To design such a unit, it is necessary to increase the diameter of the coil tubes by 1 US size and to increase the number of circuits in parallel in both heat exchangers in order to reduce the pressure

losses. Relative heat exchanger sizes are proportionally smaller (about 15 %) and compressor is a bit more than the double.
With these conditions, it is necessary to increase the air flow rate indoor in heating mode in order to get such differences in capacity and COP between heating and cooling mode. Finally, in order to simplify the simulations of the options, we keep a unit with smaller heat exchangers and air flow rates of 10 % both sides that leads to an EER of 2.9 and to a COP of 3.2.

Manufacturers say scroll is more common in this capacity range in Europe. Standard compressor efficiency would then be of 2.8 ARI EER and could be improved to 3.0. Above, it seems compressor efficiency is limited in that capacity range so that it would be necessary to use two smaller and more efficient rotary compressors instead of one with consequent refrigerant circuit and electronic modifications.

The shape of indoor and outdoor units are the same, with wall mounted unit indoor, casing specified in task 5, appendix B. Casing is larger by 1 or 2 sizes than for the 3.5 kW base case depending on the manufacturer product range strategy.

Option CP1	3.0 EER compressor
Option CP2	3.2 EER compressor (2 rotary compressors in parallel)
Option CP3	3.4 EER compressor (2 rotary twin compressors in parallel)
Option INV AC	AC compressor variable speed drive, 25-80 Hz
Option INV DC	DC compressor variable speed drive, 10-120 Hz
Option ALL DC	DC compressor and fans
Option HE1	UA value of both heat exchanger increased by 20 %
Option HE2	UA value of both heat exchanger increased by 40 %
Option HE3	UA value of both heat exchanger increased by 60 %
Option HE4	UA value of both heat exchanger increased by 80 %
Option HE5	UA value of both heat exchanger increased by 100 %
Option IF1	Service value increases by 20 %
Option IF2	Service value increases by 40 %
Option IF3	Service value increases by 60 %
Option IF4	Service value increases by 80 %
Option IF5	Service value increases by 100 %
Option OF1	Service value increases by 20 %
Option OF2	Service value increases by 40 %
Option OF3	Service value increases by 60 %
Option OF4	Service value increases by 80 %
Option OF5	Service value increases by 100 %

Option LT	Vapor injection
Options Sb1	1 W standby with separation of reactivation and crankcase functions
Option CK1	Electrified stator coil reduces crankcase heater to 20 W for 7.1 kW rated cooling capacity
Option CK2	Improved crankcase heater control enables to cut the operating time by two third
Option DEF	Improved defrost control

Cooling only 7.1 kW air conditioner

The base case has an EER of 2.5. As compared to the reversible 3.5 kW unit, relative size of heat exchangers is only 75 % or 10 % less than for the 7.1 kW reversible unit. Consequently, a supplementary option HE-1 is added in addition of the options of the 7.1 kW reversible unit that enables to recover the EER loss by increasing UA values both sides. Since 10 % has been kept for the 7.1 kW reversible unit, HE-1 is of 15 %.
Except this one, options applied are the same as for the reversible 7.1 kW unit except that the options specific to the heating mode do not apply.

7.1.3 Single duct air conditioners

The base case unit is charged with the refrigerant fluid R407C. Stakeholders have suggested that going to R410A was no more an improvement but rather the new standard. Consequently, improvement is done on a R410A unit of equivalent EER and capacity. This transformation is neutral concerning costs: indeed, stakeholders suggested that a propane unit cost was the same as for the R407C unit and following (Rice, 1997) R410A and propane should have similar designs.

Propane efficiency gain is 0-10 % over R410A: simulations led with the ORNL heat pump MARK VI model for the base case give 7 % with direct drop-in. In those conditions, it is a cost effective option to implement, with supplementary benefits because of lower TEWI. While the analysis is led for R410A units, clearly it means that cooling performance can be increased by 7 % and direct emissions linked to R410A cut thanks to this option.

Most options of the split units can be applied to the single duct. Increasing the outdoor air unit flow rate is an issue since the performance of the unit itself rated with EN 14511 standard may be improved while on the system point of view, it will contribute to increase the load and to lower the capacity of the unit in conditions comparable to the ones of split (ISO T1 conditions). Hence, we are bound to avoid the outdoor air flow rate increase at least in this average situation. Heat exchanger options HE 1 to HE 5 are only applied to the indoor side and fan efficiency is not increased so that fan power consumption increases. For the same reason, options to increase the efficiency at part load are done at constant ratio of outdoor air flow rate to cooling capacity.

The base case one centrifugal fan that supplies air to both each heat exchangers. Efficiency for this type of fan differs from split ones. Total fan efficiency is supposed to be of 0.3 with 0.6 motor efficiency and 0.5 mechanical efficiency. Efficiency can be increased to 0.4, first by moving to DC fan motor and secondly by moving to rare earth magnet DC motors.

The final list of options is presented hereafter.

Option CP1	3.0 EER compressor
Option CP2	3.2 EER compressor
Option CP3	3.4 EER compressor

Option INV AC	AC compressor variable speed drive, 25-80 Hz
Option INV DC	DC compressor variable speed drive, 10-120 Hz
Option HE1	UA value of indoor heat exchanger increased by 20 %
Option HE2	UA value of indoor heat exchanger increased by 40 %
Option HE3	UA value of indoor heat exchanger increased by 60 %
Option HE4	UA value of indoor heat exchanger increased by 80 %
Option HE5	UA value of indoor heat exchanger increased by 100 %
Option 2F	2 fans instead of one.
Option F1	Total fan and motor efficiency 0.35 both sides
Option F2	Total fan and motor efficiency 0.40 both sides
Options TXV	Gain in operation and Cd=0.12
Options EXV	Gain in operation and Cd=0.06
Options Sb1	0.3 W standby (the LCD screen is switched off in standby mode)

7.2 Environmental impact

MEEuP methodology

"Quantitative assessment of the environmental improvement per option (using EuP EcoReport)."

7.2.1 Reversible split 3.5 kW

The base case default values are changed depending on the options. The seasonal performance indexes presented in task 4 are used to assess the impact of options in cooling and in heating mode. Biases from simplified indices in cooling and in heating mode are corrected from Task 4 values in order to get similar heating and cooling energy consumption that matters for the LLCC analysis.

Variations of performances with outdoor temperature in cooling mode are issued from (JRA, 4046) standard. Variations of performances of the COP with outdoor air temperature are similar to the SP average in task 4. For units equipped with inverter, performances are modelled with two stages, 50 % and 100 %. Cycling laws with Cd and Cc coefficients as explained in task 4 are computed for each option, Cc value depending on the values of the auxiliary power modes.

Sales weighted numbers of hours and power input in the non active modes are as presented in table 4.31 and 4.34.

Simulation of options

Some explanations are added on how the options are taken into account in the computation of the energy efficiency options. Since most options interact, modelling assumptions for coupled solutions differ in some cases in paragraph 7.4.

Compressor gains

The evaluation of the compressor efficiency improvement gain is directly linked to the total efficiency. And gains at full and part load are 7 % for compressor EER 3.0, 14 % for EER = 3.2 and 21 % for EER = 3.4.

The inverter compressor options are supposed to include variable speed fan options at both heat exchangers. It enables to achieve higher gains at part load than maintaining constant fan operation. Average efficiency gains vary much according to data gathered in task 4. Certainly, AC motor efficiency would decrease at reduced speed, this applies to fans and to compressor. Consequently, performance improvement is supposed lower. AC inverter enables to increase the efficiency by 25 % at 50 % capacity in both cooling and heating modes. AC inverter can operate until 50 % capacity in both modes. DC inverters enable to reach 30 % gains at 50 % capacity and may reach 20 % of the rated capacity in both modes. Nevertheless, efficiency is peaking at about 50 % and it seems more efficient to go cycling below about 40 % so that cycling losses are accounted below 50 % capacity.

At last, when coupled with DC fans indoor and outdoor, optimisation of the required air flow enables to reach 35 % improvement at 50 % capacity.

At low outdoor air temperature, both inverter options enable to cut the resistive heating part required for the base case: at 80 Hz it is possible to reach the rated capacity at –7 °C and at 120 Hz, 150 % of the rated capacity.

Increased heat exchanger size

Gains linked to the increase of the size of both heat exchangers are coupled with improved fan options: 20 % larger heat exchangers with 20 % more efficient fans, and so on. Hence, the fan power consumption is supposed constant. The gains are of the same order of magnitude that for the inverter operating at reduced speed. The effect of reduced fan power consumption is not linear since it depends on the relative ratio between compressor power input and fan power input, but for the sake of classifying options 40 % COP and EER increase is kept for doubling UA values both sides.

Expansion valve

The gain linked to the superheat is mainly linked to part load operation. Nevertheless, in order to simplify the calculations it is supposed to apply to all operating conditions.

Frost and defrost

Default defrost modelling is a simple capacity loss of 10 % at 2 °C and starting at 5 °C and decreasing to normal low outdoor operation at –7 °C. Compressor power input is not reduced during this time. Improvement option leads to reduce capacity loss to 5 % instead of 10 %.

Low temperature heating

Capacity and COP are increased at – 7 °C as suggested by (Ding, 2004), 3 % gain on COP at –7°C and extended operation range at low ambient (until –20 °C here).

Standby

Power input is simply reduced and multiplied by the same number of hours.

Compressor oil heater for reversible units

Hours of operation or power input are modified.

Energy consumption reduction by individual options

Important gains can be expected on the cooling and heating consumption with present base case values. For parasitic consumptions, given that base case power input in these modes are low and/or control relatively optimized already, the gain that can be hoped is lower.

	Cooling kWh	Heating kWh	Thermostat off kWh	Standby kWh	Crankcase kWh	Resistive heating kWh	TOTAL kWh	GAIN
Base case	374	939	119	14	35	19	1499	0,0%
CP1	351	879	119	14	35	19	1416	5,6%
CP2	330	826	119	14	35	19	1343	10,4%
CP3	307	767	119	14	35	19	1261	15,9%
INV AC	280	804	86	14	35	0	1219	18,7%
INV DC	271	790	69	14	35	0	1178	21,4%
ALL DC	261	776	53	14	35	0	1138	24,1%
HE1	342	856	119	14	35	19	1383	7,7%
HE2	317	793	119	14	35	19	1296	13,6%
HE3	298	744	119	14	35	19	1228	18,1%
HE4	286	711	119	14	35	19	1183	21,1%
HE5	272	677	119	14	35	19	1135	24,3%
TXV	353	902	119	14	35	19	1441	3,9%
EXV	337	873	119	14	35	19	1396	6,9%
DEF	374	917	119	14	35	19	1477	1,5%
LTH	374	931	119	14	35	0	1472	1,8%

Sb	374	939	119	2	35	19	1487	0,8%
CK1	374	939	119	14	12	19	1476	1,6%
CK2	374	939	119	14	12	19	1476	1,6%

Table 7-1: Energy efficiency gains of options for reversible 3.5 kW split air conditioners

7.2.2 Cooling only split 3.5 kW

Gains by the individual options are presented hereafter.

	Cooling kWh	**Thermostat off kWh**	**Standby kWh**	**TOTAL kWh**	**GAIN**
Base case	378	23	44	445	0%
CP1	354	23	44	421	5%
CP2	333	23	44	400	10%
CP3	310	23	44	377	15%
INV AC	283	17	44	344	23%
INV DC	274	17	44	335	25%
ALL DC	264	10	44	319	28%
HE0	355	23	44	423	5%
HE1	345	23	44	412	7%
HE2	320	23	44	387	13%
HE3	301	23	44	368	17%
HE4	288	23	44	355	20%
HE5	274	23	44	342	23%
TXV	356	23	44	423	5%
EXV	340	23	44	407	9%
Sb	378	23	5	406	9%

Table 7-2: Energy efficiency gains of options for cooling only 3.5 kW split air conditioners

7.2.3 Reversible split 7.1 kW

Simulation of options

Effect of the options are about the same as for the 3.5 kW reversible units. Only the crankcase heater power consumption is slightly larger than the double because of lower initial efficiency while standby gains are lower because the absolute value of gain is the same while the size of the machine has been increased.

Energy consumption reduction by individual options

	Cooling kWh	Heating kWh	Thermostat off kWh	Standby kWh	Crankcase kWh	Resistive heating kWh	TOTAL kWh	GAIN
Base case	840	1961	218	14	81	37	3150	0,0%
CP1	787	1835	218	14	81	37	2971	5,7%
CP2	740	1725	218	14	81	37	2815	10,6%
CP3	699	1627	218	14	81	37	2676	15,0%
INV AC	631	1683	152	14	81	0	2561	18,7%
INV DC	609	1652	119	14	81	0	2475	21,4%
ALL DC	588	1623	86	14	81	0	2393	24,0%
HE0	787	1835	218	14	81	37	2971	5,7%
HE1	766	1786	218	14	81	37	2902	7,9%
HE2	711	1654	218	14	81	37	2714	13,8%
HE3	668	1552	218	14	81	37	2569	18,4%
HE4	639	1484	218	14	81	37	2472	21,5%
HE5	609	1411	218	14	81	37	2370	24,8%
LTH	840	1915	218	14	81	37	3104	1,5%
Sb	840	1965	218	14	81	0	3117	1,0%
CK1	840	1961	218	2	81	37	3139	0,4%
CK2	840	1961	218	14	27	37	3096	1,7%
TXV	840	1961	218	14	27	37	3096	1,7%
EXV	792	1884	218	14	81	37	3025	4,0%

Table 7-3: Energy efficiency gains of options for reversible 7.1 kW reversible split air conditioners

7.2.4 Cooling only split 7.1 kW

Gains are similar to the ones of the previous cooling only unit.

	Cooling kWh	Thermostat off kWh	Standby kWh	TOTAL kWh	GAIN
Base case	883	42	44	969	0%
CP1	827	42	44	914	6%
CP2	778	42	44	865	11%
CP3	734	42	44	821	15%
INV AC	666	30	44	740	24%
INV DC	645	30	44	718	26%
ALL DC	621	17	44	682	30%
HE-1	771	42	44	858	11%
HE0	819	42	44	906	7%
HE1	805	42	44	892	8%
HE2	746	42	44	833	14%
HE3	701	42	44	788	19%
HE4	671	42	44	758	22%
HE5	639	42	44	725	25%
Sb	883	42	7	932	4%
TXV	832	42	44	919	5%
EXV	794	42	44	881	9%

Table 7-4: Energy efficiency gains of options for cooling only 7.1 kW split air conditioners

7.2.5 Single duct air conditioners

Simulation of options

Average energy performance of the base case single duct air conditioner are reported in the table below:

Cooling capacity (EN14511)	2,2	kW
EER (EN14511)	2,3	-
SHR (EN14511)	0,8	-
Tset point (EN14511)	27	°C
Tblowed (°C)	12	°C
Evaporator air flow rate	380	m3/h
Condenser air flow rate	350	m3/h
Compressor EER (ARI)	2.5	-

Table 7-5: Average energy performance of single duct air conditioner

Average load ratio in operation is 50 %. Improvement is done at 50 % load ratio at 25.5 °C and 65 % indoor relative humidity; in those conditions, full load EER is 2.45.

While simulation in task 4 was led with the same cycling hypothesis as for split units, the base case is supposed equipped with a single fan that supplies air flow for both heat exchanger, which seems to be the common situation. This leads to decreased performance in cycling and consequent energy consumption increase in cooling mode from 311 kWh yearly to 334 kWh or a 7 % increase.

Because of the very different rating conditions as compared to split units, EER values could be much higher than for split units if they were not limited by heat exchanger size: about half of the finned area of a split with 3.1 EER at equal capacity. But this means also that the potential to increase efficiency at low loads or by increasing the heat exchange area is much higher. Simulations performed with ORNL Heat Pump Model shows efficiency increases by 100 % at half capacity without changing the flow rates. Nevertheless, because of the specific constraint on air flow rate, the condenser air flow should be decreased by a factor 2 as well and overall efficiency gain would be of 50 %. Some further gain can be expected of an inverter DC compressor that would have higher efficiency at lower pressure ratio, as 60 %. To reach that gain at lower air flow rate at the condenser would require a variable speed drive to be adapted on the fan of the condenser at the same time of inverter options. It is also difficult to decrease air flow rate too low at the condenser so that capacity is not supposed to decrease below 50 % of the rated capacity.

For evaporator increased size, gain is lower because of the lower UA values at the condenser and a 25 % increase is observed at full load.

It is to be noticed that SHR is very sensitive to efficiency so that a dedicated dehumification system, that could be a dedicated TXV on a part of the heat exchanger as for very efficient split units, is to be added for higher efficient units at full load. Whether gain is mostly at part load, this can be avoided. Unit would then be operated at full load part time to remove humidity when required.

The energy efficiency improvement are summarized in the following table.

Unit characteristics	Cooling kWh	Thermostat off kWh	Standby kWh	TOTAL kWh	GAIN
BASE CASE	334	47	14	394	0%
CP1	286	47	14	346	12%
CP2	271	47	14	331	16%
CP3	258	47	14	318	19%
INV AC	187	18	14	219	45%
INV DC	175	18	14	207	47%
HE1	319	47	14	380	4%
HE2	306	47	14	366	7%
HE3	293	47	14	354	10%
HE4	282	47	14	343	13%
HE5	272	47	14	332	16%
2F	320	18	14	352	11%
F1	328	41	14	382	3%
F2	323	36	14	373	5%
TXV	315	47	14	376	5%
EXV	301	47	14	362	8%
Sb	334	47	2	383	3%

Table 7-6: Energy efficiency gains of options for single duct 2.2 kW air conditioner

Largest gains are on compressor improvement and parasitic energy consumptions.

7.3 Costs

MEEuP methodology

Estimate of price increase due to implementation of these design options, either by looking at prices of products on the market and/or by applying a production cost model with sector-specific margins.

7.3.1 Reversible split 3.5 kW

In order to establish the overcost of options, a flat margin scenario is adopted. Manufacturer overcosts are directly passed to the final end-user with the intermediary multiplication factors from manufacturer cost to manufacturer selling price, installer and VAT. Average cost structure was identified thanks to information supplied by manufacturers during this study, as well as some of the option prices. List prices of components have helped to complete this information as well as other LCC studies in the US for instance (Lin, 2008) or (ANEE, 2005). Concerning the price increase of heat exchangers, the reference is the price per kW: having a unit with doubled capacity increases the manufacturing cost of 100 %; but increasing only the heat exchanger size would only affect casing, both coils and fans and refrigerant charge while compressor could be undersized thanks to the gains in cooling capacity.

	Manufacturer overcost estimate	**Price increase**	**Price**
Base case	-	-	683
CP1	Compressor price increase: + 10 %	18	701
CP2	Compressor price increase: + 35 %	63	745
CP3	Compressor price increase: + 98 %	173	855
INV AC	Frequency drive: compressor + 21 %, Electronic: Improved CPU + PCB + 48 %	58	741
INV DC	Frequency drive: compressor + 73 %, Electric + 48 %	114	796
ALL DC	Frequency drive: compressor + 73 %, Electric + 102 %, Motor fan + 36 %	169	851
HE1	Fan and coils: price increases linearly Casing: no range effect, cost increases linearly with the size Compressor linear undersizing: cost divided by 1.5 by undersizing at HE5	48	730
HE2		102	785
HE3		157	839
HE4		211	893
HE5		264	947
TXV	TXV: + 800 %	10	693
EXV	EXV: + 1600 % Electric: wiring and control + 15 %	29	711
DEF	Electric: 2 T sensors and wiring + 15 %	7	690
LTH	Modified compressor: + 75 %	89	771
Sb	Electric: 2 PCb and dedicated wiring + 23 %	22	705
CK1	Compressor modification: + 5% Electric: PCB modification + 13%	15	697
CK2	Electric: 2 T sensors, wiring, fixation + 15 %	11	694

Table 7-7: Overcost of options to enhance energy efficiency, split 3.5 kW reversible unit

7.3.2 Cooling only split 3.5 kW

As was previously explained, given the low market share of cooling only split units, it is assumed that there would be no specific design for this type of unit so that overcosts would be the same ones as for the reversible split units with slightly higher heat exchanger overcosts because of lower initial heat exchange area.

	Manufacturer overcost estimate	Price increase	Price
Base case	-	-	683
CP1	Compressor price increase: + 10 %	18	701
CP2	Compressor price increase: + 35 %	63	745
CP3	Compressor price increase: + 98 %	173	855
INV AC	Frequency drive: compressor + 21 %, Electronic: Improved PCU + PCB + 48 %	58	741
INV DC	Frequency drive: compressor + 73 %, Electric + 48 %	114	796
ALL DC	Frequency drive: compressor + 73 %, Electric + 102 %, Motor fans + 36 %	169	851
HE0	Same accounting system as below, no casing overcost	17	700
HE1	Fan and coils: price increases linearly Casing: no range effect, cost increases linearly with the size Compressor linear undersizing: cost divided by 1.5 by undersizing at HE5	65	730
HE2		119	785
HE3		174	839
HE4		228	893
HE5		281	947
TXV	TXV: + 800 % vs capillary	10	693
EXV	EXV: + 1600 % vs capillary Electric: wiring and control + 15 %	29	711
Sb	Electric: + 2 PCb and dedicated wiring + 23 %	22	705

Table 7-8: Overcost of options to enhance energy efficiency, split 3.5 kW cooling only unit

7.3.3 Reversible split 7.1 kW

Options and overcosts have the same structure as for the 3.5 kW reversible unit. Nevertheless, some differences have been underlined by manufacturers and are reported hereafter.
For compressors, as mentioned previously, manufacturers indicate that scroll would be more common in that product range with EER limited to 3.0. Hence, for CP2 and CP3, more efficient rotary compressors of smaller size enable to reach 3.2 and 3.4 EER. It becomes necessary to modify refrigerant circuiting, to improve control to manage both compressors and to plan oil level equalization of both compressor tanks to avoid damaging one compressor when operating at low load.
Regarding heat exchangers and fans, costs of fans are also estimated to be higher by manufacturers because of less units sold: this tends to increase the overcosts associated with heat exchanger size increase. It was also commented that casing size change would be higher for larger units. These overcosts have been applied to the indoor unit only ; indeed, the tendency is to design outdoor units as two smaller split indoor units superposed in order to reduce the manufacturing or buying costs of fans, coils and casings.

	Manufacturer overcost estimate	**Price increase**	**Price**
Base case	-	0	1385
CP1	Compressor price increase: + 10 %	36	1420
CP2	Compressor price increase: + 35 % Refrigerant circuiting: + 13 %, electric: + 20 %	150	1535
CP3	Compressor price increase: + 98 % Refrigerant circuiting: + 13 %, electric: + 20 %	365	1750
INV AC	Frequency drive: compressor + 21 %, Electronic: Improved CPU + PCB + 48 %	115	1499
INV DC	Frequency drive: compressor + 73 %, Electric + 48 %	222	1607
ALL DC	Frequency drive: compressor + 73 %, Electric + 102 %, Motor fan + 72 %	330	1714
HE0	Same accounting system as below, no casing overcost	68	1452
HE1	Fan and coils: price increases linearly Casing: no range effect, cost increases linearly with the size Compressor linear undersizing: cost divided by 1.45 by undersizing at HE5	230	1614
HE2		423	1807
HE3		583	1968
HE4		826	2210
HE5		1031	2415
TXV	TXV: + 800 %	19	1403
EXV	EXV: + 1600 % Electric: wiring and control + 15 %	47	1432
DEF	Electric: 2 T sensors and wiring + 15 %	14	1399
LTH	Modified compressor: + 75 %	172	1556
Sb	Electric: 2 PCb and dedicated wiring + 23 %	21	1406
CK1	Compressor modification: + 5% Electric: PCB modification + 13%	29	1413
CK2	Electric: 2 T sensors, wiring, fixation + 15 %	11	1395

Table 7-9: Overcost of options to enhance energy efficiency, split reversible 7.1 kW unit

7.3.4 Cooling only split 7.1 kW

As for 3.5 kW units, the design of the 7.1 kW units is based on the reversible unit so that overcost are the same.

	Manufacturer overcost estimate	Price increase	Price
Base case	-	0	1385
CP1	Compressor price increase: + 10 %	36	1420
CP2	Compressor price increase: + 35 % Refrigerant circuiting: + 13 %, electric: + 20 %	150	1535
CP3	Compressor price increase: + 98 % Refrigerant circuiting: + 13 %, electric: + 20 %	365	1750
INV AC	Frequency drive: compressor + 21 %, Electronic: Improved PCU + PCB + 48 %	115	1499
INV DC	Frequency drive: compressor + 73 %, Electric + 48 %	222	1607
ALL DC	Frequency drive: compressor + 73 %, Electric + 102 %, Motor fans + 36 %	330	1714
HE-1	Same system as below, no casing overcost	56	1440
HE0	Fan and coils: price increases linearly Casing: no range effect, cost increases linearly with the size Compressor linear undersizing: cost divided by 1.6 by undersizing at HE5	148	1533
HE1		302	1687
HE2		501	1886
HE3		666	2050
HE4		916	2301
HE5		1127	2512
TXV	TXV: + 800 % vs capillary	19	1403
EXV	EXV: + 1600 % vs capillary Electric: wiring and control + 15 %	47	1432
Sb	Electric: + 2 PCb and dedicated wiring + 23 %	21	1406

Table 7-10: Overcost of options to enhance energy efficiency, split cooling only 7.1 kW unit

7.3.5 Single duct air conditioners

Price increase of the compressor has been adjusted on the data supplied for split units. Overcosts may differ slightly because the original compressor is slightly less efficient and also because the weight of the compressor in the structure cost is different. The overcosts are described in the table below.

	Manufacturer overcost estimate	Price increase	Price
Base case	-	0	389,4
CP1	Compressor price increase: + 18 %	26	415,0
CP2	Compressor price increase: + 49 %	70	459,3
CP3	Compressor price increase: + 110 %	167	556,1
INV AC	Frequency drive: compressor + 21 %, Electronic: Improved PCU + PCB + 48 %	71	460,2
INV DC	Frequency drive: compressor + 73 %, Electric + 48 %	146	535,2
HE1	Fan and coils: price increases linearly with size Casing: no range effect, cost increases linearly with the size Compressor linear undersizing: cost divided by 1.125 by undersizing at HE5	23	412,6
HE2		46	435,9
HE3		70	459,1
HE4		93	482,4
HE5		116	505,6
2F	2 fans half size: fan group + 33 % Casing modification: + 20 %	30	418,9
F1	Improved motor fan: fan motor assembly + 20 %	7	396,4
F2	Improved motor fan: fan motor assembly + 50 %	18	406,9
TXV	Overcost Vs capillary TXV: + 800 %	14	403,0
EXV	Overcost Vs EXV: + 1500 % Electric: wiring and control + 15 %	37	426,0
Sb	Electric: + 1 PCb and dedicated wiring + 23 %	7	396,8

Table 7-11: Cost of options for single duct air conditioners

7.4 Analysis LLCC and BAT

MEEuP methodology :

- Ranking of the individual design options by LCC (e.g. option 1, option 2, option 3);
- Determination/ estimation of possible positive or negative ('rebound') side effects of the individual design measures;
- Estimating the accumulative improvement and cost effect of implementing the ranked options simultaneously (e.g. option 1, option 1+2, option 1+2+3, etc.), also taking into account the above side-effects;
-Ranking of the accumulative design options, drawing of a LCC-curve (Y-axis= LLCC, X-axis= options) and identifying the Least Life Cycle Cost (LLCC) point and the point with the Best Available Technology (BAT).

7.4.1 Reversible split air conditioner, 3.5 kW

Ranking of the individual options

With the hypothesis of tasks 2, 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.

Life time: 12 years
Discount rate: 2 %
Electricity price: 0.158 euro/kWh
Maintenance: 67 euro/year
Installation: 1000 euros

OPTION	Purchasing price Euros	Energy consumption kWh/year	Yearly energy bill Euros	Payback time Years	LCC Euros
BASE CASE	683	1499	237		4964
TXV	693	1584	250	0,8	4686
INV AC	741	1293	204	1,0	4238
CP1	701	1571	248	1,3	4674
EXV	711	1524	241	1,3	4603
DEF	690	1636	258	1,7	4772
INV DC	796	1240	196	1,7	4204
ALL DC	851	1190	188	2,3	4173
CP2	745	1490	235	2,3	4580
HE1	730	1535	243	2,4	4641
HE2	785	1438	227	2,9	4531
CK2	694	1641	259	3,0	4784
HE3	839	1363	215	3,3	4457
HE4	893	1313	207	3,8	4426
CK1	697	1641	259	4,0	4788
CP3	855	1400	221	4,1	4535
HE5	947	1260	199	4,1	4389
Sb	705	1652	261	12,3	4815
LTH	771	1642	259	25,4	4864

Table 7-12: Ranking of individual options by simple payback time, reversible 3.5 kW unit

Each option applied individually, except the low temperature heating, would be cost effective. The more expensive options relate to heat exchanger UA increase. Whether the simple strategy adopted is to increase the coil size, manufacturers may have other and less costly ways to improve the efficiency of heat exchangers by better fins and/or tube designs, as shown in task 6. More efficient compressors are amongst the best options, together with inverter compressor. For crankcase as well as standby, improvement over the base case level would also be cost effective even if not of first priority.

Interactions

Compressor overcost cannot be added also inverter compressor cost are not added: overcost of option CP3 is the difference between CP3 and CP2 option and overcost of ALL DC is reduced from the overcost of the option INV DC.

The EXV overcost is added to the TXV cost which is supposed to translate the necessary supplementary vane that enables to lower the evaporating temperature in cooling mode to dehumidify. Regarding heat exchangers, overcosts of options HE1 to HE5 should not be added (overcost of option HE4 should only be the difference with option HE3).

There are also interactions on the energy efficiency of the product. The main one comes from the shape of the compressor isentropic efficiency. The gain that can be obtained by decreasing the compression ratio of the compressor is somehow limited by the low pressure ratio side of the curve. Most efficient units will not have a gain of 30 % with an inverter at 50 % capacity whether their EER is already of 6 at full load. This has been taken into account so that SEERon and SCOPon values be consistent with best products for the same options. Thus, the gain in efficiency by oversizing the heat exchangers has been reduced at full and part load in order to get compatible values with known best available air conditioners (JRAIA, 2006). The option ALL DC is translated by a 20 % gain on fan power, whose power becomes of primary importance at high EER and COP; it translates the adoption of best available fan motor efficiency according to (ECCJ, 2006). Resulting energy efficiency levels are presented hereafter.

Improvement scenario

Once interactions are taken into account, the ranking of more cost effective options changes; the LTH option has been removed since it did not help much to improve efficiency once combined with inverter options. The summary of energy gains, price increase and LCC variations are gathered in the following table with computed energy consumption and economic information.

Unit description	Price euros	Yearly Energy consumed kWh	Simple Payback Years	LCC Lifetime euros	Yearly Energy cost euros
BASE CASE	683	1499,3	0,0	4963,8	236,9
TXV	693	1411,1	0,7	4823,6	222,9
INV AC	751	1156,0	1,3	4447,1	182,6
CP1	769	1089,8	1,3	4352,7	172,2
DEF	777	1071,3	1,4	4328,6	169,3
CK2	788	1048,0	1,5	4300,1	165,6
EXV	806	1029,0	1,7	4285,3	162,6
CP2	850	973,2	2,0	4234,4	153,8
INV DC	905	919,8	2,4	4198,7	145,3
ALL DC	982	851,3	2,9	4158,7	134,5
HE1	1035	816,3	3,3	4152,2	129,0
HE2	1090	784,6	3,6	4152,8	124,0
CK1	1104	776,8	3,7	4154,3	122,7

Sb	1127	765,4	3,8	4157,0	120,9
HE3	1181	741,2	4,2	4170,0	117,1
HE4	1235	721,9	4,5	4190,9	114,1
HE5	1288	707,2	4,8	4219,5	111,7
CP3	1398	680,0	5,5	4283,2	107,4

Table 7-13: Improvement of base case unit to BAT levels, split reversible 3.5 kW

The performances of these units at full and part load are presented in the following tables.

	EER	**EER 50**	**COP**	**COP50**	**SEERon**	**SCOPon**
BASE CASE	3.1	-	3.4	-	3.1	2.6
TXV	3.1	-	3.5	-	3.2	2.7
INV AC	3.1	4.1	3.5	4.3	4.3	3.2
CP1	3.4	4.4	3.7	4.6	4.6	3.4
DEF	3.4	4.4	3.7	4.6	4.6	3.5
CK2	3.4	4.4	3.7	4.6	4.6	3.5
EXV	3.4	4.4	3.8	4.7	4.7	3.6
CP2	3.6	4.7	4.0	5.0	5.0	3.8
INV DC	3.8	5.2	4.2	5.4	5.5	4.0
ALL DC	3.9	5.5	4.2	5.8	5.8	4.2
HE1	4.3	5.7	4.5	5.9	6.1	4.4
HE2	4.7	5.9	4.8	6.1	6.3	4.6
CK1	4.7	5.9	4.8	6.1	6.3	4.6
Sb	4.7	5.9	4.8	6.1	6.3	4.6
HE3	5.0	6.1	5.0	6.2	6.5	4.8
HE4	5.2	6.2	5.2	6.4	6.7	4.9
HE5	5.4	6.2	5.4	6.5	6.8	5.0
CP3	5.8	6.4	5.7	6.7	7.0	5.3

Table 7-14: Scenario of improvement of base case unit to BAT levels – efficiency levels, split reversible 3.5 kW

LLCC

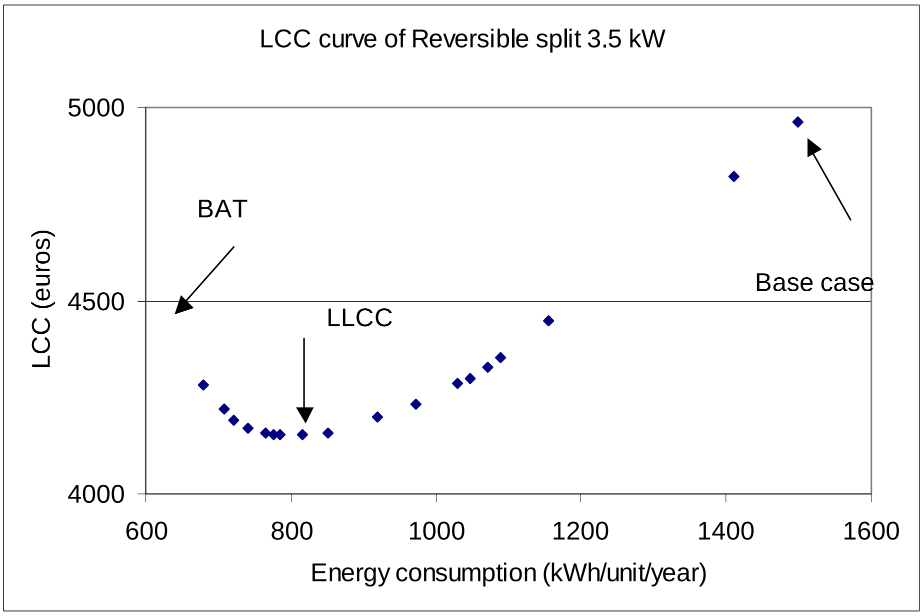


Figure 7-2: LCC curve of reversible 3.5 kW unit improvement

Value of BAT levels are slightly lower in terms of energy consumption that the ones defined in Task 6, SCOPon of 5.4 and SEERon of 8.2. Following findings of task 6 would have led to a level energy consumption about 40 % of the base case versus 44 % presently. To get these BAT levels, it is estimated it would be necessary to increase the outdoor heat exchanger and air flow rate by an additional 40 % (of their initial size) while maintaining constant fan power; this would enable to reach SEERon 8.2 for a total final price estimated to 225 %. The BAT arrow points out this point on figure 7.2 above.

For the scenario of improvement, LLCC combination energy is 54 % of the initial energy consumption while LCC is rather stable between 65 % and 45 %.

The simple payback time of the LLCC unit as compared to the base case is of 3.3 years.

It corresponds here to the combination of the different characteristics:
SEERon=6.1 (base case 3.1, BAT 8.2)
SCOPon=4.4 (base case 2.6, BAT 5.4)
Power of crankcase heater: 10 W (BAT 5 W in average with optimised control)
Power in thermostat off mode: 16 W (base case 36 W, BAT 13 W)
Standby power: 6 W (BAT 0.7 W)
Resistive heating correction: 0 kWh (thanks to the inverter, base case 19 kWh).

The price increases by 52 % (BAT estimated to 225 %).

When reporting to prices of Japanese units in task 2, best 2.8 kW units - whose performances are comparable to a unit with all simulated improvement until CP3 - were sold at 1100 euros or about 390 euro/kW. This would be 1365 euros versus 1398 euros in the present analysis.

7.4.2 Cooling only split air conditioner, 3.5 kW

Ranking of the individual options

With the hypothesis of tasks 2, 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.

Life time: 12 years
Discount rate: 2 %
Electricity price: 0.158 euro/kWh
Maintenance: 67 euro/year
Installation: 1000 euros

OPTION	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	683	445	70		3167
TXV	693	423	67	3,0	3140
Sb	705	406	64	3,6	3122
INV AC	741	344	54	3,7	3053
EXV	711	407	64	4,8	3131
CP1	701	421	67	4,9	3145
HE0	700	423	67	5,0	3147
INV DC	796	335	53	6,6	3093
ALL DC	851	319	50	8,5	3120
CP2	745	400	63	8,9	3154
HE1	730	412	65	9,2	3158
HE2	785	387	61	11,2	3171
HE3	839	368	58	12,9	3192
HE4	893	355	56	14,8	3224
CP3	855	377	60	16,2	3224
HE5	947	342	54	16,2	3255

Table 7-15: Ranking of individual options by simple payback time, split cooling only 3.5 kW unit

With major energy consumption cut, inverter is definitely one of the first options to be implemented. Standby is also a very cost effective way to improve the energy efficiency of the unit because the unit is hardwired and despite the end-user turns down the indoor unit, energy is still consumed all year long.

Improvement scenario

Interactions are the same as presented in the precedent paragraph. The summary of energy gains, price increase and LCC variations are gathered in the following table.

Unit description	Price euros	Yearly Energy consumed kWh	Simple Payback Years	LCC Lifetime euros	Yearly Energy cost euros
BASE CASE	683	444,9	-	3166,7	70,3
TXV	693	423,3	3,0	3140,1	66,9
INV AC	751	317,7	3,4	3018,5	50,2
Sb	773	280,9	3,5	2977,8	44,4
CP1	792	264,3	3,8	2968,1	41,8

CP2	836	249,9	5,0	2987,7	39,5
HE0	853	243,9	5,4	2995,0	38,5
EXV	871	238,5	5,8	3003,5	37,7
INV DC	926	222,6	6,9	3031,7	35,2
ALL DC	1003	204,2	8,4	3077,1	32,3
HE1	1056	195,3	9,5	3115,0	30,9
HE2	1111	188,5	10,6	3158,0	29,8
HE3	1165	183,1	11,7	3203,0	28,9
HE4	1219	179,1	12,8	3250,2	28,3
HE5	1273	176,8	13,9	3299,8	27,9
CP3	1383	172,5	16,3	3402,7	27,3

Table 7-16: Improvement of base case unit to BAT levels, split cooling only 3.5 kW

Unit description	**EER**	**EER 50**	**SEERon**
Base case	2,9	2,9	2,9
TXV	2,9	2,9	3,0
INV AC	2,9	4,0	4,2
Sb	2,9	4,0	4,2
CP1	3,2	4,3	4,5
CP2	3,4	4,6	4,8
HE0	3,6	4,7	4,9
EXV	3,6	4,7	5,0
INV DC	3,8	5,2	5,4
ALL DC	3,9	5,5	5,8
HE1	4,3	5,7	6,1
HE2	4,7	5,9	6,3
HE3	5,0	6,0	6,5
HE4	5,2	6,2	6,7
HE5	5,4	6,2	6,8
CP3	5,8	6,3	7,0

Table 7-17: Scenario of improvement of base case unit to BAT levels – efficiency levels, split cooling only 3.5 kW

LLCC

For the scenario of improvement, LLCC combination energy is 62 % of the initial energy consumption. The simple payback time of the unit as compared to the base case is of 3.8 years.

The same improvement options have been applied as for the reversible unit. Consequently, BAT levels are lower than presented in task 6 (SEERon of 7.0 versus 8.2).

It corresponds here to the combination of the following characteristics:
SEERon=4.5 (base case 2.9, BAT 7.0)
Power in thermostat off mode: 16 W (base case 36 W, BAT 13 W)
Standby power: 1 W (base case 6 W)

The price increases by 16 % at LLCC (BAT 203 %).

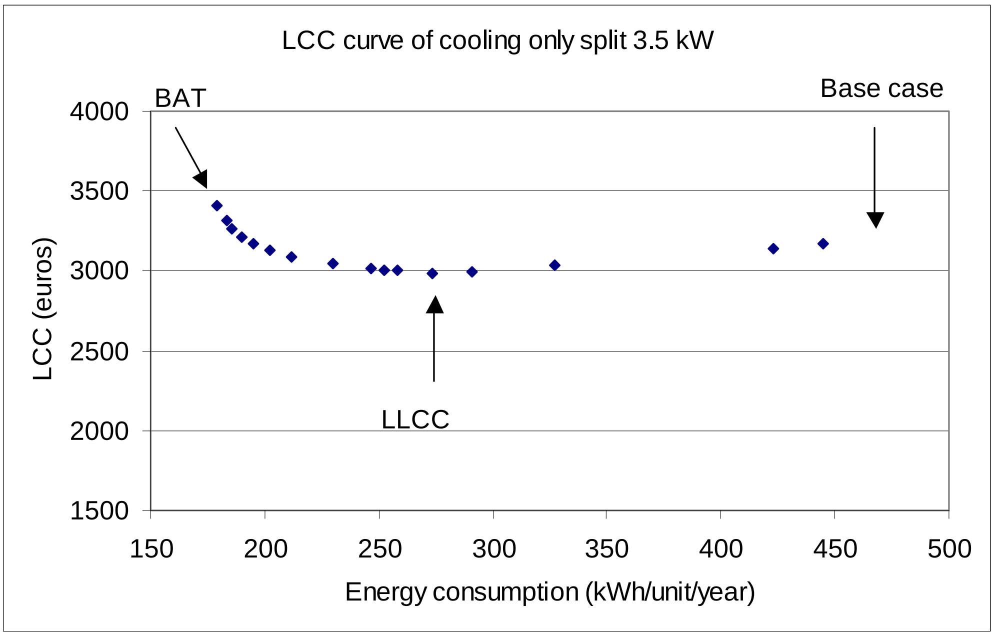


Figure 7-3: LCC curve of cooling only 3.5 kW unit improvement

7.4.3 Reversible split air conditioner, 7.1 kW

Ranking of the individual options

With the hypothesis of tasks 2, 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.

Life time: 12 years
Discount rate: 2 %
Electricity price: 0.158 euro/kWh
Maintenance: 95 euro/year
Installation: 1000 euros

OPTION	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	1385	3150	498		8782
TXV	1403	3025	478	0,7	8588
INV AC	1499	2561	405	1,0	7893
EXV	1432	2928	463	1,0	8452
CP1	1420	2971	469	1,2	8513
CK2	1395	3096	489	1,3	8700
DEF	1399	3104	490	1,6	8717
INV DC	1607	2475	391	1,7	7854
HE0	1452	2971	469	1,8	8545
ALL DC	1714	2393	378	2,2	7820
CP2	1535	2815	445	2,6	8361
HE1	1614	2902	458	2,9	8589
CK1	1413	3096	489	3,4	8718
HE2	1807	2714	429	3,7	8462
HE3	1968	2569	406	4,0	8376

HE4	2210	2472	391	4,4	8453
CP3	1750	2676	423	4,5	8340
HE5	2415	2370	374	4,8	8483
Sb	1406	3139	496	12,3	8784
LTH	1556	3117	493	32,0	8898

Table 7-18: Ranking of individual options by simple payback time, reversible 7.1 kW unit

Each option applied individually, except the low temperature heating option, would be cost effective. The more expensive options relate to heat exchanger UA increase. Whether the simple strategy adopted is to increase the coil size, manufacturers may have other and less costly ways to improve the efficiency of heat exchangers by better fins and/or tube designs, as shown in task 6. More efficient compressors are amongst the best options, together with inverter compressor. For crankcase as well as for standby, improvement over the base case level would also be cost effective even if not of first priority.

Interactions

Each price increase is taken into account when the option is implemented. For the unit 5, the EXV overcost is added to the TXV cost which is supposed to translate the necessary supplementary vane that enables to lower the evaporating temperature in cooling mode to dehumidify.

However, there are interaction on the energy efficiency of the product. The main one comes from the shape of the compressor isentropic efficiency. The gain that can be obtained by decreasing the compression ratio of the compressor is somehow limited by the low pressure ratio side of the curve. Most efficient units will not have a gain of 30 % with an inverter at 50 % capacity whether their EER is already of 6 at full load. This has been taken into account so that SEER and SCOP values be consistent with BAT products for the same options. Thus, the gain in efficiency by oversizing the heat exchangers has been reduced at part load in order to get compatible values with known best available air conditioners (JRAIA, 2006). For the same reason, the 40 % maximum gain that can be awaited from HE options are decreasing progressively, HE1 gain being more important than HE5 in relative terms.

Improvement scenario

The summary of energy gains, price increase and LCC variations are gathered in the following table with computed energy consumption and economic information. LLCC level is shown in red. The step of improvement whose performances are closest from the best known available product (following information supplied by (JRAIA, 2006)) has been added in green.

OPTION	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	1385	3150	498		8782
INV AC	1499	2541	401	1,2	7859
CP1	1535	2392	378	1,3	7641
TXV	1554	2344	370	1,3	7577
HE0	1622	2228	352	1,6	7448
DEF	1636	2191	346	1,7	7399
CK1	1665	2133	337	1,7	7328
EXV	1691	2093	331	1,8	7286
CK2	1701	2077	328	1,9	7271
INV DC	1809	1959	309	2,3	7176
ALL DC	1959	1820	288	2,7	7090
CP2	2084	1715	271	3,1	7037

HE1	2314	1642	259	3,9	7142
Sb	2336	1631	258	4,0	7144
HE2	2529	1565	247	4,6	7225
HE3	2689	1515	239	5,0	7300
CP3	2904	1455	230	5,7	7413
HE4	3147	1417	224	6,4	7591
HE5	3351	1388	219	7,1	7746

Table 7-19: Improvement of base case unit to BAT levels, split reversible 7.1 kW

The performances of these units at full and part load is presented in the following tables. For the same reason as mentioned previously for the 3.5 kW unit, BAT levels are lower than in task 6.

	EER	**EER 50**	**COP**	**COP50**	**SEERon**	**SCOPon**
Base case	2,9	-	3,2	-	2,9	2,5
INV AC	2,9	3,8	3,2	4,0	3,9	2,9
CP1	3,1	4,0	3,4	4,3	4,2	3,1
TXV	3,2	4,1	3,5	4,3	4,3	3,2
HE0	3,4	4,3	3,7	4,6	4,6	3,4
DEF	3,4	4,3	3,7	4,6	4,6	3,5
CK1	3,4	4,3	3,7	4,6	4,6	3,5
EXV	3,4	4,4	3,8	4,6	4,7	3,6
CK2	3,4	4,4	3,8	4,6	4,7	3,6
INV DC	3,6	4,8	3,9	5,0	5,1	3,8
ALL DC	3,6	5,0	4,0	5,3	5,4	3,9
CP2	3,9	5,4	4,3	5,7	5,7	4,2
HE1	4,3	5,6	4,5	5,8	6,0	4,4
Sb	4,3	5,6	4,5	5,8	6,0	4,4
HE2	4,7	5,7	4,8	6,0	6,2	4,6
HE3	5,0	5,9	5,0	6,1	6,4	4,7
CP3	5,3	6,1	5,3	6,3	6,7	5,0
HE4	5,5	6,2	5,6	6,4	6,8	5,1
HE5	5,8	6,3	5,7	6,6	6,9	5,2

Table 7-20: Scenario of improvement of base case unit to BAT levels – efficiency levels, split reversible 7.1 kW

LLCC

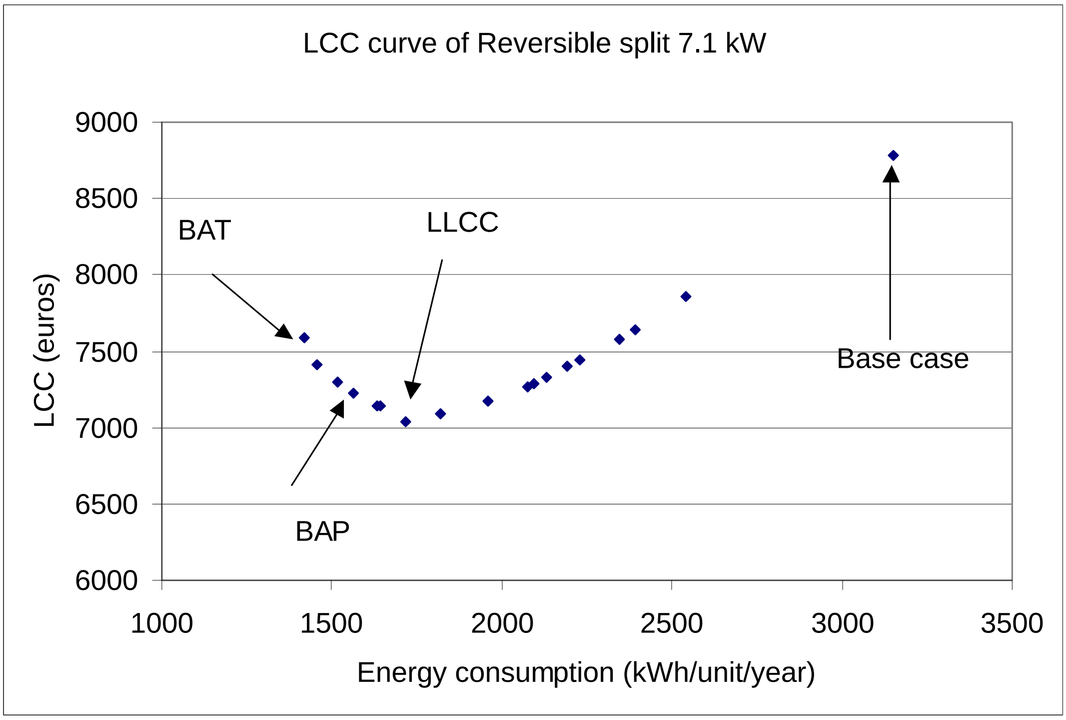


Figure 7-4: LCC curve of the reversible 7.1 kW unit improvement

For the scenario of improvement, LLCC combination energy is 56 % of the initial energy consumption. The crankcase heater option which would have a lower cost than in the case of the 3.5 kW unit makes the difference. The simple payback time of the unit as compared to the base case is of 2 years. Here again, BAT level reached with options is in good agreement as far as SCOPon is concerned with best BAT products identified in task 6 but is lower for SEERon values.

It corresponds here to the combination of the different characteristics:
SEERon=5.7 (base case 2.9, BAT 6.9)
SCOPon=4.2 (base case 2.5, BAT 5.2)
Power of crankcase heater: 30 W (BAT 5 W in average with optimised control)
Power in thermostat off mode: 6 W (base case 36 W, BAT 6W)
Standby power: 6 W (BAT 1 W)
Resistive heating correction: 0 kWh (thanks to the DC inverter, base case 25 kWh).

The price increases by 51 % (BAT 242 %).

7.4.4 Cooling only split air conditioner, 7.1 kW

Ranking of the individual options

With the hypothesis of tasks 2, 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.

Life time: 12 years
Discount rate: 2 %
Electricity price: 0.158 euro/kWh
Maintenance: 95 euro/year
Installation: 1000 euros

OPTION	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	1385	969	153		5065
TXV	1403	919	145	2,4	4998
INV AC	1499	740	117	3,2	4789
EXV	1432	881	139	3,4	4962
Sb	1406	932	147	3,7	5024
CP1	1420	914	144	4,1	5006
INV DC	1607	718	113	5,6	4860
HE-1	1440	858	136	6,3	4931
ALL DC	1714	682	108	7,3	4905
CP2	1535	865	137	9,1	5037
HE0	1533	906	143	13,8	5106
HE1	1687	892	141	14,9	5235
CP3	1750	821	130	15,6	5178
HE2	1886	833	132	16,9	5335
HE3	2050	788	124	17,7	5422
HE4	2301	758	120	20,9	5621
HE5	2512	725	115	23,0	5777

Table 7-21: Ranking of individual options by simple payback time, split cooling only 7.1 kW unit

With major energy consumption cut, inverter is definitely one of the first options to be implemented.

Improvement scenario

Interactions are the same as presented in the precedent paragraph. Seven virtual units with decreasing energy consumption and increasing cost are created. The summary of energy gains, price increase and LCC variations are gathered in the following table.

OPTION	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	1385	969	153		5065
TXV	1403	919	145	2,4	4998
INV AC	1518	700	111	3,1	4740
CP1	1554	660	104	3,5	4707
HE-1	1610	599	95	3,8	4659
Sb	1631	562	89	3,8	4618

EXV	1679	549	87	4,4	4643
INV DC	1829	511	81	6,1	4729
ALL DC	1979	474	75	7,6	4817
CP2	2094	447	71	8,6	4884
HE0	2243	419	66	9,9	4986
CP3	2486	401	63	12,3	5198
HE1	2788	379	60	15,1	5463
HE2	2987	365	58	16,8	5639
HE3	3152	354	56	18,2	5785
HE4	3402	347	55	20,5	6022
HE5	3613	342	54	22,5	6225

Table 7-22: Improvement of base case unit to BAT levels, split cooling only 7.1 kW

	EER	**EER 50**	**SEERon**
Base case	2,5	2,5	2,5
TXV	2,5	2,5	2,6
INV AC	2,5	3,3	3,5
CP1	2,7	3,5	3,8
HE-1	3,2	3,9	4,2
Sb	3,2	3,9	4,2
EXV	3,2	4,0	4,3
INV DC	3,3	4,3	4,6
ALL DC	3,4	4,6	4,9
CP2	3,6	4,9	5,2
HE0	3,9	5,2	5,6
HE1	4,3	5,4	5,8
CP3	4,6	5,7	6,2
HE2	5,0	5,9	6,4
HE3	5,3	6,1	6,7
HE4	5,5	6,2	6,8
HE5	5,7	6,3	6,9

Table 7-23: Scenario of improvement of base case unit to BAT levels – efficiency levels, split cooling only 7.1 kW

LLCC

For the scenario of improvement, LLCC combination energy is about 60 % of the initial energy consumption. The simple payback time of the unit as compared to the base case is of 3.6 years. For the same reason as mentioned previously for the 3.5 kW unit, BAT levels are lower than in task 6.

It corresponds here to the combination of the following characteristics:
SEERon=4.2 (base case 2.6, BAT 6.9)
Power in thermostat off mode: 6 W (base case 36 W)
Standby power: 6 W (BAT 1 W)

The price increases by 16 % (BAT 261 %).

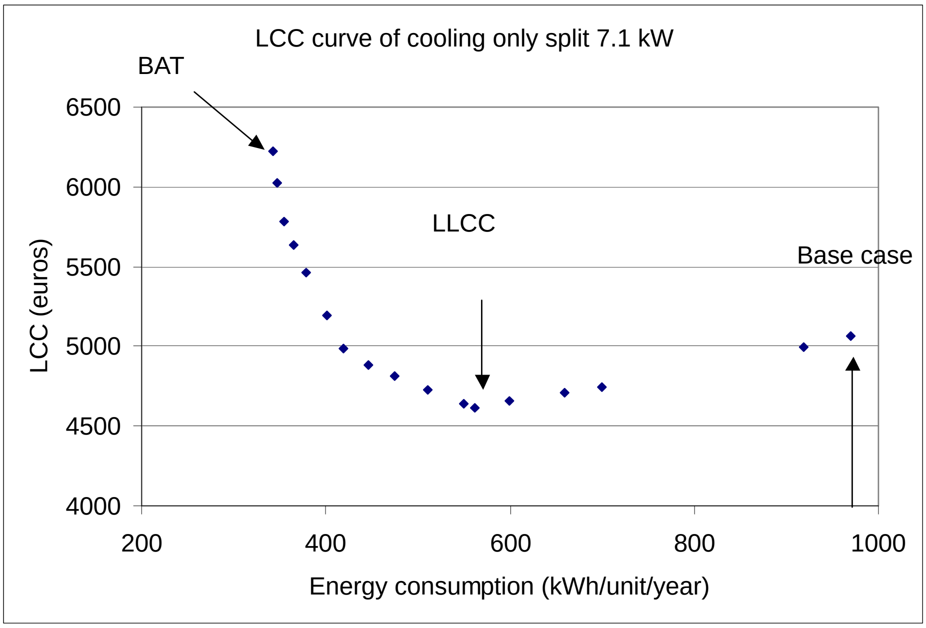


Figure 7-5: LCC curve of cooling only 7.1 kW unit improvement

7.4.5 Single duct air conditioners

Ranking of the individual options

With the hypothesis of task 2, 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.

Life time: 12 years
Discount rate: 2 %
Maintenance: 15,6 euro/year
Installation: 0 euros

Improvement	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	389	394	62		1230
INV AC	460	219	35	2,6	1032
CP1	415	346	55	3,4	1184
F1	396	382	60	3,7	1219
Sb1	397	383	61	4,1	1221
2F	419	352	56	4,4	1200
TXV	403	376	59	4,6	1217
INV DC	535	207	33	4,9	1119
F2	407	373	59	5,3	1219
CP2	459	331	52	7,0	1222
EXV	426	362	57	7,1	1226
HE1	413	380	60	9,9	1238
HE2	436	366	58	10,4	1248
HE3	459	354	56	10,9	1260
HE4	482	343	54	11,4	1274
HE5	506	332	52	11,8	1290
CP3	556	318	50	13,8	1241

Table 7-24: Ranking of individual options by simple payback time, single duct unit

Because of the high energy efficiency gain, inverter, despite the necessary variable speed drive fan to limit the condenser air flow rate, appears as one of the most cost effective way to cut the energy consumption of the unit.

Improvement scenario

Concerning interactions, it appears that the heat exchanger area increase is even less effective at half load than in the previous cases, because the compression ratio is reaching lower values.

The summary of energy gains, price increase and LCC variations are gathered in the following table.

Improvement	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros
BASE CASE	389	394	62		1230
INV AC + 2F	490	219	35	3,6	1031
Sb	497	206	33	3,6	1016
CP1	523	176	28	3,9	991
F1	530	171	27	4,0	989
F2	547	167	26	4,4	999
HE1	571	159	25	4,9	1010
EXV	605	156	25	5,7	1039
CP2	650	148	23	6,7	1070
HE2	673	143	23	7,1	1085
HE3	696	139	22	7,6	1102
INV DC	759	133	21	8,9	1153
HE4	782	130	21	9,4	1173
HE5	806	128	20	9,9	1192
CP3	858	123	19	10,9	1235

Table 7-25: Improvement of base case unit to BAT levels, single duct unit with R410A and propane

	R410A unit	Propane unit
	SEERon	**SEERon**
BASE CASE	2,1	2,2
INV AC	3,7	3,9
Sb	3,7	3,9
CP1	4,4	4,7
F1	4,5	4,8
F2	4,5	4,9
HE1	4,8	5,1
EXV	4,9	5,2
CP2	5,2	5,5
HE2	5,4	5,8
HE3	5,5	5,9
INV DC	5,9	6,3
HE4	6,0	6,4
HE5	6,1	6,5
CP3	6,4	6,9

Table 7-26: Scenario of improvement of base case unit to BAT levels – efficiency levels, single duct unit 2.2 kW

LCC curve

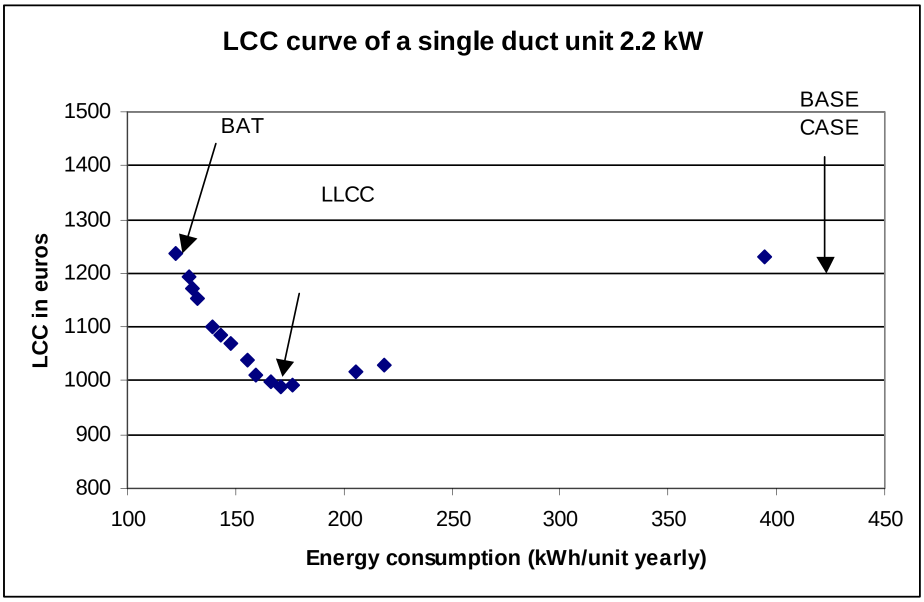


Figure 7-6: LCC curve of single duct unit improvement

LLCC

For the scenario of improvement, LLCC combination energy is 43 % of the initial energy consumption. The simple payback time of the unit as compared to the base case is of 4 years.

It corresponds here to the combination of the following characteristics:
SEERon=4.5 (base case 2.1, BAT 6.9)
Power in thermostat off mode: 23 W (base case 66 W)
Standby power: 0.3 W (BAT 0.3 W)

The price increases by 36 % (BAT 220 %).

It is to be noticed that performances with a propane unit would give about 7 % higher SEERon and EER values for about the same cost, shifting the LLCC point by 7 % to SEERon 4.8, with a supplementary advantage regarding direct emissions as compared to R410A units and is then to be kept for the LLCC value.

For the same capacity range, split units with best available technologies would enable to reach higher efficiencies for the same cooling duty.

7.4.6 Comparison of LCC analysis with standardized SEER, SCOP and APF indices

Cooling only air conditioners

For split units, SEERon values are the one found in the previous analysis since it was based already on seasonal performance indicators previously shown in Task 4.

For single duct units, average EU conditions have been used to compute the SEERon values, 25.5 °C and 65 % relative humidity. This is estimated to favour the units' performances as compared to EN14511 27(19) conditions by 6.5 %. In order to build on the existing standards, the standard temperature and humidity rating conditions are used hereafter to evaluate the SEERon, with 50 % capacity ratio.

In both cases, standard numbers of hours and electric power required in auxiliary modes including their improvement with options above are used to evaluate the additional electric consumption. The seasonal performance indice including auxiliary power modes, SEER is also added.

A summary of the options applied to improve the base case products and of their impact on SEER, SEERon and EER can be found in the table below. It appears that the same **SEER LLCC** is valid for the 3 types of units with **SEER equal to 4**. Full load standard rating EER values vary between 2.8 for single duct units and 3.2 for cooling only split units for the optimisation path identified for the base cases.

Single duct				**Split 7.1 kW**				**Split 3.5 kW**			
Options	**SEER**	**SEERon**	**EER**	**Options**	**SEER**	**SEERon**	**EER**	**Options**	**SEER**	**SEERon**	**EER**
BASE CASE	1,7	2,1	2,3	**Base case**	2,3	2,5	2,5	**Base case**	2,5	2,9	2,9
INV AC	3,2	3,7	2,3	**TXV**	2,4	2,6	2,5	**TXV**	2,6	3,0	2,9
Sb	3,4	3,7	2,3	**INV AC**	3,2	3,5	2,5	**INV AC**	3,4	4,1	2,9
CP1	3,9	4,4	2,8	**CP1**	3,4	3,8	2,7	**Sb**	3,8	4,1	2,9
F1	4,0	4,5	2,8	**HE-1**	3,7	4,2	3,2	**CP1**	4,0	4,3	3,2
F2	4,1	4,6	2,8	**Sb**	4,0	4,2	3,2	**CP2**	4,3	4,6	3,4
HE1	4,3	4,8	3,0	**EXV**	4,1	4,3	3,2	**HE0**	4,4	4,7	3,6
EXV	4,4	4,9	3,1	**INV DC**	4,4	4,6	3,3	**EXV**	4,5	4,9	3,6
CP2	4,7	5,2	3,3	**ALL DC**	4,7	4,9	3,4	**INV DC**	4,8	5,2	3,8
HE2	4,8	5,4	3,5	**CP2**	5,0	5,2	3,6	**ALL DC**	5,2	5,6	3,9
HE3	5,0	5,6	3,6	**HE0**	5,3	5,6	3,9	**HE1**	5,4	5,8	4,3
INV DC	5,2	5,9	3,9	**HE1**	5,5	5,8	4,3	**HE2**	5,6	6,1	4,7
HE4	5,3	6,0	4,0	**CP3**	5,9	6,2	4,6	**HE3**	5,8	6,3	5,0
HE5	5,4	6,1	4,2	**HE2**	6,1	6,4	5,0	**HE4**	5,9	6,4	5,2
CP3	5,6	6,4	4,4	**HE3**	6,3	6,7	5,3	**HE5**	6,0	6,5	5,4
				HE4	6,4	6,8	5,5	**CP3**	6,1	6,7	5,8
				HE5	6,5	6,9	5,7				

Table 7-27:Comparison of LLCC levels with standardized seasonal performance indices for cooling only units

Reversible split air conditioners

SEERon and SCOPon are evaluated thanks to the indices presented in task 4 as for the options hereabove ; standard numbers of hours are used to compute SEER, SCOP and APF values that include auxiliary power modes. Standard numbers of hours and electric power required in auxiliary modes including their improvement with options above are used to evaluate the additional electric consumption.

Here again, the same **energy efficiency target** can be kept with the 2 types of units with a value of **APF equal to 4.2**. Full load standard rating EER values vary between 3.9 and 4.3, full load COP at 7 °C between 4.5 and 4.3. SEER values rank higher than for cooling only units with values of 6.1 and 5.7. SCOP values that are the spine of the energy consumption because of the 610 equivalent full load hours in heating mode versus 315 in cooling mode are of 4.0 in both cases.

Split 3.5 kW								Split 7.1 kW							
Options	**EER**	**COP**	**SEERon**	**SEER**	**SCOPon**	**SCOP**	**APF**	**Options**	**EER**	**COP**	**SEERon**	**SEER**	**SCOPon**	**SCOP**	**APF**
Base case	3,1	3,4	3,1	2,8	2,6	2,3	2,4	**Base case**	2,9	3,2	2,9	2,7	2,5	2,2	2,3
TXV	3,1	3,5	3,2	2,9	2,7	2,4	2,5	**INV AC**	2,9	3,2	3,9	3,7	2,9	2,6	2,8
INV AC	3,1	3,5	4,3	3,8	3,2	2,8	3,0	**CP1**	3,1	3,4	4,2	3,9	3,1	2,8	3,0
CP1	3,4	3,7	4,6	4,1	3,4	3,0	3,2	**TXV**	3,2	3,5	4,3	4,0	3,2	2,9	3,1
DEF	3,4	3,7	4,6	4,1	3,5	3,1	3,2	**HE0**	3,4	3,7	4,6	4,2	3,4	3,0	3,3
CK2	3,4	3,7	4,6	4,1	3,5	3,1	3,3	**DEF**	3,4	3,7	4,6	4,2	3,5	3,1	3,3
EXV	3,4	3,8	4,7	4,2	3,6	3,2	3,4	**CK1**	3,4	3,7	4,6	4,2	3,5	3,2	3,4
CP2	3,6	4,0	5,0	4,4	3,8	3,4	3,6	**EXV**	3,4	3,8	4,7	4,3	3,6	3,3	3,5
INV DC	3,8	4,2	5,5	4,7	4,0	3,6	3,8	**CK2**	3,4	3,8	4,7	4,3	3,6	3,3	3,5
ALL DC	3,9	4,2	5,8	5,1	4,2	3,8	4,0	**INV DC**	3,6	3,9	5,1	4,6	3,8	3,5	3,7
HE1	4,3	4,5	6,1	5,4	4,4	4,0	4,2	**ALL DC**	3,6	4,0	5,4	5,0	3,9	3,7	4,0
HE2	4,7	4,8	6,3	5,5	4,6	4,2	4,4	**CP2**	3,9	4,3	5,7	5,3	4,2	4,0	4,2
CK1	4,7	4,8	6,3	5,5	4,6	4,2	4,4	**HE1**	4,3	4,5	6,0	5,5	4,4	4,1	4,4
Sb	4,7	4,8	6,3	5,9	4,6	4,2	4,6	**Sb**	4,3	4,5	6,0	5,7	4,4	4,1	4,5
HE3	5,0	5,0	6,5	6,1	4,8	4,4	4,8	**HE2**	4,7	4,8	6,2	5,9	4,6	4,3	4,7
HE4	5,2	5,2	6,7	6,2	4,9	4,5	4,9	**HE3**	5,0	5,0	6,4	6,1	4,7	4,5	4,8
HE5	5,4	5,4	6,8	6,3	5,0	4,6	5,0	**CP3**	5,3	5,3	6,7	6,3	5,0	4,7	5,0
CP3	5,8	5,7	7,0	6,5	5,3	4,8	5,2	**HE4**	5,5	5,6	6,8	6,4	5,1	4,8	5,2
								HE5	5,8	5,7	6,9	6,5	5,2	4,9	5,3

Table 7-28:Comparison of LLCC levels for reversible split units

It appears that a single LLCC target level can be kept for all air conditioning products if set in terms of equivalent total electricity consumption. This includes not only energy consumption in the active cooling and heating mode but also the energy consumption in the other power modes identified previously: thermostat-off, standby, off mode and crankcase heater.

7.4.7 Comparison with Japanese reversible air conditioners

The optimzation led has been done with data supplied mainly by Japanese manufacturers. It then seems useful to compare the optimisation path identified and the performances of Japanese units presented before in task 6.

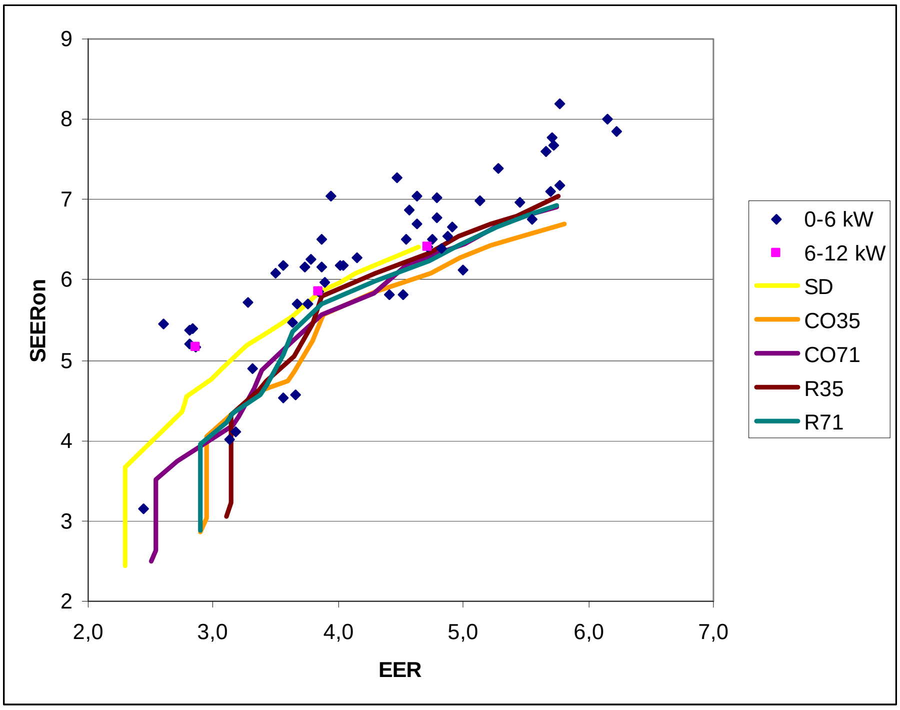
In the following figure, we have represented the relationship between EER and SEERon (and then between COP and SCOPon) for Japanese products below and above 6 kW and the optimisation led for the base cases in task 7.

For Japanese units whose cooling capacity is inferior to 6 kW, average and best units of main Japanese manufacturers from 1996 to 2006 are represented while for larger units, with cooling capacity above 6 kW only best units of two manufacturers in 2006 are available.

For the improvement options, it seems the cooling improvement potential has been underestimated, with probably too much interactions regarding the impact heat exchanger increase at part load with

DC compressor. There is also some margin in heating mode but the shape seems in good agreement with performances of real units.

Also, it should be added that best available products of 10 and 12.5 kW units does not reach the BAT levels but reach only about 6.3 in cooling mode and 4.3 in heating mode.



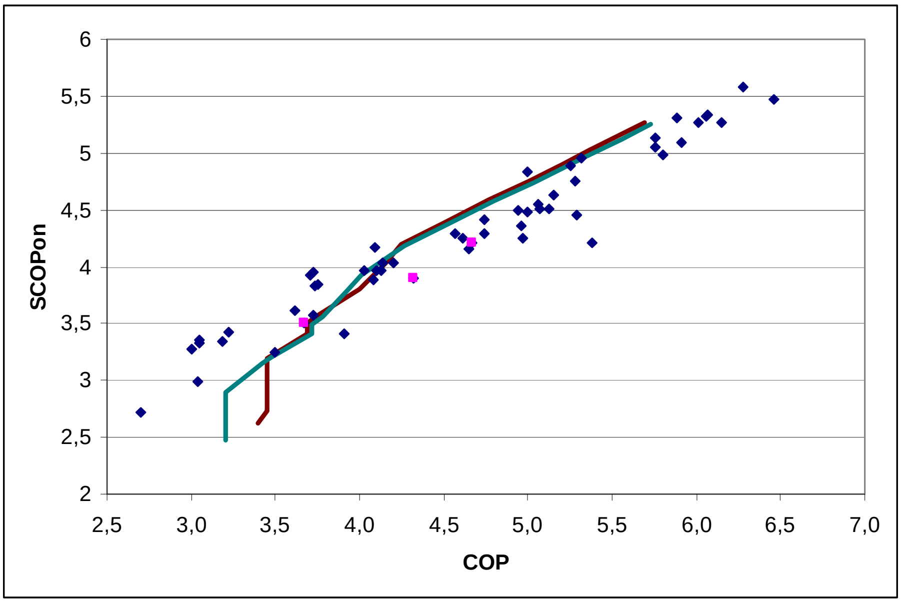


Figure 7-7: Comparison of Japanese inverter driven units [0-12 kW] and base case improvement paths – EER Vs SEERon and COP Vs SCOPon

7.4.8 LLCC results when separating heating and cooling season for reversible units

Heating and cooling are treated separately for reversible units by separating heating and cooling seasons ; effects on the results of the LLCC analysis of reversible units are studied.

7.4.8.1 Cooling mode

Whether separating heating and cooling energy consumption, there should be LLCC values for cooling and heating modes of reversible units. Results of the revised LCC optimisation for cooling mode for the 2 reversible units are presented hereunder.

For the 3.5 kW reversible unit, the computation made considering only the cooling season is reported below. SEER value at LLCC is 4.1 for the 3.5 kW unit instead of 5.4 in the case heating and cooling were considered jointly.

	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros	SEER
BASE CASE	683	413	65,3		3113	2,8
TXV	693	381	60,2	2,0	3068	2,9
INV AC	751	288	45,5	3,5	2967	3,8
CP1	769	271	42,9	3,9	2958	4,1
DEF	769	271	42,9	3,9	2958	4,1
CK2	769	271	42,9	3,9	2958	4,1
EXV	787	265	41,9	4,5	2965	4,2
CP2	831	251	39,7	5,8	2986	4,4
INV DC	887	235	37,1	7,3	3013	4,7
ALL DC	963	216	34,1	9,0	3057	5,1
HE1	1 017	207	32,7	10,2	3095	5,4
HE2	1 071	200	31,6	11,5	3137	5,5
CK1	1 071	200	31,6	11,5	3137	5,5
Sb	1 093	188	29,8	11,6	3140	5,9
HE3	1 148	183	28,9	12,8	3185	6,1
HE4	1 201	179	28,2	14,0	3232	6,2
HE5	1 255	176	27,9	15,3	3282	6,3
CP3	1 365	171	27,0	17,8	3382	6,5

Table 7-29: Results of LCC analysis for the 3.5 kW reversible unit for the cooling season

For the 7.1 kW reversible unit, SEER value at LLCC is 4.1 for the 3.5 kW unit instead of 5.4 in the case heating and cooling were considered jointly.

OPTION	Purchasing priceEuros	Energy consumption kWh life time	Year energy billEuros	Payback timeYears	LCCEuros	SEER
BASE CASE	1 385	900	142,1		4947	2,7
INV AC	1 499	657	103,8	3,0	4648	3,7
CP1	1 535	618	97,6	3,4	4616	3,9
TXV	1 554	602	95,1	3,6	4608	4,0
HE0	1 622	574	90,7	4,6	4629	4,2
DEF	1 622	574	90,7	4,6	4629	4,2
CK1	1 622	574	90,7	4,6	4629	4,2
EXV	1 648	561	88,6	4,9	4633	4,3
CK2	1 648	561	88,6	4,9	4633	4,3
INV DC	1 755	523	82,6	6,2	4675	4,6

ALL DC	1 905	482	76,2	7,9	4757	5,0
CP2	2 031	455	71,9	9,2	4835	5,3
HE1	2 260	435	68,7	11,9	5030	5,5
Sb	2 282	423	66,9	11,9	5032	5,7
HE2	2 475	408	64,4	14,0	5199	5,9
HE3	2 635	395	62,5	15,7	5338	6,1
CP3	2 850	383	60,5	18,0	5532	6,3
HE4	3 093	374	59,1	20,6	5759	6,4
HE5	3 298	369	58,3	22,8	5956	6,5

Table 7-30: Results of LCC analysis for the 7.1 kW reversible unit for the cooling season

When considering separately heating and cooling season for reversible units, the reference SEER levels at LLCC for reversible units are compatible with the one previously identified for cooling only units. A value for SEER equal to 4 can be kept for all units in cooling mode.

7.4.8.2 Heating mode

The LCC analysis has been reproduced taking only into account the heating mode. In that case, the SCOP value of the LLCC for the 3.5 kW unit decreases from 4 to 3.8 and from 4 to 3.9 for the 7.1 kW unit. A value for SCOP equal to 3.8 can be kept in heating mode.

	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros	SCOP
BASE CASE	683	1041	164,5		4183	2,3
TXV	693	1012	159,9	2,2	4143	2,4
INV AC	751	868	137,2	2,5	3957	2,8
CP1	769	818	129,3	2,5	3890	3,0
DEF	777	800	126,4	2,5	3866	3,1
CK2	788	777	122,7	2,5	3838	3,1
EXV	806	764	120,6	2,8	3833	3,2
CP2	850	722	114,1	3,3	3806	3,4
INV DC	905	685	108,2	4,0	3798	3,6
ALL DC	982	635	100,4	4,7	3791	3,8
HE1	1 035	610	96,3	5,2	3800	4,0
HE2	1 090	585	92,4	5,6	3812	4,2
CK1	1 104	577	91,2	5,8	3814	4,2
Sb	1 104	577	91,2	5,8	3814	4,2
HE3	1 159	558	88,2	6,2	3836	4,4
HE4	1 213	543	85,8	6,7	3864	4,5
HE5	1 266	531	83,9	7,2	3897	4,6
CP3	1 376	509	80,4	8,3	3970	4,8

Table 7-31: Results of LCC analysis for the 3.5 kW reversible unit for the heating season

OPTION	Purchasing price Euros	Energy consumption kWh life time	Year energy bill Euros	Payback time Years	LCC Euros	SCOP
BASE CASE	1 385	2149	339,5		7075	2,2
INV AC	1 499	1828	288,7	2,3	6643	2,6
CP1	1 535	1722	272,0	2,2	6498	2,8
TXV	1 554	1691	267,1	2,3	6464	2,8
HE0	1 622	1605	253,7	2,8	6387	3,0
DEF	1 636	1569	248,0	2,7	6340	3,1

CK1	1 665	1511	238,8	2,8	6269	3,2
EXV	1 691	1485	234,7	2,9	6251	3,2
CK2	1 701	1470	232,2	3,0	6235	3,3
INV DC	1 809	1392	220,0	3,5	6210	3,4
ALL DC	1 959	1295	204,6	4,3	6195	3,7
CP2	2 084	1221	192,8	4,8	6194	3,9
HE1	2 314	1170	184,8	6,0	6336	4,1
Sb	2 314	1170	184,8	6,0	6336	4,1
HE2	2 507	1121	177,1	6,9	6447	4,3
HE3	2 668	1084	171,3	7,6	6545	4,4
CP3	2 883	1039	164,2	8,5	6682	4,6
HE4	3 125	1010	159,7	9,7	6876	4,7
HE5	3 330	987	156,0	10,6	7042	4,9

Table 7-32: Results of LCC analysis for the 7.1 kW reversible unit for the heating season

7.4.9 Scaling old and revised seasonal performance indices

There are proposed changes on the reference seasonal performance indices. The details of the methodology are available in Task 4, Appendix B. The impacts of these changes are investigated hereafter.

7.4.9.1 Cooling mode

There are two proposals to compute SEER values, one with 3 climates to cover EU performance variations of SEER values and another one with a market weighted average indicator. The variations of the performances of air conditioners with these conditions are shown hereunder.

	Helsinki	**Milan**	**Athens**	**Ave EU**	**Task 4**	**Seville**
Base case	3,2	3,3	3,5	3,2	3,1	3,0
TXV	3,4	3,5	3,7	3,4	3,2	3,2
INV AC	4,5	4,7	4,9	4,5	4,3	4,2
CP1	4,8	5,1	5,2	4,8	4,6	4,5
DEF	4,8	5,1	5,2	4,8	4,6	4,5
CK2	4,8	5,1	5,2	4,8	4,6	4,5
EXV	4,9	5,2	5,3	5,0	4,7	4,6
CP2	5,2	5,5	5,7	5,3	5,0	4,9
INV DC	5,6	6,0	6,1	5,7	5,5	5,2
ALL DC	6,0	6,4	6,5	6,1	5,8	5,6
HE1	6,3	6,7	6,9	6,4	6,1	5,9
HE2	6,6	7,0	7,2	6,6	6,3	6,2
CK1	6,6	7,0	7,2	6,6	6,3	6,2
Sb	6,6	7,0	7,2	6,6	6,3	6,2
HE3	6,8	7,2	7,4	6,9	6,5	6,4
HE4	7,0	7,4	7,6	7,0	6,7	6,5
HE5	7,1	7,4	7,7	7,1	6,8	6,6
CP3	7,4	7,7	8,0	7,4	7,0	6,9

Table 7-33: Climate sensitivity of SEERon values for the 3.5 kW cooling only unit.

Even with extreme climate, the variation of SEERon is relatively small, the maximum difference between warmest and coldest climates lies between 15 % and 20 %. There is indeed a compensation between performance increase with outdoor temperature decrease and lower average part load ratio for mild and cold climates and more cycling losses. As compared to task 4 results, performances increase by 5 % when shifting to the new proposal for average EU conditions as compared to the old index (noted Task 4 in the table).

In order to compute an equivalent SEER including auxiliary consumption, the following operating and equivalent hours for the different climates are considered.

	Athens	**Milan**	**Helsinki**	**Weighted average EU**	**Seville**
Equivalent Hours Cooling	500	350	250	350	500
Cooling Thermo-off	128	421	569	221	603
Cooling Standby	2576	2142	1274	2142	3430
Crankcase heater(*)	2704	2563	1843	2672	5880

(*) Supposed equal to zero for small cooling air conditioners (equipped with rotary compressor) and fully accounted for larger units.

Table 7-34: Operating hours for the cooling season for different climates

This leads to the following SEER values. The variation of SEER with climate is even more limited (~12 % to 19 %). As compared to SEER values computed with Task 4 results, SEER values for the average EU climate are increased - mainly because of lower hours in auxiliary modes – from 5 % with low auxiliary power values to 20 % maximum. Consequently, the new conditions for average EU values are kept hereafter.

	Helsinki	Milan	Athens	Ave EU	Seville	Task 4
Base case	3,1	3,0	2,9	2,9	2,8	2,6
TXV	3,3	3,2	3,1	3,1	3,0	2,7
INV AC	4,3	4,2	4,0	4,1	3,9	3,5
CP1	4,6	4,4	4,3	4,3	4,1	3,7
DEF	4,6	4,4	4,3	4,3	4,1	3,7
CK2	4,6	4,4	4,3	4,3	4,1	3,7
EXV	4,7	4,5	4,4	4,4	4,2	3,8
CP2	4,9	4,8	4,6	4,7	4,4	4,0
INV DC	5,3	5,1	5,0	5,0	4,7	4,3
ALL DC	5,8	5,5	5,3	5,4	5,1	4,6
HE1	6,1	5,8	5,6	5,6	5,4	4,7
HE2	6,3	6,0	5,8	5,8	5,6	4,9
CK1	6,3	6,0	5,8	5,8	5,6	4,9
Sb	6,6	6,3	6,1	6,2	5,9	5,8
HE3	6,8	6,5	6,3	6,4	6,1	6,0
HE4	7,0	6,7	6,4	6,5	6,2	6,1
HE5	7,1	6,8	6,5	6,6	6,3	6,2
CP3	7,3	7,0	6,8	6,8	6,5	6,4

Table 7-35: SEER values for reference set of seasonal conditions for 3.5 kW reversible units

We will note hereafter SEER the SEER indice with four points resulting from average operating conditions computation and SEER2 the indice using the bin method.

For the cooling mode, the equivalence between the two different SEER indices are presented in the next table for the 5 base cases.

Single duct 2.2 kW				**Split 7.1 kW Cooling only**				**Split 3.5 kW Cooling only**			
Options	**SEER**	**SEER2**	**EER**	**Options**	**SEER**	**SEER2**	**EER**	**Options**	**SEER**	**SEER2**	**EER**
BASE CASE	1,7	1,9	2,3	**Base case**	2,3	2,5	2,5	**Base case**	2,5	2,8	2,9
INV AC	3,2	3,4	2,3	**TXV**	2,4	2,6	2,5	**TXV**	2,6	2,9	2,9
Sb	3,4	3,6	2,3	**INV AC**	3,2	3,4	2,5	**INV AC**	3,4	3,8	2,9
CP1	3,9	4,2	2,8	**CP1**	3,4	3,7	2,7	**Sb**	3,8	4,1	2,9
F1	4,0	4,3	2,8	**HE-1**	3,7	4,1	3,2	**CP1**	4,0	4,4	3,2
F2	4,1	4,4	2,8	**Sb**	4,0	4,3	3,2	**CP2**	4,3	4,6	3,4
HE1	4,3	4,6	3,0	**EXV**	4,1	4,4	3,2	**HE0**	4,4	4,7	3,6
EXV	4,4	4,7	3,1	**INV DC**	4,4	4,7	3,3	**EXV**	4,5	4,9	3,6
CP2	4,7	5,0	3,3	**ALL DC**	4,7	5,0	3,4	**INV DC**	4,8	5,2	3,8
HE2	4,8	5,2	3,5	**CP2**	5,0	5,3	3,6	**ALL DC**	5,2	5,6	3,9
HE3	5,0	5,3	3,6	**HE0**	5,3	5,7	3,9	**HE1**	5,4	5,9	4,3
INV DC	5,2	5,6	3,9	**HE1**	5,5	6,0	4,3	**HE2**	5,6	6,1	4,7
HE4	5,3	5,7	4,0	**CP3**	5,9	6,3	4,6	**HE3**	5,8	6,3	5,0
HE5	5,4	5,8	4,2	**HE2**	6,1	6,6	5,0	**HE4**	5,9	6,5	5,2
CP3	5,6	6,1	4,4	**HE3**	6,3	6,8	5,3	**HE5**	6,0	6,6	5,4

				HE4	6,4	7,0	5,5	**CP3**	6,1	6,7	5,8
				HE5	6,5	7,1	5,7				

Split 3.5 kW Reversible				**Split 7.1 kW Reversible**			
Options	**SEER**	**SEER2**	**EER**	**Options**	**SEER**	**SEER2**	**EER**
Base case	2,8	3,0	3,1	**Base case**	2,7	2,8	2,9
TXV	2,9	3,2	3,1	**INV AC**	3,7	3,8	2,9
INV AC	3,8	4,2	3,1	**CP1**	3,9	4,0	3,1
CP1	4,1	4,5	3,4	**TXV**	4,0	4,1	3,2
DEF	4,1	4,5	3,4	**HE0**	4,2	4,3	3,4
CK2	4,1	4,5	3,4	**DEF**	4,2	4,3	3,4
EXV	4,2	4,6	3,4	**CK1**	4,2	4,5	3,4
CP2	4,4	4,9	3,6	**EXV**	4,3	4,6	3,4
INV DC	4,7	5,2	3,8	**CK2**	4,3	4,6	3,4
ALL DC	5,1	5,6	3,9	**INV DC**	4,6	5,0	3,6
HE1	5,4	5,9	4,3	**ALL DC**	5,0	5,3	3,6
HE2	5,5	6,1	4,7	**CP2**	5,3	5,6	3,9
CK1	5,5	6,1	4,7	**HE1**	5,5	5,9	4,3
Sb	5,9	6,5	4,7	**Sb**	5,7	6,1	4,3
HE3	6,1	6,7	5,0	**HE2**	5,9	6,3	4,7
HE4	6,2	6,8	5,2	**HE3**	6,1	6,5	5,0
HE5	6,3	6,9	5,4	**CP3**	6,3	6,7	5,3
CP3	6,5	7,1	5,8	**HE4**	6,4	6,9	5,5
				HE5	6,5	7,0	5,8

Table 7-36: Equivalence between the two sets of average EU cooling conditions

7.4.9.2 Heating mode

In order to get comparable values for heating efficiency values in Lot 1 and Lot 10, a common reference index was built on the basis of the Strasbourg climate chosen as the reference to compute EU heating systems heating needs.

It leads to the following scaling of previous SCOP (index with 8 points developed from average operating conditions in Task 4) and HSPF (bin method with Strasbourg climate) indices.

For HSPF, we use the sizing rules adopted in PrEN14825 for air air heat pumps :

- 100 % @ 2 °C ; the declared value @ -10 °C being 186 % of the rated capacity @ 2 °C.

We keep hereafter 2 °C as the balance point, even if –2 °C or –7°C would seem more common given that this rationale seems to come from a testing problem.

The results of the LLCC analysis obtained for the cooling season are in red. It leads to a HSPF value between 3 for 7.1 kW units and 3.3 for larger units.

Split 3.5 kW reversible				**Split 7.1 kW reversible**			
	COP	**SCOP**	**HSPF**		**COP**	**SCOP**	**HSPF**
Base case	3,4	2,3	2,8	**Base case**	3,2	2,2	2,5
TXV	3,5	2,4	3,0	**INV AC**	3,2	2,6	2,8

INV AC	3,5	2,8	3,2	**CP1**	3,4	2,8	3,0
CP1	3,7	3,0	3,3	**TXV**	3,5	2,9	3,0
DEF	3,7	3,1	3,3	**HE0**	3,7	3,0	3,2
CK2	3,7	3,1	3,4	**DEF**	3,7	3,1	3,3
EXV	3,8	3,2	3,6	**CK1**	3,7	3,2	3,3
CP2	4,0	3,4	3,7	**EXV**	3,8	3,3	3,4
INV DC	4,2	3,6	3,9	**CK2**	3,8	3,3	3,4
ALL DC	4,2	3,8	4,0	**INV DC**	3,9	3,5	3,5
HE1	4,5	4,0	4,2	**ALL DC**	4,0	3,7	3,6
HE2	4,8	4,2	4,2	**CP2**	4,3	4,0	3,9
CK1	4,8	4,2	4,2	**HE1**	4,5	4,1	4,0
Sb	4,8	4,2	4,4	**Sb**	4,5	4,1	4,0
HE3	5,0	4,4	4,5	**HE2**	4,8	4,3	4,2
HE4	5,2	4,5	4,6	**HE3**	5,0	4,5	4,4
HE5	5,4	4,6	4,8	**CP3**	5,3	4,7	4,6
CP3	5,7	4,8	4,8	**HE4**	5,6	4,8	4,7
				HE5	5,7	4,9	4,8

Table 7-37: Air air heat pump COP, SCOP and HSPF values with sizing @ 2 °C for Strasbourg

The number of hours used to compute the HSPF indices in heating mode are presented in the next table. With very low number of hours of auxiliary power modes for the Strasbourg climate over the heating season and crankcase heater hours affecting mainly the cooling season, the HSPF values are almost identical to the HSPFon values.

HOURS	**Athens**	**Strasbourg**	**Helsinki**
Season Hours	4344	5088	6576
Equivalent Hours heating (*), H_{HE} (rounded) single zone	1400	1400	2100
Heating Thermo-off, H_{HTO}	755	179	131
Crankcase heater, heating H_{HKC} (=H_{HTO})	755	179	131
Heating NEEDS	**Athens**	**Strasbourg**	**Helsinki**
Equivalent Hours heating	1400	1400	2100

Table 7-38: Hours kept to compute HSPF values

The table below shows how HSPF values vary with climate. This is of course because of different climate conditions but also because of different sizing conditions and consequently of more or less resistive heating accounted. With the present sizing @ 2 °C for air air heat pumps, resistive heating is high in Strasbourg. In case of sizing @ -7 °C, this could be reduced by 9 % leading to HSPF values 9 % higher. In all cases, there is no difference between HSPF and HSPFon values because of very low energy consumption of parasitics as compared to the heating function with hours kept in the HSPF methodology.

It appears that it would be a worthy indication to know the performance in heating mode for several climates.

	Athens(*)			Strasbourg			Helsinki(*)		
	HSPF	% resist. Heat	Pdesign = CAP(2)	HSPF	% resist. Heat	Pdesign = CAP(2)*186%	HSPF	% resist. Heat	Pdesign = CAP(-7) *156%
Base case	2,8	0%	3,2	2,7	11%	6,0	2,0	16%	4,4
TXV	3,0	0%	3,2	2,8	11%	6,0	2,1	16%	4,4
INV AC	4,0	0%	3,2	3,0	11%	6,0	2,4	16%	4,4
CP1	4,3	0%	3,2	3,2	11%	6,0	2,5	16%	4,4
DEF	4,3	0%	3,4	3,3	11%	6,3	2,5	16%	4,4
CK2	4,3	0%	3,4	3,3	11%	6,3	2,5	16%	4,4
EXV	4,5	0%	3,4	3,4	11%	6,3	2,6	16%	4,4
CP2	4,7	0%	3,4	3,6	11%	6,3	2,7	16%	4,4
INV DC	5,1	0%	3,4	3,7	11%	6,3	2,8	16%	4,4
ALL DC	5,5	0%	3,4	3,9	11%	6,3	2,9	16%	4,4
HE1	5,7	0%	3,4	4,0	11%	6,3	2,9	16%	4,4
HE2	5,8	0%	3,4	4,2	11%	6,3	3,0	16%	4,4
CK1	5,8	0%	3,4	4,2	11%	6,3	3,0	16%	4,4
Sb	5,8	0%	3,4	4,2	11%	6,3	3,0	16%	4,4
HE3	6,0	0%	3,4	4,4	11%	6,3	3,0	16%	4,4
HE4	6,1	0%	3,4	4,5	11%	6,3	3,1	16%	4,4
HE5	6,2	0%	3,4	4,6	11%	6,3	3,1	16%	4,4
CP3	6,4	0%	3,4	4,8	11%	6,3	3,2	16%	4,4

(*) For Athens, the declared Pdesign value is the capacity at 2 °C and at Helsinki, it is 156 % of –7 °C capacity.

Table 7-39: Climate sensitivity of the HSPF indice for the 3.5 kW reversible unit

7.4.10 Comparison of the LCC analysis with Lot 1 outcome

Net efficiency of heating systems in the EuP study Lot 1 is defined as the ratio of heating needs to primary heating energy consumption of the whole system, boiler, controls, fans and pumps. For this net efficiency, the scale resulting from this work is reported in the table below. Following the EuP methodology for boiler systems, a LCC analysis was performed and the LLCC leads to minimum energy performance requirements to be set at 76 % of net efficiency (www.ecoboiler.org).

Labelling of net efficiency, Lot 1 - 2007			
A3 (*)	Superior to		120%
A2	Between	104%	120%
A1	Between	88%	104%
A	Between	80%	88%
MEPS		MEPS Lot 1	76%
B	Between	72%	80%
C	Between	64%	72%
D	Between	56%	64%
E	Between	48%	56%
F	Between	40%	48%
G	Inferior to	40%	40%

Table 7-40: Lot 1 labelling scale, (*) A+++ transformed to A3 following latest Commission proposal

To translate these primary energy net efficiency values in terms of equivalent seasonal coefficient of performances for air to air heat pumps, some corrections are required above the 2.5 coefficient of primary energy.

- Spatial variations or stratification: some default values used in national thermal regulations are referenced in the EN 15316-2-1 and stratification leads to decrease heating efficiency with a correction factor between 0,9 and 0,85. The following definition is proposed: **Qstrat** is stratification losses, with **Qstrat = (Csstrat + cband*2%),** where **Csstrat** is system-specific constant[1] and **cband** is the control-band, i.e. the maximum deviation up- and downwards from the set room temperature[2]. Cband would be typically between 1 and 2 K for air to air heat pumps. So the correction is between 12 and 14 %.

- Temporal variations: the control not being perfect, there are also temperature variations linked to the control accuracy of the unit temperature controller. Some default temperature correction for set point used in national thermal regulations are referenced in the EN 15316-2-1. For air conditioners, this would typically lead to +/- 1.5 K. Default value is computed with the following formula **Qfluct= (Cfluct + cband*4%)**. A default value of 13 % is kept with inverters as the reference. **Cfluct** is system-specific constant[3]. So the correction is between 13 % and 17 %.

- Multizone control : in Lot 1, only heating systems designed for a whole house get credit for multizone control since different set points can be fixed in different zones. There is here a credit of 5 % to 10 % for multi zone products versus single zone ones depending on the internal heat transfer between zones and of the differences in set points applied. Heating systems should be oversized by 15 % to take benefit of the load reduction. With dwellings being in majority not ventilated in Europe, heat transfer between zones is generally small and a default 9 % is used.

- Setback: night setback is considered in Lot 1 only for multizone systems and it leads to a reduction of 12 % of the heating needs. In order to be credited of these 12 %, the capacity of the heat pump should be sized 20 % above the requirements for multizone systems without setback.

All in all, this leads to an overall correction coefficient lying between 3.7 and 4.1, with a default value of 3.8, to be applied to compare lot 1 and lot 10 results. What could be the scale of air to air heat pumps compared to boilers in Lot 1 model is presented in the table below.

Whether optimisation is led on the heating and cooling functions separately, requirements should match. Adopting options leading to LLCC requirements in cooling mode would lead to minimum performance of 3.3 in heating mode. This would then be very close to requirements for other heating systems.

Lot 1 heating system label		**Air air heat pump**		
Grade	**Net efficiency**	**SCOPmin**	**SCOPmax**	**SCOPave**
A+++	120%	4,5	4,9	4,6
A++	104%	3,9	4,3	4,0
LLCC LOT 10 for yearly consumption	104%			4,0
A+	88%	3,3	3,6	3,4

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[1] Estimate for central air-heating Cstrat=7%, for local heaters 10%.

[2] A room temperature of 19 oC that fluctuates between 18 and 20 °C has cband=1.

[3] Estimate for central air-heating and Cfluct=6% and for local heaters 9%.

A	80%	3,0	3,3	3,1
LLCC LOT 10 forcooling consumption	77%			3,0
MEPS	76%	2,8	3,1	2,9
B	72%	2,7	3,0	2,8
C	64%	2,4	2,6	2,5
D	56%	2,1	2,3	2,2
E	48%	1,8	2,0	1,9
F	40%	1,5	1,6	1,5
G	40%	1,5	1,6	1,5

Table 7-41: Air air heat pump HSPF values corresponding to Lot 1 labelling grades and MEPS

7.5 Long-term targets (BNAT) and systems analysis

MEEuP methodology

- Discussion of long-term technical potential on the basis of outcomes of applied and fundamental research, but still in the context of the present product archetype;
- Discussion of long-term potential on the basis of changes of the total system to which the present archetype product belongs: Societal transitions, product-services substitution, dematerialisation, etc.

7.5.1 Present product archetype

The efficiency of the products in the scope is very dependant of the temperatures and load ratio in the standards. A split air conditioner rated 3 in the US in heating mode could well reach 5 or 6 on the JRA or EU standard. Based on this remark the first point is to find a common reference to compare the different products.

In cooling mode, at rated capacity (ISO T1 conditions), the reference “ideal” Carnot EER is of 128. The Carnot potential at reduced outdoor temperature is about 300.

The US Department of Energy planned a feasibility limit of SEER 9.1 (SI units) with the ARI standard, but this was while maintaining the dehumidification capacity of the units. With the separation of the functions of cooling and dehumidification, it should be possible to go beyond this SEER limit.

The race is no longer on full but at part load which is still a rather new territory to look for energy efficiency gains. For instance, the compressor are today designed for 1 single point, rating standard cooling conditions and the adoption of seasonal performance standards could change this and enable to get better performances where it matters for air conditioners rather than for the compressor standard point.

In heating mode, perspectives of improvement are more limited, since the Carnot equivalent H1 “ideal efficiency” would be of 22.5 and would decrease at 16.3 at 2 °C outdoor and at about 10 for – 7°C. The present efficiency levels of air to air heat pumps tends to show that there is not so much gain possible in heating mode as in cooling mode.

The analysis of alternative refrigerant fluids has shown that a transition to other refrigerant would be problematic either for energy efficiency or for security.

According to Japanese manufacturers (ECCJ, 2006), limits in size of the unit, in material input and in noise will limit further efficiency improvement of the units in both modes as compared to these long term potentials; it is however difficult to make a prediction.

7.5.2 Long-term potential

The energy efficiency could be still improved by a closer interaction with outdoor climate by implementation of “adaptive” set points in cooling mode – whether it is finally acceptable by the end-user, integration of fresh air introduction for a full control of the free cooling potential - that necessitates a transformation of the present split product archetype and cannot be applied to all situations, as previously explained in task 6.1.

To go beyond traditional vapor compression cycle limits, several potential candidates are commonly quoted. One can find an extract in the lot 12 final report of alternative cooling technologies.

At the present stage of development of vapor compression technologies, it seems that only the integration of “more” renewable energy in the energy balance of the cooling or heating functions can lead to further improvement.

Sanyo (NYT, 2007) announced the release of a product coupling solar panels and a classical air conditioner plus batteries. Cooling loads being high when electricity can be produced a small battery is advertised to be enough for the product to be almost independent from the grid. The selling price of 10900 US$ (or 7630 euros) is indicated for what seems to be a 2.8 kW air conditioner unit but the total area of the panels is not known. Solar panel is still sold at high prices, between 3 and 5 US$ per W. At the moment, the solar photovoltaic cells are not cheap enough to be sold without getting important subsidies. In Europe, these subsidies are in majority the results of a specific selling price of the kWh under a production contract with the electricity grid, and this appears as a vital component of the solar cells market uptake. Whether this is indeed a product that can be sold and installed, there should be no specific problem to integrate the share of renewable energy and thus decreasing its energy consumption index. It is to be noticed that other competitors made similar announcement, as Solcool on the US market. They will have to compete in the coming future with air conditioners supplied by electricity from the grid with a lower carbon content, according to the EU objective in that matter.

The absorption cycle (Ammonia/water) seems to provide the more viable solution for the development of renewable cooling and heating. Heat can be provided by solar panels or by a heat network and enables cooling with an EER of 0.7 in cooling mode for single effect machines and a heating COP of 1.2; mini reversible water based heat pumps are commercially available in the 5 tons range and are being developed for smaller sizes. In addition, the heat of the absorber is recovered in the cycle and a cooling tower is not necessary to evacuate these calories. Recent research programs led in the USA (ORNL, 2008) intend to develop heating COP of 2 and higher and cooling COP of 1.1 or higher. The cycle still requires an important part of electric consumption in fans and pumps.
To give an order of magnitude with present EER of 0.7 and COP of 1.2, the Rotartica (www.rotartica.com) 4.5 kW water based absorption heat pump still requires 500 W for fan power and suggested required circulation pump is of 480 W. It means maximum performance for 100 % renewable heat is of EER=4.5 and COP=10.8[4]. The circulation pump for the water distribution system in the house is not included. It is not a problem to imagine an air based system with the same working principle by adding an indoor fan and performance would remain of the same order of magnitude. The results of the Ecodesign study of Lot 11 on pumps, fans and motors, suggest that with BAT available technologies for fans and pumps, EER and COP 30 % higher than present values could be reached. The coupling with vacutubes could enable to reach EER of 9 and COP of 22 with 100 % solar hot water source but the intermittency problem remains.

Climatewell solution (www.climatewell.com) is an innovation in the field of absorption heating and cooling. “The ClimateWell 10 can operate in three modes – charging, heating and cooling. Charging mode stores energy through drying a salt (Lithium Chloride - LiCl) that subsequently can be used whenever required.” The manufacturer gives the following average characteristics.

Figure 7-8: Climatewell energy characteristics

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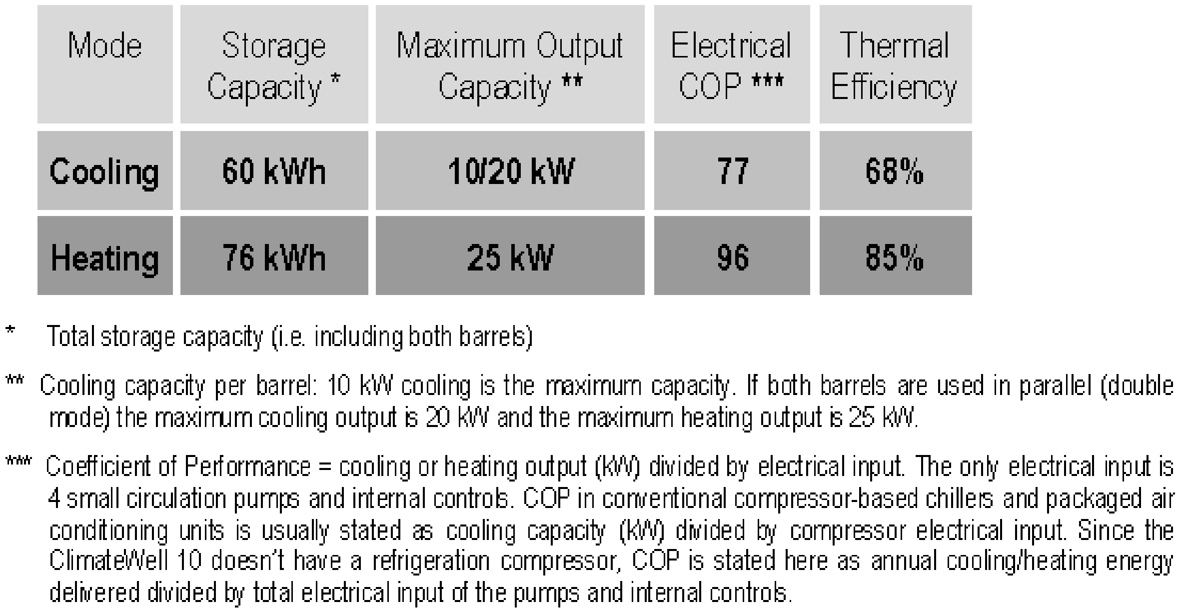
[4] Leaving water temperatures are of 18 °C and 45 °C respectively in cooling and in heating mode and heat source temperature of 90 °C.



Mode	Storage Capacity *	Maximum Output Capacity **	Electrical COP ***	Thermal Efficiency
Cooling	**60 kWh**	**10/20 kW**	**77**	**68%**
Heating	**76 kWh**	**25 kW**	**96**	**85%**

* Total storage capacity (i.e. including both barrels)

** Cooling capacity per barrel: 10 kW cooling is the maximum capacity. If both barrels are used in parallel (double mode) the maximum cooling output is 20 kW and the maximum heating output is 25 kW.

*** Coefficient of Performance = cooling or heating output (kW) divided by electrical input. The only electrical input is 4 small circulation pumps and internal controls. COP in conventional compressor-based chillers and packaged air conditioning units is usually stated as cooling capacity (kW) divided by compressor electrical input. Since the ClimateWell 10 doesn't have a refrigeration compressor, COP is stated here as annual cooling/heating energy delivered divided by total electrical input of the pumps and internal controls.

COP and EER that can be reached by this solution seems well above the ones of the absorption, but the circulation pump for solar collector and for water distribution are not included. The electric power required is of 130 W, ie 65 W for a 5 kW unit, about one tenth of the Rotartica unit. The manufacturer advises a surface between 20 and 50 m^2 of solar thermal collectors for 1 Climatewell 10 unit, depending on the thermal requirements and solar radiations of the site. The coupling with vacutubes (without pump) could enable to reach the EER and COP announced in Figure 7-8. Technical detailed information is lacking to make a more detailed comparison.

For these two products, the variation of the heat source availability remains and manufacturers advise to complete the installation with backup means when solar heat is used. Heating network are another solution for the backup or main heat source to integrate renewable energy.

The same problem will appear with other potential candidate for renewable heating and cooling like adsorption cycles and desiccant systems (the latter in cooling mode only).

For other cooling and heating alternative cycles, only the Stirling cycle cooler -that is intrinsically reversible-, since it is driven by electricity, could know a development comparable to the one of the present technology. A prototype developed for residential air conditioning (Janssen, 2002) showed efficiency levels comparable to the ones of average reversible split air conditioners in Europe today, but the prototype had a smaller capacity than required. The theoretical potential for energy efficiency improvement is higher than for the vapor compression cycle but technical barriers remain.

Conclusions

An engineering approach has been adopted to perform the life cycle cost of the improvement of base case units. This study was led using the seasonal performance indices derived from Task 4 in both cooling and heating mode.

For cooling units, the potential of improvement has been estimated to be:
- Split 3.5 kW cooling only: LLCC combination energy is 62 % of the initial energy consumption. The simple payback time of the unit as compared to the base case is of 3.8 years. It corresponds for the options computed to a SEERon of 4.5 (base case 2.9, BAT 7.0). The price increases by 16 % at LLCC (BAT 203 %).
- Split 7.1 kW cooling only: LLCC combination energy is also about 60 % of the initial energy consumption. It corresponds for the options computed to a SEERon of 4.2 (base case 2.6, BAT 6.9). The price increases by 16 % (BAT 261 %).
- Single duct 2.2 kW: LLCC combination energy is 43 % of the initial energy consumption. It corresponds for the options computed to a SEERon of 4.5 (base case 1.9, BAT 6.9). Optimisation has been led at constant ratio between outdoor air flow rate and cooling capacity in order to avoid a loss of functionality for the end-user. The price increases by 36 % (BAT 220 %). It is to be noticed that performances with a propane unit would give about 7 % higher SEER and EER values for about the same cost, shifting the LLCC point by 7 % to SEERon 4.8, with a supplementary advantage regarding direct emissions as compared to R410A units and is then to be kept for the LLCC value. Also, for the same capacity range, split units with best available technologies would enable to reach higher efficiencies for the same cooling duty.

For reversible units, when considering the summation of cooling and heating consumption, the potential of improvement has been estimated to be:
- Split 3.5 kW reversible: LLCC combination energy is 54 % of the initial energy consumption. The simple payback time of the unit as compared to the base case is of 3.3 years. It corresponds for the options computed to a SEERon of 6.1 (base case 3.1, BAT 8.2) and a SCOPon of 4.4 (base case 2.6, BAT 5.6). The price increases by 52 % (BAT estimated to 225 %).
- Split 7.1 kW reversible: LLCC combination energy is 56 % of the initial energy consumption. It corresponds for the options computed to a SEERon of 5.7 (base case 2.9, BAT 6.9) and a SCOPon of 4.2 (base case 2.7, BAT 5.3). The price increases by 51 % (BAT 242 %).

The results of the improvement scenarios have been compared with products available on other markets and the relation between seasonal performances and rated performances are similar. The sensitivity analysis has been conducted for different countries and proved to be robust for different climates and energy costs.

In all the simulations, inverter driven compressor was one of the primary energy efficiency options to implement. Increase in heat exchanger size has been found more costly at equal gain level. For standby and crankcase heaters, results depend on the cases.

Following comments received on these results, a separate optimisation for heating and cooling seasons has been undertaken. It appears that for the cooling season LLCC levels of reversible units are comparable to the ones of cooling only units. Since a new seasonal performance indicator in cooling mode based on the bin method has been proposed, seasonal efficiency values have been translated for this new indicator.

Regarding heating, results have been compared to requirements established in the EuP study Lot 1 for other heating systems. To that extent, a revised heating seasonal performance factor has been developed for split air conditioners and rules set up for the comparison of air based and water based heating systems.

It appears finally that the improvement potential of air conditioners in heating mode according to our calculations is higher than was computed for other heating systems. With the obligation to have compatible requirements for the cooling and heating seasons for reversible units, adopting the options leading to the LLCC for the cooling season would result in requirements in heating mode compatible with the requirements of other heating systems.

Concerning long term potential on the basis of this product architecture, “ideal” Carnot indications show that going to seasonal energy performances in cooling mode could help in finding energy efficiency gains that become more difficult to achieve at rated conditions at BAT levels. In heating mode, there is much less potential to increase the performances than in cooling mode.

Further progress will come from a change in the product architecture, integration within the buildings, capability to manage fresh air renewal to enable free cooling and from the introduction of renewable energy with cooling from solar hot water or electricity supplied by renewable sources.

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