Preparatory Studies for Ecodesign Requirements of EuPs (III)

ENER Lot 21 – Central heating products that use hot air to distribute heat – Task 7: Improvement options

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Table of Contents

List of Tables

List of Figures

Task 7: Improvement potential

Task 7 quantitatively analyses design improvement options, based on the Best Available Technologies (BATs) described in Task 6 for each of the product Base-Cases. The environmental impacts of each of these options are calculated by using the MEEuP EcoReport tool. The economic impacts of each design option are assessed in terms of Life Cycle Cost (LCC). The assessment of LCC is relevant as it indicates whether design solutions may impact the costs to users over the total lifetime of the product (purchase, operating, end-of-life costs, etc.). The assessment of both environmental and economic impacts allows the identification of the design improvement with the Least Life Cycle Costs (LLCC) and that results in the most significant reductions in environmental impacts. The Best Not yet Available Technologies (BNAT) are also discussed, assessing long-term improvement potential of the product groups.

7.1.1 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,
- not entail excessive costs and impacts on the manufacturer.

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 assumed that the improvement options are equally applicable to all sub-types of equipment in each product category. The improvement potential of a particular improvement option or a combination of improvement options is evaluated by using the MEEuP EcoReport tool. The cost effectiveness of an improvement option is expressed in terms of payback time in years, defined as a ratio between:

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

In Task 8, some possible scenarios will be investigated as a basis for defining future Ecodesign requirements, taking into account - among other parameters - life cycle costs and technical constraints.

7.1.2 Base-Case 1A: Residential warm air heater

Task 5 identified that reducing total energy consumption during use would be an effective way to also reduce the overall environmental impacts of a warm air heaters. Task 6 identified the improvement options that aim to reduce the total energy consumption. Each of the improvement options applicable to residential warm air heaters are presented here with their relative impact on the product cost compared to the Base-Case. Table 7—1 presents the summary of the selected improvement options.

As it can be seen from the table, although option 1 provides fuel savings, an increase of electricity consumption is expected at the same time. However, the amount of electricity required is very low compared to the annual fuel consumption. The addition of a heat exchanger to the system would also increase the environmental impacts of materials and the end-of-life.

Apart from the energy savings, the design options could result in some other constraints, which would have to be taken into consideration. Switching from a burning pilot light to an electric ignition device, may result in heaters that are more susceptible to corrosion and condensation. A two-step burner and continuous modulating burner are more complex products, which could require more maintenance, and might lack the reliability of a standard warm air heater. According to some stakeholders, a continuous modulating burner is assumed to have 10% to 25% higher maintenance costs compared to a non-modulating burner.

Table 7—1: Identified energy saving potentials for BC 1A: residential warm air heaters

Improvement options	Description	Annual electricity consumption (kWh)	Annual energy consumption (kWh)	Product price (€)	Electricity savings compared to Base-Case (%)	Heat energy savings compared to Base-Case (%)	Annual efficiency	Increase in product price compared to Base-Case (€)	Payback time (years)
Base-Case 1A	**Residential gas warm air heater**	325.5	47,582	1500	0%	0%	62%	0	
Option 1	Electric ignition device	325.5	46,631	1700	0%	2%	63%	200	0.00
Option 2	High efficiency condensing furnace: Primary and secondary heat exchanger and electric ignition device	325.5	39,493	2000	0%	17%	74%	500	3.97
Option 3	Continuous modulating burner	325.5	44,251	2100	0%	7%	67%	600	1.17
Option 4	DC variable speed fan for controlling hot air flow	216.8	47,582	1590	33%	0%	62%	90	3.40
Options 1+3	Combination 1	325.5	43,300	2300	0%	9%	68%	800	4.73
Options 2+4	Combination 2	216.8	43,300	2090	33%	9%	68%	590	3.53
Options 2+3+4	Combination 3	216.8	35,687	2690	33%	25%	83%	1,190	2.40

7.1.3 Base-Case 1B: Non-residential warm air heater

The selected improvement options for non-residential warm air heaters do not differ much from those analysed in the section above. The implementation of control mechanisms such as thermostats and dampers in a non-residential warm air heater can have a great influence over the overall efficiency of the system with minimum cost increase. Table 7—2 shows the potential energy savings, price increase and payback times for each of the design options selected.

Due to the large size of non-residential warm air heaters, the cost increase of some options is higher than for B-C 1A, while for some others no difference in costs are recorded. As with the residential warm air heaters according to some stakeholders, besides the immediate rise in production costs and purchase price, a continuous modulating burner is expected to lead to an increase in the frequency and cost of maintenance in the range of 10% to 25%.

Table 7—2: Identified energy saving potentials for BC 1B: non-residential warm air heaters

Improvement option	Description	Annual electricity consumption (kWh)	Annual energy consumption (kWh)	Product price (€)	Electricity savings compared to Base-Case (%)	Heat energy savings compared to Base-Case (%)	Annual efficiency	Increase in product price compared to Base-Case (€)	Payback time (years)
Base-Case 1B	**Non-residential gas warm air heater**	1,440	213,510	7,300	0%	0%	55%	0	-
Option 1	Electric ignition device	1,440	211,375	7,500	0%	1%	56%	200	2.09
Option 2	High efficiency condensing furnace: Primary and secondary heat exchanger and electric ignition device	1,440	177,213	7,390	0%	17%	66%	90	0.06
Option 3	Continuous modulating burner	1,440	196,429	7,900	0%	8%	60%	600	0.78
Option 4	DC variable speed fan for controlling hot air flow	959	213,510	10,250	33%	0%	56%	2,950	38.36
Option 5	Thermostat and Damper	1,440	187,889	7,360	0%	12%	63%	60	0.05
Options 1+3	Combination 1	1,440	196,429	8,100	0%	8%	60%	800	1.04
Options 2+4	Combination 2	959	177,213	10,340	33%	17%	67%	3,040	1.78
Options 2+3+4	Combination 3	959	162,267	10,940	33%	24%	73%	3,640	1.53
Options 2+3+4+5	Combination 4	959	149,457	11,000	33%	30%	79%	3,700	0.00

7.1.4 Base-Case 2: Single split heat pump

The summary of potential design improvements for single split heat pumps can be seen in Table 7—3. As for warm air heaters some of these improvements could entail certain constraints and specific environmental impacts (although the overall environmental impacts would decrease). Increasing the surface area of the heat exchanger in the outdoor unit would result in both an increase of the material used as well as the waste generated at the end-of-life. In addition, the use of a larger heat exchanger would result in the need for more refrigerant. This could pose greater environmental risks in the case of leakage, if a non-environmentally friendly refrigerant is used.

Due to reliability issues, micro channel heat exchangers are manufactured from different materials than those used in conventional heat exchangers. The use of aluminium and other ceramic materials is more extensive, and could result in higher environmental impacts as those materials are more energy intensive to produce. On the other hand, due to their higher efficiency, less refrigerant fluid is needed. Other improvement options such as noise reduction come at the expense of energy efficiency.

Furthermore, the use of an electronic expansion valve would result in a better SCOP (seasonal coefficient of performance) at the expense of more maintenance as it might not be as robust as a mechanical valve. Furthermore, if an electronic expansion valve is used and is not tuned properly, this can actually result in a negative effect to energy efficiency. Although some of the refrigerants proposed can offer better performance and minimise the environmental impacts, there are some safety considerations. R290 is a flammable refrigerant and therefore, its use is limited. Moreover, due to required safety regulations and measures the use of R290 may decrease the COP of a unit as discussed in Task 6. R32, a BAT, is included in the quantitative analysis of single split and VRF as a reference for potential technology, however, its actual implementation will require some years for the industry to adapt.

Table 7—3: Identified energy saving potentials for BC 2: single split heat pumps

Improvement option	Description	Annual electricity consumption (kWh)	Product price (€)	Energy savings compared to Base-Case (%)	SCOP	Increase in product price compared to Base-Case (€)	Payback time (years)
Base-Case 2	**Single split heat pump**	8,522	6,450	0%	2.4	0	-
Option 1	Increase heat exchanger surface in outdoor unit	7,797	6,570	8.5%	2.62	120	1.04
Option 2	Micro channel heat exchanger in indoor unit(s)	7,755	6,450	9%	2.64	0	0.00
Option 3	Increase heat exchanger surface in indoor unit(s)	7,797	6,570	8.5%	2.62	120	1.04
Option 4	Reduce crankcase heater time	8,368	6,450	1.8%	2.44	0	-
Option 5	Improved EEV control	8,010	6,450	6%	2.55	0	-
Option 6	Refrigerant R290	8,096	6,570	5%	2.53	120	1.76
Option 7	Refrigerant R32	7,669	7,482	10%	2.67	1,032	7.57
Options 1+2	Combination 1	7,096	6,570	16.7%	2.88	120	0.53
Options 1+3	Combination 2	7,135	6,690	16.3%	2.87	240	1.08
Options 1+3+4	Combination 3	7,006	6,690	17.8%	2.92	240	0.99
Options 1+3+4+5	Combination 4	6,586	6,690	22.7%	3.11	240	0.78
Options 1+3+4+7	Combination 5	6,305	7,676	26%	3.24	1,226	3.46
Options 1+3+4+5+7	Combination 6	5,927	7,676	30.4%	3.45	1,226	2.95

7.1.5 Base-Case 3: VRF heat pump

Looking at the improvement potentials of the various options for VRF (Variable Refrigerant Flow) heat pumps in Table 7—4, similar performance enhancements could be achieved as those for single split heat pumps. Apart from one design improvement option, the same constraints and issues will apply for VRF as for single split heat pump systems. For both VRF and single split heat pumps, the combination of improvement options will also entail the same constraints of each individual option.

The use of refrigerant R290 is limited due to its flammability, thus it is not commonly used in larger systems. On the other hand, the use of R744 as a refrigerant requires a more complex system compared to traditional HFCs, and the price of the product would be expected to increase considerably. As discussed in Task 6, the COPs of systems using R744 are sensitive to climatic conditions. For applications in hot climates, the COP is reduced in around 20% whereas in cold climates the COP is expected to be similar to conventional units. In the following quantitative analysis, it is assumed that R744 will be employed on units only in cold climate conditions (in order to minimise the performance variability).

Table 7—4: Identified energy saving potentials for BC 3: VRF heat pumps

Improvement option	Description	Annual electricity consumption (kWh)	Product price (€)	Energy savings compared to Base-Case (%)	SCOP	Increase in product price compared to Base-Case (€)	Payback time (years)
Base-Case 3	**VRF heat pump**	20,085	23,650	0%	2.96	0	-
Option 1	Increase heat exchanger surface in outdoor unit	18,378	24,050	8.5%	3.23	400	1.47
Option 2	Micro channel heat exchanger in indoor unit(s)	18,277	23,650	9%	3.25	0	0.00
Option 3	Increase heat exchanger surface in indoor unit(s)	18,378	24,050	8.5%	3.23	400	1.47
Option 4	Reduce crankcase heater time	19,944	23,650	0.7%	2.98	0	-
Option 5	Refrigerant R744	20,085	47,300	0%	2.96	23,650	-
Option 6	Refrigerant R32	18,077	27,434	10%	3.29	3,784	11.78
Options 1+2	Combination 1	16,724	24,050	16.7%	3.55	400	0.74
Options 2+3	Combination 2	16,816	24,450	16.3%	3.54	800	1.53
Options 1+3+4	Combination 3	16,698	24,450	16.9%	3.56	800	1.48
Options 1+3+4+5	Combination 4	16,698	49,665	16.9%	3.56	26,015	48.03
Options 1+3+4+6	Combination 5	15,028	29,799	25.2%	3.96	6,149	7.60

7.2 Analysis BAT and LLCC

The design option(s) identified in the technical, environmental and economic analyses are ranked to identify the design improvement option with the least life cycle environmental impacts and the Least Life Cycle Costs (LLCC). Constructing an energy-LCC-curve (Y-axis= energy consumed and LCC, X-axis=options) allows the LLCC and BATs to be identified[1].

The performance of each improvement option will be compared using the Base-Case. The comparison is made in terms of primary energy consumption and LCC. If some of the options are only applicable to a small share of the market, the impact on the energy will be weighted and then compared.

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

7.2.1 Base-Case 1A: Residential warm air heater

An environmental and economic assessment was carried out for each improvement option relevant for residential warm air heaters using the EcoReport tool. Outcomes of this, taking into account the whole life cycle, are provided in Table 7—5 with absolute values (in units) and variations compared with the Base-Case.

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

Table 7—5: Environmental impacts of the BC1A and its improvement options

Life-cycle indicators per unit	unit	Base-Case 1A	Option 1	Option 2	Option 3	Option 4	Options 1+3	Options 2+4	Options 2+3+4
Total Energy (GER)	GJ	3175.7	3113.4	2646.2	2957.7	3158.6	2895.4	2878.3	2379.9
	% change with BC	0%	-2%	-17%	-7%	-1%	-9%	-9%	-25%
of which, electricity	primary GJ	55.1	55.1	55.1	55.1	38.0	55.1	38.0	38.0
	final MWh	5.2	5.2	5.2	5.2	3.6	5.2	3.6	3.6
	% change with BC	0%	0%	0%	0%	-31%	0%	-31%	-31%
Water (process)	m^3	6.4	6.4	6.4	6.4	5.3	6.4	5.3	5.3
	% change with BC	0%	0%	0%	0%	-18%	0%	-18%	-18%
Water (cooling)	m^3	137.9	137.9	137.9	137.9	92.3	137.9	92.3	92.3
	% change with BC	0%	0%	0%	0%	-33%	0%	-33%	-33%
Waste, non-haz./ landfill	kg	160.8	160.8	160.8	160.8	140.9	160.8	140.9	140.9
	% change with BC	0%	0%	0%	0%	-12%	0%	-12%	-12%
Waste, hazardous/ incinerated	kg	5.5	5.5	5.5	5.5	5.1	5.5	5.1	5.1
	% change with BC	0%	0%	0%	0%	-7%	0%	-7%	-7%
Greenhouse Gases in GWP100	t CO2 eq.	175.1	171.6	145.8	163.0	174.3	159.6	158.8	131.3
	% change with BC	0%	-2%	-17%	-7%	0%	-9%	-9%	-25%

Life-cycle indicators per unit	unit	Base-Case 1A	Option 1	Option 2	Option 3	Option 4	Options 1+3	Options 2+4	Options 2+3+4
Acidification, emissions	kg SO2 eq.	67.0	66.0	58.5	63.5	62.6	62.5	58.1	50.1
	% change with BC	0%	-1%	-13%	-5%	-7%	-7%	-13%	-25%
Volatile Organic Compounds (VOC)	kg	2.4	2.3	2.0	2.2	2.3	2.1	2.1	1.8
	% change with BC	0%	-2%	-16%	-7%	0%	-9%	-9%	-24%
Persistent Organic Pollutants (POP)	µg i-Teq	1.2	1.2	1.2	1.2	1.1	1.2	1.1	1.1
	% change with BC	0%	0%	0%	0%	-9%	0%	-9%	-9%
Heavy Metals to air	g Ni eq.	1.7	1.7	1.7	1.7	1.4	1.7	1.4	1.4
	% change with BC	0%	0%	0%	0%	-18%	0%	-18%	-18%
PAHs	g Ni eq.	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4
	% change with BC	0%	0%	-1%	0%	-2%	-1%	-3%	-4%
Particulate Matter (PM, dust)	kg	5.3	5.3	5.2	5.3	5.2	5.2	5.1	5.0
	% change with BC	0%	0%	-3%	-1%	-2%	-1%	-3%	-6%
Heavy Metals to water	g Hg/20	2.6	2.6	2.6	2.6	2.5	2.6	2.5	2.5
	% change with BC	0%	0%	0%	0%	-4%	0%	-4%	-4%
Eutrophication	kg PO4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	% change with BC	0%	0%	0%	0%	-1%	0%	-1%	-1%
Life-cycle cost	€	37,736.0	37,303.5	32,860.1	36,608.8	37,614.5	35,689.9	35,754.8	31,295.1
	% change with BC	0%	-1%	-13%	-3%	0%	-5%	-5%	-17%

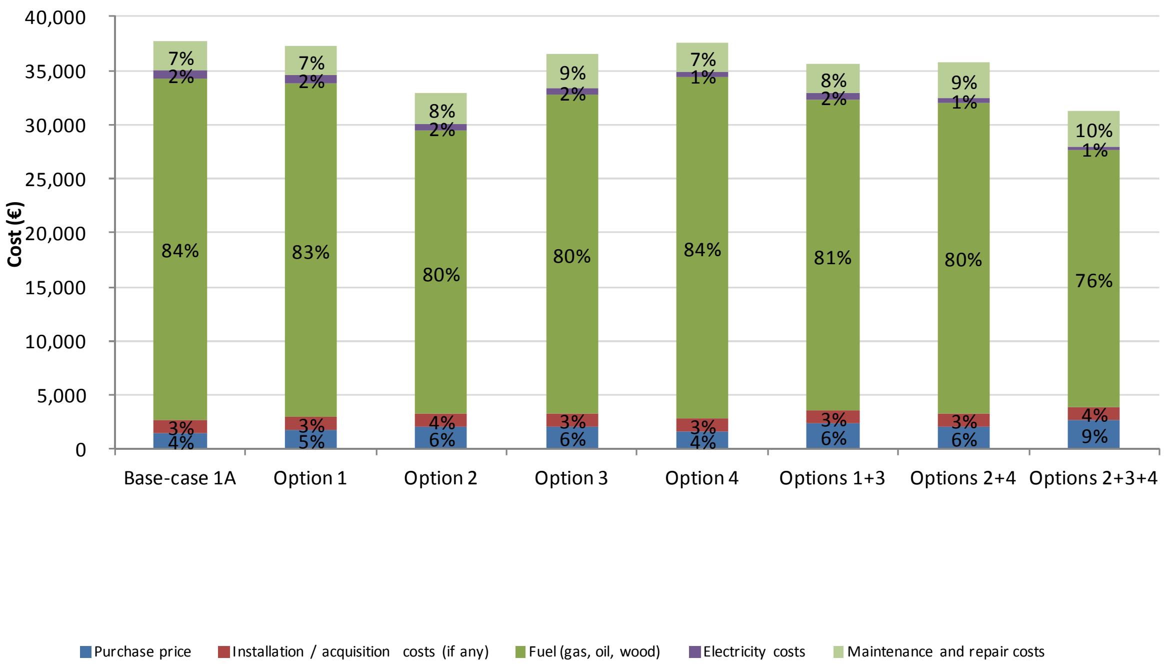
Design improvement options

Option 1	Option 2	Option 3	Option 4
Electric ignition device	High efficiency condensing furnace: Primary and secondary heat exchanger	Continuous modulating burner	DC variable speed fan for controlling hot air flow

The environmental impacts related to the electricity production are higher in option 1 than in the Base-Case due to the higher electricity consumption. However, the primary energy consumption is lower than in the Base-Case. The lowest environmental impacts are achieved in option 4 and the combination of options 2+3+4.

Figure 7-1 shows the share of costs of the LCC for the Base-Case and the improvement options. The fuel costs are the highest share of the LCC, and the second greatest expenses are the maintenance and repair costs over the lifetime of the heater.

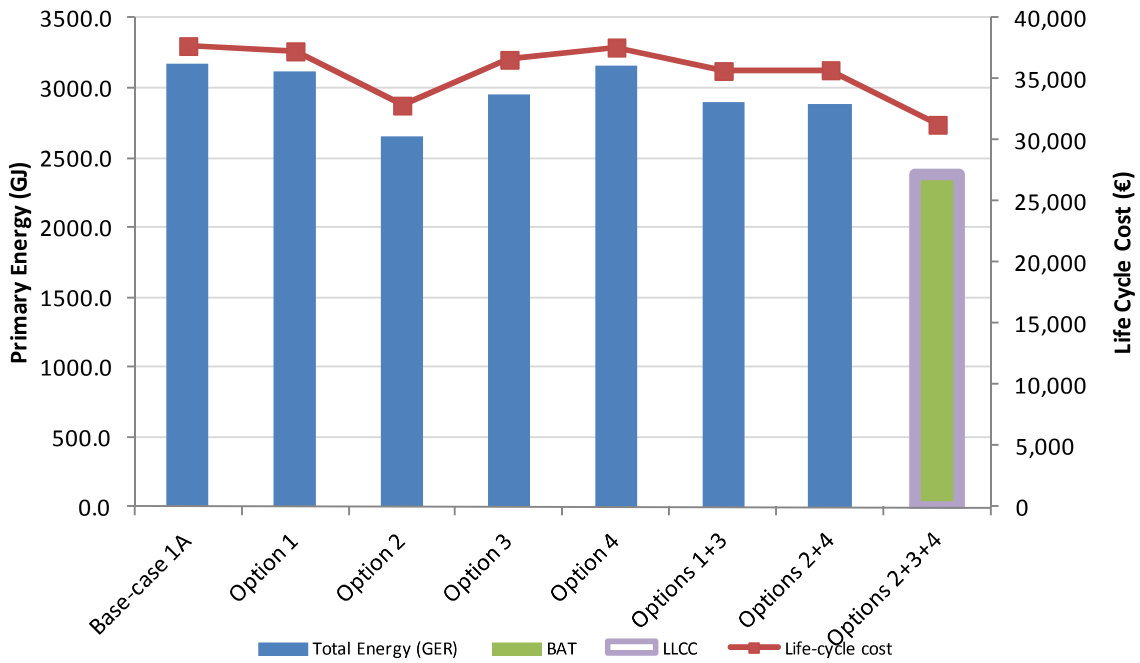
Figure 7-1: Life cycle costs of the improvement options for BC1A



Option 1	Option 2	Option 3	Option 4
Electric ignition device	High efficiency condensing furnace: Primary and secondary heat exchanger	Continuous modulating burner	DC variable speed fan for controlling hot air flow

As shown in Figure 7-2, LLCC is the combination of options 2+3+4, and this option is the design improvement option with least energy consumption as well. The primary energy consumed is around 25% lower than the Base-Case and the LCC are 17% lower. The second highest energy savings are achieved by option 1 (around 17%), which presents also the second lowest LCC (around 13% lower).

Figure 7-2: Identification of design improvement options in relation to energy consumption and LLCC for BC1A



Option 1	Option 2	Option 3	Option 4
High efficiency condensing furnace: Primary and secondary heat exchanger	Electric ignition device	Continuous modulating burner	DC variable speed fan for controlling hot air flow

7.2.2 Base-Case 1B: Non-residential warm air heater

Table 7—6 shows the environmental and economic impacts of the improvement options selected for BC1B. Option 1 achieves a reduction in primary energy consumption, but the impacts related to electricity are higher than in the Base-Case. The options with lower environmental impacts are option 4 and the combination of options 1 to 5. The lowest life cycle cost is also achieved with the combination of options 1 to 5.

Table 7—6: Environmental impacts of the BC1B and its improvement options

Life-cycle indicators per unit	unit	Base-Case 1B	Option 1	Option 2	Option 3	Option 4	Option 5	Options 1+3	Options 2+4	Options 2+3+4	Options 2+3+4+5
Total Energy (GER)	GJ	14239.2	14099.4	11863.1	13121.0	14163.4	12562.0	13121.0	11787.4	10809.0	9970.4
	% change with BC	0%	-1%	-17%	-8%	-1%	-12%	-8%	-17%	-24%	-30%
of which, electricity	primary GJ	242.0	242.0	242.0	242.0	166.2	242.0	242.0	166.2	166.2	166.2
	final MWh	23.0	23.0	23.0	23.0	15.8	23.0	23.0	15.8	15.8	15.8
	% change with BC	0%	0%	0%	0%	-31%	0%	0%	-31%	-31%	-31%
Water (process)	m^3	27.1	27.1	27.1	27.1	22.0	27.1	27.1	22.0	22.0	22.0
	% change with BC	0%	0%	0%	0%	-19%	0%	0%	-19%	-19%	-19%
Water (cooling)	m^3	609.7	609.7	609.7	609.7	407.7	609.7	609.7	407.7	407.7	407.7
	% change with BC	0%	0%	0%	0%	-33%	0%	0%	-33%	-33%	-33%
Waste, non-haz./ landfill	kg	664.2	664.2	664.2	664.2	576.4	664.2	664.2	576.4	576.4	576.4
	% change with BC	0%	0%	0%	0%	-13%	0%	0%	-13%	-13%	-13%
Waste, hazardous/ incinerated	kg	22.4	22.4	22.4	22.4	20.6	22.4	22.4	20.6	20.6	20.6
	% change with BC	0%	0%	0%	0%	-8%	0%	0%	-8%	-8%	-8%
Greenhouse Gases in GWP100	t CO_2 eq.	784.9	777.1	653.5	723.0	781.6	692.1	723.0	650.2	596.1	549.7
	% change with BC	0%	-1%	-17%	-8%	0%	-12%	-8%	-17%	-24%	-30%
Acidification, emissions	kg SO_2 eq.	297.4	295.2	259.2	279.4	277.9	270.4	279.4	239.7	223.9	210.4
	% change with BC	0%	-1%	-13%	-6%	-7%	-9%	-6%	-19%	-25%	-29%
Volatile Organic Compounds (VOC)	kg	10.5	10.4	8.7	9.6	10.4	9.2	9.6	8.7	8.0	7.4
	% change with BC	0%	-1%	-17%	-8%	0%	-12%	-8%	-17%	-24%	-29%
Persistent Organic Pollutants (POP)	µg i-Teq	4.8	4.8	4.8	4.8	4.3	4.8	4.8	4.3	4.3	4.3
	% change with BC	0%	0%	0%	0%	-10%	0%	0%	-10%	-10%	-10%

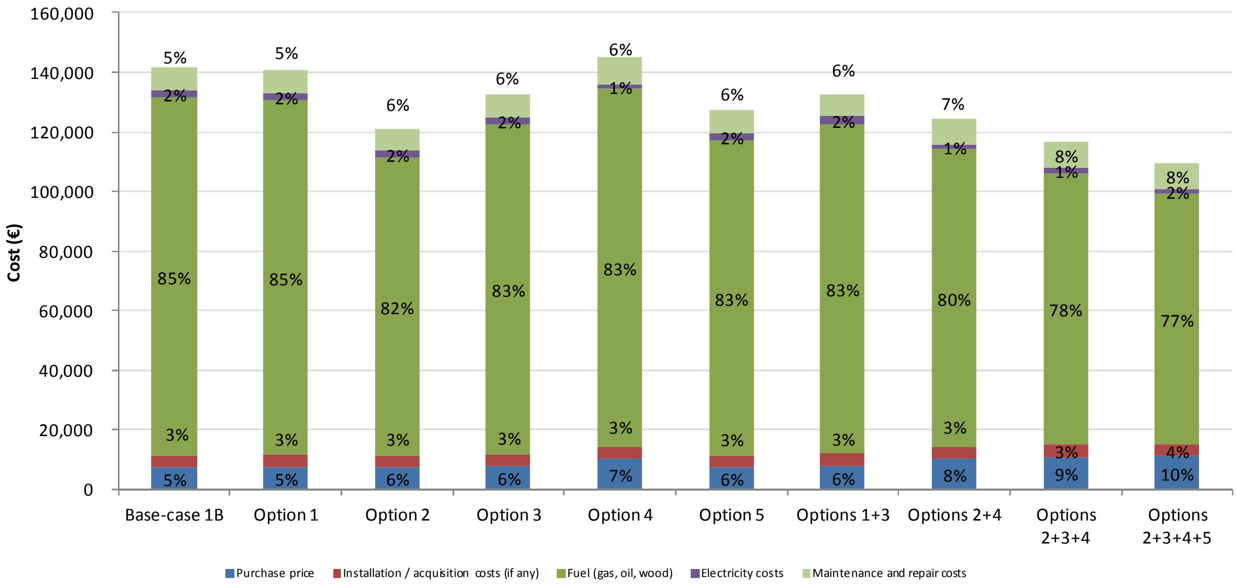
Life-cycle indicators per unit	unit	Base-Case 1B	Option 1	Option 2	Option 3	Option 4	Option 5	Options 1+3	Options 2+4	Options 2+3+4	Options 2+3+4+5
Heavy Metals to air	g Ni eq.	6.8	6.8	6.8	6.8	5.5	6.8	6.8	5.5	5.5	5.5
	% change with BC	0%	0%	0%	0%	-19%	0%	0%	-19%	-19%	-19%
PAHs	g Ni eq.	5.7	5.7	5.7	5.7	5.6	5.7	5.7	5.5	5.5	5.5
	% change with BC	0%	0%	-1%	-1%	-3%	-1%	-1%	-4%	-4%	-5%
Particulate Matter (PM, dust)	kg	12.3	12.3	11.6	12.0	11.9	11.8	12.0	11.2	10.9	10.7
	% change with BC	0%	0%	-5%	-3%	-3%	-4%	-3%	-9%	-11%	-13%
Heavy Metals to water	g Hg/20	10.5	10.5	10.5	10.5	10.0	10.5	10.5	10.0	10.0	10.0
	% change with BC	0%	0%	0%	0%	-5%	0%	0%	-5%	-5%	-5%
Eutrophication	kg PO4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	% change with BC	0%	0%	0%	0%	-1%	0%	0%	-1%	-1%	-1%
Life-cycle cost	€	141,544.1	140,542.3	121,203.7	132,529.8	144,952.4	127,182.6	132,729.8	124,612.0	116,799.4	109,648.7
	% change with BC	0%	-1%	-14%	-6%	2%	-10%	-6%	-12%	-17%	-23%

Design improvement options

Option 1	Option 2	Option 3	Option 4	Option 5
Electric ignition device	DC variable speed fan for controlling hot air flow	High efficiency condensing furnace: Primary and secondary heat exchanger	Continuous modulating burner	Thermostat and Damper

Figure 7-3 shows the different shares of consumer expenditure throughout the life cycle of BC1B and the design options. For all the cases, the fuel costs are the highest share (between 77% and 85% of the total). Variations in the rest of the life cycle costs are negligible.

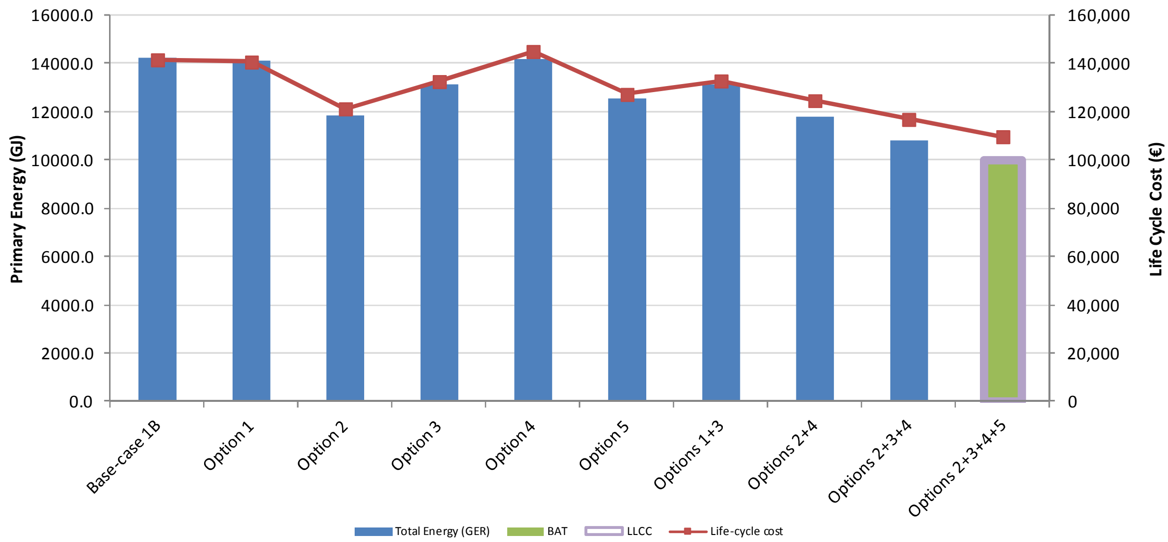
Figure 7-3: Life cycle cost of the improvement options for BC1B



Option 1	Option 2	Option 3	Option 4	Option 5
Electric ignition device	DC variable speed fan for controlling hot air flow	High efficiency condensing furnace: Primary and secondary heat exchanger	Continuous modulating burner	Thermostat and Damper

Figure 7-4 shows the comparison between LCC and primary energy consumption of BC1B and its design options. As in the case of BC1A, the combination of options 2+3+4+5 (including thermostats and dampers) is the option with lowest environmental impacts and LLCC. This combination of options presents the LCC 23% lower than the Base-Case and the primary energy consumption as 30% lower than the Base-Case. The second option that achieves the highest environmental and economic benefits is options 2+3+4, which reduces the total primary energy by 24% and the LCC by 17%.

Figure 7-4: Identification of design improvement options with least energy consumption and LLCC for BC1B



Option 1	Option 2	Option 3	Option 4	Option 5
Electric ignition device	DC variable speed fan for controlling hot air flow	High efficiency condensing furnace: Primary and secondary heat exchanger	Continuous modulating burner	Thermostat and Damper

7.2.3 Base-Case 2: Single split heat pump

The results of the environmental analysis of the different design options for BC2 are presented in Table 7—7. The combination of options 1+3+4+5+7 is the most optimal regarding the environmental impacts.

The combination of options 1+3+4+5 allows significant primary energy and LCC reductions. On the other hand, the contribution of the change of refrigerant (options 6 and 7) to the reduction of total GWP emissions is not very high (-10% and -13%, respectively).

Table 7—7: Environmental impacts of the BC2 and its improvement options

Life-cycle indicators per unit	unit	Base-Case 2	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 1+2	Option1+3	Option 1+3+4	Option 1+3+4+5	Option 1+3+4+7	Option 1+3+4+5+7
Total Energy (GER)	GJ	1352.8	1238.9	1231.8	1238.9	1328.6	1272.3	1285.7	1218.6	1128.2	1134.7	1114.5	1048.3	1004.2	944.6
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-17%	-16%	-18%	-23%	-26%	-30%
of which, electricity	primary GJ	1346.1	1232.1	1225.3	1232.1	1322.0	1265.6	1279.0	1211.9	1121.5	1127.8	1107.5	1041.3	997.2	937.6
	final MWh	128.2	117.3	116.7	117.3	125.9	120.5	121.8	115.4	106.8	107.4	105.5	99.2	95.0	89.3
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-17%	-16%	-18%	-23%	-26%	-30%
Water (process)	m^3	91.6	84.0	83.6	84.0	90.0	86.3	87.2	82.7	76.7	77.1	75.7	71.3	68.4	64.4
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-16%	-16%	-17%	-22%	-25%	-30%
Water (cooling)	m^3	3581.2	3276.9	3259.0	3276.9	3516.7	3366.4	3402.2	3223.2	2982.2	2998.6	2944.6	2768.1	2650.4	2491.5
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-17%	-16%	-18%	-23%	-26%	-30%
Waste, non-haz./ landfill	kg	1628.9	1505.4	1480.2	1505.4	1600.9	1535.6	1551.1	1473.3	1368.5	1393.0	1369.6	1292.8	1241.7	1172.6
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-16%	-14%	-16%	-21%	-24%	-28%
Waste, hazardous/ incinerated	kg	39.4	36.8	36.7	36.8	38.9	37.6	37.9	36.3	34.3	34.4	33.9	32.4	31.4	30.0
	% change with BC	0%	-7%	-7%	-7%	-1%	-5%	-4%	-8%	-13%	-13%	-14%	-18%	-20%	-24%
Greenhouse Gases in GWP100	t CO_2 eq.	62.7	57.7	57.4	57.7	61.6	59.2	56.3	54.3	49.4	53.2	48.8	49.4	45.0	42.4
	% change with BC	0%	-8%	-8%	-8%	-2%	-6%	-10%	-13%	-21%	-15%	-22%	-21%	-28%	-32%
Acidification, emissions	kg SO_2 eq.	348.6	319.3	317.5	319.3	342.4	327.9	331.3	314.0	290.8	292.4	287.2	270.2	258.8	243.5
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-17%	-16%	-18%	-22%	-26%	-30%
Volatile Organic Compounds (VOC)	kg	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4
	% change with BC	0%	-7%	-8%	-7%	-2%	-5%	-5%	-9%	-15%	-14%	-16%	-20%	-23%	-27%
Persistent Organic Pollutants (POP)	µg i-Teq	9.3	8.7	8.4	8.7	9.2	8.8	8.9	8.4	7.8	8.1	8.0	7.6	7.3	6.9
	% change with BC	0%	-7%	-10%	-7%	-2%	-6%	-5%	-9%	-16%	-13%	-14%	-19%	-22%	-26%

Life-cycle indicators per unit	unit	Base-Case 2	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 1+2	Option1+3	Option 1+3+4	Option 1+3+4+5	Option 1+3+4+7	Option 1+3+4+5+7
Heavy Metals to air	g Ni eq.	23.8	21.8	21.6	21.8	23.3	22.4	22.6	21.5	19.9	20.1	19.7	18.6	17.8	16.8
	% change with BC	0%	-8%	-9%	-8%	-2%	-6%	-5%	-10%	-16%	-15%	-17%	-22%	-25%	-29%
PAHs	g Ni eq.	3.5	3.3	3.3	3.3	3.4	3.3	3.4	3.2	3.0	3.1	3.0	2.9	2.8	2.7
	% change with BC	0%	-6%	-7%	-6%	-1%	-5%	-4%	-8%	-13%	-12%	-13%	-17%	-20%	-23%
Particulate Matter (PM, dust)	kg	13.6	13.0	12.9	13.0	13.5	13.2	13.2	12.9	12.4	12.5	12.4	12.0	11.8	11.5
	% change with BC	0%	-4%	-5%	-4%	-1%	-3%	-3%	-5%	-9%	-8%	-9%	-12%	-13%	-16%
Heavy Metals to water	g Hg/20	10.0	9.3	9.2	9.3	9.8	9.5	9.5	9.1	8.5	8.6	8.5	8.0	7.8	7.4
	% change with BC	0%	-7%	-8%	-7%	-2%	-5%	-4%	-9%	-15%	-14%	-15%	-19%	-22%	-26%
Eutrophication	kg PO4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	% change with BC	0%	-4%	-6%	-4%	-1%	-4%	-3%	-6%	-10%	-8%	-9%	-12%	-14%	-17%
Life-cycle cost	€	28,547.3	27,379.6	27,183.8	27,379.6	28,274.6	27,638.3	27,909.8	28,064.3	26,132.0	26,321.3	26,093.0	25,345.7	25,832.9	25,160.3
	% change with BC	0%	-4%	-5%	-4%	-1%	-3%	-2%	-2%	-8%	-8%	-9%	-11%	-10%	-12%

Design improvement options

Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Increase heat exchanger surface in outdoor unit	Micro channel heat exchanger in indoor unit(s)	Increase heat exchanger surface in indoor unit	Reduce crankcase heater time	Improved EEV control	Refrigerant R290	Refrigerant R32

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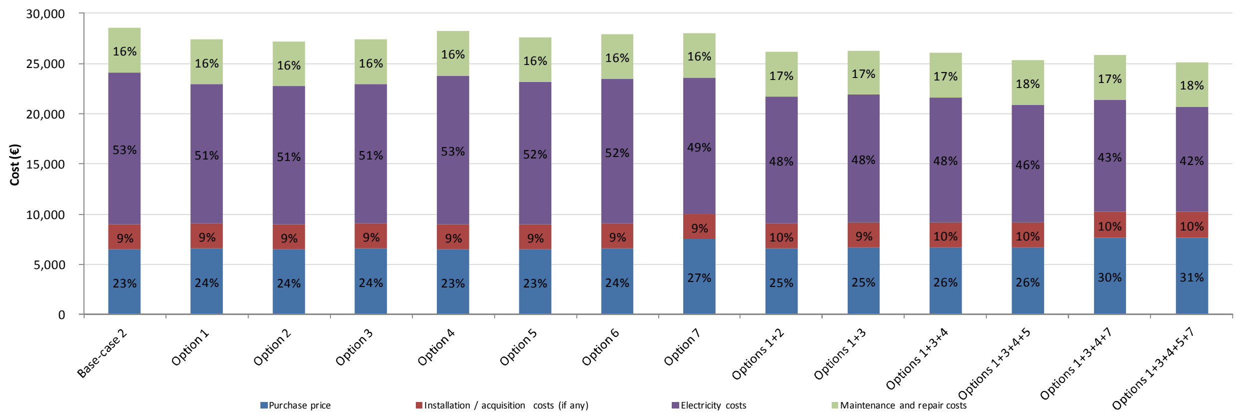
Figure 7-5 shows the shares of life cycle costs of the BC2 and its different design options. In all cases, the electricity consumption is the highest expenditure throughout the life cycle, accounting for between 49% and 53% of the total. Purchase costs and maintenance costs mean around 23% to 31% and from 15% to 18% of the total, respectively.

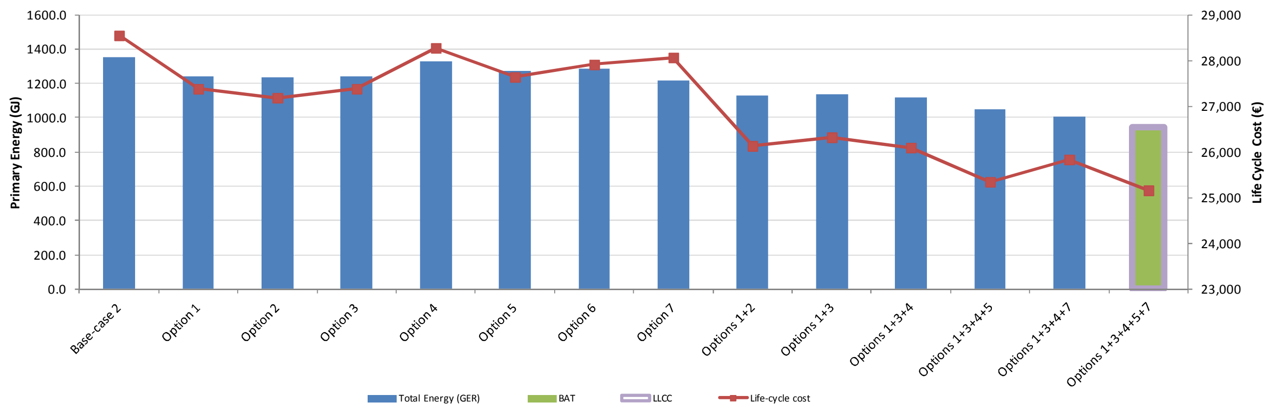
Figure 7-5: Life cycle cost of the improvement options for BC2



Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Increase heat exchanger surface in outdoor unit	Micro channel heat exchanger in indoor unit(s)	Increase heat exchanger surface in indoor unit	Reduce crankcase heater time	Improved EEV control	Refrigerant R290	Refrigerant R32

Figure 7-6presents the comparison of primary energy consumption and life cycle costs for BC2 and the design options. For this Base-Case, the combination of options 1+3+4+5+7 is the optimal design improvement, achieving 30% energy savings and 12% reduction in life cycle costs. The combination of options 1+3+4+5 presents 18% lower energy consumption and 18% lower consumer expenditure.

Figure 7-6: Identification of design improvement options with least energy consumption and LLCC for BC2



Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
Increase heat exchanger surface in outdoor unit	Micro channel heat exchanger in indoor unit(s)	Increase heat exchanger surface in indoor unit	Reduce crankcase heater time	Improved EEV control	Refrigerant R290	Refrigerant R32

7.2.4 Base-Case 3: VRF heat pump

The environmental and economic analyses of the BC3· and its design options are shown in Table 7—8. As in the case of BC2, a similar combination of options 1+3+4+6 (excluding EEV) is the design option that allows the highest reduction of environmental impacts and consumer expenditure over the life cycle. The change of refrigerant can reduces the total GWP emissions in both cases by 24% 0.

Table 7—8: Environmental impacts of the BC3 and its improvement options

Life-cycle indicators per unit	unit	Base-Case 3	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 1+2	Option 1+3	Option 1+3+4	Option 1+3+4+5	Option 1+3+6
Total Energy (GER)	GJ	3211.3	2942.8	2926.6	2942.8	3189.1	3211.3	2895.0	2681.9	2697.2	2678.7	2678.7	2415.7
	% change with BC	0%	-8%	-9%	-8%	-1%	0%	-10%	-16%	-16%	-17%	-17%	-25%
of which, electricity	primary GJ	3179.2	2910.4	2894.5	2910.4	3157.1	3179.2	2862.9	2649.8	2664.5	2645.9	2645.9	2382.9
	final MWh	302.8	277.2	275.7	277.2	300.7	302.8	272.7	252.4	253.8	252.0	252.0	226.9
	% change with BC	0%	-8%	-9%	-8%	-1%	0%	-10%	-17%	-16%	-17%	-17%	-25%
Water (process)	m^3	222.8	204.9	203.8	204.9	221.4	222.8	201.7	187.5	188.5	187.3	187.3	169.7
	% change with BC	0%	-8%	-9%	-8%	-1%	0%	-9%	-16%	-15%	-16%	-16%	-24%
Water (cooling)	m^3	8442.8	7725.7	7683.5	7725.7	8383.7	8442.8	7599.2	7031.0	7069.6	7020.2	7020.2	6318.9
	% change with BC	0%	-8%	-9%	-8%	-1%	0%	-10%	-17%	-16%	-17%	-17%	-25%
Waste, non-haz./ landfill	kg	4244.3	3950.0	3914.2	3950.0	4218.7	4244.3	3877.6	3630.5	3682.1	3660.6	3660.6	3355.7
	% change with BC	0%	-7%	-8%	-7%	-1%	0%	-9%	-14%	-13%	-14%	-14%	-21%
Waste, hazardous/ incinerated	kg	87.9	81.7	81.3	81.7	87.4	87.9	80.6	75.7	76.0	75.6	75.6	69.5
	% change with BC	0%	-7%	-7%	-7%	-1%	0%	-8%	-14%	-13%	-14%	-14%	-21%
Greenhouse Gases in GWP100	t CO_2 eq.	184.4	172.7	172.0	172.7	183.5	141.0	139.6	146.3	118.6	161.2	117.8	149.7
	% change with BC	0%	-6%	-7%	-6%	-1%	-24%	-24%	-21%	-36%	-13%	-36%	-19%
Acidification, emissions	kg SO_2 eq.	832.2	763.1	758.9	763.1	826.5	832.2	750.8	695.9	699.8	695.0	695.0	627.3
	% change with BC	0%	-8%	-9%	-8%	-1%	0%	-10%	-16%	-16%	-16%	-16%	-25%
Volatile Organic Compounds (VOC)	kg	1.4	1.3	1.3	1.3	1.4	1.4	1.3	1.2	1.2	1.2	1.2	1.1
	% change with BC	0%	-7%	-7%	-7%	-1%	0%	-8%	-14%	-13%	-14%	-14%	-21%
Persistent Organic Pollutants (POP)	µg i-Teq	24.4	22.9	22.6	22.9	24.3	24.4	22.3	20.9	21.5	21.4	21.4	19.7
	% change with BC	0%	-6%	-8%	-6%	-1%	0%	-8%	-14%	-12%	-12%	-12%	-19%

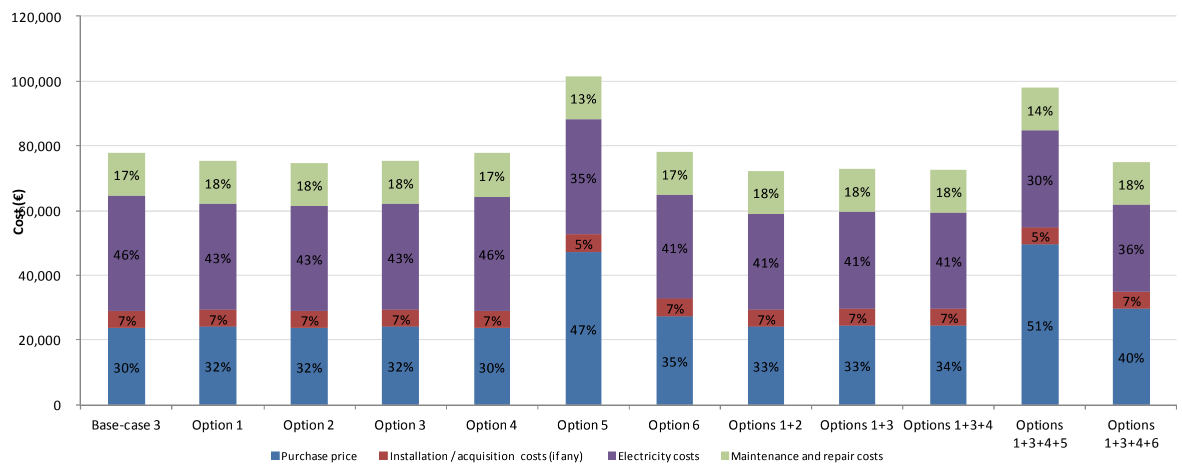
Life-cycle indicators per unit	unit	Base-Case 3	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 1+2	Option 1+3	Option 1+3+4	Option 1+3+4+5	Option 1+3+6
Heavy Metals to air	g Ni eq.	58.5	54.0	53.6	54.0	58.1	58.5	53.1	49.4	49.8	49.5	49.5	45.0
	% change with BC	0%	-8%	-8%	-8%	-1%	0%	-9%	-16%	-15%	-15%	-15%	-23%
PAHs	g Ni eq.	15.6	15.0	15.0	15.0	15.5	15.6	14.9	14.5	14.6	14.5	14.5	14.0
	% change with BC	0%	-3%	-4%	-3%	0%	0%	-4%	-7%	-7%	-7%	-7%	-10%
Particulate Matter (PM, dust)	kg	33.3	31.9	31.7	31.9	33.2	33.3	31.6	30.4	30.7	30.6	30.6	29.1
	% change with BC	0%	-4%	-5%	-4%	0%	0%	-5%	-9%	-8%	-8%	-8%	-13%
Heavy Metals to water	g Hg/20	31.0	29.3	29.2	29.3	30.8	31.0	29.0	27.6	27.7	27.6	27.6	25.9
	% change with BC	0%	-5%	-6%	-5%	0%	0%	-7%	-11%	-10%	-11%	-11%	-16%
Eutrophication	kg PO4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	% change with BC	0%	-3%	-3%	-3%	0%	0%	-4%	-6%	-5%	-5%	-5%	-8%
Life-cycle cost	€	77,999.9	75,364.7	74,786.2	75,364.7	77,749.9	101,649.9	78,213.1	72,424.2	72,987.5	72,778.3	97,993.3	75,158.6
	% change with BC	0%	-3%	-4%	-3%	0%	30%	0%	-7%	-6%	-7%	26%	-4%

Design improvement options

Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Increase heat exchanger surface in outdoor unit	Micro channel heat exchanger in indoor unit(s)	Increase heat exchanger surface in indoor unit(s)	Reduce crankcase heater time	Refrigerant R744	Refrigerant R32

The share of LCC is shown in Figure 7-7. The electricity consumption accounts for between 41% to 46% of the total consumer expenditure over the life cycle for options excluding the refrigerants and as low as 30% for options including the refrigerant change. Purchase price is the second highest share of costs, between 30% and 47% for options including the refrigerant change.

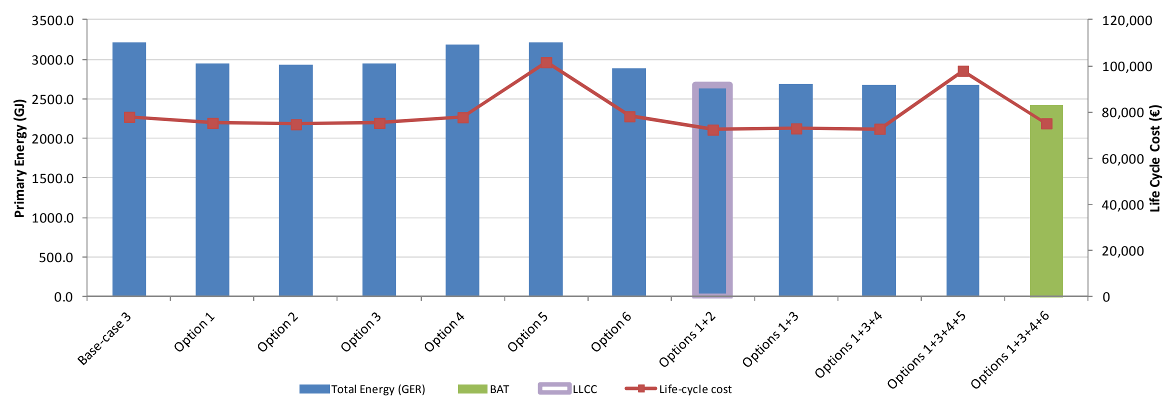
Figure 7-7: Life cycle cost of the improvement options for BC3



Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Increase heat exchanger surface in outdoor unit	Micro channel heat exchanger in indoor unit(s)	Increase heat exchanger surface in indoor unit(s)	Reduce crankcase heater time	Refrigerant R744	Refrigerant R32

Figure 7-8 presents the comparison between primary energy consumption and life cycle costs of the Base-Case and its design options. The least life cycle cost option is the combination of options 1+2. This combination of options allows 16% energy savings and 7% reduction of consumer expenditure. The BAT is the combination of options 1+3+4+6, which achieves the highest energy savings of 25% and significant cost savings of 4% over the Base-Case.

Figure 7-8: Identification of design improvement options with least energy consumption and LLCC for BC3



Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Increase heat exchanger surface in outdoor unit	Micro channel heat exchanger in indoor unit(s)	Increase heat exchanger surface in indoor unit(s)	Reduce crankcase heater time	Refrigerant R744	Refrigerant R32

7.3 BNAT and long-term systems analysis

Not all possible improvement options were considered in the preceding sections. Some are still prohibitively expensive or not yet widely available. Such options can be described as BNAT and considered as long-term targets.

Some of these improvement options may therefore only become available in the coming years, and only be applicable to some products on the market. Other improvements are related to the heating system of the building rather than the product itself.

7.3.1 Warm air heaters

In Task 6, various design options were considered for improving the material efficiency of central air heaters. Since material use is closely related to production costs and product performance, the options related to material substitution were identified as having the most potential for improving the design. The design options that result in the highest gains in material efficiency of central air heaters are: 1) Changing the type of refrigerant and 2) Using micro-channel heat exchangers (MCHX). Except for refrigerants and MCHX, no other design improvement options related to material efficiency were identified in Task 7, since a reduction of materials might lead to a poorer insulation of the heater. This poorer insulation can affect the safety of the product negatively (higher external surface temperature) and the heat losses in heat generation and distribution. On the other hand, it might be possible to improve the insulation of the heater and ducts by using a higher quantity of materials or alternative materials with better insulating properties. This way, the heat losses through heater casing and ducts could be reduced. Nevertheless, the jacket losses of the Base-Cases analysed in Task 5 are around 1% of the total energy consumption. Increasing the casing insulation would lead to rather insignificant potential energy savings. Duct losses, as well, account for around 1% of the total energy consumption of the air-based central heating products. Better insulation would achieve little energy savings in this case. Furthermore, ducts are not part of the heater and the decision to insulate ducts are related to their installation. Similarly, mini ducts systems could theoretically provide some energy and material savings in warm air distribution. Since ducts are part of the product extended approach, their influence on the energy consumption is clear, but the influence of Ecodesign of air-based central heating products on the design of ducts is limited.

Other system option not analysed in this task is furnace-integrated heat pumps. As other hybrid systems, this option is not an actual improvement of current warm air heaters on the market, but a different concept of central warm air heating. The combined operation of heat pumps and furnaces might provide higher efficiency, but this solution is more related to the design of the building and its heating system than to warm air heaters manufacturers.

In Task 6, other improvement options were described as Best Not yet Available Technologies. Regenerative and recuperative burners, low-NO_x burner solutions, or recently developed technologies for heat exchangers are possible options for improving the efficiency of warm air heaters in the future. However, as these options are still not yet available in the market, no further analysis was carried out on them.

It is important to take into account the applicability of the design options analysed to the entire range of products represented by the Base-Cases. As explained in Task 5, the analysis of Base-Cases and their improvement options is an exercise thought to represent a wider scope of products in a simplified example. Due to their low market penetration, other types of warm air heaters were not selected to be studied as Base-Cases in Task 5, e.g. electric, oil and multi-fuel warm air heaters. The design options related to capacity control and burner efficiency are not applicable to these types of warm air heaters. Electric heaters can control the output power by using intermediate steps, but capacity control has not been developed for oil and multi-fuel heaters. The heat generation efficiency of electric heaters compared with gas and oil heaters was already discussed in Task 4. Condensing technology is theoretically applicable to all types of heaters that use combustion for heat generation. However, the amount of latent heat in the flue gasses might vary for different types of burners.

The remaining design options regarding heat distribution and reduction of the auxiliary energy would also be applicable to electric, oil and multi-fuel warm air heaters.

7.3.2 Heat pumps

Regarding heat pumps, Task 6 described some improvement options related to the design of the entire heating system in the building. Integrated heat pump systems, solar assisted heat pumps, integrated furnace heat pumps and heat recovery technologies can provide higher seasonal efficiencies and energy savings compared with traditional heat pumps, but their main advantage relies on the combination of different functions and/or technologies in order to improve the overall performance. As in the case of warm air heaters, the field of application of Ecodesign measures does not go further than the product design, therefore these system improvements are not analysed any further here.

Some Best Not yet Available Technologies for heat pumps have been presented in Task 6. Some examples are new refrigerants, oil-free compressors or outdoor units with no defrost cycles. These options are possible technologies for the future, but they are not developed at the time of writing and therefore do not form part of this analysis. However, they could give an idea of the possible improvement potential expected in the medium- or long term.

Some heat pump technologies already available in the market were not selected for being studied as Base-Cases in Task 5 due to their low market penetration in the EU, i.e. ground-source, water-source, and gas-engine heat pumps. Some of the design options studied in this task are equally applicable to other the heat pump types covered in the scope of this preparatory study, with the exception of those related to heat exchangers or compressor technology. This issue will be taken into account in the discussion of policy options in Task 8.

7.4 Conclusions

Several improvement options are available for each product group, usually with short payback times and only few constraints. Combinations of these improvement options provide potential for significant energy savings, leading to reduced environmental impact and lower LCC.

There is also potential for currently not available improvement options to become more affordable over the coming years. Nonetheless, some technologies such as magnetic refrigeration are relatively far from market introduction.

Regarding direct emissions from refrigerants in heat pumps, using alternative refrigerants would help to reduce GWP. However, any refrigerant substitution that lowers overall efficiency is likely to have more adverse environmental impacts than benefits, due to the low significance of the refrigerant emissions compared with the total GHG emissions during the life cycle of the heat pump.

Hence, steadily increasing levels of energy efficiency without significant increase in other environmental impacts should be achievable. These results will therefore be discussed in the context of potential policy options in Task 8.

However, the overall energy efficiency of a central heating system depends much more on appropriate adjustments of the heat demand and supply than to the energy efficiency of each product. Therefore, the development of capacity control technologies and methods for testing the seasonal performance are a key issue in order to achieve the total improvement potential of the central heating products studied here.

Alternative refrigerants and micro-channel heat exchangers (MCHX), which can replace copper with aluminium, were identified as the most relevant options for improving material efficiency.

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