European Commission DG ENTR

Preparatory Study for Eco-design Requirements of EuPs

[Contract N° S12.515749]

Lot 1

Refrigerating and freezing equipment:

Service cabinets, blast cabinets, walk-in cold rooms, industrial process chillers, water dispensers, ice-makers, dessert and beverage machines, minibars, wine storage appliances and packaged condensing units

Task 6: Improvement Potential

Final report

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Bio Intelligence Service - Scaling sustainable development
Industrial Ecology - Nutritional Health

Bio Intelligence Service S.A.S - bio@biois.com
20-22 Villa Deshayes - 75014 Paris - France
Tél. +33 (0)1 53 90 11 80 - Fax. +33 (0)1 56 53 99 90

Contact BIO Intelligence Service S.A.S.
Shailendra Mudgal – Jonathan Bain
☏ +33 (0)1 53 90 11 80
shailendra.mudgal@biois.com
jonathan.bain@biois.com

Project Team

BIO Intelligence Service

Mr. Shailendra Mudgal

Mr. Benoît Tinetti

Mr. Jonathan Bain

Mr. Raul Cervantes

Mr. Alvaro de Prado Trigo

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6. Improvement Potential

6.1. INTRODUCTION

Task 6 quantitatively analyses design options, based on the prioritised improvement options selected in Task 5, for each of the product groups. The impact of each of these "options" is calculated using the MEEuP EcoReport tool, and their environmental costs and benefits, particularly relative energy consumption, and economic impacts, in terms of Life Cycle Cost (LCC), are assessed. The assessment of monetary LCC is relevant as it indicates whether design solutions may impact the user expenditure over the total lifetime of the product (purchase, operating, end-of-life costs, etc.).

This allows identification of the Best Available Technology (BAT) solution, and the option with the Least Life Cycle Costs (LLCC). The BAT will be the option that results in the most significant reductions in environmental impacts and indicates a short- to medium-term target that will probably be more subject to promotion measures than to restrictive action. In the case where the LLCC solution is set as a minimum target, the distance between the LLCC and the BAT indicates the remaining space for product-differentiation (competition).

The Best Not yet Available Technologies (BNAT) are also discussed, assessing longer-term improvement potential of the product groups.

6.2. IDENTIFICATION OF DESIGN OPTIONS

This section presents the different improvement options applicable to each Base Case. The design option(s) should:

- not have a significant variation in the functionality and in the performance parameters compared to the Base Cases and in the product-specific inputs;
- have a significant potential for ecodesign improvement without significantly deteriorating other impact parameters; and
- not entail excessive costs, and Impacts on the manufacturer should be investigated.

The energy savings per technology are not additive. Instead, a common methodology for all products has been used as described in Task 5 (section § 5.5). The energy saving for the different improvement options are not additive. The percentage of savings per option is subtracted from the energy consumption level that already accounts for reductions enabled by other improvement options already considered. The example below gives a better idea of the calculation methodology (figures do not correspond to any particular product).

Improvement option	Energy saving of AEC enabled by improvement (%)	Product AEC (%)
Improvement 1	5	(100-5)
Improvement 2	10	(100-10)
Improvement 3	20	(100-20)
TOTAL	35	65

Final AEC = 100*((100-5)*(100-10)*(100-20)) = 68.4% of original
(reduction of 31.6% instead of the 35% calculated by addition of improvements)

For each of the improvement options, the modifications implied by their implementation in the Base Case are quantified by the change in energy consumption. It is currently assumed that the differences in the material used for the improvement options are not significant, and hence changes in material quantities have not been assessed. Besides, **it is assumed that the improvement options are equally applicable to all sub-types of equipment in each product category**. However, **the analysis differentiates between positive and negative operating temperatures for service cabinets, chillers and remote condensing units** (as does the Base Case). The improvement potential of a particular improvement option or a combination of improvement options is evaluated using the MEEuP EcoReport tool.

The cost effectiveness of an improvement option can be expressed in terms payback time in years, defined as a ratio between:

(Cost increase with reference to the Base Case) and (annual electricity consumption difference in kWh*electricity tariff)

Besides, the impact on the **life cycle cost** of the Base Case of each individual design option can be calculated. On this basis, the combination of design options with the **least life cycle cost** can be identified.

In Task 7, the scenarios will be investigated as a basis for defining future Ecodesign requirements, taking into account, among other parameters, life cycle costs and technical constrains.

6.2.1. HT AND LT SERVICE CABINET BASE CASES

After an analysis of available technologies in Task 5, the improvement options selected to reduce the environmental impacts of a service cabinet aim at reducing the total energy consumption (TEC) of the cabinet. Each of the improvement options applicable to the Base Case are presented in this section with their relative impacts on the product cost compared to the Base Case.

Table 6-1 and Table 6-2 present the summary of the selected improvement options of the Base Cases for service cabinets at high temperature (HT) and low temperature (LT).

Table 6-1: Identified energy saving potentials for the HT service cabinet Base Case

	Improvement option	TEC savings compared to Base Case (%)	Increase of product price compared to Base Case (€)	Payback time (years)
Option 1	High efficiency compressor	7%	20	1.19
Option 2	ECM evaporator fan motor	12%	18	0.63
Option 3	ECM condenser fan motor	8%	20	1.04
Option 4	High efficiency fan blades	3%	5	0.69
Option 5	Sealing door frame	19%	0	0.00
Option 6	R290	5%	40	3.33
Option 7	Thicker insulation	4%	100	10.42
Scenario A	Incorporates options 1+2+3+4+5+7	43%	163	1.58
Scenario B	Incorporates options 1+2+3+4+5+6+7	46%	203	1.84
Weighted real BAT improvement	As described in Task 5, this product includes R290	75%	1300	7.22

Table 6-2: Identified energy saving potentials for the LT service cabinet Base Case

	Improvement option	TEC savings compared to Base Case (%)	Increase of product price compared to Base Case (€)	Payback time (years)
Option 1	High efficiency compressor	10%	40	0.67
Option 2	ECM evap	7%	18	0.43
Option 3	ECM cond	3%	20	1.11
Option 4	High Efficiency Fan Blades	3%	5	0.28
Option 5	Sealing door frame	26%	0	0.00
Option 6	R290	5%	40	1.33
Option 7	Thicker insulation	5%	110	3.67
Scenario A	Incorporates options 1+2+3+4+5	45%	193	0.71
Scenario B	Incorporates options 1+2+3+4+5+6+7	47%	233	0.83
Weighted real BAT improvement	As described in Task 5, this product includes R290	56%	1450	4.32

6.2.1.1 Option 1: High efficiency compressor

- Environmental impacts: by using a high efficiency compressor, the equipment has a better performance and requires about 7% less energy input for HT, and 10% for LT, to achieve the same temperature targets.
- Costs: the cost of the original HT Base Case would increase approximately €20 if this technology is implemented, and €40 for LT.
- Constraints: none identified.

6.2.1.2 Option 2: ECM fans for evaporator

- Environmental impacts: ECM is more efficient, hence draws less power and produces a lower heat load, reducing the burden on the refrigeration system. This technology is estimated to save about 12% of the TEC for HT and 7% for LT.
- Costs: € 18 for HT and LT, under 1% of the purchase prices.
- Constraints: none identified.

6.2.1.3 Option 3: ECM fans for condenser

- Environmental impacts: ECM is more efficient, hence draws less. This technology is estimated to save about 8% of the TEC for HT and 3% for LT.
- Costs: €20 for HT and LT, 1% of the purchase prices.
- Constraints: none identified.

6.2.1.4 Option 4: High efficiency fan blades

- Environmental impacts: these could reduce the required power of the fan motor, due to their high efficiency, hence reduce consumption of energy and lower heat load created by the motors, also reducing the burden on the refrigeration system. This technology is estimated to save about 3% of the TEC for HT and LT.
- Costs: €5 for HT and LT, under 1% of the purchase prices.
- Constraints: none identified.

6.2.1.5 Option 5: Sealing door frame

- Environmental impacts: this design feature reduces the heat infiltration into the internal volume of the product, thereby reducing the load on the refrigeration system. This option could reduce TEC by 19% for HT and 26% for LT.
- Costs: this option is thought to incur no additional costs.
- Constraints: none identified.

6.2.1.6 Option 6: R290

- Environmental impacts: this technology would reduce consumption of energy of the refrigeration system, saving about 5% of the TEC for HT and LT, and reduce the GWP due to leakage.
- Costs: €40 for HT and LT.
- Constraints: the flammability of the refrigerant would need to be carefully and safely managed. Products would need modification to eliminate potential sources of sparking (e.g. the internal light fitting and possibly motor starter). As hydrocarbons are already widely used in the commercial market and domestic sector, it is conceived that this is not a significant issue.

6.2.1.7 Option 7: Thicker insulation

- Environmental impacts: this technology would reduce consumption of energy of the refrigeration system, saving about 4% of the TEC for HT and 5% LT
- Costs: approximately €100 for HT, and €110 for LT.
- Constraints: If the external dimensions of the product are constrained, thicker insulation will reduce the internal storage.

6.2.1.8 Scenario A: Incorporates options 1+2+3+4+5+7

- Environmental impacts: the combination of these technologies is estimated to reduce TEC by 43% for HT and 45% for LT.
- Costs: €163 for HT and €193 LT.
- Constraints: this option has the same constraint as each of its components.

6.2.1.9 Scenario B: Incorporates options 1+2+3+4+5+6+7

- Environmental impacts: the combination of these technologies is estimated to reduce TEC by 46% for HT and 47% for LT.
- Costs: €203 for HT and €233 for LT.
- Constraints: this option has the same constraint as each of its components. The use of R290 has been cautioned by some stakeholders.

6.2.2. Blast cabinet Base Case

The potential improvement options for blast cabinets are expressed in Table 6-3. The improvement options aim to reduce the TEC of the equipment, by reducing the electricity consumption during the use-phase. By comparison of the price of the actual BAT model and the improvement potentials, the prices of the latter might have been underestimated.

Table 6-3: Identified energy saving potentials for the Base Case Blast Cabinets

	Improvement option	TEC savings compared to base-case (%)	Increase of product price compared to base-case (€)	Payback time (years)
Option 1	High Efficiency Fan Blades	9%	10	0.3
Option 2	Electronic expansion valve	12%	100	1.8
Option 3	Variable speed drive (VSD) compressor	10%	200	5.5
Option 4	Insulation thickness	4%	100	6.9
Option 5	ECM Fan for evaporator	7%	64	1.6
Option 6	R290	5%	200	11.0
Scenario A	1+2+3+4	31%	410	5.1
Scenario B	1+2+3+4+5	36%	450	4.7
Scenario C	1+2+3+4+5+6	39%	650	5.7
Weighted real BAT improvement	As described in Task 5	35%	753	5.9

6.2.2.1 Option 1: High efficiency fan blades

- Environmental impacts: this technology is estimated to save around 9% of the TEC. It is relevant for blast cabinets due to the high use of energy used by the fans.

- Costs: the implementation of this option is estimated to increase the price by € 10 per fan per product. The payback period of this technology is less than 1 year when compared to the weighted product price.
- Constraints: none identified.

6.2.2.2 Option 2: Electronic Expansion Valve (EEV)

- Environmental impacts: in contrast to traditional expansion valve, it is not activated by thermostatic forces auctioning springs, bellows or pushing rods. EEV are activated by more accurate signals emitted from an electronic controller. Therefore, these are considered to be more precise and to have fewer variations. Thanks to this, the TEC can be decreased by around 12%.
- Costs: the cost increase due to the addition of electronic expansion valve to blast cabinets is about €100 per valve. The payback period of this technology is less than 2 year when compared to the weighted product price.
- Constraints: this technology provides significant improvement, but requires more maintenance as it is non-mechanical and less-robust.

6.2.2.3 Option 3: Variable speed drive (VSD) compressor

- Environmental impacts: VSD for compressors allows operation at a wide range of workloads optimising the energy consumption and increasing the efficiency. By using this technology it is possible to save up to 10% of the TEC.
- Costs: this technology increases the cost of the Base Case by € 400. The payback period of this technology is less than 6 years when compared to the weighted product price.
- Constraints: this technology could, if not controlled properly, reduce the energy efficiency of the whole system by decreasing the heat exchange rate and making the chilling or freezing process longer. Since food safety is the main requirement of blast equipment, this option has to be carefully controlled to avoid extra cycle time.

6.2.2.4 Option 4: Insulation thickness

- Environmental impacts: the heat transfer from the exterior is reduced by this option, avoiding extra heat coming from the surroundings. In this way, the refrigeration system is only focused on the heat load of the foodstuff. Using this technology there is a potential to save up to 4%energy.
- Costs: the cost of the Base Case increases by € 100, i.e. 1.7% of the total price. The payback time is estimated to be almost 7 years. The proportion of increase in price to the energy savings prevents to integrate this improvement option to other ones.
- Constraints: this option depends on the availability of space to fit the new thickness of insulation. It is necessary to determine the optimal thickness during the designing phase.

6.2.2.5 Option 5: Evaporator ECM fans

- Environmental impacts: This technology increases the efficiency of the system and leads to 7% energy savings as compared to the TEC.
- Costs: the implementation of this technology implies € 64 increase in cost as compared to the initial Base Case, i.e. 1% of the final cost. The payback period of this technology is less than 2 years when compared to the weighted product price.
- Constraints: none identified.

6.2.2.6 Option 6: R290

- Environmental impacts: This technology increases the energy efficiency of these machines, and reduces the GWP. The potential energy savings from using R290 are 5%.
- Costs: the implementation of this technology implies 5% increase in cost as compared to the initial Base Case, i.e. € 200. The payback period of this technology is less than 11 years when compared to the weighted product price.
- Constraints: safety problems due to its flammability.

6.2.2.7 Scenario A: Incorporates options 1+2+3+4

- Environmental impacts: this option combines the benefits of option 1, 2, 3 and 4 which results in an estimated 31% of savings in the TEC. This saving is not a simple addition of the savings resulting from each of the 4 options considered here, but it is rather an estimation which considers possible overlaps. The energy savings of every technology has been deducted from the reduced energy used when applied another technology. In cost addition, this option is the least expensive.
- Costs: the total increase in cost due to the combination presented in this option is € 410, and has a payback time of 3.7 years.
- Constraints: this option has the same constraint as each of its components.

6.2.2.8 Scenario B: Incorporates options 1+2+3+4+5

- Environmental impacts: this option combines the benefits of option 1, 2, 3, 4 and 5 which results in an estimated 36% of savings in the TEC. This saving is not a simple addition of the savings resulting from each of the 5 options considered here, but it is rather an estimation which considers possible overlaps. The energy savings of every technology has been deducted from the reduced energy used when applied another technology.
- Costs: the total increase in cost due to this combination is € 450, and it has payback time of 3.5 years.
- Constraints: this option has the same constraint as each of its components.

6.2.2.9 Scenario C: Incorporates options 1+2+3+4+5+6

- Environmental impacts: this option combines the benefits of option 1, 2, 3, 4, 5 and 6 which results in an estimated 39% of savings in the TEC. This saving is not a simple addition of the savings resulting from each of the 6 options considered here, but it is rather an estimation which considers possible overlaps. The energy savings of every technology has been deducted from the reduced energy used when applied another technology. In cost addition, this option is the most expensive.
- Costs: the total increase in cost due to this combination is € 650, and it has payback time of about 4.5 years.
- Constraints: this option has the same constraint as each of its components.

6.2.3. WALK-IN COLD ROOM BASE CASE

After a detailed analysis of available technologies in Task 5, the improvement options selected to reduce the environmental impacts of a service cabinet aim at reducing the TEC. Each of the improvement options applicable to the Base Case are presented here with their relative impact on the product cost compared to the Base Case. Table 6-4 presents the summary of the selected improvement options.

Table 6-4: Identified energy saving potentials for the walk-in cold room Base Case

	Improvement option	TEC savings compared to Base Case (%)	Increase of product price compared to Base Case (€)	Payback time (years)
Option 1	Strip door curtains	13%	70	0.37
Option 2	Auto door closer	12%	111	0.63
Option 3	PSC evaporator fan	10%	100	0.69
Option 4	ECM evaporator fan	13%	150	0.79
Option 5	High efficiency fan blades	3%	50	1.14
Option 6	Insulation thickness	15%	250	1.14
Option 7	ECM condenser fan	3%	60	1.37
Option 8	R134a to replace R404a at HT, and R410a to replace R404a at LT	0%	0	0.00
Option 9	High efficiency LED light bulbs	4%	200	3.43
Option 10	Floating head pressure (plus electronic expansion valve)	8%	150	1.29
Option 11	Ambient subcooling	4%	170	2.91
Option 12	High efficiency compressor	5%	200	2.74
Scenario A	Incorporates options 1+3+5+6+7	37%	530	0.98
Scenario B	Incorporates all options 2+4+5 to 12	48%	1,341	1.92
Weighted real	As described in Task 5, this	35%	1,760	3.45

	Improvement option	TEC savings compared to Base Case (%)	Increase of product price compared to Base Case (€)	Payback time (years)
BAT improvement	product includes R134a/R410a			

6.2.3.1 Option 1: Strip door curtains

- Environmental impacts: this technology is estimated to save about 13% of the TEC
- Costs: €70, under 1% of the purchase price.
- Constraints: none identified.

6.2.3.2 Option 2: Auto door closer

- Environmental impacts: this technology is estimated to save about 12% of the TEC.
- Costs: €111, just over 1% of the purchase price.
- Constraints: none identified.

6.2.3.3 Options 3: PSCM fan for evaporator

- Environmental impacts: ECM is more efficient, hence draws less power and produces a lower heat load, reducing the burden on the refrigeration system. This technology is estimated to save about 10% of the TEC.
- Costs: €100, just over 1% of the purchase price.
- Constraints: none identified.

6.2.3.4 Options 4: ECM fan for evaporator

- Environmental impacts: ECM is more efficient, hence draws less power and produces a lower heat load, reducing the burden on the refrigeration system. This technology is estimated to save about 13% of the TEC.
- Costs: €150, just over 1% of the purchase price.
- Constraints: none identified.

6.2.3.5 Option 5: High efficiency fan blades

- Environmental impacts: these could reduce the required power of the fan motor, due to their high efficiency, hence reducing consumption of energy and lower heat load created by the motors, also reducing the burden on the refrigeration system. This technology is estimated to save about 3% of the TEC.
- Costs: €50.
- Constraints: none identified.

6.2.3.6 Option 6: Thicker insulation

- Environmental impacts: this technology would reduce the heat load, hence reduce consumption of energy of the refrigeration system, saving about 15% of the TEC.
- Costs: €250, 3% of the purchase price.
- Constraints: this option would reduce the internal storage volume or increase the product footprint.

6.2.3.7 Option 7: ECM fan for condenser

- Environmental impacts: ECM is more efficient, hence draws less power. This technology is estimated to save about 3% of the TEC.
- Costs: €60.
- Constraints: none identified.

6.2.3.8 Option 8: R134a to replace R404a at HT, and R410a to replace R404a at LT

- Environmental impacts: this technology will reduce the GWP caused during use and at disposal.
- Costs: this option is believed to have no additional costs.
- Constraints: none identified.

6.2.3.9 Option 9: High efficiency LED lighting

- Environmental impacts: this technology is estimated to save about 4% of the TEC.
- Costs: €200.
- Constraints: none identified.

6.2.3.10 Option 10: Floating head pressure (plus electronic expansion valve)

- Environmental impacts: this technology could replace electric defrost, hence reducing consumption of energy, saving about 8% of the TEC. The additional piping and connections required would potentially increase leakage of refrigerant from the product, and the size of the refrigerant charge would need to be increased.
- Costs: €150, around 3.5% of the purchase price.
- Constraints: none identified.

6.2.3.11 Option 11: Ambient subcooling

- Environmental impacts: this technology is estimated to save about 4% of the TEC.
- Costs: €170.

* Constraints: none identified.

6.2.3.12 Option 12: High efficiency compressor

* Environmental impacts: this technology is estimated to save about 5% of the TEC.
* Costs: €200.
* Constraints: none identified.

6.2.3.13 Scenario A: Incorporates options 1+3+5+6+7

Options 1 and 3 are selected in place of 2 and 4, to provide a “low-cost” option.

* Environmental impacts: the combination of these technologies is estimated to be able to reduce TEC by 37%.
* Costs: €530.
* Constraints: this option has the same constraint as each of its components.

6.2.3.14 Scenario B: Incorporates options 2+4+5 to 12

Options 2 and 4 are selected in place of 1 and 3, to provide a “high-savings” option.

* Environmental impacts: the combination of these technologies is estimated to be able to reduce TEC by 48%.
* Costs: €1,341.
* Constraints: this option has the same constraint as each of its components.

6.2.4. MT and LT industrial process chiller Base Cases

The analysis of available technologies for MT and LT chillers in Task 5 serves as input for determining the best options and their environmental and economic input in the present section. The objective of these technologies is to decrease TEC.

The summary of the costs and TEC savings of the improvement options considered for MT and LT chillers are presented in Table 6-5 and Table 6-6.

The BAT model is presented as well. The increase in price for this has been estimated by stakeholder to be around 50% of the product price. However, compared to the single improvements it is not consistent. The resulting gap can be the product of underestimation of the single improvement option prices and the overestimation of the BAT price.

Table 6-5: Identified energy saving potentials for the MT chillers Base Case

	Improvement option	TEC savings compared to base-case (%)	Increase of product price compared to base-case (€)	Payback time (years)
Option 1	Electronic expansion valve*	5%	1,000	0.40

	Improvement option	TEC savings compared to base-case (%)	Increase of product price compared to base-case (€)	Payback time (years)
Option 2	High efficiency compressor**	5%	6,000	2.38
Option 3	Improved heat exchange**	15%	11,000	1.45
Option 4	ECM fan condenser***	2%	2,200	2.18
Option 5	R290	5%	2,750	1.09
Scenario A	Option 1+2+3	23%	18,000	1.53
Scenario B	Option 1+2+3+5	27%	20,750	1.51
Weighted real BAT improvement	As described in Task 5	9%	27,500	6.05

**Savings only applicable to part-load. Energy savings possible, but this options does not change the COP value*

***Including several features within the options for increasing the component efficiency*

****Only applicable to air-cooled chillers. To be considered for the MEPS (see Task 7)*

Table 6-6: Identified energy saving potentials for the LT chillers Base Case

	Improvement option	TEC savings compared to base-case (%)	Increase of product price compared to base-case (€)	Payback time (years)
Option 1	Electronic expansion valve*	5%	1,000	0.28
Option 2	High efficiency compressor**	5%	7,000	1.99
Option 3	Improved heat exchange**	15%	14,000	1.32
Option 4	ECM fan condenser***	2%	2,800	1.99
Option 5	R290	5%	3,500	0.99
Scenario A	Option 1+2+3	23%	22,000	1.34
Scenario B	Option 1+2+3+5	27%	25,500	1.33
Weighted real BAT improvement	As described in Task 5	9%	35,000	5.51

**Savings only applicable to part-load. Energy savings possible, but this options does not change the COP value*

***Including several features within the options for increasing the component efficiency*

****Only applicable to air-cooled chillers. To be considered for the MEPS (see Task 7)*

6.2.4.1 Option 1: Electronic expansion valve

- Environmental impacts: this kind of expansion valves do not use springs, bellows or pushing rods activated by thermostatic forces to activate or de-activate the system. Instead, they are activated through electronic signal coming from electronic controllers. This results in chillers with more adaptability and less energy consumption, around 5% reduction in TEC. It is applicable only to part-load conditions. Hence, it has impact on the energy consumption, but not on the COP value.
- Costs: the additional cost due to the electronic expansion valve to blast cabinets is about € 1,000. The payback time is considered to be less than half a year.

- Constraints: None identified.

6.2.4.2 Option 2: High efficiency compressor

- Environmental impacts: this option considers the use of any of the technologies as expressed in Task 5 that improve the efficiency of the equipment, e.g. change of compressor type for more performing ones, etc. The use of a high efficiency compressor allows better performance of the equipment and leads to a reduction of 5% in energy consumption.
- Costs: this technology increases the equipment cost by €6,000 to 7,000, i.e. 10%, and has a payback period of around 2.5 for medium temperature equipment and around 2 years for low temperature machines.
- Constraints: the applicability and results of this depends on the working requirements of the product.

6.2.4.3 Option 3: Improved heat exchange

- Environmental impacts: this technology might include new heat exchanger surfaces, e.g. microchannel, non-circular tubes (AC), flooded heat exchanger (WC), and/or sub-cooling (AC/WC), selected from the relevant alternatives for heat exchange technologies as stated in Task 5. According to stakeholders[1] and literature, the improvement of heat exchangers may vary between 10 to 20% for water-cooled and, it is expected to be 15% for air-cooled. Therefore, for this analysis it is considered that this option could lead to 15% of energy consumption reduction.
- Costs: this technology increases the equipment cost by €11,000 (MT) or €14,000 (LT). The payback time is considered to be less than 2 years.
- Constraints: the applicability and results of this depends on the working requirements of the product.

6.2.4.4 Option 4: ECM fan condenser

- Environmental impacts: this technology could lead to 2% of savings in the TEC. It is applicable only to air-cooled chillers. Therefore, it is considered only for establishing the MEPS in task 7, but not during the analysis of this task.
- Costs: the increase in price is estimated to be around €2,200 and €2,800 for medium and low temperature respectively. The estimated payback time under these conditions is almost 2 years.
- Constraints: reduced flow on the condenser can lead to reduction of the heat transfer. The application requires appropriate tuning, otherwise it can lead to decrease in performance.

[1] Source: Daikin, Trane, chiller expert

6.2.4.5 Option 5: Refrigerant R290

- Environmental impacts: it provides 5% of energy reduction, while it presents a lower GWP value. An additional benefit is represented by the lower amount of refrigerant needed in the equipment.
- Costs: the ambient sub-cooling is considered to increase the cost of the Base Case between €2,750 and €3,500, 5% of the total cost. The payback time of this option is around 1 year.
- Constraints: this option presents safety issues related to handling dangerous materials.

6.2.4.6 Scenario A: Incorporates options 1+2+3

- Environmental impacts: the combination of the improvement options 1+2+3 is estimated to provide 23% of energy savings for both MT chillers and LT chillers.
- Costs: the total increase in cost due to this combination is €18,000 and €22,000, and has a payback time of little less than 2 year.
- Constraints: this option has the same constraint as each of its components.

6.2.4.7 Scenario B: Incorporates options 1+2+3+5

- Environmental impacts: the simultaneous application of options 1+2+3+4+5 can provide up to 27% of energy savings.
- Costs: the total increase in cost due to this combination is €20,750 to 25,500 (for MT and LT respectively), and has a payback time of almost 2 years.
- Constraints: this option has the same constraint as each of its components.

6.2.5. MT and LT remote condensing unit Base Cases

The technical analysis of best performance remote condensing units carried out in Task 5 showed several technologies are considered by stakeholders as potential energy saving options.

Most of them are already in the market implemented in some products, even though the high cost of some of them prevent their application to all the product ranges.

Regarding other environmental aspects of the product, some alternative refrigerants have been pointed out by stakeholders, presenting lower GWP and similar energy performance in the system, as shown in Task 5. However, only Propane has been prioritised for the analysis when compared with the other improvement options.

The table below summarises some of these improvement measures.

Some of the improvement options selected do not have effect in the COP of the condensing unit, being only beneficial for the lower annual energy consumption in part load or seasonal conditions. Therefore, the power input reduction used in Task 7 is also presented in the tables.

Table 6-7: Identified energy saving potentials for the MT remote condensing unit Base Case

	Improvement option	TEC savings compared to Base Case (%)	Power input reduction compared to Base Case (%)	Increase of product price compared to Base Case (€)	Payback time (years)
Option 1	Increase heat exchanger surfaces	5	5	199	1.1
Option 2	ECM compressor	9	9	663	2.0
Option 3	Digital modulation control for compressor*	10	0	663	1.8
Option 4	Scroll compressor	10	10	1,060	2.8
Option 5	Variable speed drive*	10	0	1,657	4.4
Option 6	High efficiency fan blades	0.5	0.5	133	7.1
Option 7	ECM for fans	0.5	0.5	331	17.7
Option 8	R290**	5	5	30	0.2
Scenario A	Options 1+4+5+6+7+8	28	20	3,410	3.3
Scenario B	Options 1+2+3+6+7	23	14	1,988	2.3
Weighted real BAT improvement	As described in Task 5	19	10	335	0.5

*Improvement at part load not reflected in COP
**This improvement also has lower direct GWP emissions

Table 6-8: Identified energy saving potentials for the LT remote condensing unit Base Case

	Improvement option	TEC savings compared to Base Case (%)	Power input reduction compared to Base Case (%)	Increase of product price compared to Base Case (€)	Payback time (years)
Option 1	Increase heat exchanger surfaces	5	5	238	0.8
Option 2	ECM compressor	9	9	793	1.5
Option 3	Digital modulation control for compressor*	10	0	793	1.3
Option 4	Scroll compressor	10	10	1,269	2.1
Option 5	Variable speed drive*	10	0	1,983	3.3
Option 6	High efficiency fan blades	0.5	0.5	159	5.3
Option 7	ECM for fans	1	1	397	6.6
Option 8	R290**	5	5	40	0.1
Scenario A	Options 1+4+5+6+7+8	28	20	4,086	2.4
Scenario B	Options 1+2+3+6+7	23	15	2,380	1.7
Weighted real BAT improvement	As described in Task 5	20	11	5,478	4.6

*Improvement at part load not reflected in COP
**This improvement also has lower direct GWP emissions

6.2.5.1 Option 1: Increased exchanger surfaces

- Environmental impacts: Increased heat exchanger surfaces can save up to 5% TEC.
- Cost: The increase in price of increased heat exchanger surface is €199 for MT Base Case and €238 for LT Base Case. The payback period is 1.1 and 0.8 years, respectively.
- Constraints: To increase the heat exchanger surface increases also the product footprint, usually a quite important aspect for the end user.

6.2.5.2 Option 2: ECM compressor

- Environmental impacts: ECM compressor can save up to 9% of TEC in MT and LT condensing units.
- Cost: the increase in price of condensing units using ECM is up to 10% compared to the Base Case, and the payback period is around 2.0 years for MT Base Case and 1.5 years for LT Base Case.
- Constraints: no drawback has been found for this improvement option.

6.2.5.3 Option 3: Digital modulation control for compressor

- Environmental impacts: A digital controlled motor for compressors allows the condensing unit to modulate not only the rotation speed of the compressor but also the flow of the refrigerant, optimising the energy consumption. This allows the condensing unit to work at a wide range of workloads optimising the energy consumption. This technology can save 10% of TEC compared to the Base Case, depending on the operating conditions and characteristics of the system.
- Cost: the increase in price of condensing units using digital controls is up to 10% compared to the Base Case, and the payback period is around 1.8 years for MT Base Case and 1.3 years for LT Base Case.
- Constraints: this improvement is not reflected in a COP increase since this is tested at one point, and does not take into account partial load conditions.

6.2.5.4 Option 4: Scroll compressor

- Environmental impacts: scroll compressors usually are more efficient than hermetic reciprocating compressors, allowing up to 10% reduction in TEC, depending on the size of the compressor and the cooling capacity of the condensing unit.
- Cost: the increase in price of condensing units using scroll compressors is around 16% compared to the Base Case, and the payback period is around 2.8 years for MT Base Case and 2.1 years for LT Base Case.
- Constraints: due to the increase in price scroll compressors are more suitable to be used in condensing units for MT over 10kW of cooling capacity. For LT condensing units, scroll compressors are usually only used up to 10 kW.

6.2.5.5 Option 5: Variable Speed Drive

- Environmental impacts: Variable speed drive for compressors allows the condensing unit to work at a wide range of workloads optimising the energy consumption. This technology can save 10% of TEC compared to the Base Case, depending on the operating conditions and characteristics of the system.
- Cost: the increase in price of condensing units using variable speed is up to 10% compared to the Base Case, and the payback period is around 4.4 years for MT Base Case and 3.3 years for LT Base Case.
- Constraints: this improvement is not reflected in a COP increase since this is tested at one point, and does not take into account partial load conditions.

6.2.5.6 Option 6: High efficiency fan blades

- Environmental impacts: high efficiency fan blades for condenser can achieve up to 0.5% of energy savings of the total energy consumption of the condensing unit.
- Cost: the cost increase of high efficiency fan blades is around 0.5% of the price of the condensing unit. The payback period of this improvement is about 7.1 years for MT condensing units and 5.3 years for LT condensing units
- Constraints: no drawback has been found for this improvement option.

6.2.5.7 Option 7: ECM for fans

- Environmental impacts: Electronically commutated motor for fans can achieve 0.5% of energy savings for MT remote condensing units and 1% of energy savings for LT remote condensing units.
- Cost: The cost increase of ECM fans is around 5% of the total price of the condensing unit. The payback period is of 17.7 years for MT Base Case and 6.6 years for LT Base Case.
- Constraints: no drawback has been found for this improvement option.

6.2.5.8 Option 8: Refrigerant R290

- Environmental impacts: the use of propane as refrigerant can provide 5% energy savings compared to the Base Case, and the GWP direct emissions will be much lower.
- Cost: the cost of using propane in remote condensing units around €30 per MT unit and €40 per LT unit, and the payback time is around two months for MT and LT condensing units.
- Constraints: propane is a flammable refrigerant, and its use is restricted depending on the type of facility.

6.2.5.9 Scenario A: Increased exchanger surfaces + Scroll compressor + Variable Speed Drive + High efficiency fan blades + ECM for fans + Refrigerant R290

- Environmental impacts: the combination of these technologies can achieve up to 28% reduction in TEC compared to the condensing unit Base Case. However, due to that some of the options included only achieve gains through better part load performance, the power input reduction would be only of 20%.
- Cost: a condensing unit combining these technologies can increase the price by €3,400 for MT and €4,000 for LT and the corresponding payback period is around 3.3 years for MT and 2.4 years for LT.
- Constraints: some of these improvements are not reflected in a COP increase since this is tested at one point, and does not take into account partial load conditions.

6.2.5.10 Scenario B: Increased exchanger surfaces + ECM compressor + Digital modulation for compressor + High efficiency fan blades + ECM for fans

- Environmental impacts: the combination of these technologies can achieve up to 23% reduction in TEC compared to the condensing unit Base Case. However, due to that some of the options included only achieve gains through better part load performance, the power input reduction would be only of 14% for medium temperature condensing units and 15% for low temperature units.
- Cost: a condensing unit combining these technologies can result in an increase of the price by €2,000 for MT and €2,400 for LT, and the corresponding payback period is around 2.3 years for MT and 1.7 years for LT.
- Constraints: some of these improvements are not reflected in a COP increase since this is tested at one point, and does not take into account partial load conditions.

6.3. ANALYSIS BAT AND LLCC

Scope: The design option(s) identified in the technical, environmental and economic analysis in subtask 6.1 will be ranked to identify the Best Available Technology (BAT) defined in subtask 5.1 and the LLCC. Drawing of a LCC-curve (Y-axis= LLCC, X-axis=options) allows identification of these LLCC and BAT points[2].

The performance will be compared using the weighted Base Case and applying to this the improvement options. The comparison is made in terms of TEC, GWP, electricity use and LCC. If some of the options are only applicable to small share of the market, the impact on the energy will be weighted and then compared.

[2] This is usually the last point of the curve showing the product design with the lowest environmental impact, irrespective of the price.

LLC is the sum of the Base Case price, plus cost of improvements, added to the costs of electricity, and the costs of installation and maintenance as described in Task 4.

6.3.1. HT AND LT SERVICE CABINET BASE CASES

The following tables Table 6-10indicate the main impacts of the improvement options proposed for the service cabinet Base Case. Combinations of the individual options are also analysed.

Table 6-9: Summary of the cost and benefit effects of implementing individual improvement options for the HT service cabinet Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			2,000	17.00	9.26	1701	2784
Option 1	High efficiency compressor	7%	20 €	1,860	15.81	8.71	1582	2685
Option 2	ECM evaporator fan motor	12%	18 €	1,760	14.96	8.32	1497	2598
Option 3	ECM condenser fan motor	8%	20 €	1,840	15.64	8.63	1565	2668
Option 4	High efficiency fan blades	3%	5 €	1,940	16.49	9.02	1650	2738
Option 5	Sealing door frame	19%	0 €	1,620	13.77	7.78	1378	2461
Option 6	R290	5%	40 €	1,900	16.15	8.48	1616	2739
Option 7	Thicker insulation	4%	100 €	1,920	16.32	8.95	1633	2816
Scenario A	Incorporates options 1+2+3+4+5+7	43%	163 €	1,140	9.69	5.91	970	2216
Scenario B	Incorporates options 1+2+3+4+5+6+7	46%	203 €	1,080	9.18	4.05	697	2205
Weighted real BAT improvement	As described in Task 5, this product includes R290	75%	1,300 €	500	4.25	3.02	425	2809

**: during the use phase*

Table 6-10: Summary of the cost and benefit effects of implementing individual improvement options for the Base Case LT service cabinet Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			5,000	42.50	21.19	4252	5436
Option 1	High efficiency compressor	10%	40 €	4,500	38.25	20.22	3827	5051
Option 2	ECM evap	7%	18 €	4,650	39.53	20.81	3955	5156
Option 3	ECM cond	3%	20 €	4,850	41.23	21.59	4125	5328
Option 4	High Efficiency Fan Blades	3%	5 €	4,850	41.23	21.59	4125	5313
Option 5	Sealing door frame	26%	0 €	3,700	31.45	17.11	3147	4330
Option 6	R290	5%	40 €	4,750	40.38	19.67	4040	5263
Option 7	Thicker insulation	5%	110 €	4,750	40.38	21.20	4040	5333
Scenario A	Incorporates options 1+2+3+4+5	45%	193 €	2,750	23.38	13.41	2339	3715
Scenario B	Incorporates options 1+2+3+4+5+6+7	47%	233 €	2,650	22.53	11.49	2254	3670

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
Weighted real BAT improvement	As described in Task 5, this product includes R290	56%	1,450 €	2,200	18.70	9.74	1871	4504

**: during the use phase*

An environmental and economic assessment was carried out for each improvement option and for their combination, using the EcoReport tool. Outcomes of these assessments, taking into account the whole life cycle, are provided in Table 6-11 and Table 6-12 with absolute values (in units) and variations with the Base Case.

Table 6-11: Environmental impacts of the HT service cabinet Base Case and its improvement options

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Scenario A	Scenario B	Weighted real BAT improvement
Other resources and waste												
Total Energy (GER)	GJ	194.97	182.47	173.55	180.69	189.61	161.05	186.04	187.83	118.21	112.86	61.09
	% change with BC	0.00%	-6.41%	-10.99%	-7.32%	-2.75%	-17.40%	-4.58%	-3.66%	-39.37%	-42.11%	-68.67%
of which, electricity	primary GJ	182.06	169.57	160.64	167.78	176.71	148.15	173.14	174.92	105.31	99.95	48.19
	MWh	17.34	16.15	15.30	15.98	16.83	14.11	16.49	16.66	10.03	9.52	4.59
	% change with BC	0.00%	-6.86%	-11.77%	-7.84%	-2.94%	-18.63%	-4.90%	-3.92%	-42.16%	-45.10%	-73.53%
Water (process)	kL	18.18	17.35	16.75	17.23	17.82	15.92	17.59	17.70	13.06	12.71	9.26
	% change with BC	0.00%	-4.58%	-7.85%	-5.24%	-1.96%	-12.44%	-3.27%	-2.62%	-28.15%	-30.11%	-49.09%
Water (cooling)	kL	484.99	451.67	427.87	446.91	470.71	394.55	461.19	465.95	280.31	266.03	127.99
	% change with BC	0.00%	-6.87%	-11.78%	-7.85%	-2.94%	-18.65%	-4.91%	-3.93%	-42.20%	-45.15%	-73.61%
Waste, non-haz./ landfill	kg	412.34	397.86	387.51	395.79	406.13	373.02	402.00	404.06	323.35	317.14	257.12
	% change with BC	0.00%	-3.51%	-6.02%	-4.02%	-1.51%	-9.54%	-2.51%	-2.01%	-21.58%	-23.09%	-37.64%
Waste, hazardous/ incinerated	kg	24.95	24.67	24.46	24.63	24.83	24.17	24.75	24.79	23.19	23.06	21.87
	% change with BC	0.00%	-1.15%	-1.98%	-1.32%	-0.49%	-3.13%	-0.82%	-0.66%	-7.09%	-7.58%	-12.36%
Emissions (Air)												
Greenhouse Gases in GWP100	t CO2 eq.	9.26	8.71	8.32	8.63	9.02	7.78	8.48	8.95	5.91	5.28	3.02
	% change with BC	0.00%	-5.89%	-10.10%	-6.73%	-2.52%	-15.99%	-8.44%	-3.37%	-36.18%	-42.94%	-67.34%
Acidification, emissions	kg SO2 eq.	52.44	49.22	46.92	48.76	51.06	43.70	50.14	50.60	32.67	31.29	17.96
	% change with BC	0.00%	-6.14%	-10.52%	-7.01%	-2.63%	-16.65%	-4.38%	-3.51%	-37.69%	-40.32%	-65.74%
Volatile Organic Compounds (VOC)	g	126.60	121.90	118.53	121.22	124.59	113.83	123.24	123.91	97.69	95.68	76.18
	% change with BC	0.00%	-3.72%	-6.37%	-4.25%	-1.59%	-10.09%	-2.66%	-2.12%	-22.83%	-24.43%	-39.83%
Persistent Organic Pollutants (POP)	ng i-Teq	2876.81	2794.91	2736.41	2783.21	2841.71	2654.51	2818.31	2830.01	2373.71	2338.61	1999.31
	% change with BC	0.00%	-2.85%	-4.88%	-3.25%	-1.22%	-7.73%	-2.03%	-1.63%	-17.49%	-18.71%	-30.50%
Heavy Metals	mg Ni eq.	12748.05	12533.6 8	12380.56	12503.06	12656.18	12166.20	12594.93	12625.55	11431.22	11339.35	10451.26
	% change with BC	0.00%	-1.68%	-2.88%	-1.92%	-0.72%	-4.56%	-1.20%	-0.96%	-10.33%	-11.05%	-18.02%
PAHs	mg Ni eq.	1387.37	1362.75	1345.17	1359.24	1376.82	1320.56	1369.79	1373.30	1236.16	1225.61	1123.63
	% change with BC	0.00%	-1.77%	-3.04%	-2.03%	-0.76%	-4.82%	-1.27%	-1.01%	-10.90%	-11.66%	-19.01%

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Scenario A	Scenario B	Weighted real BAT improvement
Particulate Matter (PM, dust)	kg	9.51	9.44	9.39	9.43	9.48	9.32	9.46	9.47	9.08	9.05	8.77
	% change with BC	0.00%	-0.72%	-1.24%	-0.83%	-0.31%	-1.96%	-0.52%	-0.41%	-4.44%	-4.75%	-7.75%
Emissions (Water)												
Heavy Metals	mg Hg/20	7357.64	7277.07	7219.53	7265.56	7323.11	7138.96	7300.09	7311.60	6862.74	6828.22	6494.45
	% change with BC	0.00%	-1.09%	-1.88%	-1.25%	-0.47%	-2.97%	-0.78%	-0.63%	-6.73%	-7.20%	-11.73%
Eutrophication	gg PO4	273.02	272.64	272.37	272.59	272.86	271.98	272.75	272.80	270.66	270.50	268.91
	% change with BC	0.00%	-0.14%	-0.24%	-0.16%	-0.06%	-0.38%	-0.10%	-0.08%	-0.86%	-0.92%	-1.51%
Economic indicators												
Electricity cost	€	1701	1582	1497	1565	1650	1378	1616	1633	970	919	425
	% change with BC	0.00%	-7.00%	-12.00%	-8.00%	-3.00%	-19.00%	-5.00%	-4.00%	-43.00%	-46.00%	-75.00%
Life-cycle cost	€	2784	2685	2598	2668	2738	2461	2739	2816	2216	2205	2809
	% change with BC	0.00%	-3.56%	-6.68%	-4.17%	-1.65%	-11.61%	-1.62%	1.15%	-20.04%	-20.81%	0.87%

Table 6-12: Environmental impacts of the LT service cabinet Base Case and its improvement options

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Scenario A	Scenario B	Weighted real BAT improvement
Other resources and waste												
Total Energy (GER)	GJ	464.16	419.53	432.92	450.77	450.77	348.13	441.84	441.84	263.34	254.42	214.26
	% change with BC	0.00%	-9.61%	-6.73%	-2.88%	-2.88%	-25.00%	-4.81%	-4.81%	-43.26%	-45.19%	-53.84%
of which, electricity	primary GJ	450.17	405.55	418.93	436.78	436.78	334.15	427.86	427.86	249.36	240.43	200.27
	MWh	42.87	38.62	39.90	41.60	41.60	31.82	40.75	40.75	23.75	22.90	19.07
	% change with BC	0.00%	-9.91%	-6.94%	-2.97%	-2.97%	-25.77%	-4.96%	-4.96%	-44.61%	-46.59%	-55.51%
Water (process)	kL	36.66	33.68	34.58	35.77	35.77	28.92	35.17	35.17	23.27	22.68	20.00
	% change with BC	0.00%	-8.12%	-5.68%	-2.43%	-2.43%	-21.10%	-4.06%	-4.06%	-36.52%	-38.14%	-45.45%
Water (cooling)	kL	1199.89	1080.89	1116.59	1164.19	1164.19	890.49	1140.39	1140.39	664.39	640.59	533.49
	% change with BC	0.00%	-9.92%	-6.94%	-2.98%	-2.98%	-25.79%	-4.96%	-4.96%	-44.63%	-46.61%	-55.54%
Waste, non-haz./	kg	743.22	691.48	707.00	727.70	727.70	608.69	717.35	717.35	510.39	500.04	453.47

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Scenario A	Scenario B	Weighted real BAT improvement
landfill	**% change with BC**	0.00%	-6.96%	-4.87%	-2.09%	-2.09%	-18.10%	-3.48%	-3.48%	-31.33%	-32.72%	-38.99%
Waste, hazardous/ incinerated	**kg**	33.21	32.18	32.49	32.90	32.90	30.53	32.69	32.69	28.58	28.37	27.45
	% change with BC	0.00%	-3.10%	-2.17%	-0.93%	-0.93%	-8.05%	-1.55%	-1.55%	-13.94%	-14.55%	-17.34%
Emissions (Air)												
Greenhouse Gases in GWP100	**t CO2 eq.**	21.19	20.22	20.81	21.59	21.59	17.11	19.67	21.20	13.41	11.49	9.74
	% change with BC	0.00%	-4.56%	-1.80%	1.88%	1.88%	-19.26%	-7.16%	0.04%	-36.73%	-45.76%	-54.03%
Acidification, emissions	**kg SO2 eq.**	121.99	110.50	113.95	118.54	118.54	92.11	116.25	116.25	70.28	67.98	57.64
	% change with BC	0.00%	-9.42%	-6.59%	-2.83%	-2.83%	-24.49%	-4.71%	-4.71%	-42.39%	-44.27%	-52.75%
Volatile Organic Compounds (VOC)	**g**	230.26	213.45	218.49	225.21	225.21	186.56	221.85	221.85	154.63	151.26	136.14
	% change with BC	0.00%	-7.30%	-5.11%	-2.19%	-2.19%	-18.98%	-3.65%	-3.65%	-32.85%	-34.31%	-40.88%
Persistent Organic Pollutants (POP)	**ng i-Teq**	4801.90	4509.40	4597.15	4714.15	4714.15	4041.40	4655.65	4655.65	3485.65	3427.15	3163.91
	% change with BC	0.00%	-6.09%	-4.26%	-1.83%	-1.83%	-15.84%	-3.05%	-3.05%	-27.41%	-28.63%	-34.11%
Heavy Metals	**mg Ni eq.**	18304.95	17539.35	17769.03	18075.27	18075.27	16314.40	17922.15	17922.15	14859.77	14706.65	14017.61
	% change with BC	0.00%	-4.18%	-2.93%	-1.25%	-1.25%	-10.87%	-2.09%	-2.09%	-18.82%	-19.66%	-23.42%
PAHs	**mg Ni eq.**	2011.50	1923.59	1949.96	1985.13	1985.13	1782.93	1967.54	1967.54	1615.90	1598.31	1519.19
	% change with BC	0.00%	-4.37%	-3.06%	-1.31%	-1.31%	-11.36%	-2.19%	-2.19%	-19.67%	-20.54%	-24.47%
Particulate Matter (PM, dust)	**kg**	11.32	11.07	11.15	11.24	11.24	10.68	11.20	11.20	10.21	10.16	9.94
	% change with BC	0.00%	-2.17%	-1.52%	-0.65%	-0.65%	-5.64%	-1.08%	-1.08%	-9.76%	-10.19%	-12.14%
Emissions (Water)												
Heavy Metals	**mg Hg/20**	9704.52	9416.79	9503.11	9618.20	9618.20	8956.42	9560.65	9560.65	8409.74	8352.19	8093.24
	% change with BC	0.00%	-2.96%	-2.08%	-0.89%	-0.89%	-7.71%	-1.48%	-1.48%	-13.34%	-13.94%	-16.60%
Eutrophication	**gg PO4**	308.01	306.64	307.05	307.60	307.60	304.44	307.32	307.32	301.83	301.56	300.32
	% change with BC	0.00%	-0.45%	-0.31%	-0.13%	-0.13%	-1.16%	-0.22%	-0.22%	-2.00%	-2.09%	-2.49%
Economic indicators												
Electricity cost	**€**	4252	3827	3955	4125	4125	3147	4040	4040	2339	2254	1871
	% change with BC	0.00%	-10.00%	-7.00%	-3.00%	-3.00%	-26.00%	-5.00%	-5.00%	-45.00%	-47.00%	-56.00%
Life-cycle cost	**€**	5436	5051	5156	5328	5313	4330	5263	5333	3715	3670	4504
	% change with BC	0.00%	-7.09%	-5.14%	-1.98%	-2.25%	-20.34%	-3.18%	-1.89%	-31.66%	-32.48%	-17.13%

For high-temperature, the LLCC is Scenario B and the real weighted BAT is the BAT option. The LLCC model allows GER saving of 42% compared to Base Case, and MWh saving of 46%.

For low-temperature Scenario B is again the LLCC, while the real weigheted BAT is the BAT option. The LLC model allows GER saving of 45% compared to Base Case, and MWh saving of 47%.

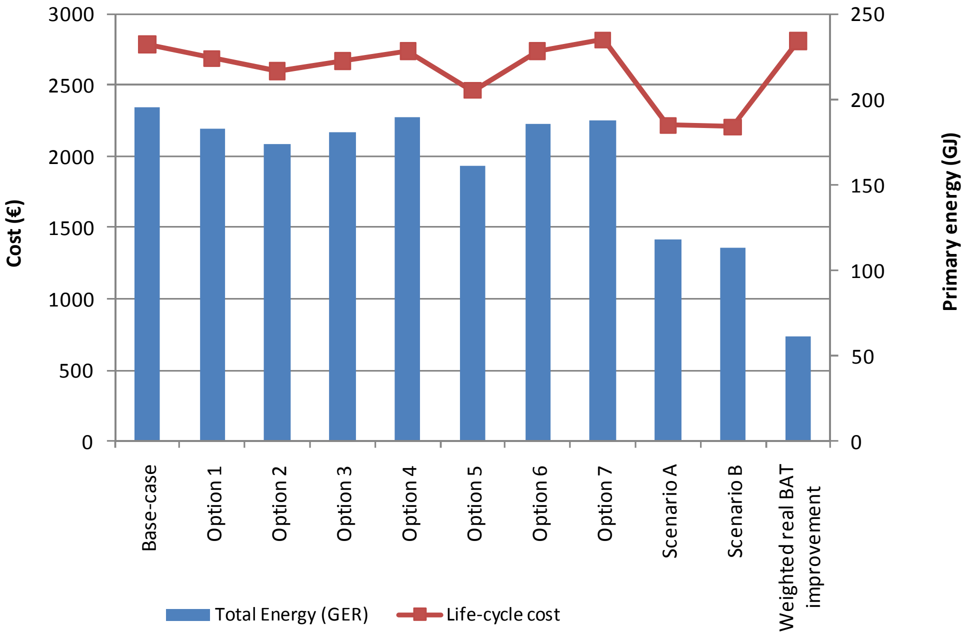

Figure 6-1: HT service cabinet Base Case – TEC and LCC

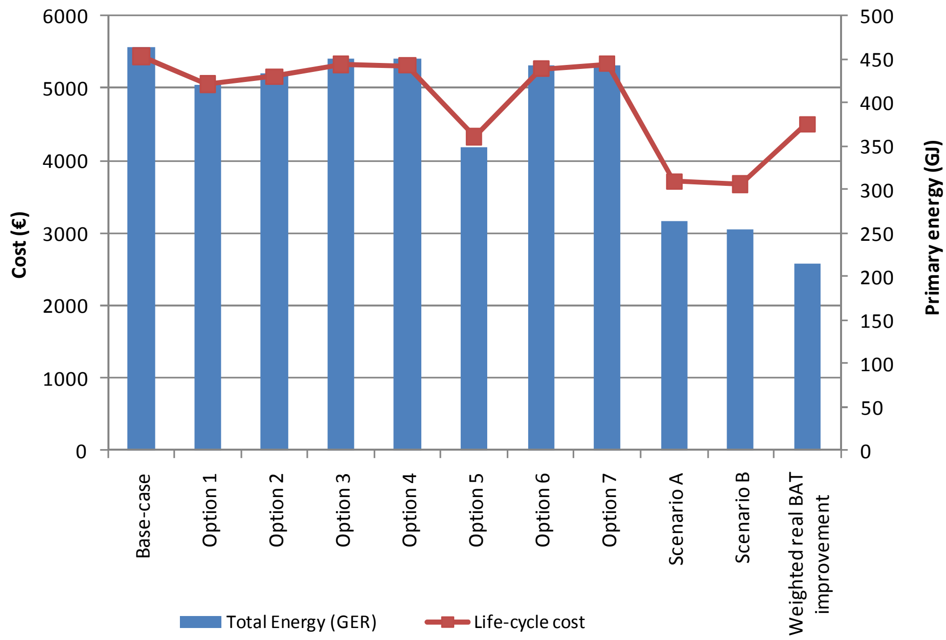

Figure 6-2: LT service cabinet Base Case – TEC and LCC

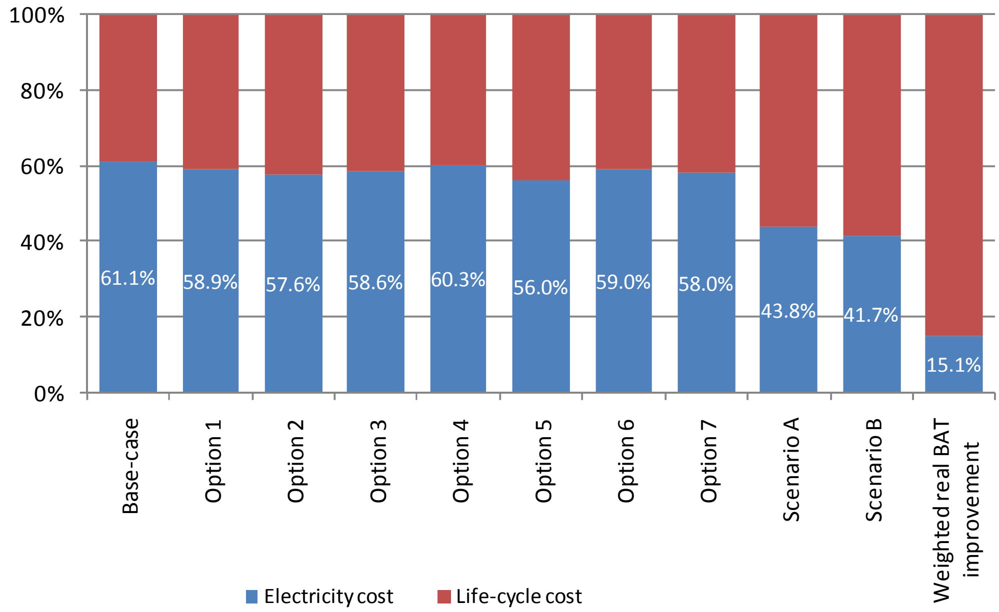

Figure 6-3: HT service cabinet Base Case – LCC and electricity costs

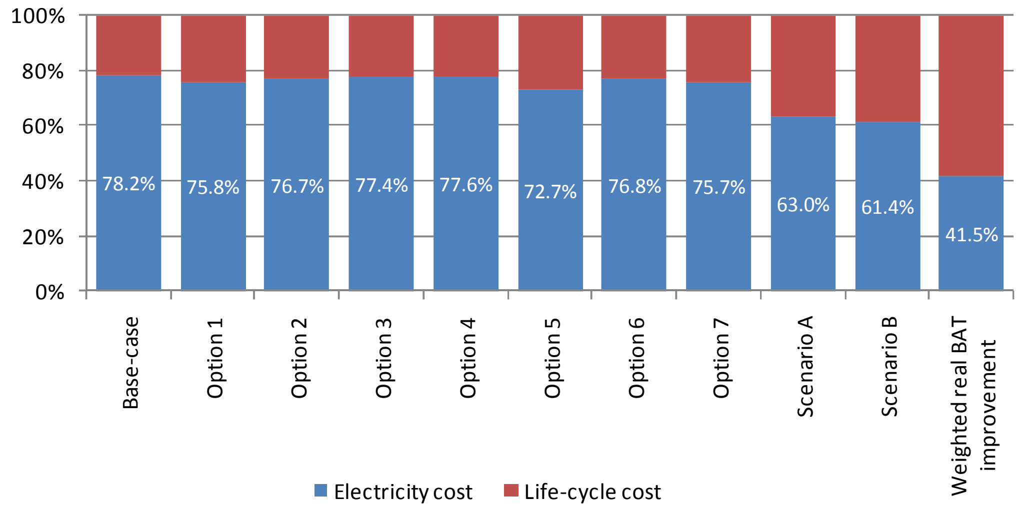

Figure 6-4: LT service cabinet Base Case – LCC and electricity costs

6.3.2. BLAST CABINET BASE CASE

The main impacts of the improvement options for blast cabinets are shown in the Table 6-13. Three combinations of four individual options each are also analysed.

Table 6-13: Summary of the cost and benefit effects of implementing individual improvement options for the Base Case Blast cabinet

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (Ton eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			3,031	25.8	27.9	2,578	9,512
Option 1	High Efficiency Fan Blades	9%	10	2,758	25.7	26.9	2,346	9,290
Option 2	Electronic expansion valve	12%	100	2,667	25.7	26.5	2,268	9,310
Option 3	Variable speed drive (VSD) compressor	10%	200	2,728	25.7	26.8	2,320	9,470
Option 4	Insulation thickness	4%	100	2,910	25.8	27.5	2,475	9,517
Option 5	ECM Fan for evaporator	7%	40	2,819	25.7	27.1	2,398	9,375
Option 6	R290	5%	200	2,879	25.8	12.2	2,449	9,599
Scenario A	1+2+3+4	31%	410	2,097	25.7	24.3	1,783	9,161
Scenario B	1+2+3+4+5	36%	450	1,950	25.7	23.7	1,658	9,080
Scenario C	1+2+3+4+5+6	39%	650	1,853	25.7	8.2	1,576	9,214
Weighted real BAT improvement	As described in Task 5	35%	753	1,970	25.7	23.8	1,675	9,425

Using the EcoReport tool, the economic and environmental impact of the different individual options and its combinations was done for the whole product life cycle. The results of these analyses are presented in Table 6-14.

Table 6-14: Environmental impacts of the Base Case Blast cabinet and its improvement options

life-cycle indicators per unit	unit	Base-case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 5	Scenario A	Scenario B	Scenario C	Weighted real BAT improvement
Other resources and waste												
Total Energy (GER)	GJ	283.77	259.41	251.29	256.73	272.97	264.85	270.21	200.41	187.29	178.64	189.08
	% change with BC	0.00%	-8.59%	-11.45%	-9.53%	-3.81%	-6.67%	-4.78%	-29.38%	-34.00%	-37.05%	-33.37%
of which, electricity	primary GJ	272.71	248.34	240.22	245.66	261.91	253.78	259.14	189.35	176.23	167.57	178.01
	MWh	25.97	23.65	22.88	23.40	24.94	24.17	24.68	18.03	16.78	15.96	16.95
	% change with BC	0.00%	-8.93%	-11.91%	-9.92%	-3.96%	-6.94%	-4.97%	-30.57%	-35.38%	-38.55%	-34.72%
Water (process)	kL	22.84	21.21	20.67	21.03	22.12	21.58	21.93	17.28	16.41	15.83	16.52
	% change with BC	0.00%	-7.11%	-9.48%	-7.89%	-3.15%	-5.52%	-3.96%	-24.33%	-28.16%	-30.69%	-27.64%
Water (cooling)	kL	724.93	659.96	638.30	652.82	696.13	674.48	688.76	502.64	467.65	444.57	472.41
	% change with BC	0.00%	-8.96%	-11.95%	-9.95%	-3.97%	-6.96%	-4.99%	-30.66%	-35.49%	-38.67%	-34.83%
Waste, non-haz./ landfill	kg	505.80	477.55	468.13	474.44	493.28	483.86	490.07	409.15	393.94	383.90	396.01
	% change with BC	0.00%	-5.59%	-7.45%	-6.20%	-2.48%	-4.34%	-3.11%	-19.11%	-22.12%	-24.10%	-21.71%
Waste, hazardous/ incinerated	kg	18.20	17.64	17.45	17.58	17.95	17.76	17.89	16.28	15.98	15.78	16.02
	% change with BC	0.00%	-3.09%	-4.11%	-3.42%	-1.37%	-2.40%	-1.72%	-10.56%	-12.22%	-13.31%	-11.99%
Emissions (Air)												
Greenhouse Gases in GWP100	t CO2 eq.	27.94	26.87	26.52	26.76	27.47	27.11	12.19	24.30	23.73	8.21	23.81
	% change with BC	0.00%	-3.81%	-5.07%	-4.22%	-1.69%	-2.96%	-56.37%	-13.02%	-15.07%	-70.61%	-14.79%
Acidification, emissions	kg SO2 eq.	75.63	69.35	67.26	68.66	72.85	70.76	72.13	54.16	50.78	48.56	51.24
	% change with BC	0.00%	-8.30%	-11.06%	-9.21%	-3.68%	-6.44%	-4.62%	-28.38%	-32.85%	-35.80%	-32.24%
Volatile Organic Compounds (VOC)	g	178.10	168.92	165.86	167.91	174.03	170.97	172.99	146.70	141.76	138.50	142.43
	% change with BC	0.00%	-5.15%	-6.87%	-5.72%	-2.28%	-4.00%	-2.87%	-17.63%	-20.40%	-22.23%	-20.03%
Persistent Organic	ng i-Teq	3211.37	3051.67	2998.43	3034.12	3140.59	3087.35	3122.45	2664.99	2578.99	2522.25	2590.69

life-cycle indicators per unit	unit	Base-case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 5	Scenario A	Scenario B	Scenario C	Weighted real BAT improvement
Pollutants (POP)	% change with BC	0.00%	-4.97%	-6.63%	-5.52%	-2.20%	-3.86%	-2.77%	-17.01%	-19.69%	-21.46%	-19.33%
Heavy Metals	mg Ni eq.	12819.05	12401.03	12261.70	12355.10	12633.78	12494.44	12586.31	11388.91	11163.83	11015.30	11194.45
	% change with BC	0.00%	-3.26%	-4.35%	-3.62%	-1.45%	-2.53%	-1.82%	-11.16%	-12.91%	-14.07%	-12.67%
PAHs	mg Ni eq.	1203.13	1155.13	1139.13	1149.86	1181.86	1165.86	1176.41	1038.91	1013.07	996.01	1016.58
	% change with BC	0.00%	-3.99%	-5.32%	-4.43%	-1.77%	-3.10%	-2.22%	-13.65%	-15.80%	-17.22%	-15.51%
Particulate Matter (PM, dust)	kg	4.88	4.74	4.70	4.73	4.82	4.77	4.80	4.42	4.35	4.30	4.36
	% change with BC	0.00%	-2.75%	-3.66%	-3.05%	-1.22%	-2.13%	-1.53%	-9.40%	-10.88%	-11.85%	-10.68%
Emissions (Water)												
Heavy Metals	mg Hg/20	6671.17	6514.07	6461.70	6496.81	6601.54	6549.17	6583.70	6133.69	6049.10	5993.28	6060.61
	% change with BC	0.00%	-2.35%	-3.14%	-2.61%	-1.04%	-1.83%	-1.31%	-8.06%	-9.32%	-10.16%	-9.15%
Eutrophication	gg PO4	186.24	185.49	185.24	185.41	185.91	185.66	185.82	183.68	183.27	183.01	183.33
	% change with BC	0.00%	-0.40%	-0.54%	-0.45%	-0.18%	-0.31%	-0.22%	-1.38%	-1.59%	-1.74%	-1.56%
Economic indicators												
Electricity cost	€	2578	2346	2268	2320	2475	2398	2449	1783	1658	1576	1675
	% change with BC	0.00%	-9.01%	-12.01%	-10.00%	-3.99%	-6.99%	-5.01%	-30.81%	-35.66%	-38.87%	-35.00%
Life-cycle cost	€	9512	9290	9310	9470	9517	9375	9599	9161	9080	9214	9425
	% change with BC	0.00%	-2.33%	-2.12%	-0.43%	0.06%	-1.44%	0.92%	-3.68%	-4.54%	-3.13%	-0.91%

The Scenario C results in the least energy consuming product having 37% of energy reduction. It is not the Least Life Cycle Cost (LLCC) scenario, but it decrease in 3% the Life Cycle Cost (LCC) of the weighted Base Case.

The Scenario B represents the LLCC scenario. It reduces about 4% the LCC, while it reduces in 34% the energy consumption.

Even though there is a combination of options which achieves lower LCC (options 1+2+5, with LCC 0.07% lower than Scenario B), the energy savings are lower (around 26%). Therefore, this option has not been selected as LLCC.

In terms of GWP, the Scenario C is the one presenting the most improvement. The GWP is reduced by 70% with the introduction of R290 as refrigerant.

This comparison between all options is made in Figure 6-5 and Figure 6-6.

These results indicate that combined Scenario B is the LLCC and the theoretical model Scenario C is the least energy consuming.

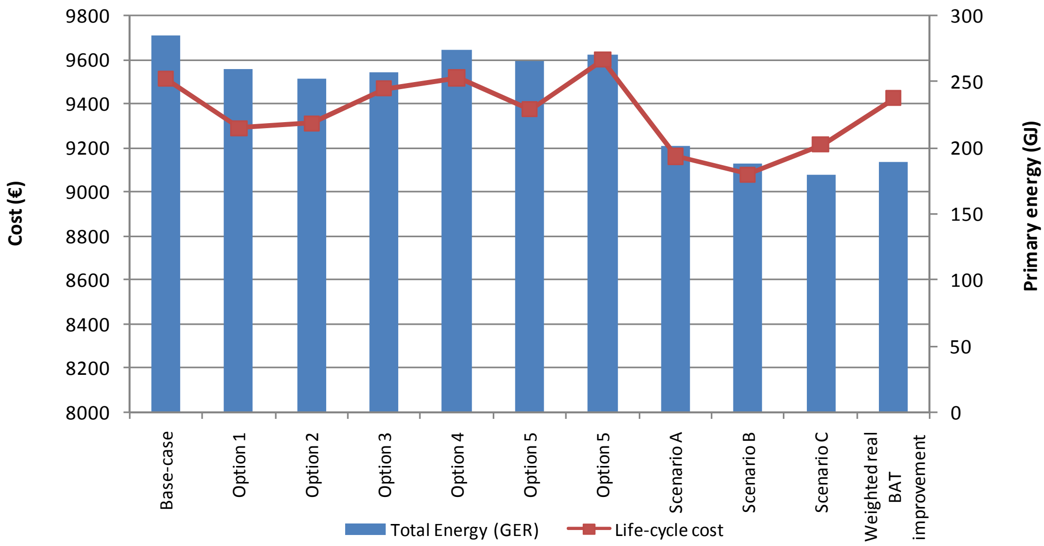

Figure 6-5: Base Case Blast cabinet – TEC and LCC

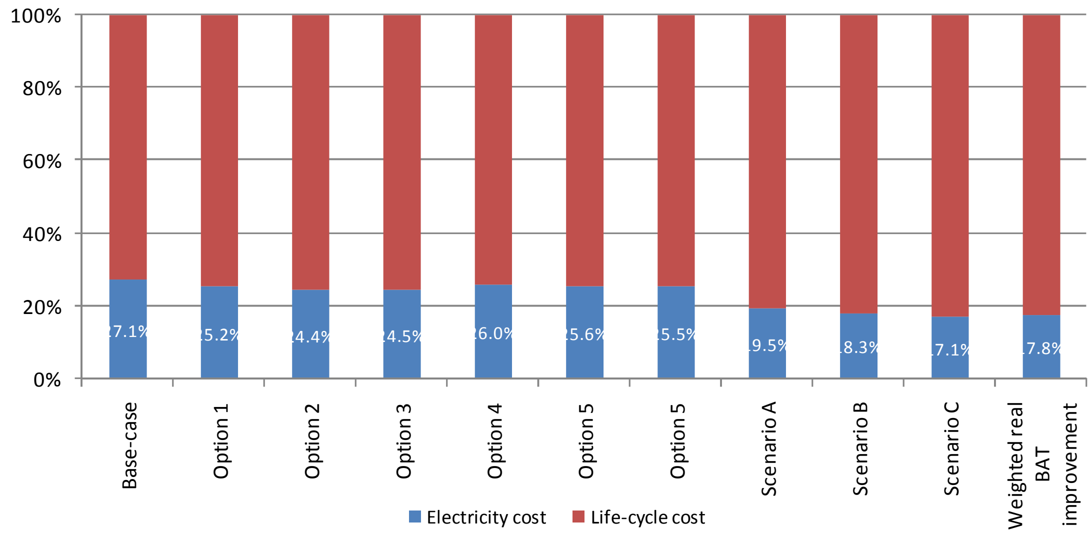

Figure 6-6: Base Case Blast cabinet – LCC and electricity costs

6.3.3. Walk-in cold room Base Case

Table 6-15 indicates the main impacts of the improvement options proposed for the walk-in cold room Base Case. Combinations of the individual options are also analysed.

Table 6-15: Summary of the cost and benefit effects of implementing individual improvement options for the HT walk-in cold room Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			12,155	121.5	86.6	11830	23104
Option 1	Strip door curtains	13%	70 €	10,575	105.7	79.3	10292	21636
Option 2	Auto door closer	12%	111 €	10,696	107.0	79.9	10411	21795
Option 3	PSC evaporator fan	10%	100 €	10,939	109.4	81.0	10647	22021
Option 4	ECM evaporator fan	13%	150 €	10,575	105.7	79.3	10292	21716
Option 5	High efficiency fan blades	3%	50 €	11,790	117.9	84.9	11475	22799
Option 6	Insulation thickness	15%	250 €	10,332	103.3	78.2	10056	21580
Option 7	ECM condenser fan	3%	60 €	11,790	117.9	84.9	11475	22809
Option 8	R134a to replace R404a at HT, and R410a to replace R404a at LT	0%	0 €	12,155	121.5	72.0	11830	23104
Option 9	High efficiency LED light bulbs	4%	200 €	11,669	116.7	84.3	11357	22831
Option 10	Floating head pressure (plus	8%	150 €	11,182	111.8	82.1	10884	22308

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
	electronic expansion valve)							
Option 11	Ambient subcooling	4%	170 €	11,669	116.7	84.3	11357	22801
Option 12	High efficiency compressor	5%	200 €	11,547	115.5	83.8	11239	22713
Scenario A	Incorporates options 1+2+3+4+5+6	37%	530 €	7,658	76.6	65.9	7453	19257
Scenario B	Incorporates all options 1 to 12	48%	1,341 €	6,321	63.2	45.3	6152	18767
Weighted real BAT improvement	As described in Task 5, this product includes R134a/R410a	35%	1,760 €	7,901	79.0	52.5	7690	20724

**: during the use phase*

An environmental and economic assessment was carried out for each improvement option and for their combination, using the EcoReport tool. Outcomes of these assessments, taking into account the whole life cycle, are provided in Table 6-16 with absolute values (in units) and variations with the Base Case.

Table 6-16: Environmental impacts of the walk-in cold room Base Case and its improvement options

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10	Option 11	Option 12	Scenario A	Scenario B	Weighted real BAT improvement
	Other resources and waste																
Total Energy (GER)	GJ	1475.34	1309.42	1322.18	1347.71	1309.42	1437.05	1283.90	1437.05	1475.34	1424.29	1373.24	1424.29	1411.52	1003.12	862.73	1028.65
	% change with BC	0.00%	-11.25%	-10.38%	-8.65%	-11.25%	-2.60%	-12.98%	-2.60%	0.00%	-3.46%	-6.92%	-3.46%	-4.33%	-32.01%	-41.52%	-30.28%
of which, electricity	primary GJ	1386.50	1220.59	1233.35	1258.87	1220.59	1348.21	1195.06	1348.21	1386.50	1335.45	1284.40	1335.45	1322.69	914.28	773.90	939.81
	MWh	132.05	116.25	117.46	119.89	116.25	128.40	113.82	128.40	132.05	127.19	122.32	127.19	125.97	87.07	73.70	89.51
	% change with BC	0.00%	-11.97%	-11.05%	-9.20%	-11.97%	-2.76%	-13.81%	-2.76%	0.00%	-3.68%	-7.36%	-3.68%	-4.60%	-34.06%	-44.18%	-32.22%
Water (process)	kL	148.61	137.55	138.40	140.10	137.55	146.06	135.85	146.06	148.61	145.21	141.80	145.21	144.35	117.13	107.77	118.83
	% change with BC	0.00%	-7.44%	-6.87%	-5.73%	-7.44%	-1.72%	-8.59%	-1.72%	0.00%	-2.29%	-4.58%	-2.29%	-2.86%	-21.18%	-27.48%	-20.04%
Water (cooling)	kL	3496.69	3054.26	3088.29	3156.36	3054.26	3394.59	2986.19	3394.59	3496.69	3360.56	3224.43	3360.56	3326.53	2237.45	1863.09	2305.52
	% change with BC	0.00%	-12.65%	-11.68%	-9.73%	-12.65%	-2.92%	-14.60%	-2.92%	0.00%	-3.89%	-7.79%	-3.89%	-4.87%	-36.01%	-46.72%	-34.07%
Waste, non-haz./ landfill	kg	3513.50	3321.13	3335.93	3365.52	3321.13	3469.10	3291.53	3469.10	3513.50	3454.31	3395.12	3454.31	3439.51	2965.99	2803.22	2995.59
	% change with BC	0.00%	-5.48%	-5.05%	-4.21%	-5.48%	-1.26%	-6.32%	-1.26%	0.00%	-1.68%	-3.37%	-1.68%	-2.11%	-15.58%	-20.22%	-14.74%
Waste, hazardous/ incinerated	kg	120.35	116.53	116.82	117.41	116.53	119.47	115.94	119.47	120.35	119.17	118.00	119.17	118.88	109.47	106.23	110.06
	% change with BC	0.00%	-3.18%	-2.93%	-2.44%	-3.18%	-0.73%	-3.67%	-0.73%	0.00%	-0.98%	-1.95%	-0.98%	-1.22%	-9.04%	-11.73%	-8.55%
	Emissions (Air)																
Greenhouse Gases in GWP100	t CO2 eq.	86.56	79.32	79.87	80.99	79.32	84.89	78.20	84.89	72.03	84.33	82.10	84.33	83.77	65.95	45.30	52.54
	% change with BC	0.00%	-8.36%	-7.72%	-6.43%	-8.36%	-1.93%	-9.65%	-1.93%	-16.78%	-2.57%	-5.15%	-2.57%	-3.22%	-23.81%	-47.67%	-39.30%
Acidification, emissions	kg SO2 eq.	442.91	400.19	403.48	410.05	400.19	433.06	393.62	433.06	442.91	429.77	416.62	429.77	426.48	321.32	285.17	327.89
	% change with BC	0.00%	-9.65%	-8.90%	-7.42%	-9.65%	-2.23%	-11.13%	-2.23%	0.00%	-2.97%	-5.94%	-2.97%	-3.71%	-27.45%	-35.62%	-25.97%
Volatile Organic Compounds (VOC)	g	1044.68	982.19	987.00	996.61	982.19	1030.26	972.58	1030.26	1044.68	1025.45	1006.23	1025.45	1020.65	866.83	813.96	876.44
	% change with BC	0.00%	-5.98%	-5.52%	-4.60%	-5.98%	-1.38%	-6.90%	-1.38%	0.00%	-1.84%	-3.68%	-1.84%	-2.30%	-17.02%	-22.09%	-16.10%
Persistent	ng i-Teq	32295.66	31208.17	31291.8	31459.13	31208.17	32044.70	31040.86	32044.70	32295.66	31961.05	31626.43	31961.05	31877.39	29200.49	28280.30	29367.79

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9	Option 10	Option 11	Option 12	Scenario A	Scenario B	Weighted real BAT improvement
Organic Pollutants (POP)	% change with BC	0.00%	-3.37%	2 -3.11%	-2.59%	-3.37%	-0.78%	-3.89%	-0.78%	0.00%	-1.04%	-2.07%	-1.04%	-1.30%	-9.58%	-12.43%	-9.07%
Heavy Metals	mg Ni eq.	820161.44	817314.99	817533.95	817971.87	817314.99	819504.57	816877.08	819504.57	820161.44	819285.61	818409.78	819285.61	819066.65	812060.01	809651.48	812497.93
	% change with BC	0.00%	-0.35%	-0.32%	-0.27%	-0.35%	-0.08%	-0.40%	-0.08%	0.00%	-0.11%	-0.21%	-0.11%	-0.13%	-0.99%	-1.28%	-0.93%
PAHs	mg Ni eq.	8014.01	7687.16	7712.30	7762.58	7687.16	7938.58	7636.87	7938.58	8014.01	7913.44	7812.87	7913.44	7888.30	7083.74	6807.17	7134.02
	% change with BC	0.00%	-4.08%	-3.76%	-3.14%	-4.08%	-0.94%	-4.71%	-0.94%	0.00%	-1.25%	-2.51%	-1.25%	-1.57%	-11.61%	-15.06%	-10.98%
Particulate Matter (PM, dust)	kg	79.63	78.71	78.78	78.92	78.71	79.41	78.57	79.41	79.63	79.34	79.06	79.34	79.27	77.03	76.26	77.17
	% change with BC	0.00%	-1.15%	-1.06%	-0.88%	-1.15%	-0.26%	-1.32%	-0.26%	0.00%	-0.35%	-0.71%	-0.35%	-0.44%	-3.26%	-4.23%	-3.09%
		Emissions (Water)															
Heavy Metals	mg Hg/20	79337.92	78268.16	78350.45	78515.03	78268.16	79091.06	78103.58	79091.06	79337.92	79008.77	78679.61	79008.77	78926.48	76293.22	75388.04	76457.80
	% change with BC	0.00%	-1.35%	-1.24%	-1.04%	-1.35%	-0.31%	-1.56%	-0.31%	0.00%	-0.41%	-0.83%	-0.41%	-0.52%	-3.84%	-4.98%	-3.63%
Eutrophication	gg PO4	5254.03	5248.93	5249.32	5250.11	5248.93	5252.85	5248.14	5252.85	5254.03	5252.46	5250.89	5252.46	5252.07	5239.51	5235.20	5240.30
	% change with BC	0.00%	-0.10%	-0.09%	-0.07%	-0.10%	-0.02%	-0.11%	-0.02%	0.00%	-0.03%	-0.06%	-0.03%	-0.04%	-0.28%	-0.36%	-0.26%
		Economic indicators															
Electricity cost	€	11830	10292	10411	10647	10292	11475	10056	11475	11830	11357	10884	11357	11239	7453	6152	7690
	% change with BC	0.00%	-13.00%	-12.00%	-10.00%	-13.00%	-3.00%	-15.00%	-3.00%	0.00%	-4.00%	-8.00%	-4.00%	-5.00%	-37.00%	-48.00%	-35.00%
Life-cycle cost	€	23104	21636	21795	22021	21716	22799	21580	22809	23104	22831	22308	22801	22713	19257	18767	20724
	% change with BC	0.00%	-6.35%	-5.66%	-4.69%	-6.01%	-1.32%	-6.60%	-1.28%	0.00%	-1.18%	-3.45%	-1.31%	-1.69%	-16.65%	-18.77%	-10.30%

Scenario B leads to the highest reduction in environmental impacts, as the use phase is the main contributor of environmental impacts. Therefore, over the life cycle of a walk-in cold room, these combination of improvement options could allow GER saving of 42% compared to the Base Case, and MWh saving of 48%.

In terms of economic impacts, the life-cycle cost of Scenario B is 19% lower than the one of the Base Case. Thus, Scenario B is considered as the LLCC and BAT option.

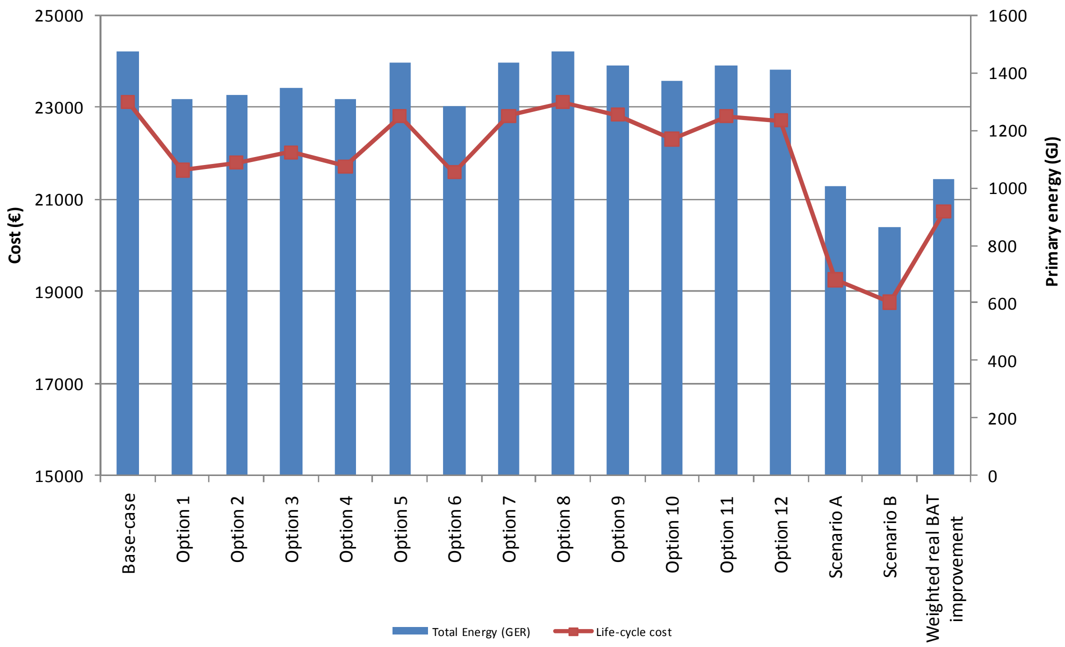

Figure 6-7: Walk-in cold room Base Case – TEC and LCC

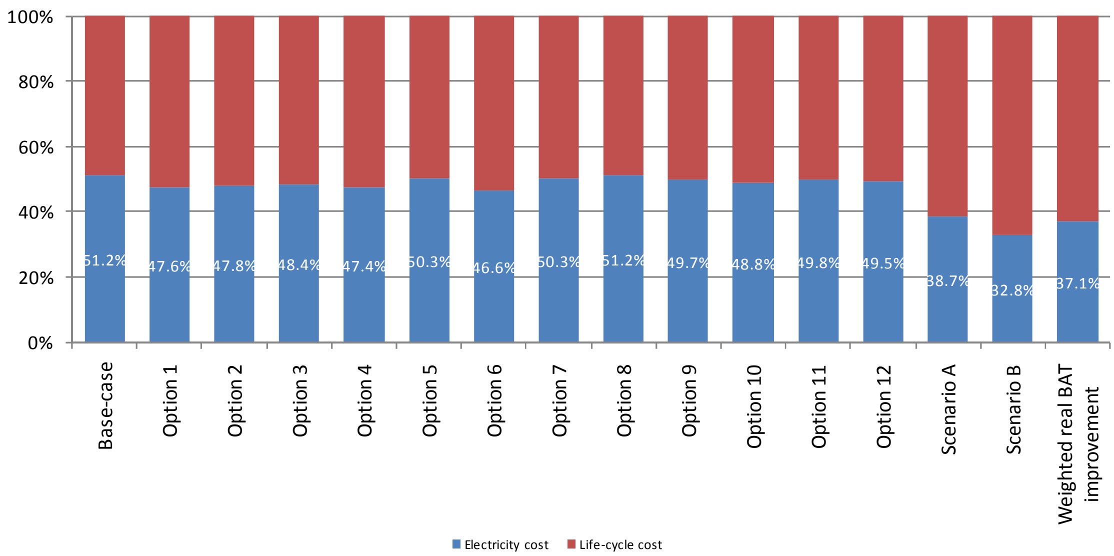

Figure 6-8: Walk-in cold room Base Case – LCC and electricity costs

6.3.4. MT AND LT PROCESS CHILLER BASE CASES

Table 6-21 and Table 6-22 indicate the main impacts of the improvement options proposed for the chillers Base Case. Combinations of the individual options are also analysed.

Table 6-17: Summary of the cost and benefit effects of implementing individual improvement options for the MT chiller Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			420,946	5,861	2,783	521,361	580,437
Option 1	Electronic expansion valve*	5%	1,000	399,898	5,859	2,846	533,547	599,298
Option 2	High efficiency compressor**	5%	6,000	399,898	5,859	2,846	533,547	605,169
Option 3	Improved heat exchange**	15%	11,000	357,804	5,853	2,556	477,384	554,876
Option 4	ECM fan condenser***	2%	2,200	412,527	5,860	2,933	550,396	617,556
Option 5	R290	5%	2,750	399,898	5,859	2,761	533,547	601,353
Scenario A	Option 1+2+3	23%	18,000	322,918	5,848	2,317	430,839	516,550
Scenario B	Option 1+2+3+5	27%	20,750	306,772	5,846	2,121	409,297	498,237
Weighted real BAT improvement	As described in Task 5	9%	27,500	383,061	5,856	2,730	511,082	607,947

**Including several features within the options for increasing the component efficiency*
*** Only applicable to air-cooled chillers. Not considered in this analysis, but in task 7*
****Changes in the system are required. Integrated with a secondary fluid*

Table 6-18: Summary of the cost and benefit effects of implementing individual improvement options for the Base Case LT chillers Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			587,659	8,183	4,011	727,834	810,022
Option 1	Electronic expansion valve*	5%	1,000	558,276	8,179	4,099	744,855	828,218
Option 2	High efficiency compressor**	5%	7,000	558,276	8,179	4,099	744,855	835,262
Option 3	Improved	15%	14,000	499,510	8,170	3,695	666,449	765,075

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
	heat exchange**							
Option 4	ECM fan condenser***	2%	2,800	575,905	8,181	4,220	768,377	853,853
Option 5	R290	5%	3,500	558,276	8,179	4,220	768,377	853,853
Scenario A	Option 1+2+3	23%	22,000	450,808	8,164	3,360	601,470	709,490
Scenario B	Option 1+2+3+5	27%	25,500	428,267	8,161	2,958	571,397	683,526
Weighted real BAT improvement	As described in Task 5	9%	35,000	534,769	8,175	3,937	713,493	836,776
0	Base Case			587,659	8,183	4,011	727,834	810,022

**Including several features within the options for increasing the component efficiency*
*** Only applicable to air-cooled chillers. Not considered in this analysis, but in task 7*
****Changes in the system are required. Integrated with a secondary fluid*

The environmental and economic assessment results for the different options are presented in Table 6-19 and Table 6-20. These results were carried out by using the Ecoreport tool.

Table 6-19: Environmental impacts of the MT chillers Base Case and its improvement options

life-cycle indicators per unit	unit	Base-case	Option 1	Option 2	Option 3	Option 5	Scenario A	Scenario B	Weighted real BAT improvement
Other resources and waste									
Total Energy (GER)	GJ	61742.54	63181.12	63181.12	56551.22	63181.12	51056.70	48513.72	60529.16
	% change with BC	0.00%	2.33%	2.33%	-8.41%	2.33%	-17.31%	-21.43%	-1.97%
of which, electricity	primary GJ	61587.34	63025.92	63025.92	56396.02	63025.92	50901.50	48358.52	60373.96
	MWh	5865.46	6002.47	6002.47	5371.05	6002.47	4847.76	4605.57	5749.90
	% change with BC	0.00%	2.34%	2.34%	-8.43%	2.34%	-17.35%	-21.48%	-1.97%
Water (process)	kL	4142.00	4237.90	4237.90	3795.91	4237.90	3429.61	3260.08	4061.10
	% change with BC	0.00%	2.32%	2.32%	-8.36%	2.32%	-17.20%	-21.29%	-1.95%
Water (cooling)	kL	164242.29	168078.49	168078.49	150398.77	168078.49	135746.71	128965.43	161006.61
	% change with BC	0.00%	2.34%	2.34%	-8.43%	2.34%	-17.35%	-21.48%	-1.97%
Waste, non-haz./ landfill	kg	75430.38	77098.33	77098.33	69411.34	77098.33	63040.75	60092.31	74023.54
	% change with BC	0.00%	2.21%	2.21%	-7.98%	2.21%	-16.43%	-20.33%	-1.87%
Waste, hazardous/ incinerated	kg	1429.16	1462.30	1462.30	1309.53	1462.30	1182.92	1124.32	1401.20
	% change with BC	0.00%	2.32%	2.32%	-8.37%	2.32%	-17.23%	-21.33%	-1.96%
Emissions (Air)									
Greenhouse Gases in GWP100	t CO2 eq.	2782.95	2845.73	2845.73	2556.41	2760.80	2316.63	2120.72	2730.00
	% change with BC	0.00%	2.26%	2.26%	-8.14%	-0.80%	-16.76%	-23.80%	-1.90%
Acidification, emissions	kg SO2 eq.	15927.95	16298.38	16298.38	14591.18	16298.38	13176.34	12521.53	15615.50
	% change with BC	0.00%	2.33%	2.33%	-8.39%	2.33%	-17.28%	-21.39%	-1.96%
Volatile Organic Compounds (VOC)	g	23919.46	24461.26	24461.26	21964.28	24461.26	19894.90	18937.15	23462.47
	% change with BC	0.00%	2.27%	2.27%	-8.17%	2.27%	-16.83%	-20.83%	-1.91%
Persistent Organic Pollutants (POP)	ng i-Teq	442577.07	452006.34	452006.34	408550.14	452006.34	372535.82	355867.65	434623.86
	% change with BC	0.00%	2.13%	2.13%	-7.69%	2.13%	-15.83%	-19.59%	-1.80%
Heavy Metals	mg Ni eq.	1182020.62	1206701.17	1206701.17	1092957.18	1206701.17	998691.85	955063.92	1161203.58
	% change with BC	0.00%	2.09%	2.09%	-7.53%	2.09%	-15.51%	-19.20%	-1.76%
PAHs	mg Ni eq.	124267.98	127101.99	127101.99	114041.02	127101.99	103216.74	98207.04	121877.60
	% change with BC	0.00%	2.28%	2.28%	-8.23%	2.28%	-16.94%	-20.97%	-1.92%
Particulate Matter (PM, dust)	kg	413.24	421.15	421.15	384.69	421.15	354.47	340.48	406.57
	% change with BC	0.00%	1.91%	1.91%	-6.91%	1.91%	-14.22%	-17.61%	-1.61%
Emissions (Water)									
Heavy Metals	mg Hg/20	441421.65	450697.17	450697.17	407949.56	450697.17	372522.49	356126.11	433598.13
	% change with BC	0.00%	2.10%	2.10%	-7.58%	2.10%	-15.61%	-19.32%	-1.77%
Eutrophication	gg PO4	5894.21	5938.44	5938.44	5734.60	5938.44	5565.67	5487.48	5856.90
	% change with BC	0.00%	0.75%	0.75%	-2.71%	0.75%	-5.57%	-6.90%	-0.63%
Economic indicators									
Electricity cost	€	521361	533547	533547	477384	533547	430839	409297	511082
	% change with BC	0.00%	2.34%	2.34%	-8.43%	2.34%	-17.36%	-21.49%	-1.97%
Life-cycle cost	€	580437	599298	605169	554876	601353	516550	498237	607947
	% change with BC	0.00%	3.25%	4.26%	-4.40%	3.60%	-11.01%	-14.16%	4.74%

Table 6-20: Environmental impacts of the LT chillers Base Case and its improvement options

life-cycle indicators per unit	unit	Base-case	Option 1	Option 2	Option 3	Option 5	Scenario A	Scenario B	Weighted real BAT improvement
Other resources and waste									
Total Energy (GER)	**GJ**	86143.76	88153.10	88153.10	78897.48	88153.10	71226.88	67676.77	84450.85
	% change with BC	0.00%	2.33%	2.33%	-8.41%	2.33%	-17.32%	-21.44%	-1.97%
of which, electricity	**primary GJ**	85966.15	87975.50	87975.50	78719.87	87975.50	71049.28	67499.17	84273.25
	MWh	8187.25	8378.62	8378.62	7497.13	8378.62	6766.60	6428.49	8026.02
	% change with BC	0.00%	2.34%	2.34%	-8.43%	2.34%	-17.35%	-21.48%	-1.97%
Water (process)	**kL**	5770.25	5904.21	5904.21	5287.17	5904.21	4775.80	4539.12	5657.39
	% change with BC	0.00%	2.32%	2.32%	-8.37%	2.32%	-17.23%	-21.34%	-1.96%
Water (cooling)	**kL**	229256.86	234615.11	234615.11	209933.45	234615.11	189478.52	180011.56	224742.44
	% change with BC	0.00%	2.34%	2.34%	-8.43%	2.34%	-17.35%	-21.48%	-1.97%
Waste, non-haz./ landfill	**kg**	104265.18	106594.90	106594.90	95863.53	106594.90	86969.91	82853.76	102302.35
	% change with BC	0.00%	2.23%	2.23%	-8.06%	2.23%	-16.59%	-20.54%	-1.88%
Waste, hazardous/ incinerated	**kg**	1992.43	2038.73	2038.73	1825.45	2038.73	1648.70	1566.89	1953.42
	% change with BC	0.00%	2.32%	2.32%	-8.38%	2.32%	-17.25%	-21.36%	-1.96%
Emissions (Air)									
Greenhouse Gases in GWP100	**t CO2 eq.**	4011.18	4098.86	4098.86	3694.95	3851.10	3360.21	2957.53	3937.30
	% change with BC	0.00%	2.19%	2.19%	-7.88%	-3.99%	-16.23%	-26.27%	-1.84%
Acidification, emissions	**kg SO2 eq.**	22215.54	22732.94	22732.94	20349.62	22732.94	18374.44	17460.29	21779.62
	% change with BC	0.00%	2.33%	2.33%	-8.40%	2.33%	-17.29%	-21.41%	-1.96%
Volatile Organic Compounds (VOC)	**g**	33200.27	33957.04	33957.04	30471.14	33957.04	27582.21	26245.15	32562.68
	% change with BC	0.00%	2.28%	2.28%	-8.22%	2.28%	-16.92%	-20.95%	-1.92%
Persistent Organic Pollutants (POP)	**ng i-Teq**	606179.75	619350.15	619350.15	558683.40	619350.15	508405.83	485136.34	595083.45
	% change with BC	0.00%	2.17%	2.17%	-7.84%	2.17%	-16.13%	-19.97%	-1.83%
Heavy Metals	**mg Ni eq.**	1614353.54	1648826.27	1648826.27	1490034.70	1648826.27	1358436.18	1297529.68	1585309.64
	% change with BC	0.00%	2.14%	2.14%	-7.70%	2.14%	-15.85%	-19.63%	-1.80%
PAHs	**mg Ni eq.**	172761.49	176719.92	176719.92	158486.24	176719.92	143375.07	136381.31	169426.45
	% change with BC	0.00%	2.29%	2.29%	-8.26%	2.29%	-17.01%	-21.06%	-1.93%
Particulate Matter (PM, dust)	**kg**	560.36	571.41	571.41	520.51	571.41	478.32	458.79	551.05
	% change with BC	0.00%	1.97%	1.97%	-7.11%	1.97%	-14.64%	-18.13%	-1.66%
Emissions (Water)									
Heavy Metals	**mg Hg/20**	605261.71	618217.36	618217.36	558539.83	618217.36	509082.09	486192.03	594346.35
	% change with BC	0.00%	2.14%	2.14%	-7.72%	2.14%	-15.89%	-19.67%	-1.80%
Eutrophication	**gg PO4**	7070.38	7132.16	7132.16	6847.58	7132.16	6611.74	6502.59	7018.33
	% change with BC	0.00%	0.87%	0.87%	-3.15%	0.87%	-6.49%	-8.03%	-0.74%
Economic indicators									
Electricity cost	**€**	727834	744855	744855	666449	744855	601470	571397	713493
	% change with BC	0.00%	2.34%	2.34%	-8.43%	2.34%	-17.36%	-21.49%	-1.97%
Life-cycle cost	**€**	810022	828218	835262	765075	831153	709490	683526	836776
	% change with BC	0.00%	2.25%	3.12%	-5.55%	2.61%	-12.41%	-15.62%	3.30%

The combined Scenario B leads to the highest reduction in all environmental indicators for MT and LT. This is not surprising since the use-phase is the main contributor of environmental impacts, and all the improvement options increase the energy efficiency of the Base Case.

Therefore, over the life cycle of a chiller using Scenario B saves 21% of energy for MT and LT products.

Scenario B also represents the LLCC, having saving of around 15% in the economic expenditure. These savings are translated into €80,000 for MT process chillers and around €130,000 for LT process chillers.

The GWP is reduced under the scenario B as well, from 25 to 26% for both temperature ranges.

The figures below show the comparison between the TEC, the LCC and the electricity costs of the different options analysed for chillers.

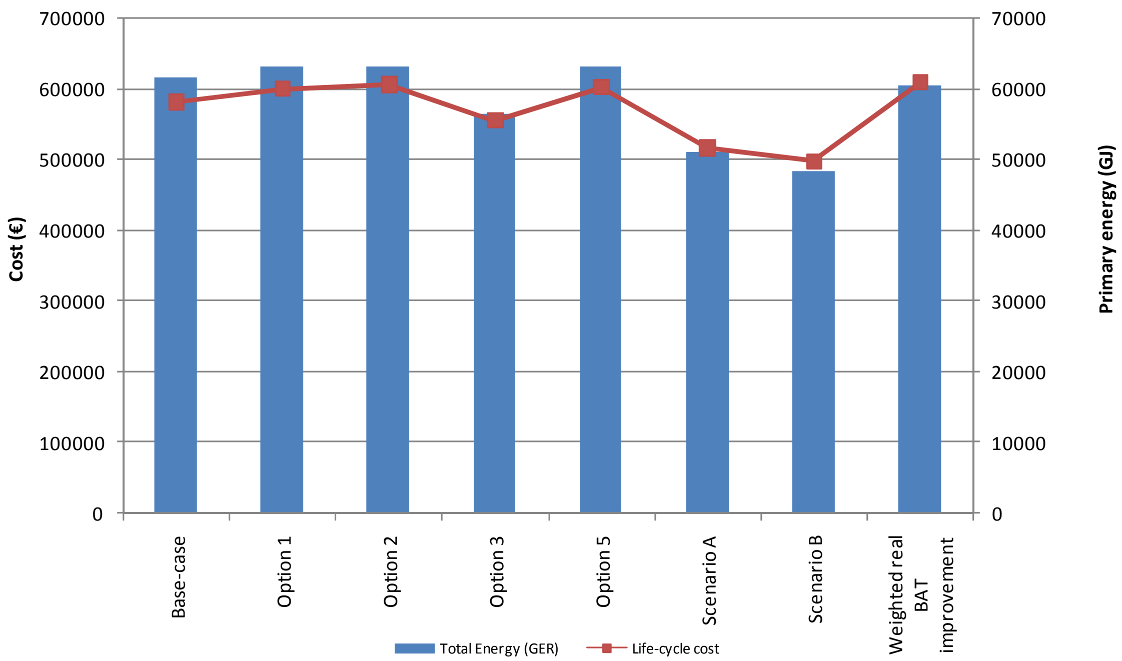

Figure 6-9: MT process chillers Base Case – TEC and LCC

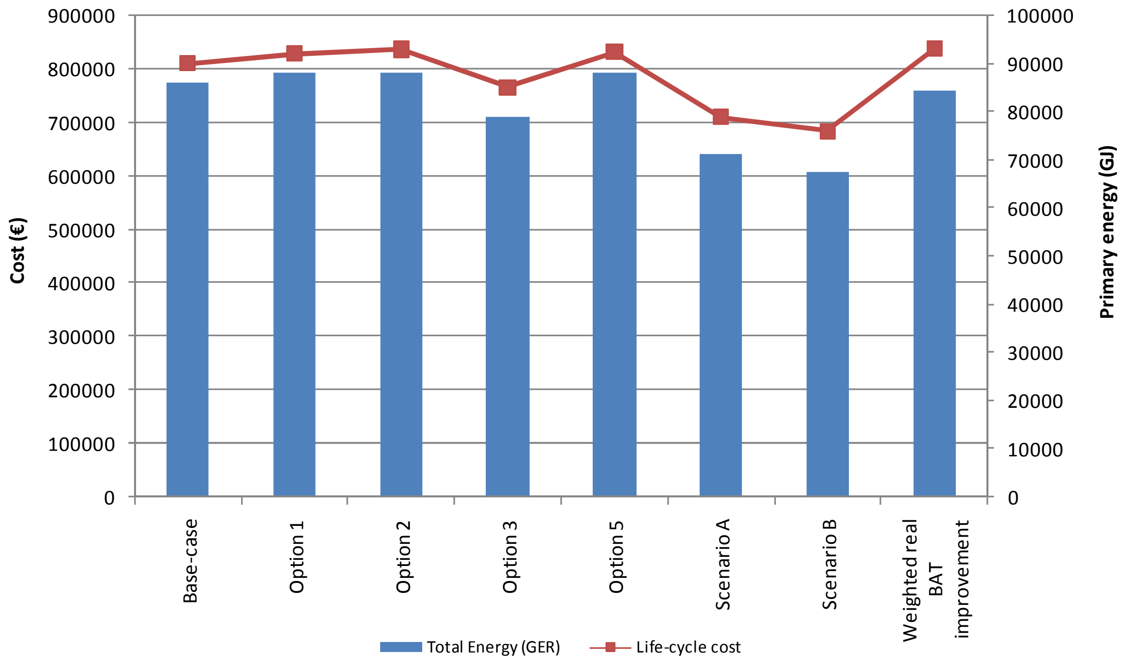

Figure 6-10: LT chillers Base Case – TEC and LCC

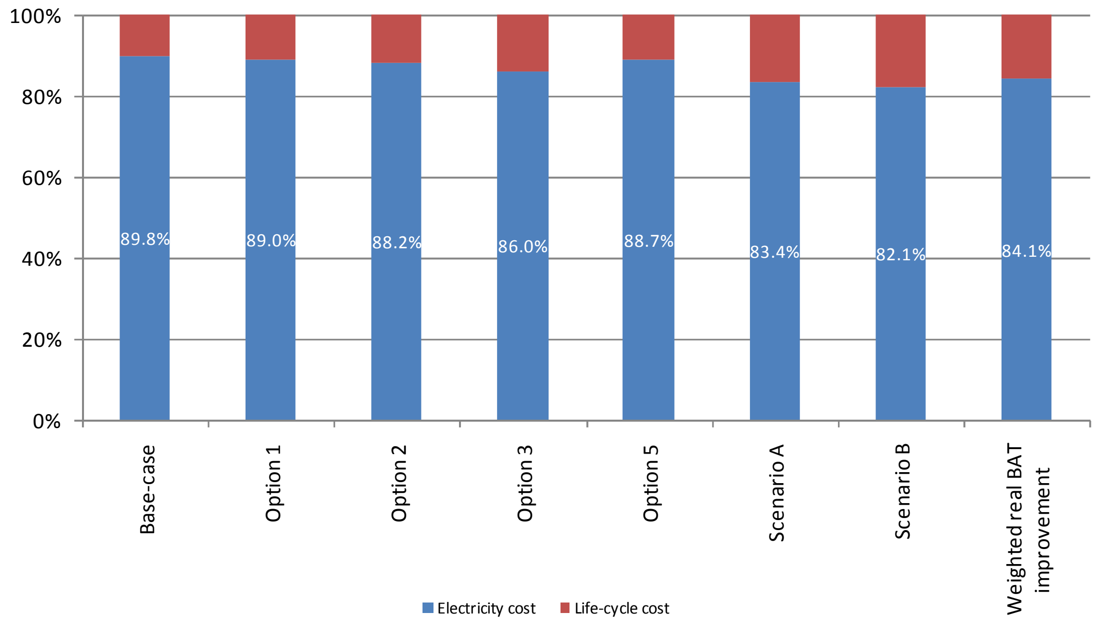

Figure 6-11: MT process chillers Base Case – LCC and electricity costs

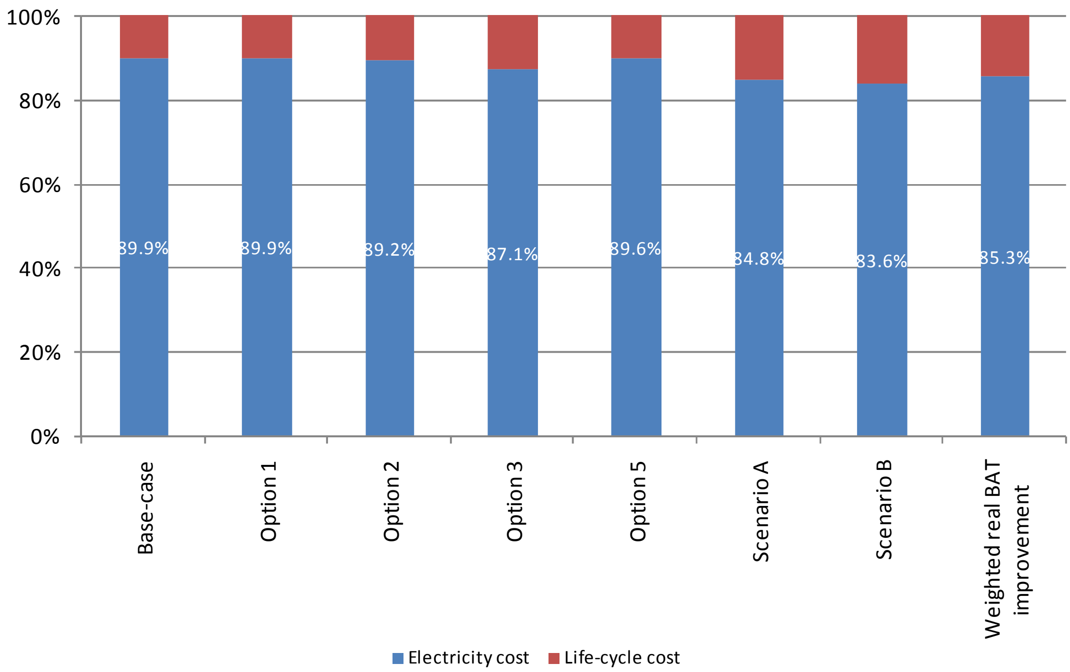

Figure 6-12: LT process chillers Base Case – LCC and electricity costs

6.3.5. MT AND LT REMOTE CONDENSING UNIT BASE CASES

The tables below indicate the main impacts and costs of the different improvement options proposed for the remote condensing unit Base Case, and the analysis of benefits and costs of the combination of these individual options.

Table 6-21: Summary of the cost and benefit effects of implementing individual improvement options for the LT remote condensing unit Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
0	Base Case			50,106	401.01	256.35	40482	49875
Option 1	Increase heat exchanger surfaces	5	238	47,600	380.97	247.17	38458	48089
Option 2	ECM compressor	9	793	45,596	364.93	239.82	36839	47025
Option 3	Digital modulation for compressor	10	793	45,095	360.93	237.98	36434	46620
Option 4	Scroll compressor	10	1,269	45,095	360.93	237.98	36434	47096
Option 5	Variable Speed drive	10	1,983	45,095	360.93	237.98	36434	47810
Option 6	High efficiency fan blades	0.5	159	49,855	399.01	255.43	40279	49832
Option 7	ECM for fans	1	397	49,605	397.00	254.51	40077	49867
Option 8	Refrigerant R290	5	40	47,600	380.97	175.21	38458	47891
Scenario A	Options	28	4,086	36,081	288.81	132.98	29151	42630

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
	1+4+5+6+7+8							
Scenario B	Options 1+2+3+6+7	23	2,380	38,402	307.38	141.49	31026	42799
Weighted real BAT improvement	As described in Task 5	20	5,478	40,180	321.60	185.70	32462	42100

*: during the use phase

Table 6-22: Summary of the cost and benefit effects of implementing individual improvement options for the MT remote condensing unit Base Case

Option	Option description	TEC savings (%)	Cost increase (Euros)	Annual Energy consumption (kWh)	Total Electricity consumption (MWh)*	Total CO2 emissions (kg eq. CO2)	Electricity costs (Euros)	LCC (Euros)
	Base Case			31,270	250.30	187.19	25264	33111
Option 1	Increase heat exchanger surfaces	5	199	29,707	237.79	181.46	24001	30948
Option 2	ECM compressor	9	663	28,456	227.78	176.87	22990	30402
Option 3	Digital modulation for compressor	10	663	28,143	225.28	175.72	22738	30149
Option 4	Scroll compressor	10	1,060	28,143	225.28	175.72	22738	30547
Option 5	Variable Speed drive	10	1,657	28,143	225.28	175.72	22738	31143
Option 6	High efficiency fan blades	0.5	133	31,114	249.05	186.61	25138	32019
Option 7	ECM for fans	0.5	331	31,114	249.05	186.61	25138	32218
Option 8	Refrigerant R290	5	30	29,707	237.79	109.50	24001	30780
Scenario A	Options1+4+5+6 +7+8	28	3,410	22,631	181.19	83.56	18284	28443
Scenario B	Options 1+2+3+6+7	23	1,988	24,087	192.83	88.90	19461	28197
Weighted real BAT improvement	As described in Task 5	19	335	25,202	201.75	100.11	20361	27224

*: during the use phase

An environmental and economic assessment was carried out for each improvement option and for their combination of these individual options, using the EcoReport tool. Outcomes of these assessments, taking into account the whole life cycle, are provided in Table 6-23 and

Table 6-24 below which present the absolute values (in units) and variations with the Base Case.

Table 6-23: Environmental impacts of the LT remote condensing unit Base Case and its improvement options

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Scenario A	Scenario B	Weighted real BAT
Other resources and waste													
Total Energy (GER)	GJ	4218.95	4008.50	3840.15	3798.06	3798.06	3798.06	4197.90	4176.86	4008.50	3040.87	3235.83	3385.17
	% change with BC	0.00%	-4.99%	-8.98%	-9.98%	-9.98%	-9.98%	-0.50%	-1.00%	-4.99%	-27.92%	-23.30%	-19.76%
of which, electricity	primary GJ	4210.60	4000.16	3831.80	3789.72	3789.72	3789.72	4189.56	4168.51	4000.16	3032.52	3227.49	3376.82
	MWh	401.01	380.97	364.93	360.93	360.93	360.93	399.01	397.00	380.97	288.81	307.38	321.60
	% change with BC	0.00%	-5.00%	-9.00%	-10.00%	-10.00%	-10.00%	-0.50%	-1.00%	-5.00%	-27.98%	-23.35%	-19.80%
Water (process)	kL	281.88	267.85	256.63	253.82	253.82	253.82	280.48	279.08	267.85	203.34	216.34	226.30
	% change with BC	0.00%	-4.98%	-8.96%	-9.95%	-9.95%	-9.95%	-0.50%	-1.00%	-4.98%	-27.86%	-23.25%	-19.72%
Water (cooling)	kL	11225.22	10664.04	10215.09	10102.86	10102.86	10102.86	11169.11	11112.99	10664.04	8083.67	8603.58	9001.81
	% change with BC	0.00%	-5.00%	-9.00%	-10.00%	-10.00%	-10.00%	-0.50%	-1.00%	-5.00%	-27.99%	-23.35%	-19.81%
Waste, non-haz./ landfill	kg	5231.11	4987.11	4791.92	4743.12	4743.12	4743.12	5206.71	5182.31	4987.11	3865.19	4091.24	4264.39
	% change with BC	0.00%	-4.66%	-8.40%	-9.33%	-9.33%	-9.33%	-0.47%	-0.93%	-4.66%	-26.11%	-21.79%	-18.48%
Waste, hazardous/ incinerated	kg	100.33	95.48	91.60	90.63	90.63	90.63	99.85	99.36	95.48	73.18	77.68	81.12
	% change with BC	0.00%	-4.83%	-8.70%	-9.67%	-9.67%	-9.67%	-0.48%	-0.97%	-4.83%	-27.06%	-22.58%	-19.15%
Emissions (Air)													
Greenhouse Gases in GWP100	t CO2 eq.	256.35	247.17	239.82	237.98	237.98	237.98	255.43	254.51	175.21	132.98	141.49	185.70
	% change with BC	0.00%	-3.58%	-6.45%	-7.16%	-7.16%	-7.16%	-0.36%	-0.72%	-31.65%	-48.12%	-44.81%	-27.56%
Acidification, emissions	kg SO2 eq.	1087.06	1032.87	989.52	978.68	978.68	978.68	1081.64	1076.23	1032.87	783.71	833.91	872.36
	% change with BC	0.00%	-4.98%	-8.97%	-9.97%	-9.97%	-9.97%	-0.50%	-1.00%	-4.98%	-27.91%	-23.29%	-19.75%
Volatile Organic Compounds (VOC)	g	1627.92	1548.66	1485.25	1469.40	1469.40	1469.40	1619.99	1612.06	1548.66	1184.22	1257.65	1313.89
	% change with BC	0.00%	-4.87%	-8.76%	-9.74%	-9.74%	-9.74%	-0.49%	-0.97%	-4.87%	-27.26%	-22.74%	-19.29%
Persistent Organic Pollutants (POP)	ng i-Teq	31588.48	30209.10	29105.60	28829.73	28829.73	28829.73	31450.54	31312.60	30209.10	23866.64	25144.55	26123.40
	% change with BC	0.00%	-4.37%	-7.86%	-8.73%	-8.73%	-8.73%	-0.44%	-0.87%	-4.37%	-24.45%	-20.40%	-17.30%
Heavy Metals	mg Ni eq.	74319.71	70709.28	67820.94	67098.85	67098.85	67098.85	73958.66	73597.62	70709.28	54108.26	57453.10	60015.20
	% change with BC	0.00%	-4.86%	-8.74%	-9.72%	-9.72%	-9.72%	-0.49%	-0.97%	-4.86%	-27.20%	-22.69%	-19.25%
PAHs	mg Ni eq.	8562.35	8147.77	7816.11	7733.20	7733.20	7733.20	8520.89	8479.43	8147.77	6241.52	6625.60	6919.80
	% change with BC	0.00%	-4.84%	-8.72%	-9.68%	-9.68%	-9.68%	-0.48%	-0.97%	-4.84%	-27.11%	-22.62%	-19.18%
Particulate Matter (PM, dust)	kg	27.74	26.58	25.66	25.43	25.43	25.43	27.62	27.51	26.58	21.26	22.33	23.15
	% change with BC	0.00%	-4.17%	-7.51%	-8.34%	-8.34%	-8.34%	-0.42%	-0.83%	-4.17%	-23.36%	-19.49%	-16.53%
Emissions (Water)													
Heavy Metals	mg Hg/20	27681.07	26324.19	25238.69	24967.31	24967.31	24967.31	27545.39	27409.70	26324.19	20085.15	21342.22	22305.11
	% change with BC	0.00%	-4.90%	-8.82%	-9.80%	-9.80%	-9.80%	-0.49%	-0.98%	-4.90%	-27.44%	-22.90%	-19.42%
Eutrophication	gg PO4	155.02	148.55	143.37	142.08	142.08	142.08	154.37	153.73	148.55	118.80	124.79	129.38
	% change with BC	0.00%	-4.17%	-7.51%	-8.35%	-8.35%	-8.35%	-0.42%	-0.83%	-4.17%	-23.37%	-19.50%	-16.54%
Economic indicators													
Electricity cost	€	40482	38458	36839	36434	36434	36434	40279	40077	38458	29151	31026	32462
	% change with BC	0.00%	-5.00%	-9.00%	-10.00%	-10.00%	-10.00%	-0.50%	-1.00%	-5.00%	-27.99%	-23.36%	-19.81%
Life-cycle cost	€	49875	48089	47025	46620	47096	47810	49832	49867	47891	42630	42799	42100
	% change with BC	0.00%	-3.58%	-5.71%	-6.53%	-5.57%	-4.14%	-0.09%	-0.02%	-3.98%	-14.53%	-14.19%	-15.59%

Table 6-24: Environmental impacts of the MT remote condensing unit Base Case and its improvement options

life-cycle indicators per unit	unit	Base Case	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Scenario A	Scenario B	Weighted real BAT
	Other resources and waste												
Total Energy (GER)	**GJ**	2635.08	2503.75	2398.68	2372.41	2372.41	2372.41	2621.95	2621.95	2503.75	1909.41	2031.70	2125.37
	% change with BC	0.00%	-4.98%	-8.97%	-9.97%	-9.97%	-9.97%	-0.50%	-0.50%	-4.98%	-27.54%	-22.90%	-19.34%
of which, electricity	**primary GJ**	2628.12	2496.78	2391.72	2365.45	2365.45	2365.45	2614.98	2614.98	2496.78	1902.45	2024.74	2118.41
	MWh	250.30	237.79	227.78	225.28	225.28	225.28	249.05	249.05	237.79	181.19	192.83	201.75
	% change with BC	0.00%	-5.00%	-9.00%	-9.99%	-9.99%	-9.99%	-0.50%	-0.50%	-5.00%	-27.61%	-22.96%	-19.39%
Water (process)	**kL**	176.19	167.43	160.43	158.68	158.68	158.68	175.31	175.31	167.43	127.81	135.96	142.21
	% change with BC	0.00%	-4.97%	-8.95%	-9.94%	-9.94%	-9.94%	-0.50%	-0.50%	-4.97%	-27.46%	-22.83%	-19.29%
Water (cooling)	**kL**	7005.77	6655.55	6375.37	6305.32	6305.32	6305.32	6970.75	6970.75	6655.55	5070.66	5396.76	5646.55
	% change with BC	0.00%	-5.00%	-9.00%	-10.00%	-10.00%	-10.00%	-0.50%	-0.50%	-5.00%	-27.62%	-22.97%	-19.40%
Waste, non-haz./ landfill	**kg**	3338.13	3185.85	3064.03	3033.58	3033.58	3033.58	3322.90	3322.90	3185.85	2496.76	2638.54	2747.15
	% change with BC	0.00%	-4.56%	-8.21%	-9.12%	-9.12%	-9.12%	-0.46%	-0.46%	-4.56%	-25.20%	-20.96%	-17.70%
Waste, hazardous/ incinerated	**kg**	63.31	60.29	57.87	57.26	57.26	57.26	63.01	63.01	60.29	46.59	49.41	51.57
	% change with BC	0.00%	-4.78%	-8.60%	-9.56%	-9.56%	-9.56%	-0.48%	-0.48%	-4.78%	-26.41%	-21.96%	-18.55%
	Emissions (Air)												
Greenhouse Gases in GWP100	**t CO2 eq.**	187.19	181.46	176.87	175.72	175.72	175.72	186.61	186.61	109.50	83.56	88.90	100.11
	% change with BC	0.00%	-3.06%	-5.51%	-6.12%	-6.12%	-6.12%	-0.31%	-0.31%	-41.50%	-55.36%	-52.51%	-46.52%
Acidification, emissions	**kg SO2 eq.**	679.10	645.28	618.23	611.47	611.47	611.47	675.72	675.72	645.28	492.24	523.73	547.85
	% change with BC	0.00%	-4.98%	-8.96%	-9.96%	-9.96%	-9.96%	-0.50%	-0.50%	-4.98%	-27.52%	-22.88%	-19.33%
Volatile Organic Compounds (VOC)	**g**	1024.90	975.44	935.87	925.98	925.98	925.98	1019.96	1019.96	975.44	751.60	797.66	832.94
	% change with BC	0.00%	-4.83%	-8.69%	-9.65%	-9.65%	-9.65%	-0.48%	-0.48%	-4.83%	-26.67%	-22.17%	-18.73%
Persistent Organic Pollutants (POP)	**ng i-Teq**	20551.03	19690.19	19001.52	18829.35	18829.35	18829.35	20464.95	20464.95	19690.19	15794.60	16596.14	17210.11
	% change with BC	0.00%	-4.19%	-7.54%	-8.38%	-8.38%	-8.38%	-0.42%	-0.42%	-4.19%	-23.14%	-19.24%	-16.26%
Heavy Metals	**mg Ni eq.**	46823.70	44570.51	42767.95	42317.31	42317.31	42317.31	46598.38	46598.38	44570.51	34374.02	36472.02	38079.04
	% change with BC	0.00%	-4.81%	-8.66%	-9.62%	-9.62%	-9.62%	-0.48%	-0.48%	-4.81%	-26.59%	-22.11%	-18.68%
PAHs	**mg Ni eq.**	5400.70	5141.97	4934.99	4883.24	4883.24	4883.24	5374.83	5374.83	5141.97	3971.13	4212.04	4396.57
	% change with BC	0.00%	-4.79%	-8.62%	-9.58%	-9.58%	-9.58%	-0.48%	-0.48%	-4.79%	-26.47%	-22.01%	-18.59%
Particulate Matter (PM, dust)	**kg**	18.27	17.55	16.97	16.83	16.83	16.83	18.20	18.20	17.55	14.28	14.95	15.47
	% change with BC	0.00%	-3.95%	-7.12%	-7.91%	-7.91%	-7.91%	-0.40%	-0.40%	-3.95%	-21.84%	-18.16%	-15.34%
	Emissions (Water)												
Heavy Metals	**mg Hg/20**	17388.96	16542.15	15864.71	15695.35	15695.35	15695.35	17304.28	17304.28	16542.15	12710.08	13498.56	14102.51
	% change with BC	0.00%	-4.87%	-8.77%	-9.74%	-9.74%	-9.74%	-0.49%	-0.49%	-4.87%	-26.91%	-22.37%	-18.90%
Eutrophication	**gg PO4**	102.11	98.07	94.84	94.03	94.03	94.03	101.70	101.70	98.07	79.79	83.55	86.43
	% change with BC	0.00%	-3.95%	-7.12%	-7.91%	-7.91%	-7.91%	-0.40%	-0.40%	-3.95%	-21.85%	-18.17%	-15.35%
	Economic indicators												
Electricity cost	**€**	25264	24001	22990	22738	22738	22738	25138	25138	24001	18284	19461	20361
	% change with BC	0.00%	-5.00%	-9.00%	-10.00%	-10.00%	-10.00%	-0.50%	-0.50%	-5.00%	-27.63%	-22.97%	-19.41%
Life-cycle cost	**€**	33111	30948	30402	30149	30547	31143	32019	32218	30780	28443	28197	27224
	% change with BC	0.00%	-6.53%	-8.18%	-8.95%	-7.75%	-5.94%	-3.30%	-2.70%	-7.04%	-14.10%	-14.84%	-17.78%

In both Base Cases for low and medium temperature the option which achieves highest reduction in environmental impacts (hence the BAT option) of all the impact categories is the Scenario A, which reduces the impact by around 21% to 54%.

In terms of economic impact during the entire lifespan, Scenario A is the LLCC option for low temperature, with a Life Cycle Cost 14.5% lower than the Base Case and for medium temperature the Scenario B is the LLCC option, 14.8% lower than the Base Case.

Figure 6-13 to Figure 6-16 show the comparison between the TEC, the LCC and the electricity costs of the different options analysed.

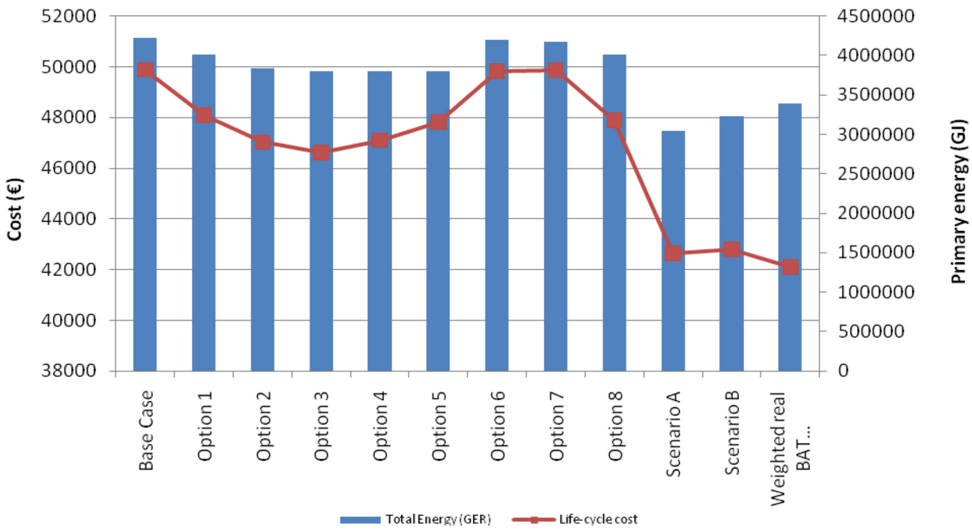

Figure 6-13: LT remote condensing unit Base Case – TEC and LCC

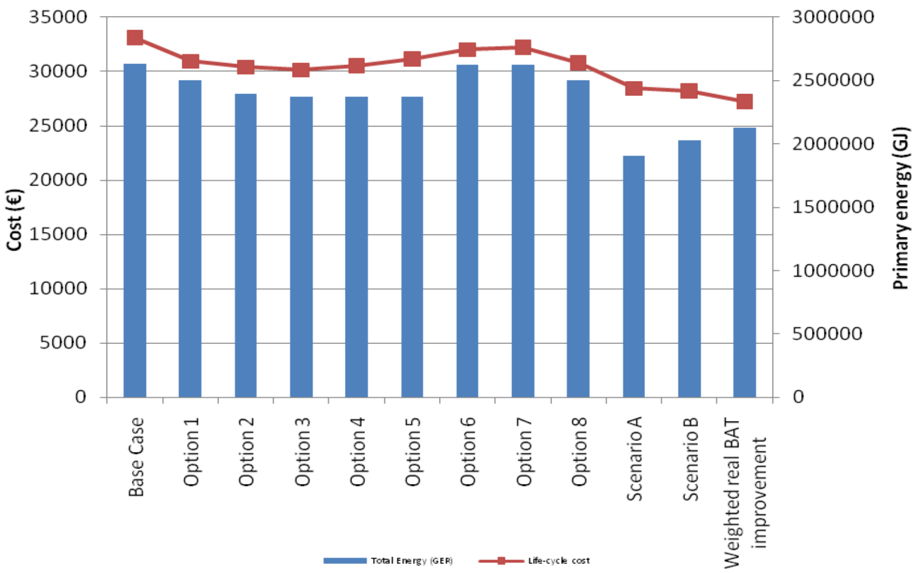

Figure 6-14: MT remote condensing unit Base Case – TEC and LCC

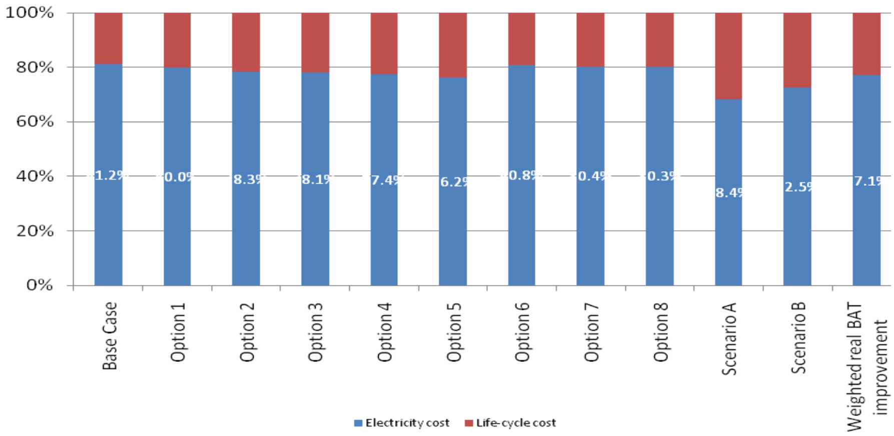

Figure 6-15: LT remote condensing unit Base Case – LCC and electricity costs

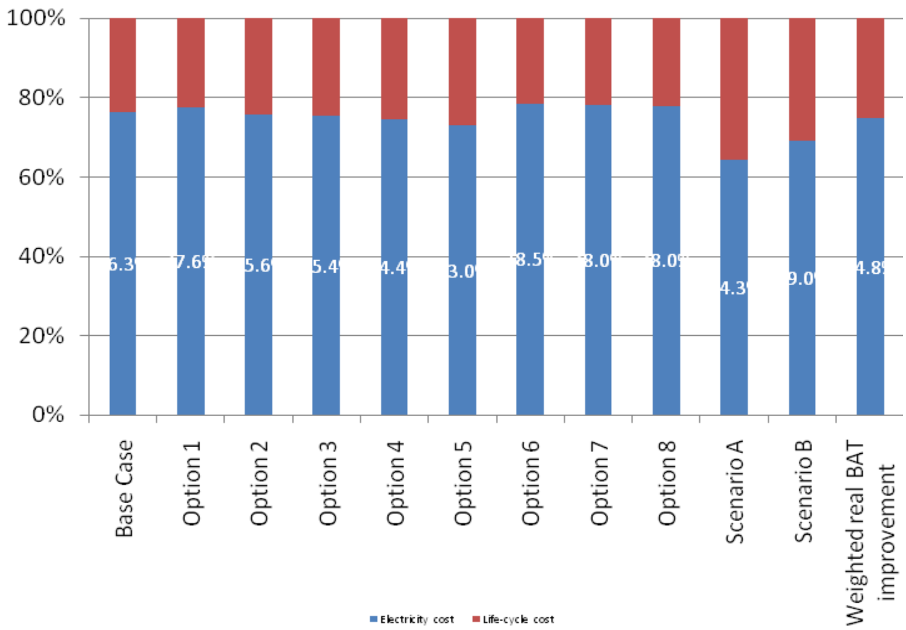

Figure 6-16: MT remote condensing unit Base Case – LCC and electricity costs

6.4. BNAT AND LONG-TERM SYSTEMS ANALYSIS

The full lists of improvement options described for each product group in Task 5 are not all analysed in section, due to issues such high cost or consideration on their availability (hence could be described as BNAT). Some of these may therefore become less costly to manufacturers in the coming years, and be applicable to products on the market.

Some specific product issues to highlight:

- No real long-term target options have been identified for blast cabinets. The applicability of the heat exchanger options will depend on the availability of space for fitting the units due to volume constraints. The further development of new heat transfer technologies might overcome this issue. The EEV is not commonly applied, although it can be found in some products in the market. The use of natural refrigerant can become an acceptable practice after overcoming the safety issues. The resulting increase in the cost for the unit is one of the highest, translated into higher capital cost, possibly the reason for its lack of application.

- Some of the improvement options identified as BNAT for remote condensing units are technically feasible but as they are not common technologies the price is too high to be used in condensing units of all capacity ranges, but they are expected to become economically viable in around 5 years. This is the case with some natural refrigerants or water and evaporative cooling systems.

In addition, BNAT technologies, such as magnetic refrigeration, were identified in Task 5, and it is estimated these may also be brought onto the market in the next 5 to 10 years.

Lastly, referring back to Task 2, there are certain trends that may have an impact on the future development of refrigeration and freezing equipment:

- Centralisation of catering – more remote systems for efficiency.
- Integration of HVAC and refrigeration for Energy Efficiency: the integration of all cooling requirements of facilities in the same system allows achieving higher efficiencies using bigger condensing units, and modulating the workload for each of them. The implementation of heat recovery for air conditioning or cascade systems is also possible in integral cooling and refrigeration systems, allowing higher efficiencies when the entire system is considered.
- Transfer to alternative (low GWP) refrigerants: some of the alternative refrigerants present issues of adapting the systems to their requirements due to safety reasons and technical requirements. This is the case for carbon dioxide and hydrocarbons, which could be applied in remote installations or cascade systems that might enable their use.

6.5. SENSITIVITY ANALYSIS OF THE MAIN PARAMETERS

In the following sections, a sensitivity analysis, covering the following parameters is carried out and discussed for each Base Case:

- Product price
- Product lifetime
- Annual electricity consumption
- Electricity tariff and discount rate
- Product stock

The robustness of the outcomes of the study depends on the underlying assumptions. These assumptions have been explicitly mentioned at the relevant steps of the study.

In this section, the sensitivity of the results to the most critical parameters and assumptions is tested.

6.5.1. ASSUMPTIONS RELATED TO THE PRODUCT PRICE

The range of products within each product group is very wide. Products with different characteristics and different purchase prices exist on the EU market.

Therefore, compared to the product price defined for Base Cases, two scenarios are defined, to take into account the fact that on the one hand the price may be underestimated, and on the other that there is often a significant reduction paid by consumers compared to the list price (if purchased in bulk):

- An increase of 20%
- A decrease of 40%

The variation of the LCC compared to the Base is provided in Figure 6-17 for each Base Case. The impact of such a variation is quite negligible for chillers, due to the small share of the product price in the LCC (<10%, see

**Including several features within the options for increasing the component efficiency*
*** Only applicable to air-cooled chillers. Not considered in this analysis, but in task 7*
****Changes in the system are required. Integrated with a secondary fluid*

Table 6-18

).

On the contrary, for blast cabinets, the purchase price has a significant impact on the LCC: variation of +13%/-25% for the LCC for a variation of +20%/-40% of the purchase price respectively, and an increase of 24% in the LCC when the transformer is 30% more expensive. Such variations come from the high share of the product price in the LCC for this type of transformer (between 50% and 65%, see Figure 6-18).

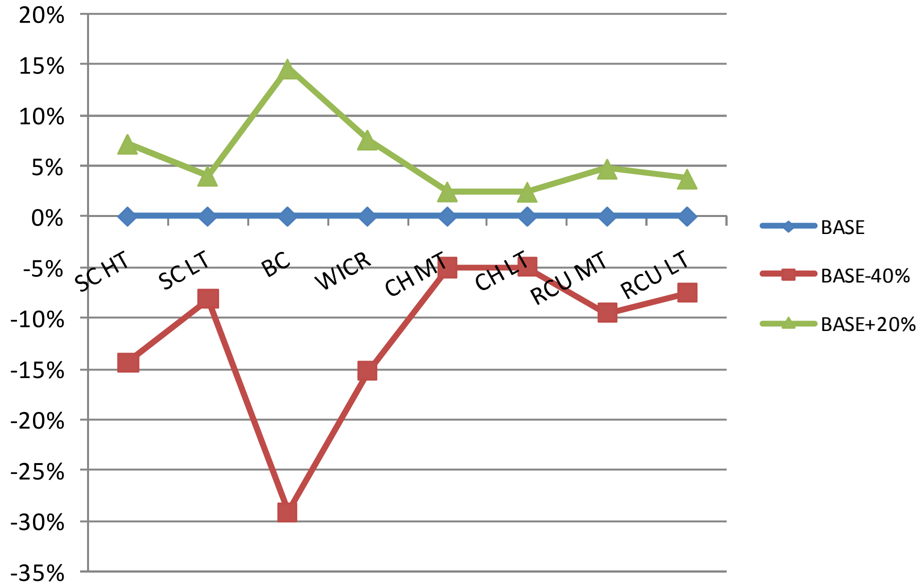

Figure 6-17: Product price - Variation of the LCC compared to the Base

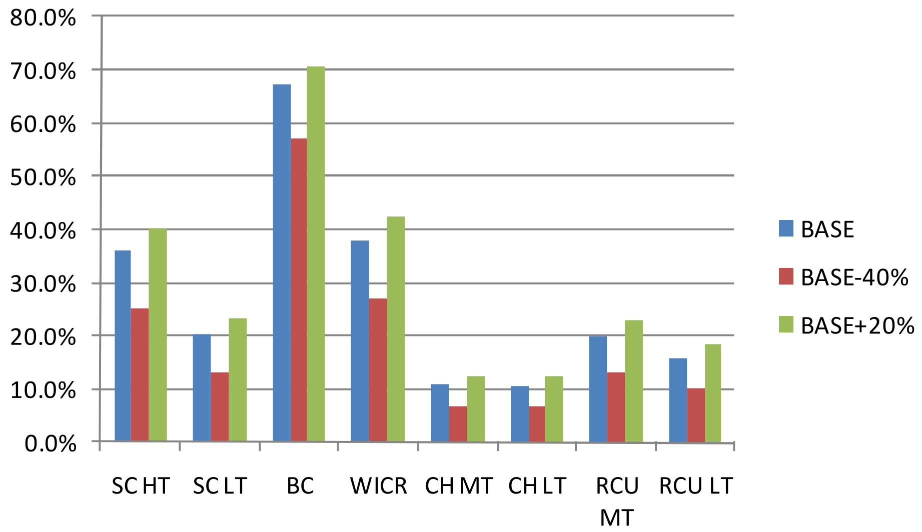

Figure 6-18: Product price - Share of the product price in the LCC

Impact of any variation in the product price of the Base Case on its LCC and on one of its improvement options is quite straightforward. Indeed, a constant price (which is the variation with the base) will be added for all options. For instance, for the Base Case Service cabinet HT, the scenario BASE+20% implies an increase of 400€ whereas the scenario BASE-40% implies a decrease of 800€ for all improvement options. Therefore, the ranking of options in terms of LCC remains similar; only absolute values change. This is obviously the case for all Base Cases.

6.5.2. ASSUMPTIONS RELATED TO THE PRODUCT LIFETIME

Average lifetimes are used in the EcoReport tool to assess environmental and LCC over the whole life cycle of the Base Cases. However, some products can have a shorter or a longer lifetime. These extreme values, based on alternatives from the literature and stakeholder feedback, are presented in Table 6-25 and used in this sensitivity analysis to analyse the impact of this parameter on the LCC of the Base Cases and their electricity consumption during the use phase.

Table 6-25: Assumptions related to product lifetime

Base Case	Base	MIN	MAX
Service Cabinet HT	8.5	8	12
Service Cabinet LT	8.5	8	12
Blast Cabinet	8.5	6	10
WICR	10	10	18
Chiller MT	15	15	20
Chiller LT	15	15	20
RCU MT	8	8	12
RCU LT	8	8	12

Figure 6-19 indicates the variation of the electricity consumed during the use phase according to the lifetime of products.

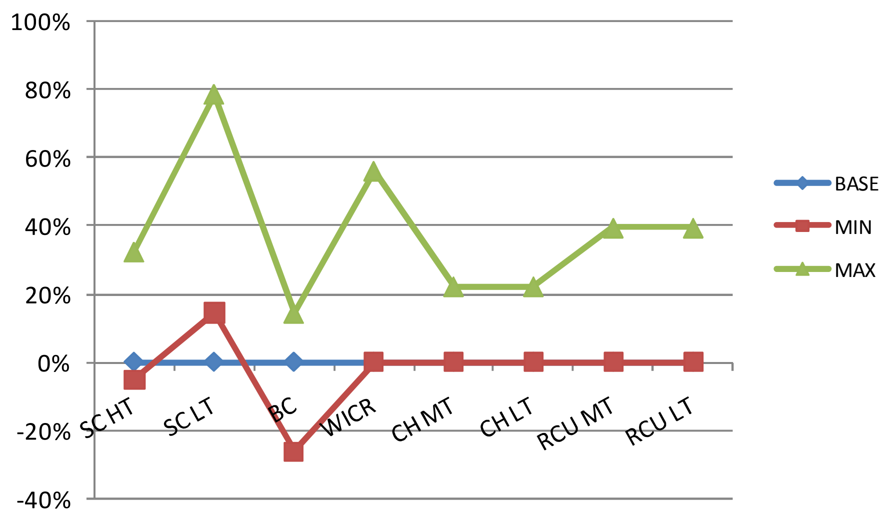

Figure 6-19: Product lifetime - Variation of the electricity consumption compared to the Base

Figure 6-20 presents for each Base Case the effect on the LCC of extreme lifetimes compared to the average value used in Task 4. The greater impact is for WICR for which an extension of 80% in the lifetime (18 years compared to 10 years) implies an increase of about 60% of the LCC.

This figure has to be analysed carefully, as the relative extension of the lifetime is not similar for all Base Cases, e.g. +80% for WICR whereas +18% for blast cabinet.

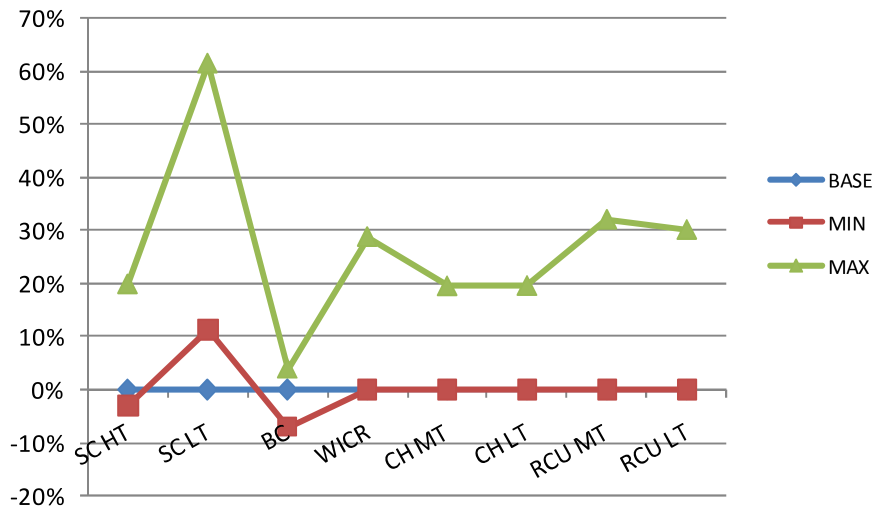

Figure 6-20: Product lifetime - Variation of the LCC compared to the Base

Figure 6-21 to Figure 6-28 present for each Base Case and its improvement options, the LCC depending on the lifetimes specified in Table 6-25.

The variation in the lifetime does not have any impact on the order of options per Base Case, except for RCU MT. Indeed, the two proposed options have similar LCC, and variations in the product lifetime can vary their total life cycle costs. With a shorter lifetime, scenario A would be the LLCC option, whereas assuming longer lifetime, Scenario B would be the option with lower consumer expenditure per product.

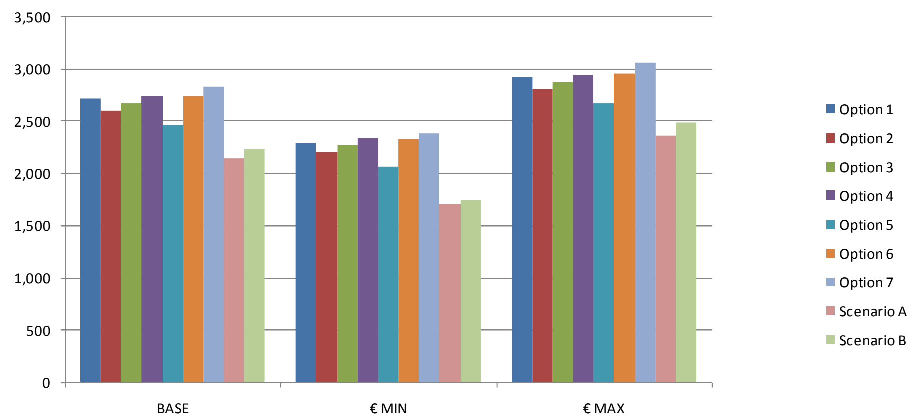

Figure 6-21: Base Case Service cabinet HT and its improvement options – Impact of lifetime on the LCC (€)

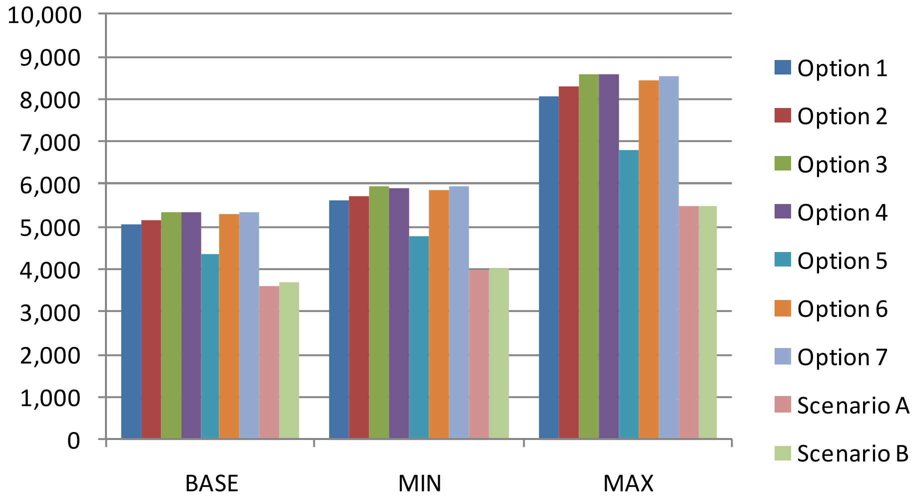

Figure 6-22: Base Case Service cabinet LT and its improvement options – Impact of lifetime on the LCC (€)

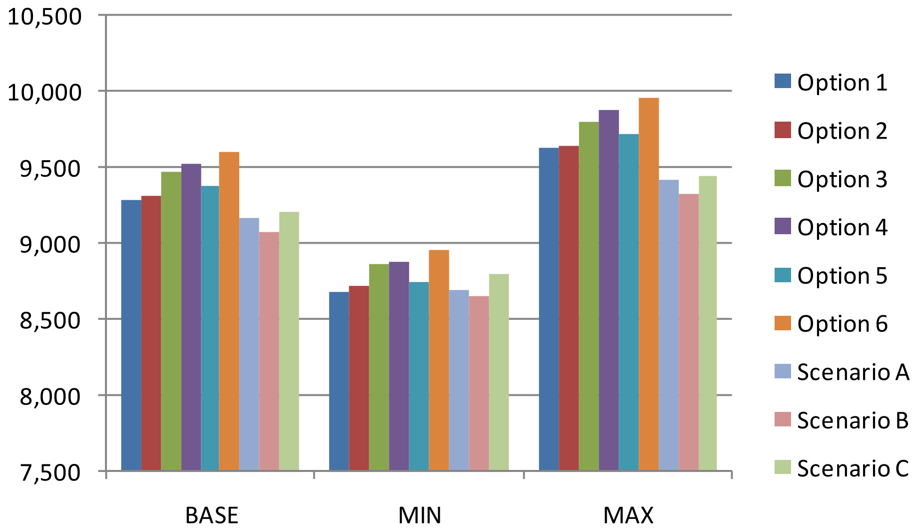

Figure 6-23: Base Case Blast cabinet and its improvement options – Impact of lifetime on the LCC (€)

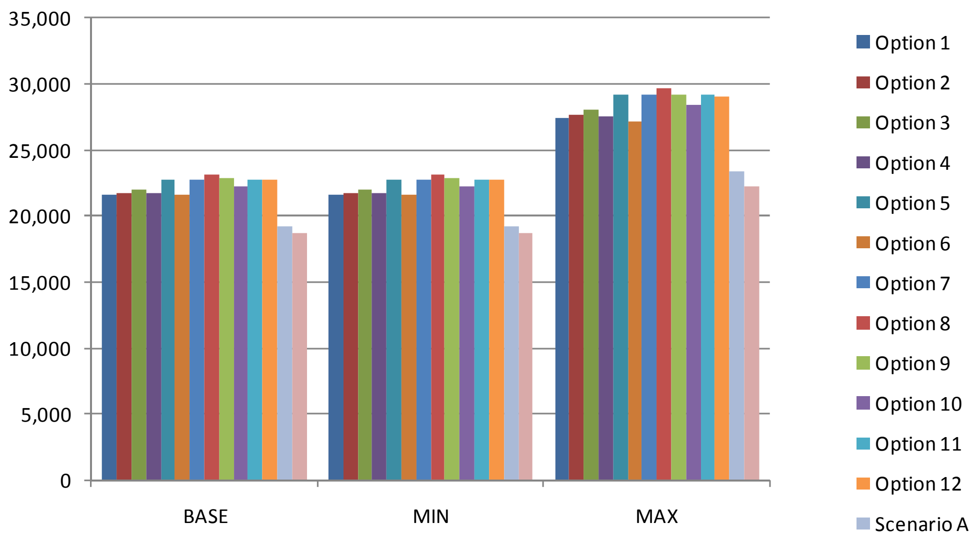

Figure 6-24: Base Case WICR and its improvement options – Impact of lifetime on the LCC (€)

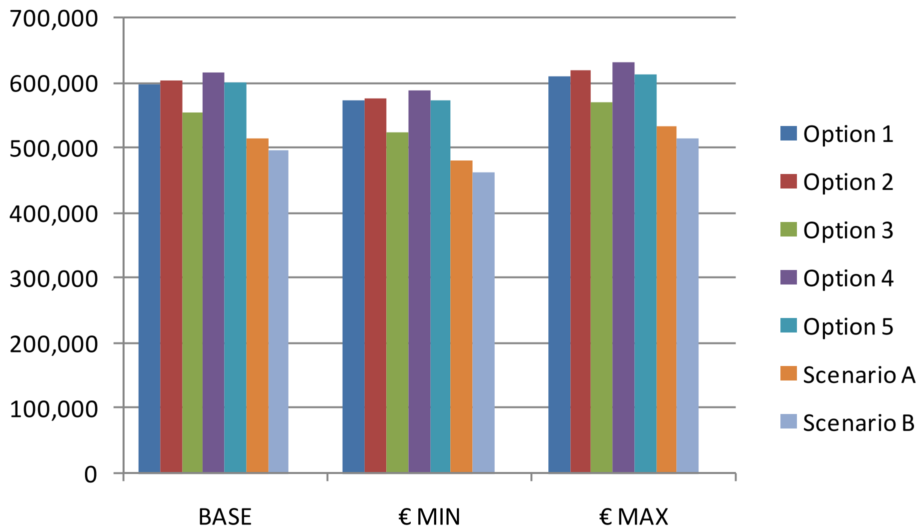

Figure 6-25: Base Case Chiller MT and its improvement options – Impact of lifetime on the LCC (€)

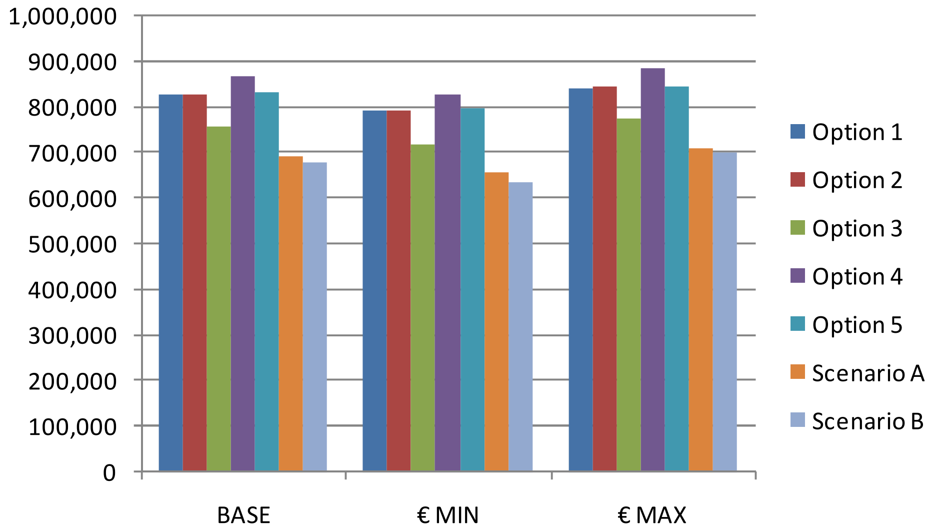

Figure 6-26: Base Case Chiller LT and its improvement options – Impact of lifetime on the LCC (€)

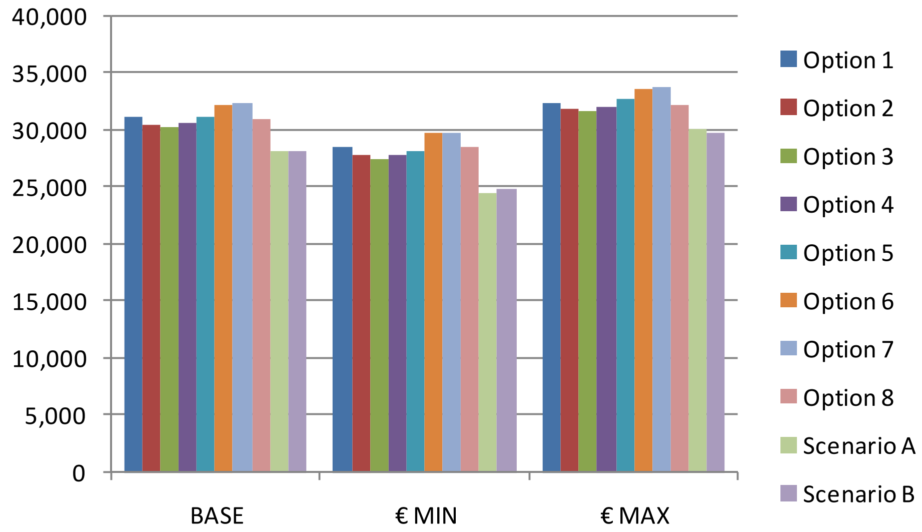

Figure 6-27: Base Case RCU MT and its improvement options – Impact of lifetime on the LCC (€)

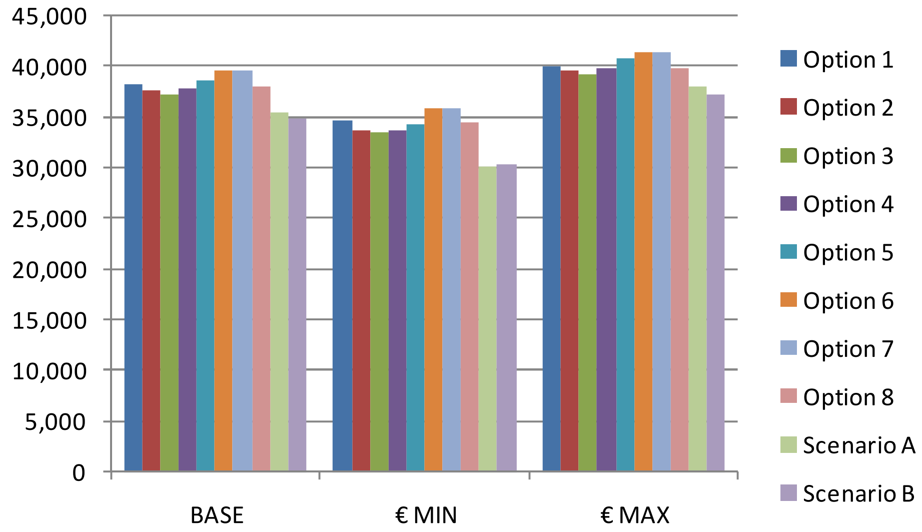

Figure 6-28: Base Case RCU LT and its improvement options – Impact of lifetime on the LCC (€)

6.5.3. Assumptions related to the annual electricity consumption of the Base Cases

As for all energy-using products, electricity consumption is considered as a major impact. In Task 4, average electricity consumptions were defined for all Base Cases based on data provided by manufacturers. Nevertheless, as the range of models is very wide within each product category, it is worthwhile carrying out a sensitivity analysis on this parameter.

Therefore, compared to the annual electricity consumption defined for Base Cases in Task 4, 2 scenarios are defined:

- An increase of 40%
- A decrease of 20%

The variation in the LCC compared to the Base is provided in Figure 6-29 for each Base Case. The impact of such a variation is quite significant for chillers due to the high share of the electricity cost in the LCC (>85%, see Figure 6-30).

On the contrary, for blast cabinet, the purchase price has a significant impact on the LCC: variation of +14%/-7% in the LCC for a variation of +40%/-20% in the electricity consumption. Such variations come from the high share of the electricity cost in the LCC for this type of appliance (about 35%, see Figure 6-30).

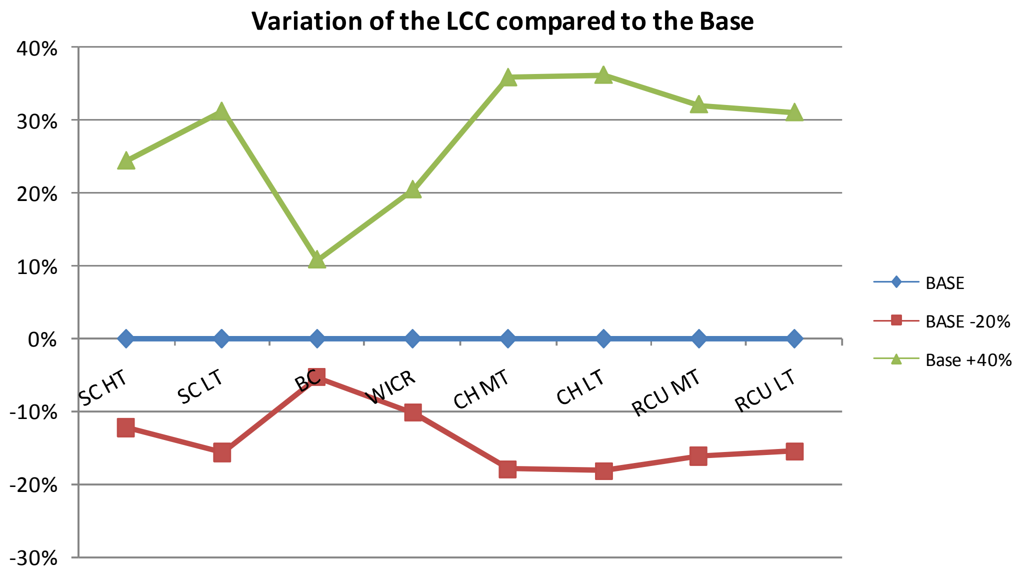

Figure 6-29: Product electricity consumption - Variation of the LCC compared to the Base

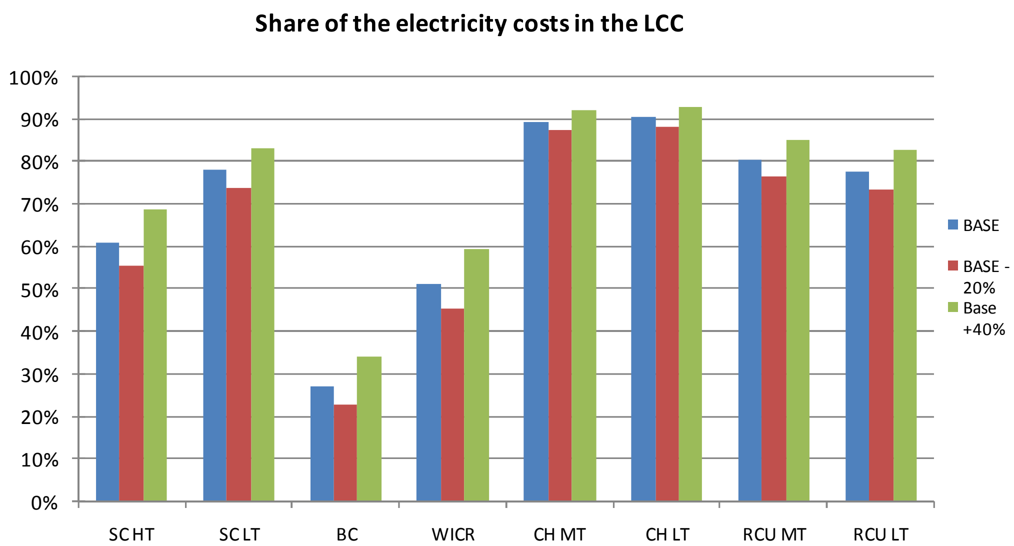

Figure 6-30: Product electricity consumption - Share of the electricity cost in the LCC

Figure 6-31 to Figure 6-38 present the LCC of each Base Case and its improvement options with different values of electricity consumption for the Base Case. Obviously, the higher the consumption of the Base Case is, the higher the gap between the Base Case and the LLCC option.

The improvement option leading to the LLCC remains the same whatever the Base Case and its annual electricity consumption is, except for the Base Case RCU. Indeed, for this

Base Case with a high value of electricity consumption, the LCC of each option can vary slightly, and due to the different payback periods of the different options, the LLCC option can be the option 5 (VSD) if the electricity consumption is lower than the estimated for the base case, or Scenario A when the electricity is increased in 40%.

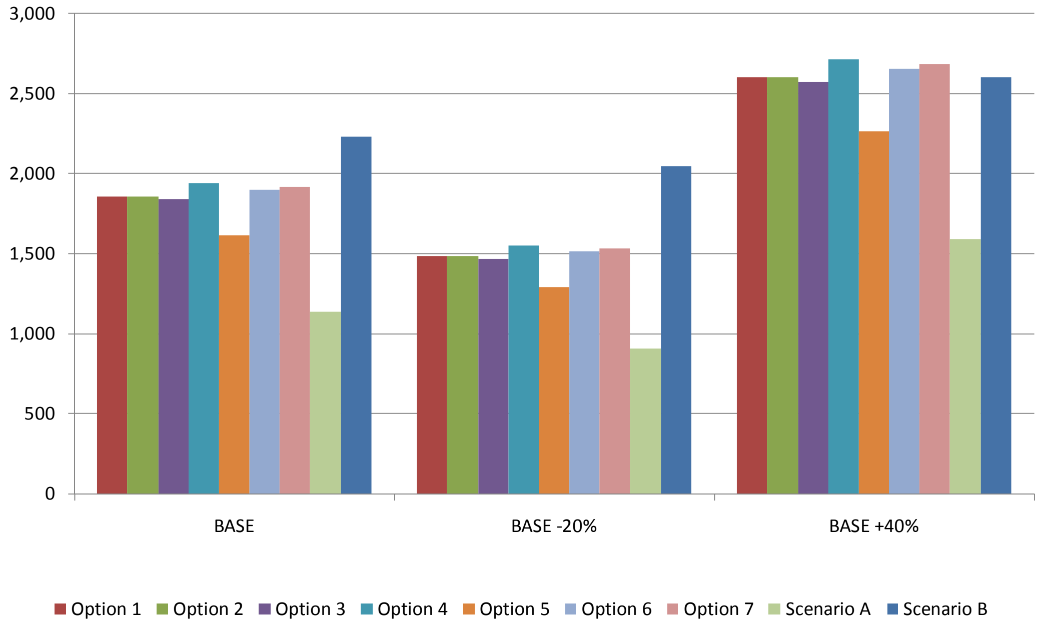

Figure 6-31: Base Case Service cabinet HT and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

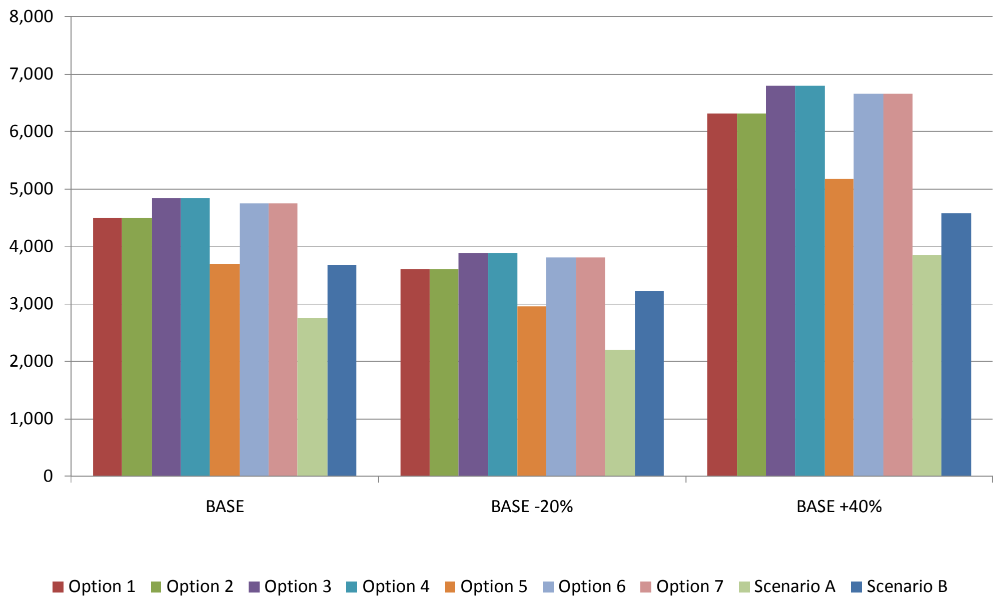

Figure 6-32: Base Case Service cabinet LT and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

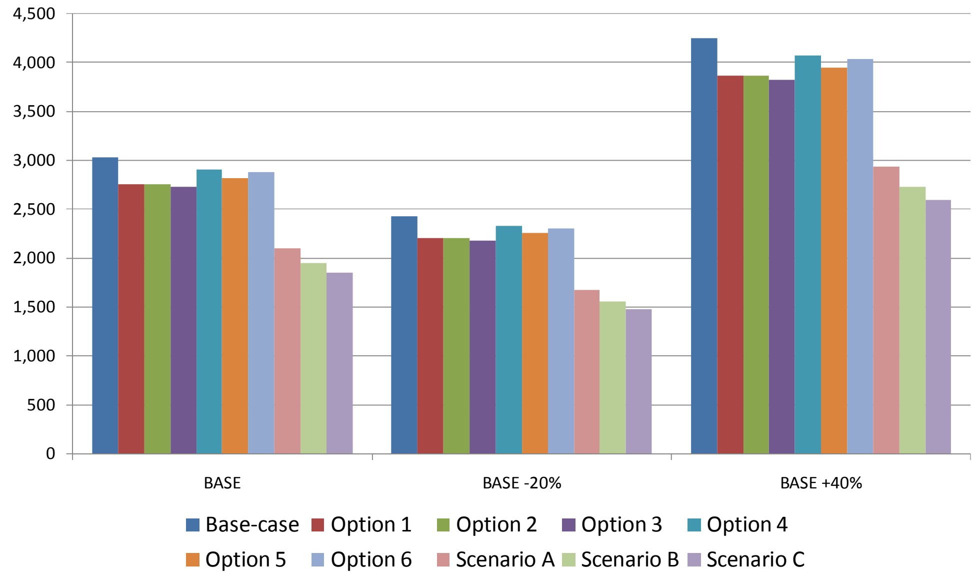

Figure 6-33: Base Case Blast cabinet and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

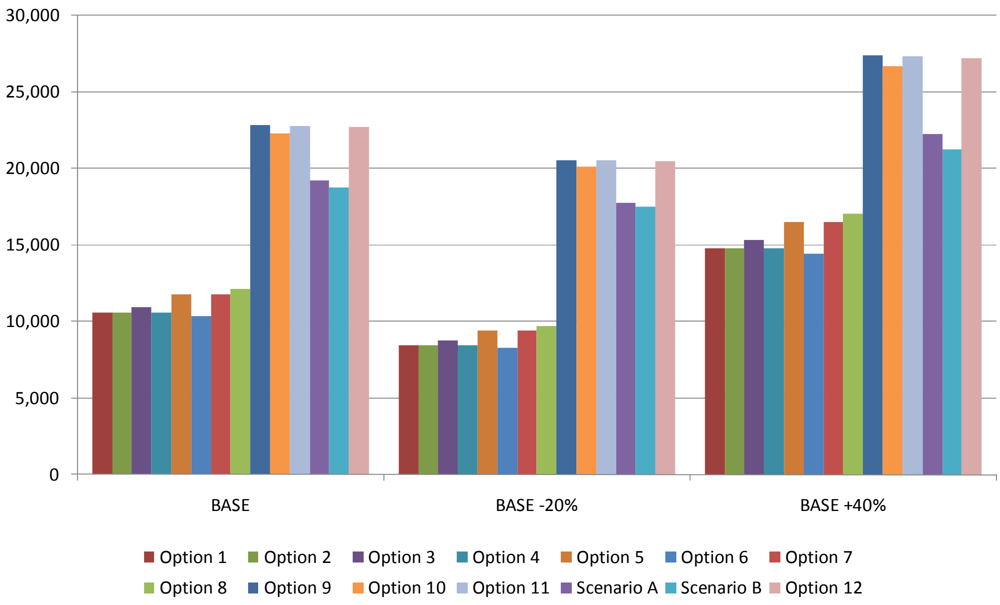

Figure 6-34: Base Case WICR and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

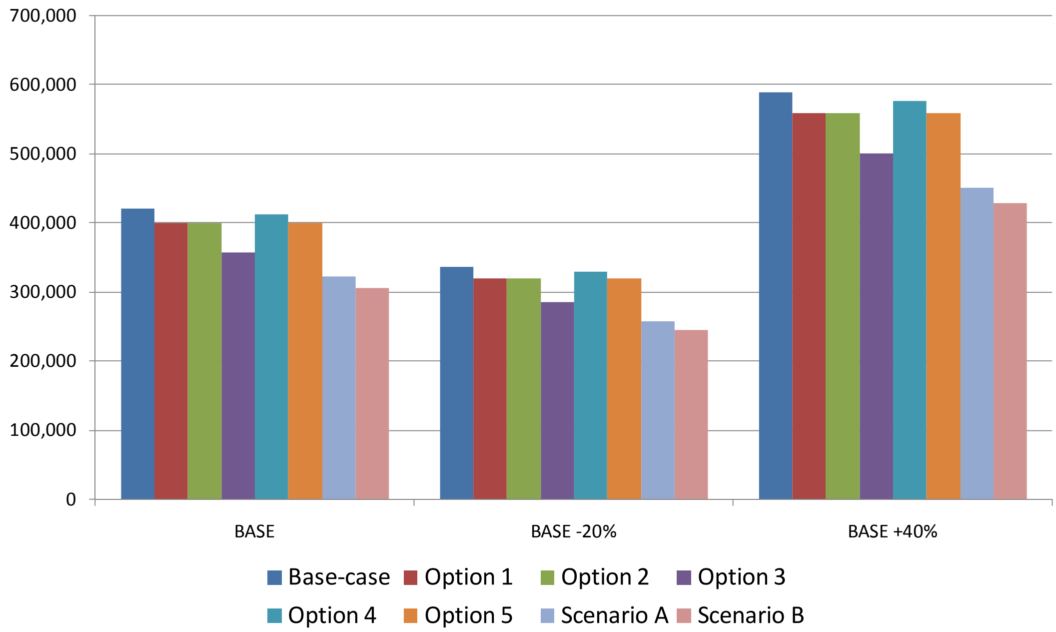

Figure 6-35: Base Case Chiller MT and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

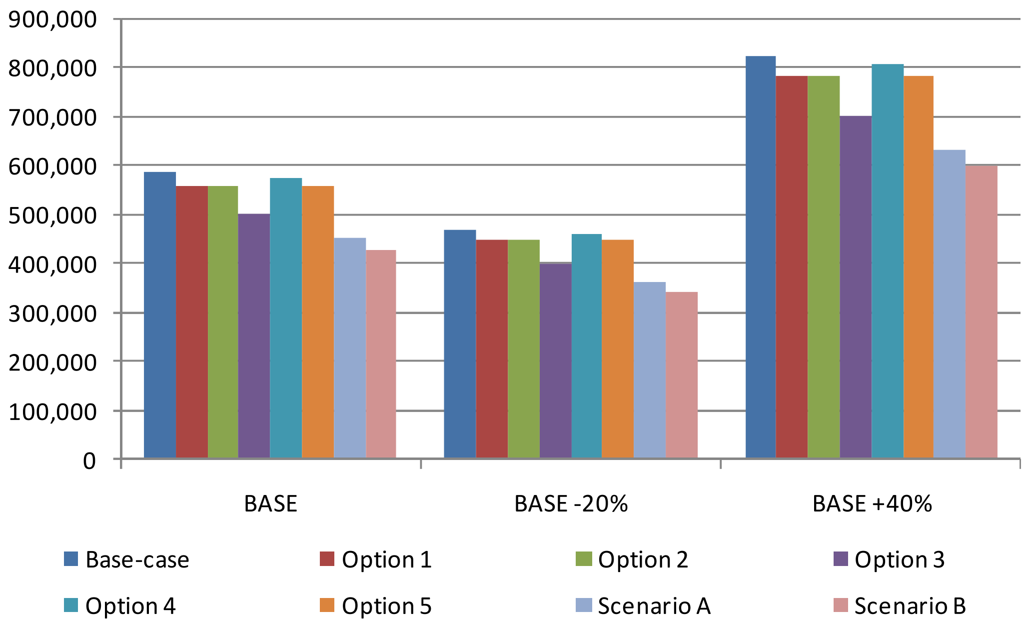

Figure 6-36: Base Case Chiller LT and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

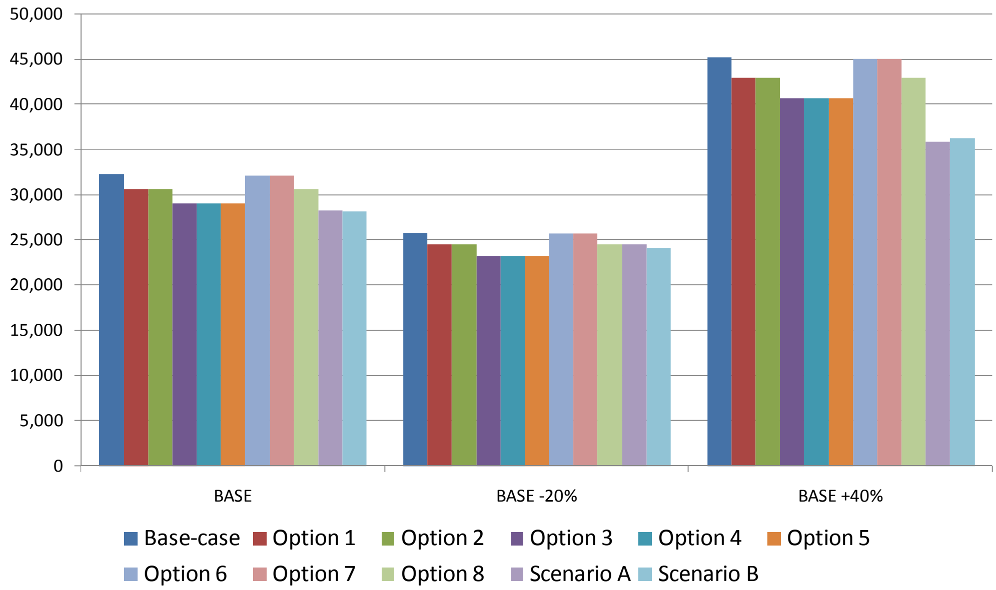

Figure 6-37: Base Case RCU MT and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

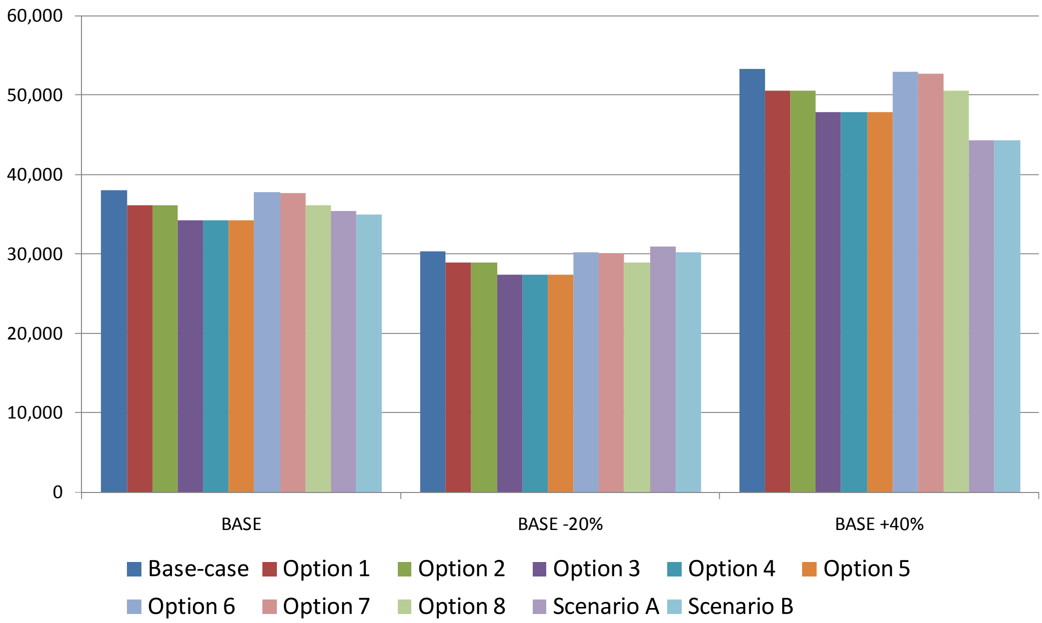

Figure 6-38: Base Case RCU LT and its improvement options – Impact of electricity consumption of the Base Case on the LCC (€)

6.5.4. Assumptions related to the electricity tariff and the discount rate

For all Base Cases and their improvement options, an average EU-27 electricity tariff of 0.12 €/kWh was used[3]. However, if the lowest electricity tariff (i.e. 0.07 €/kWh in

[3] Based on the data from Eurostat

Estonia) and the highest electricity tariff (i.e. 0.21 €/kWh in Denmark) are applied, this could lead to different LCC for the Base Cases and their improvement options.

In the same way, the discount rate (interest minus inflation rate) influences the LCC calculation. Higher values than the one used in Tasks 4 & 6 are employed to assess the impact of this parameter.

Table 6-26: Assumptions related to electricity tariff and discount rate

	Average (used in Tasks 4 and 6)	MIN	MAX
Electricity tariff (€/kWh)	0.12	0.07 (Estonia)	0.21 (Denmark)
	Average (used in Tasks 4 and 6)	**MAX**	**MAX+**
Discount rate (%)	4	6	2

Figure 6-39 to Figure 6-46 present the LCC of each Base Case and its improvement options with the basic assumptions and with the extreme values of electricity tariff and discount rate.

The order of the improvement options whatever the electricity tariff and the discount rate used remains quite similar.

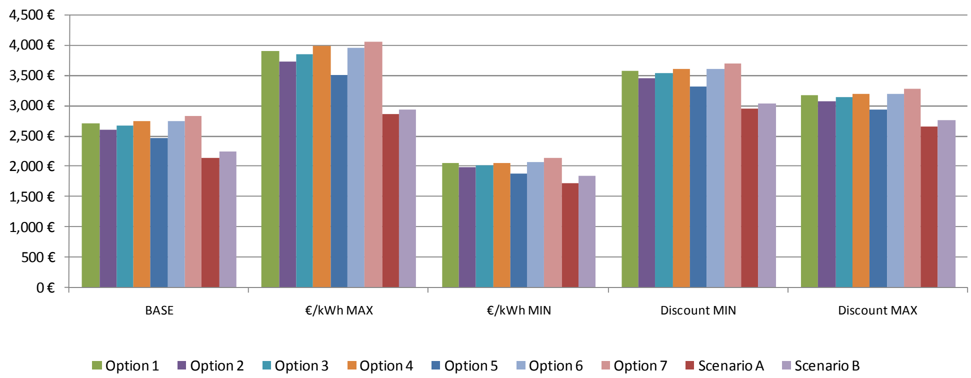

Figure 6-39: Base Case Service cabinet HT and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

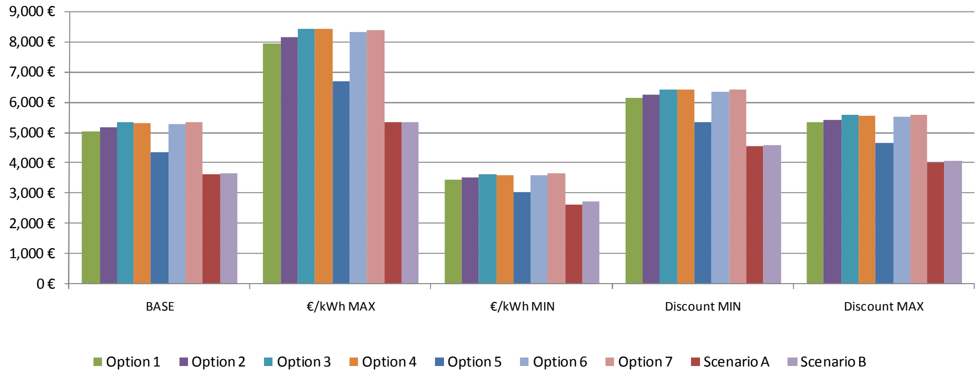

Figure 6-40: Base Case Service cabinet LT and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

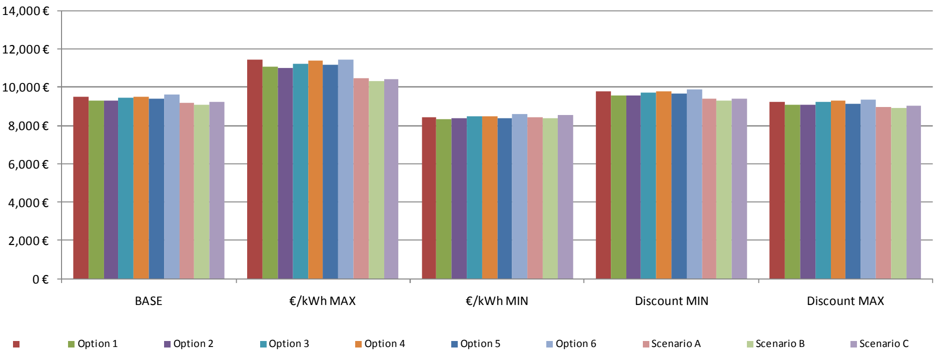

Figure 6-41: Base Case Blast cabinet and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

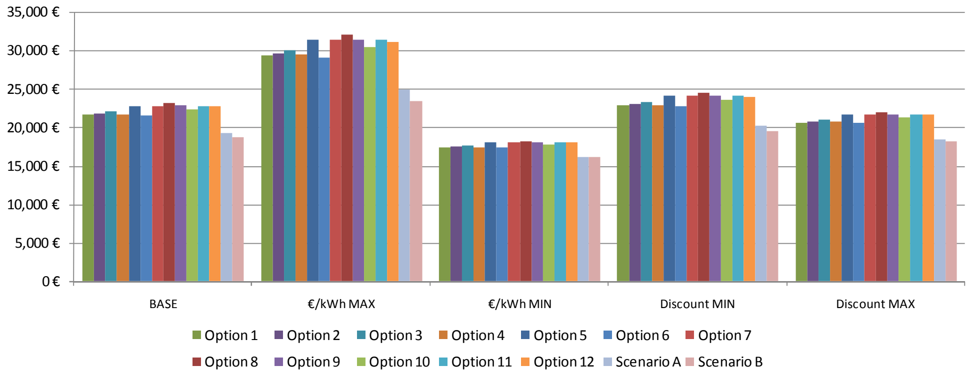

Figure 6-42: Base Case WICR and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

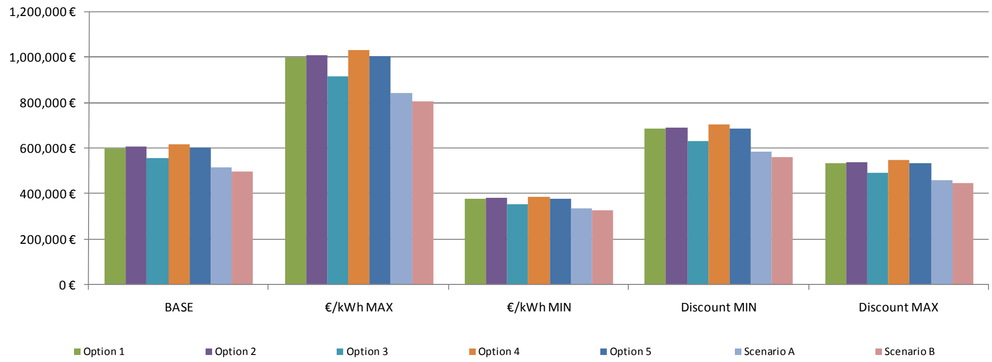

Figure 6-43: Base Case Chiller MT and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

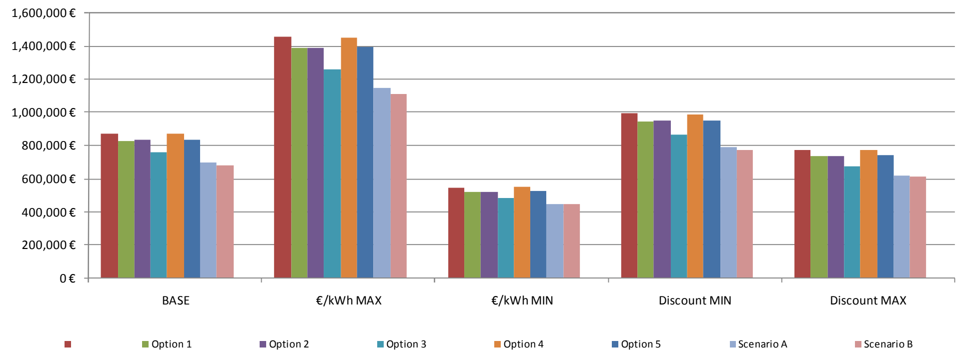

Figure 6-44: Base Case Chiller LT and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

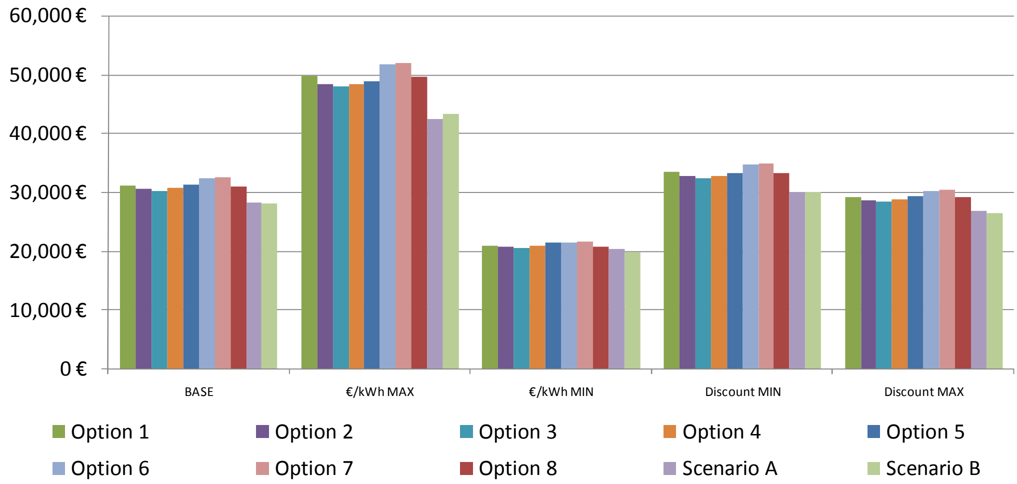

Figure 6-45: Base Case RCU MT and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

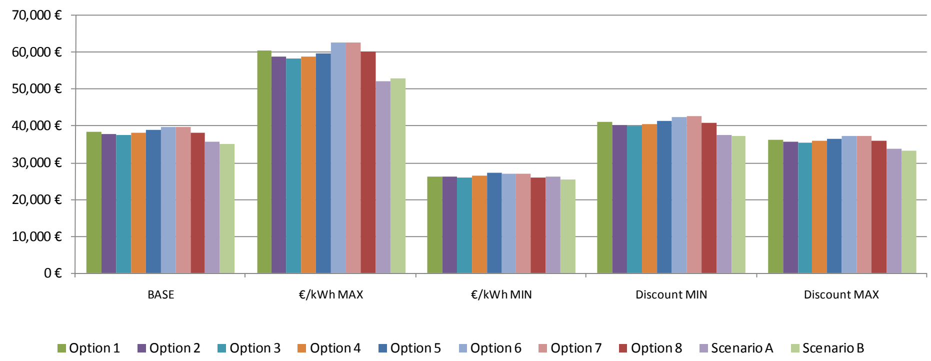

Figure 6-46: Base Case RCU LT and its improvement options – Impact of the electricity tariff and the discount rate on the LCC (€)

6.5.5. ASSUMPTIONS RELATED TO THE PRODUCT STOCK

Estimating the stock of refrigerating and freezing equipments is not an easy task due to the fragmented nature of the market and also limited availability of corresponding market data.

In Task 2, stock data was defined based on available information and inputs provided by stakeholders. These values were used in Task 4 to assess electricity consumption (and other environmental impacts) at EU level. However, the accuracy of these stock data is quite limited and a sensitivity analysis on this parameter is therefore desirable.

Figure 6-47 to Figure 6-48 show the electricity consumption of the whole EU stock (assuming that all products have the same characteristics as the Base Cases) with different stocks values. Therefore, if the maximum stock values are considered, the electricity consumption included in the scope of this study would be 19% higher compared to the Base (2388 TWh vs. 2001 TWh).

Table 6-27: Assumptions related to product stock (in 2008)

Base Case	Base	MIN		MAX	
Service Cabinet HT	2,053,903	-10%	2,053,903	10%	2,510,326
Service Cabinet LT	880,244	-10%	880,244	10%	1,075,854
Blast Cabinet	931,838	-30%	931,838	50%	1,996,795
WICR	1,369,493	-10%	1,369,493	10%	1,673,825
Chiller MT	161,857	-20%	161,857	20%	242,786
Chiller LT	161,857	-20%	161,857	20%	242,786
RCU MT	3,541,819	-10%	2,971,817	10%	4,328,890
RCU LT	885,455	-10%	742,954	10%	1,082,222

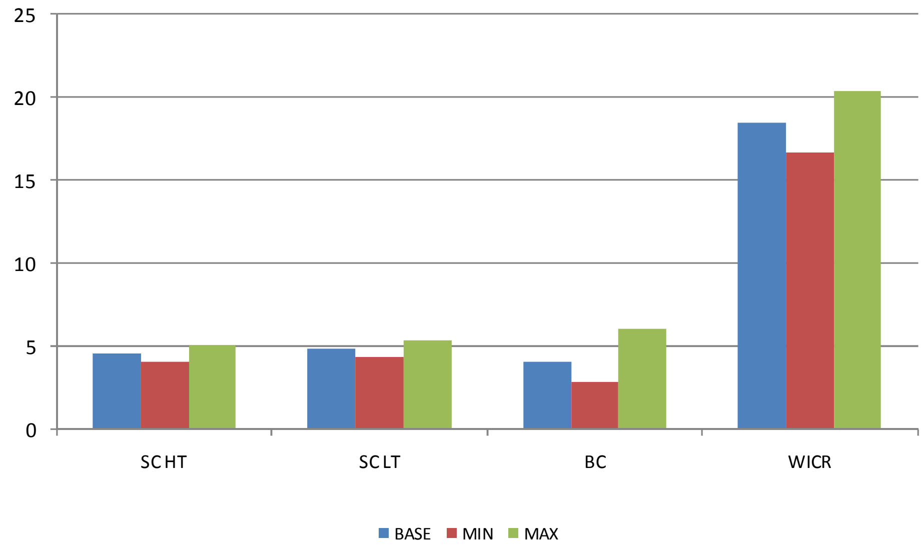

Figure 6-47: Electricity consumption (in TWh) of the EU stock (without process chillers and remote condensing units)

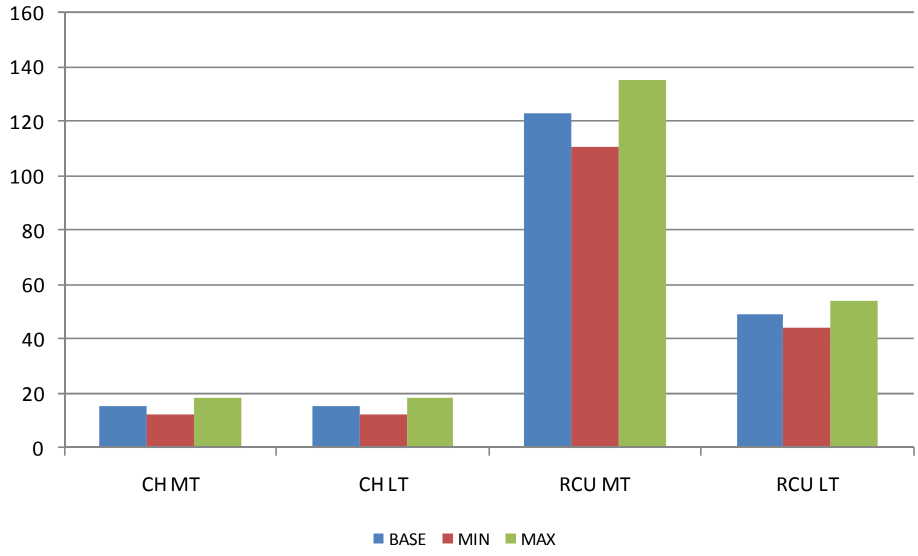

Figure 6-48: Electricity consumption (in TWh) of the EU stock of process chillers and remote condensing units

6.6. CONCLUSIONS

Several improvement options are available for each product group, usually with short payback times and only very few constraints. Combinations of these improvement options provide potential for a BAT with significantly reduced electricity consumption, leading to reduced environmental impact and lower LCC.

Regarding direct emissions from refrigerants, using alternative refrigerants would help to reduce GWP. But any refrigerant substitution that lowers overall efficiency is likely to have more adverse environmental impacts than benefits.

There is also potential for current available but high-cost improvement options to become more affordable over the coming years, however in terms of BNAT options, some technologies such as magnetic refrigeration are relatively far from market in these product groups, and likely only to be available in coming 5 to 10 years.

Hence, steadily increasing levels of energy efficiency without significant increase in other environmental impacts should be achievable. These results will therefore be discussed in context of potential policy options in Task 7.

However, the overall energy efficiency of a refrigerating system depends much more on the sensible adjustments of the components to each other than to the energy efficiency of each component alone. Furthermore, the capability of control and vary these parameters depending on the workload and the seasonal conditions seems to be the mean to achieve greater energy savings.

Lastly, the sensitivity analysis demonstrates the importance of certain parameters, the uncertainty of which has an effect on the results of analysis, such as the impact of blast cabinets, chillers and remote condensing units stock numbers on total EU electricity consumption.