Preparatory Studies for Ecodesign Requirements of EuPs (III)

ENER Lot 21 – Central heating products that use hot air to distribute heat
Task 5: Definition of Base-Cases

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Task 5: Definition of Base-Case

This task provides an environmental and economic impact assessment of the average air-based central heating systems in the EU-27, also known as the "Base-Cases". A Base-Case (BC) is "a conscious abstraction of reality" used to represent a range of similar products on the market to serve as the reference for any design improvements. The aim of the assessment is to quantify:

- The environmental impacts of the product throughout its life
- The economic Life Cycle Costs (LCC)

The assessment includes all stages of the Base-Case's life from the extraction of the materials contained within its components, to the disposal of these materials at the end-of-life. The method used to develop these impacts is Life Cycle Analysis (LCA). In this study a simplified LCA tool is used to calculate the environmental impacts and LCC. The tool, which is called EcoReport, is part of the MEEuP methodology, required by the European Commission for undertaking all preparatory studies under the Ecodesign Directive[1].

While this study has been completed as comprehensively and accurately as possible, it relies on data which has been extrapolated from literature and information provided by stakeholders. The performance of real-life appliances can vary substantially from the data provided in this report. This is understood and mitigated as much as possible while processing and calculating the data during the analysis, however rough approximations are ultimately unavoidable. The results of the study nevertheless are valuable as they represent the best indication to date of the environmental impacts of the air-based central heating products in Europe.

The description of the Base-Cases is the synthesis of the results of Tasks 1 to 4. The environmental and life cycle cost analyses of the selected Base-Cases provide the main results of this study and it serves as the point-of-reference for Task 6 (technical analysis of Best Available Technologies), Task 7 (improvement potential), and Task 8 (policy analysis).

5.1 Overview of Base-Cases

5.1.1 Criteria for defining Base-Cases

According to the Ecodesign Directive (2009/125/EC), the products subject to future establishment of implementing measures should meet three criteria:

- Significant market share
- Significant environmental impact
- Significant improvement potential

[1] MEEuP – Methodology Study Eco-design of Energy Using Products. Kemna, R. et al. (VHK) for DG ENTR of the European Commission, MEEuP Methodology Final Report, 2005. Accessible at: ec.europa.eu/enterprise/eco_design/finalreport1.pdf

The reason for these criteria is that implementing measures should target appliances which are common on the EU market, bear a large environmental burden, and have the potential to improve their environmental performance. An appliance that does not meet these three criteria provides little opportunity for policy action, and therefore is not considered as a Base-Case. The most appropriate BCs for this study were selected through discussion with stakeholders, using the above criteria as guidelines. As mentioned previously, Base-Cases are not necessarily representative of real products. When two products have a similar bill of materials, technology and efficiency and life cycle, they may be represented by a single Base-Case.

The selection of Base-Cases in this preparatory study was done so that they would reasonably represent the wide range of air-based central heating products currently on the EU market. The selection was agreed together with the stakeholders, the ENTR Lot 6[2] project team and the Commission. . The selected Base-Cases are also used as representative for the most common air-based central heating products installed in the EU stock.

As seen in the Tasks 1 and 2 of this preparatory study, the two main technologies that are used for air-based central heating are combustion appliances and heat pumps. Within the combustion appliances, those that use natural gas are the most common in the EU, even though their market penetration is not comparable to other central heating technologies, such as hydronic systems. Warm air heaters that use electricity, oil or solid fuels are not commonly used in the EU for central heating. On/off gas burners with pilot flame ignition are still the most used technology in the EU installed stock, although the market share of burners including capacity controls and electric igniters is increasing.

Gas-fired warm air heaters are used both in residential and non-residential applications. As seen in Task 2, their heating capacities vary from 4 kW to 75 kW (residential) and over 65 kW (non-residential).

Regarding heat pumps, the most used technology for air heating in the EU is air-to-air electric heat pumps. Ground-to-air and water-to-air heat pumps are not commonly used. Depending on the size of the installation, single split heat pumps or VRF (Variable Refrigerant Flow) heat pumps are the most common products. Gas engine driven heat pumps are an alternative technology to all-electric heat pumps, but their presence in the EU market is limited. The most used compressor type in air-to-air electric heat pumps is scroll compressors with capacity control. The most common refrigerant used is R410A.

Based on this, two Base-Cases were selected in the product group "warm air heaters" (residential and non-residential) and two Base-Cases in the product group "heat pumps" (single-split and VRF).

5.1.2 Description of selected Base-Cases

The characteristics of the products used for the construction of the Base-Cases that represent their respective categories are summarised in Table 5—1. These products are selected based on

[2] DG ENTR Lot 6 preparatory study on non-residential air conditioning and ventilation shares some of the same products as ENER Lot 21

the market shares presented in Task 2 and information provided by stakeholders. The Base-Cases therefore serve to represent the rest of the products in the market.

Table 5—1: Description of the selected Base-Cases

Base-Case	Product	Average heating capacity [kW]
BC-1A	Residential gas warm air heater	15
BC-1B	Non-residential gas warm air heater	120
BC-2	Single split heat pump	16
BC-3	VRF heat pump	55

5.1.2.1 *BC-1A: Residential warm air heater*

The Base-Case for residential warm air heaters is an indirect warm air unit of 15 kW heating capacity. The heater includes an atmospheric burner, without any combustion fans; and a on/off heat generation control system (capable of only running at full load). The burner ignition system is a constantly alight pilot flame. Industry common practice presents the thermal efficiency of a warm air heater by net calorific value, however the gross calorific value is provided in this study for a full picture. The average characteristics of residential warm air heaters in the EU market are used to build this representative Base-Case. These characteristics are summarised in Table 5—2.

Table 5—2: Base-Case of residential warm air heater

Product type	Indirect-fired gas warm air heater
Application	Residential heating
Heating capacity	15 kW
Fuel used	Natural gas
Burner type	Atmospheric
Type of draught	Natural
Control	On/off
Ignition type	Pilot burner
Average heat generation efficiency (% based on NCV)	84%
Average heat generation efficiency (% based on GCV)	76%
Air temperature rise (°C)	45°C-55°C

5.1.2.2 *BC-1B: Non-residential warm air heater*

The Base-Case for non-residential warm air heaters includes the same features and characteristics as the Base-Case for residential warm air heaters (BC-1A), but with a difference in the heating capacity. For BC-1B the heating power output is assumed to be 120 kW.The characteristics of BC-1B are summarised in Table 5—3.

Table 5—3: Base-Case of Non-residential warm air heater

Product type	Indirect-fired gas warm air heater
Application	Non-residential heating
Heating capacity	120 kW
Fuel used	Natural gas
Burner type	Atmospheric
Type of draught	Natural
Control	On/off
Ignition type	Pilot burner
Average heat generation efficiency (% based on NCV)	90%
Average heat generation efficiency (% based on GCV)	81%
Air temperature rise (°C)	45°C-55°C

5.1.2.3 *BC-2: Single split heat pump*

The Base-Case for a single split heat pump (BC-2) represents a heat pump for non-residential buildings with a heating capacity of 16kW with one outdoor and one indoor unit. A scroll compressor is the most common type of compressor used in this kind of heat pumps in the EU, and it has compressor speed control. Refrigerant R410A is used as the heat transfer medium. Fans assist the air flow through the heat exchangers in both the indoor and outdoor units.

The characteristics of BC-2, which represents non-residential single split heat pumps, are presented in Table 5—4.

Table 5—4: Base-case of Single split heat pump

Product type	Single spit heat pump
Application	Non-residential heating
Heating capacity	16 kW
Heat source	Air
Compressor type	Scroll
Refrigerant used	R410A
Number of units outdoor:indoor	1:1
Control	Compressor speed control
Average COP (7°C/20°C) (EN 14511)	3.34

5.1.2.4 *BC-3: VRF heat pump*

BC-3 is a VFR heat pump, which represents a typical heat pump for non-residential buildings with a capacity of 55 kW with one outdoor and nine indoor units. The most common compressor technology used in this kind of product is a scroll compressor with variable speed drive. The refrigerant R410A is used as the heat transfer medium. The heat exchange in the indoor units and in the outdoor unit is assisted by fans, which force ambient air to pass through the heat exchangers. The characteristics of BC-3 representing non-residential VRF heat pumps are summarised in Table 5—5.

Table 5—5: Base-Case of VRF heat pump

Product type	VRF heat pump
Application	Non-residential heating
Heating capacity	55 kW
Heat source	Air
Compressor type	Scroll
Refrigerant used	R410A
Number of units outdoor:indoor	1:9
Control	Modulating
Average COP (7°C/20°C) (EN 14511)	3.98

5.1.3 Estimation of system heating demand and energy consumption

The aim of this section is to estimate the heating demand over one year of standard types of residential and non-residential buildings in which air-based central heating products might be used. The annual heating demand of the building will serve as a baseline and input to calculate the annual energy consumed by the air-based central heating products to meet the heating demand.

Table 5—6: Product groups and typical building types, where they are installed

Product groups	Building types
Residential warm air heaters	Residential buildings: single family, multi family and high rises
Non-residential warm air heaters	Industrial buildings Warehouses Sports halls Churches
Reversible heat pumps/ Single split >12 kW and VRF	Service buildings (commercial and public sector) Sports halls Churches

The heating demand is a function of climate (e.g. outdoor temperature, solar radiation), indoor temperature setting, building envelope, heated volume, ventilation, occupancy pattern, etc. The energy consumed by the heating system depends on the efficiency of the product, its correct sizing to match the heating demand and its capability to work at variable capacity settings.

The calculation method in this preparatory study consists of two different methods: one for heat pumps and one for warm air heaters, since these appliances have different working principles.

5.1.3.1 *Heat pumps*

The standard prEN 14825 was developed in order to provide guidelines to test residential air conditioners, chilling packages and heat pumps in real conditions over a season. It is based on three typical climatic conditions (Athens (Greece), Strasbourg (France) and Helsinki (Finland)), reference annual heating demands of three different buildings, and average use patterns in Europe.

As the prEN 14825 standard proposes a method that has been agreed and will be used in the industry for testing the seasonal performance of heat pumps, it fulfils the requirements needed for the present preparatory study. The data used is valid for the entire EU and the calculation method is clear and replicable. This standard estimates the number of hours that a heat pump works in thermostat off mode, standby mode, crankcase heater mode and off mode. The standard also estimates the equivalent hours per year for "heating only" appliances. However, these calculations were developed for heat pumps not exceeding 12 kW of cooling capacity, and therefore the data used for the building heating demand relate to residential buildings, small offices or small shops. The building types in which ENER Lot 21 products are used, are typically larger non-residential buildings. Nevertheless, heat pump manufacturers have suggested that the calculation method and the working hours proposed in the prEN 14825 standard could be applied to the non-residential applications for the purposes of this study.

Therefore, based on the input from stakeholders, the working hours proposed in the prEN 14825 standard are used in the energy and annual efficiency calculation in this preparatory study.

Table 5—7: number of hours used for calculation of energy consumption and SCOP

Mode	Hours per year
Equivalent heating hours	1,400
Off mode hours	3,672
Thermostat off mode hours	179
Crankcase heater hours	3,851
Standby mode hours	0

The standard prEN14825 includes the method for calculation of SCOP (Seasonal Coefficient of Performance):

(1) $$SCOP = \frac{reference\ annual\ heating\ demand}{annual\ electricity\ consumption}$$

As the calculation of the annual electricity consumption is necessary for the SCOP calculation, the same calculation method for annual electricity consumption (AEC) as prEN 14825 was used by the project team:

(2) $$AEC = \frac{Q_e}{SCOP_{on}} + H_{to} * P_{to} + H_{sb} * P_{sb} + H_{ck} * P_{ck} + H_{off} * P_{off}$$

Where,

Q_{he} is the reference annual heating demand, expressed in kWh;

H_{to}, H_{sb}, H_{ck} and H_{off} are the number of working hours in thermostat off mode, standby mode, crankcase heater mode and off mode, respectively;

P_{to}, P_{sb}, P_{ck} and P_{off} are the electricity consumption during thermostat off mode, standby mode, crankcase heater mode and off mode, respectively.

$SCOP_{on}$ is the seasonal efficiency of a unit in active mode

The reference annual heating demand can be calculated as follows:

(3) $$Q_e = P_{design} * H_e$$

Where,

P_{design} is the full load capacity in heating mode

H_{he} is the number of equivalent hours per year in heating mode

The seasonal efficiency in heating mode $SCOP_{on}$ is calculated as follows:

(4) $$SCOP_{on} = \frac{\sum_{j=1j}^{n} \cdot P(T_j)}{\sum_{j=1j}^{n} \cdot (\frac{P(T_j) - elbu(T_j)}{COP(T_j)} + elbu(T_j))}$$

Where,

T_j is the bin temperature
J is the bin number
n is the amount of bins
$P_h(T_j)$ is the heating demand of the building in kW for the corresponding temperature T_j
h_j is the number of bin hours occurring at the corresponding temperature T_j
$COP(T_j)$ is the COP value of the unit for the corresponding temperature T_j
elbu is the capacity in kW of an electric backup heater with a COP of 1

The values to be used for j, T_j, and h_j are given in the standard prEN 14825.

The formulas (2), (3) and (4) are included in a spreadsheet developed by experts in the CEN/TC113/WG07 for preparing the prEN 14825 standard, to calculate the Seasonal Coefficient Of Performance of heat pumps.

The necessary values to perform the calculation are provided by manufacturers:

- $COP(T_j)$
- P_{to}, P_{sb}, P_{ck} and P_{off}
- P_{design}
- Bivalent temperature
- Minimum operation temperature

5.1.3.2 Warm air heaters

The energy efficiency calculations of the standard prEN 14825 do not apply to warm air heaters. Therefore, an alternative method must be used to calculate the annual energy consumption. There is no standard at EU level that present a method for calculating annual energy consumption and annual energy efficiency of warm air heaters. CEN/TC180 started recently working on a methodology for calculating seasonal performance of decentralised gas warm air heaters. However, that methodology would presumably only apply to decentralised heaters, and not to central warm air heaters covered in this study.

This section presents a method developed in this study for the calculation of the annual energy consumption and efficiency of warm air heaters. This method has been developed by a technical expert of the project team for this study, and has been agreed with the stakeholders. However, this method is not standardised, which is a prerequisite if it is to be used as basis for future regulations. The recommendations on standardisation mandates will be developed further in Task 8 of this preparatory study.

As in the case of heat pumps, the heat demand and working hours of warm air heaters is calculated based on the bin method, with the bin data from Strasbourg (average climate).

Ideally, the heating capacity should always match the heat demand. However, the heat delivered by a heater is not the same as the energy consumed. Losses can occur during heat generation, transmission and emission. The annual energy consumed for furnaces and warm air heaters to meet the heat demand depends on:

- the heating demand
- the thermal efficiency of the burner and its capability to modulate the heat output
- the efficiency of the room temperature controls (thermostats)
- the efficiency of the heat emission in the room
- the heat losses:
  - jacket losses
  - heat distribution losses
  - purge losses

The different energy sources used by furnaces and warm air heaters (fuel for combustion to generate heat and electricity for auxiliary functions) have to be taken into account by converting the energy consumed into primary energy. The primary energy conversion factors are already included in the EcoReport tool.

The modelled system is a recirculating system. There are installed ducts for flow and return air flow. The flow temperature is in the range of 40 – 60 °C and the return temperature is at room temperature (i.e. 20 °C).

The fuel used in terms of energy after Gross calorific value is:

$$E = Q_{net}/(\eta_{temp} \times \eta_{em}) + Q_{flue\text{-}gas} + Q_{jacket} + Q_{start} + Q_{duct} + Q_{pilot}, \quad (1)$$

Where
E is energy used after Gross calorific value
Q_{net} *is the net energy consumption*
η_{temp} *and* η_{em} *are efficiencies for the control of temperature and emission of heat in the room*[3]
$Q_{flue\text{-}gas}$ *is flue gas loss in burner on periods*
Q_{start} *is the start loss: unburnt fuel in start phase, pre - and post purge losses*
Q_{jacket} *is heat loss from the Jacket*
Q_{duct} *is heat loss from the ducts to the rooms. Normally only heat loss from the flow ducts are significant*
Q_{pilot} *is energy consumption from the pilot flame.*

To this energy consumption the auxiliary energy has to be added. Then, the annual efficiency and the total primary energy consumed can be expressed as:

[3] As given in DIN V 18599-5. Calculation of the energy needs, delivered energy and primary energy for heating, cooling, ventilation, domestic hot water and lighting — Part 5: Delivered energy for heating systems

(2) $$Annual\ energy\ efficiency = \frac{Q}{Eprim}$$

(3) $$E_{prim} = \frac{\frac{Q}{\eta_{temp} * \eta_{em}} + heat\ losses}{(\eta_{gen} + \Delta\eta_{ctr})} + Q_{pilot} + Q_{start} + f_{aux} * f_{p,aux}$$

Where,

(4) $$\eta_{gen} = \frac{P_{in} - P_{flue}}{P_{in}}$$

E_{prim} is the annual primary energy consumption
Q is the reference annual heating demand, expressed in kWh
η_{temp} is the room temperature control efficiency
η_{em} is the efficiency of the heat emission in the room
"heat losses" includes jacket losses and losses from the ducts
η_{gen} is the thermal efficiency of the heat generation[4]
P_{in} is input power at a full load test
P_{flue} is flue gas loss in kW at full load test, corrected for amount of condensate
$\Delta\eta_{ctr}$ is the influence of capacity controls in the thermal efficiency[5]
Q_{pilot} and Q_{start} are the heat losses of the pilot flame and the unburnt fuel at start-up
f_{aux} is the auxiliary energy consumed
$f_{p,aux}$ is the primary energy factor for electricity

η_{ctr},, η_{em} parameters:

η_{ctr} takes into account the control efficiency. In the case of temperature variations within the room, the basic idea is that the temperature should not drop below a certain level. With temperature variations, the mean temperature must be higher than in the case with a constant temperature. On/off furnaces may influence this, so energy savings can be achieved with a modulating or two – stage burner.

η_{em} takes into account the temperature distribution in the room and it is assumed that an even room temperature distribution may give energy savings.

Flue gas loss, efficiency and part load efficiency

$Q_{flue\text{-}gas}$ is the flue gas loss due to exhaust system when the burner is in operation. The flue gas is measured based on the flue gas temperature and the concentration of CO_2 or O_2 in the flue. The flue gas loss will be close to zero, if the flue gas temperature is 20°C (most of the water vapour in the combustion products is in liquid state) taking into account the heat of condensation of water

[4] EN 1319, 2010: Domestic gas-fires forced convection air heaters for space heating, with fan assisted burners not exceeding a net heat input of 70 kW

[5] According to the UK Standard Assessment Procedure (SAP) for Energy Rating of Buildings (draft 2012), warm air heaters with capacity control are rated two points over their thermal efficiency.

vapour in the combustion gas. The amount of condensate is measured directly, or by using a wet bulb thermometer. Condensation takes place when the combustion gases pass a surface at a temperature below the dew point of the gases. The dew point depends on the excess air in the combustion. For natural gas, the dew point is approximately 58°C with 30% excess air. For domestic fuel oil, the dew point is approximately 48°C. The thermodynamic limit for an air furnace (not taking into account the electricity consumption of the fans) is an efficiency corresponding to a value close to the gross calorific value of the fuel. The air flow is much larger than the flow of combustion gases, so the gases can be cooled to 20°C. At this temperature most of the water is in liquid state.

$\Delta\eta_{ctr}$ takes into account that flue gas loss (as a percentage of input power) decreases for a modulating device at part load, in the case that combustion air is controlled proportional to the flow of fuel. For an atmospheric burner without air control, the flue gas loss in percent normally increases with decreasing input, so $\Delta\eta_{ctr}$ is negative in such cases. The EN 1319 reference 1 states that the efficiency must not drop more that 5% at part load. For modulating devices, the efficiency will increase at part load. The flue gas loss will depend on the flow and temperature of the air in the rooms. The model does not take into account this effect. Flue gas loss data is available from standard test reports. The flue gas must be lower than 24% (GVC) at full load and 29% at part load according to EN 1319.

To determine an average value of the flue gas loss, a bin method is used (based on the Strasbourg climate). In the bin calculation, the average load can also be calculated to get an average value of the percentage flue gas loss.

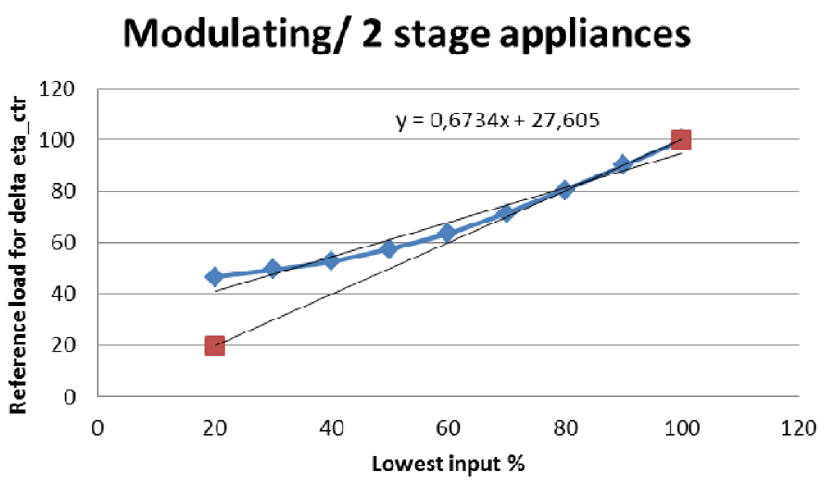


Figure 5-1: Calculation of the reference load to find the $\Delta\eta_{ctr}$, using a bin method on Strasburg outdoor temperature data.

For a modulating appliance that has the lowest input at 40%, the flue gas loss at 55% load represents the average flue gas loss. The flue gas loss can be determined by interpolation between the maximum and minimum load.

It is not possible, or at least very difficult, to measure the efficiency directly on the air side (unlike boilers where the water flow and temperature can be measured fairly accurately). The reason for this is that temperature stratification in the ducts and difficulties in measuring the air flow reduce the accuracy. A direct measurement of the part load efficiency is even more difficult. When jacket losses are not known, an indirect measurement of the part load efficiency at a given part load rate is therefore also very difficult.

The seasonal efficiency based on a weighted average between minimum load and full load should therefore be modified. If the maximum load is 100% and the minimum is 20%, as it is for the best modulating devices, the efficiency at 45 – 50% should be chosen as typical for the annual efficiency. The weighting factor therefore depends on the degree of modulation. The weighting factors are calculated based on Strasbourg bin data.

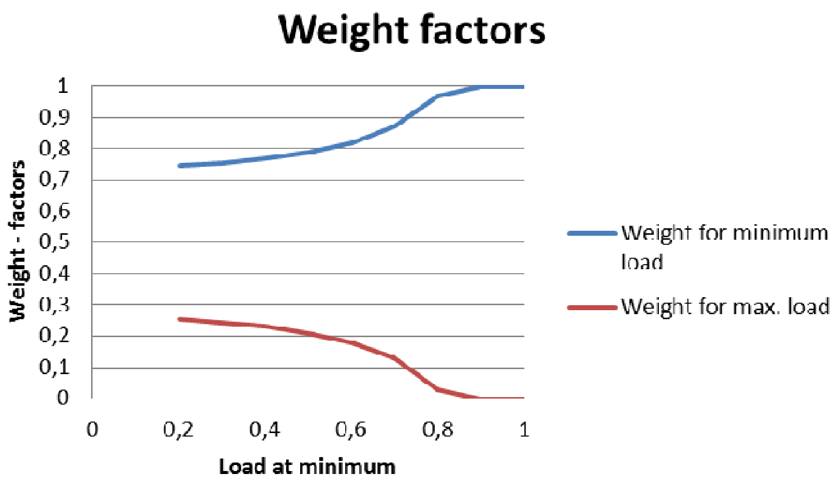


Figure 5-2 If the minimum load is 20%, the annual efficiency is calculated from 75% minimum load and 25% maximum load.

Jacket losses

In a burner, the energy found in the heated air is expressed as:

$$(5) \qquad P_{air} = P_{in} - P_{flue} - P_{jacket}$$

The energy of the air is difficult to measure accurately, as it is done in water boiler standards. Jacket losses are instead determined by measuring the surface temperatures and areas of the envelope of the furnace. Surface temperatures in EN 1319 are related to safety. Often jacket losses are considered to be useful heat in the building, but this depends on the actual circumstances, e.g. when heat is needed in the room where the appliance is installed. The standard needs a supplement to determine the areas and temperatures of the surfaces. The heat loss is then given by:

(6)

$$\alpha_{convection} = 46 \cdot \left(\frac{T_{surf} + T_{AMB}}{2} \right)^{-0.62} \cdot \left(T_{surf} - T_{AMB} \right)^{0.33}$$

$$\alpha_{radiation} = \frac{\varepsilon\sigma(T_{surf}^4 - T_{AMB}^4)}{T_{surf} - T_{AMB}}$$

$$Temperatures\ in\ K$$

$$\sigma = 5.67 \cdot 10^{-8}$$

$$\varepsilon = emissivity\ of\ the\ surface$$

In the model for calculating energy consumption, the jacket losses are assumed to be proportional to the heat load. For water boilers, the so-called indirect method is often used especially for larger boilers in situ[6].

[6] Schweitzer, J. et al. (2003) The indirect determination of boiler efficiency. A more accurate and cheaper way to assess the efficiency in laboratory and on site. DGC.

Duct losses and electricity consumption

Ducts are normally designed for an air speed in the range of 3 – 5 m/s. When the temperature increase in the furnace and the number of parallel ducts is known, the mean diameter can be estimated, see Table 5—8. When assuming an insulation thickness, the duct heat loss can also be estimated. Depending on the installation conditions, the heat loss may be more or less useful energy. In the model used in this study, 50% of the duct losses is considered to be useful energy. The electricity consumption for the total system is given by pressure drops in ducts, filters and over heat exchangers. For the burner side with for example 20 m^3/hour flue gas, the hydraulic work is only 5 – 10 W depending on the air control device and system layout (which is around 50 W in total). For the air side with 1000 m^3/h, the friction in the ducts including dampers and filters, etc., will be in the range of 200 Pa. Including the heat exchanger, in total about 150 W of auxiliary energy are consumed in residential central warm air heaters. The filters should be designed with a starting pressure preferably well below 100 Pa. Here the pressure drop is set to 100 Pa as a mean value. The filter may in some situations cause a significant increase of the electricity power consumption. Some filters can be maintained by regular vacuum cleaning and washing.

Table 5—8: Filter data from Kemna et al. (2007)[7]

Parameter	Unit	Value
Air flow rate	m^3/h	1100
Cleaning efficiency	%	80 - 90
Size	m x m	0.5 x 0.5
Fan efficiency	%	50
Pressure drop, start	Pa	20
Pressure drop, end	Pa	120
Mean	Pa	70
Hydraulic work	W	21
Electricity consumption (average)	W	43

The appliance and the fan should be well designed for the fan consumption to be below 150 W. Electricity consumption should be added to this. This includes the burner fan and the control system, solenoid valves, etc., which together could be around 50 – 100 W.

[7] Kemna, R.et al.(2007) Ecodesign of Central Heating Boilers, Task 4 final report. Prepared for the European Commission, DG Energy.

Table 5—9: Estimation of the heat loss and pressure drop in ducts and filter for a gas fired appliance

Parameter	Unit	Value
Input		
Duct length	m/kW	5
Number of duct in parallel		6
Operation time	hours	1954
Efficiency Fan	%	50
Furnace power output, P (= building demand)	kW	14
T_{flow} (at design outdoor temperature)	°C	60
Air speed in ducts (3 is max because of noise)		3
Part of ducts outdoor	%	50
Insulation thickness	mm	50
Amb for duct		20
Lmbda insul	W/mK	0.04
Alfa out	W/m^2K	6
Alfa i		12
Output		
Annual consumption	kWh	27,354
Length	m	70
Length, per duct	m	11.7
Total flow	m^3/h	1,049
Flow per duct	m^3/h	175
Diameter	m	0.144
D_{outer}	m	0.244
P_{insul}	W/m	15.96
P_{insul}	kW	1.12
Annual loss weathered system	kWh	2,183
Annual loss weathered system	%	7.4
Annual loss indoor system	kWh	1092
Annual loss indoor system	%	3.8
Pressure drop	Pa	30
Pressure drop in dampers, etc. for hydraulic balancing	Pa	30
Total pressure drop flow and return	Pa	120
Filter pressure drop, average between service	Pa	100
Hydraulic work	W	64

Parameter	Unit	Value
Fan electricity	W	128
Simplified seasonal consumption	kWh elec.	250

Start/stop losses

The unburnt fuel in the start phase was studied in the *Boilsim* projects[8]. For gas boilers, figures in the range of one second of burner operation are considered to be the maximum value for older atmospheric burners. This depends on the distance between the ignition system and the gas entrance in the combustion chamber. This figure is in the range of what is also given in the ENER Lot 1 preparatory study. For fan-assisted burners, 1 second is assumed to be a very conservative value.

The pre-purge losses are assumed to be negligible, as the heat exchanger starts at room temperature in most situations and the accumulated heat is small. The post purge losses are estimated from a boiler test using a flue gas thermometer with a low time constant to see the decay in flue gas temperature. In this study, it is assumed that the post purge losses correspond to 50% of the flue gas losses in 20 seconds after the burner stop.

Table 5—10: Calculation of start/stop loss

Parameter	Unit	Value
Heater power	kW	15
Flue gas loss	%	12
Unburnt fuel time	s	1
Post purge time	s	20
Flue loss in post, % of flue gas loss	%	50
Loss per start/stop fuel	kWh	0.0042
Loss in post purge period	kWh	0.0050
Start/stop loss per period	kWh	0.0092
Total losses with 20000 starts per year	kWh	183

The number of stop/starts is calculated from a load distribution for the climate of Strasbourg, using bins at 1 degree. The results are not very sensitive to the choice of this distribution.

[8] www.boilsim.com/

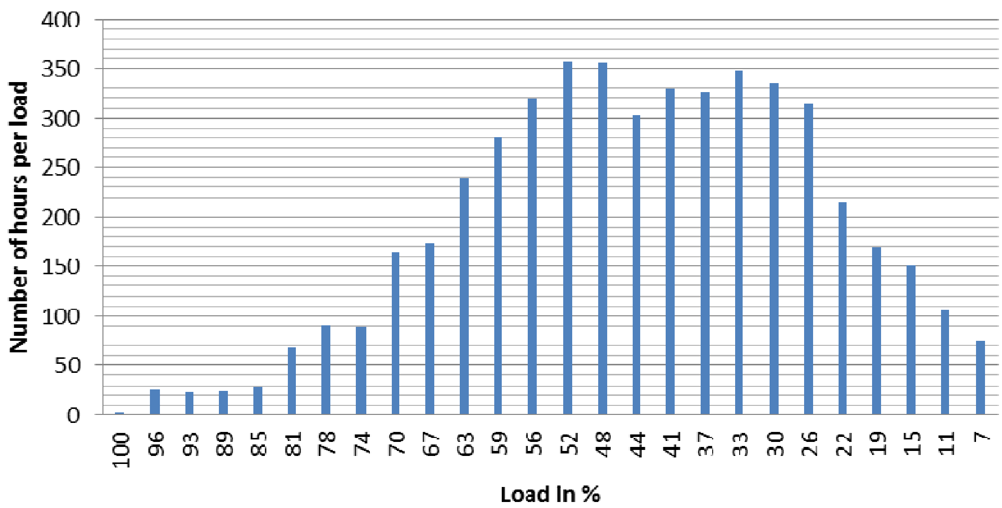


Figure 5-3: Load distribution for Strasbourg

A general model for starting frequency is introduced:

$$P(1-B)\Delta\tau = C \cdot \Delta T \quad (7)$$

Where:

P is burner power in kW

B is actual load /P

Δτ is the burner on time in seconds

C is a formal heat capacity for the building kJ/K

ΔT is a formal thermostat difference.

With Δτ = B/f, where f is the starting frequency s^{-1}*:*

$$f = B(1-B) \cdot \frac{P}{C \cdot \Delta T} \quad (8)$$

Where,

f is starting frequency in starts per seconds

The equation says that f is equal to zero, when the load is zero or max. The maximum frequency is found at half load. In the calculation, the factor P/(C x ΔT) is treated as a parameter set to 16 s^{-1} corresponding to 4 starts per hour at 50% load, giving an on-time of 7.5 minutes.

For a single stage device with 4 starts per hour at 50% load, the annual number of starts is 4000 x 4 = 16,000. For modulating devices with the lowest possible load at 40% the number of starts is 600 x 4 = 2400 starts per year. In the latter case, the maximum starting frequency is found at 20% load.

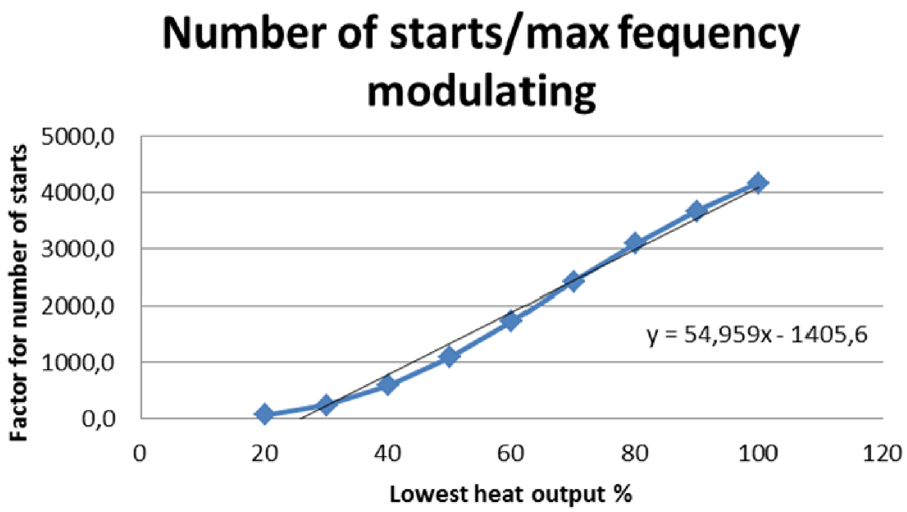


Figure 5-4: Number of starts for modulating burners

For a two stage device, the minimum number of starts is found when the minimum burner load is in the range of 60%. The lower load for two stage devices is also in the range of 60%.

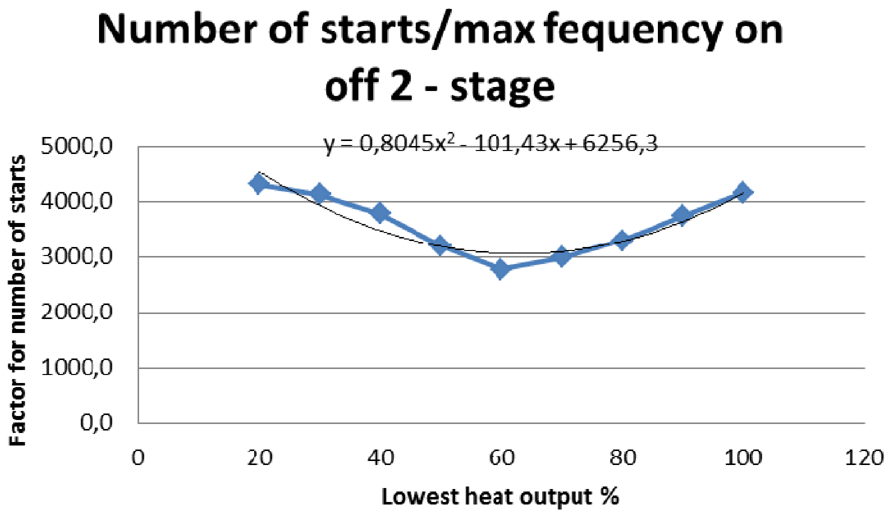


Figure 5-5: Number of starts for on-off burner

Pilot flame

The pilot flame's consumption of energy is in the range of 100 – 500 W. If the air side fan is running continuously, the pilot flame energy may be used in the system. Otherwise, it will be lost in the flue. When the burner is on, the pilot supply is a part of the main burner supply. To calculate the annual loss, the annual off time is needed. For the single stage burner this is simple. For two stage and modulation devices the bin calculations are used.

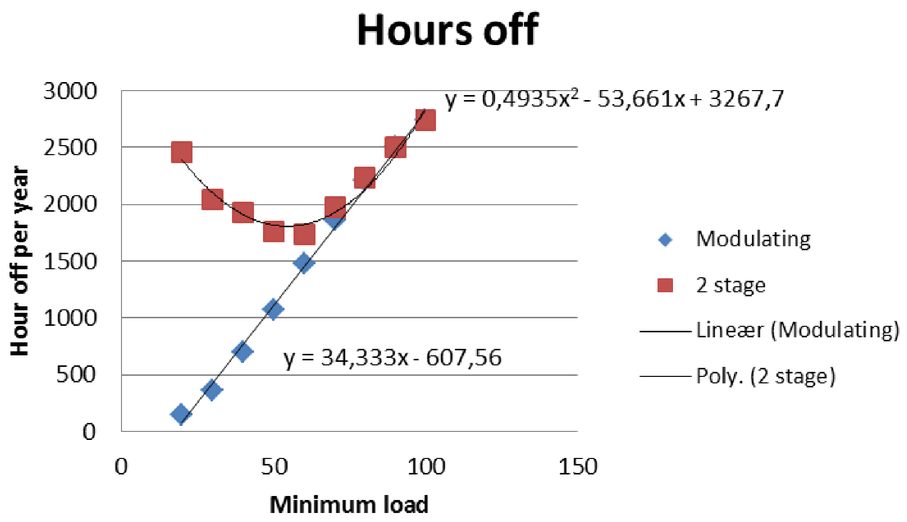


Figure 5-6: Calculation of off time

The heater is supposed to be turned off in the summer time. In the case where the appliance is in operation during the summer, 3,850 hours are added to the figures above. Again, it can be seen that the two-stage burner has the least number of off hours when the minimum load is 60%.

Summary of calculation model

The model presented here represents a simple approach taking into account the most important parameters as detailed laboratory data was not available. In order to be able to do a more accurate analysis for systems in practice, some laboratory tests would be useful. The most important parameters are:

- Efficiency after EN 1319 at full load and part load
- Electricity consumption at full load and part load (at different air flows and pressures)
- Jacket loss calculated from mean surface temperature and surface area of the cabinet
- Information on start losses. Unburnt hydrocarbons may be a growing issue, since CH_4 is a greenhouse gas
- Test data on post purge losses

As a summary, this preparatory study uses the model just presented to calculate the annual efficiency of gas and oil fired air furnaces for central heating. Some parameters had to be estimated on an annual basis. To this purpose a *bin* method was used for Strasbourg climatic data. The bin method produces figures for number of stop/starts, the burner off hours and the average situation for the flue gas losses.

Some more detailed data from laboratory tests would improve the validity of the calculations. The calculations performed nevertheless show that there is some potential for improving these systems.

5.1.4 Product specific inputs

In this section a description of the characteristics of the selected Base-Cases and the specific inputs needed for the environmental and economic analysis are presented, as well as the justification of all the assumptions made.

In order to ensure the validity of the results, a sensitivity analysis is performed for some relevant factors in section 5.7.

5.1.4.1 BC-1A: Residential warm air heater

The information used in the environmental and economic analysis of the Base-Cases for residential warm air heater is provided by stakeholders and completed with information from publicly available literature.

5.1.4.1.1 *Inputs in the production and distribution phase*

Four bills of materials of residential warm air heaters were received from stakeholders. The average composition including packaging is presented in Table 5—11. The biggest share of packaging materials is characterised by the manufacturers as "other". In this case, it is assumed to be wood, but as this choice cannot be made in the EcoReport tool, it is modelled as cardboard.

Table 5—11: Bill of Materials of BC-1A (residential warm air heater)

	Material	Share (%)	Weight (kg)
Product	Steel	72.14	59.47
	Cast iron	0.50	0.41
	Other ferrous metals	0.00	0.00
	Non-ferrous metals	11.00	9.07
	Plastics	5.94	4.90
	Coatings	1.33	1.10
	Electronics	6.65	5.48
	Other materials	2.43	2.00
	Total weight	**100%**	**82.43**
Packaging	Plastics	4.17	0.24
	Cardboard	43.33	2.49
	Paper	0.00	0.00
	Other	52.50	3.02
	Total weight	**100%**	**5.75**
Sheetmetal scrap fraction		5%	
Total volume of packaged product (m^3)		0.705	

5.1.4.1.2 *Inputs in the use phase*

The economic product life, use pattern and energy consumption of residential warm air heaters were provided by stakeholders.

The average working hours per year and the calculation of energy consumption of central heating appliances were presented in section 5.1.3.

The distance covered by maintenance services during the product's entire life is estimated to be 90 km, following information found in the ENER Lot 1 preparatory study on boilers[9]. This corresponds to an average of 6 km per year for annual maintenance checks.

Table 5—12: Inputs in the use phase of residential warm air heater

Product life (years)		15
Heating capacity (kW)		15
Equivalent heating hours per year (H_{HE})		2,170
Heat demand (kWh)		30,000
Efficiency of temperature control (η_{temp})		90%
Efficiency of the heat emission in the room (η_{em})		98%
Jacket losses (kWh | %)	400	1%
Duct losses (kWh | %)	900	2%
Heat generation efficiency, GCV (η_{gen})		76%
Influence of capacity controls in thermal efficiency ($\Delta\eta_{gen,ctr}$)		0%
Losses from pilot flame (Q_{pilot}) (kWh | %)	777	1.6%
Losses at start-up (Q_{start}) (kWh | %)	141	0.3%
Heat energy consumed per year (kWh)		47,582
Auxiliary energy consumed per year (kWh)		326
Annual efficiency in primary energy (%)		62%
No. of km by maintenance services over product-life (km)		90

5.1.4.1.3 *Inputs in the end-of-life phase*

As explained in Task 4, the percentage in weight of the product destined to landfill is estimated to be 5%, the materials recycling rate is 83% and the energy recovery rate is 12%. For its use in the EcoReport tool, the reuse, recycling and incineration rates have been recalculated for the plastic fraction. The recycling rate of the metal and miscellaneous fraction is fixed by the MEEuP at 95%.

[9] VHK (2007) ENER Lot 1 preparatory study. Final Report for DG ENER of the European Commission.

Table 5—13: Inputs in the end-of-life phase of residential warm air heater

Landfill (fraction products not recovered)	5%
Re-use, recycling	
Plastics: Re-use, Closed Loop Recycling	0%
Plastics: Materials Recycling	87%
Plastics: Thermal Recycling	13%

5.1.4.1.4 *Economic inputs*

The market data, product price and user expenditure inputs are provided by stakeholders and shown in detail in the Task 2 report.

The electricity and gas rates for industrial consumers are calculated in Task 2 using data available from Eurostat for EU-27 in 2010. Average values for the EU-27 have been taken. The discount rate is defined as the interest rate minus the inflation rate. A discount rate of 4%[10] (same for all Base-Cases) is used for the Life Cycle Cost (LCC) analysis.

Table 5—14: Economic inputs of residential warm air heater

Annual sales 2010 (million units)	0.009
EU stock 2010 (million units)	0.4
Average product purchase price (€)	1,500
Installation/acquisition costs (€)	1,200
Fuel rate (gas) (€/GJ)	14.7
Electricity rate (€/kWh)	0.175
Repair & maintenance costs (€ over life span)	3,750
Discount rate (interest minus inflation)	4.0%

[10] This is in line with the value suggested for discount rate in the Commission's revised Impact Assessment Guidelines (2009). See: http://ec.europa.eu/governance/impact/commission_guidelines/docs/iag_2009_en.pdf (page39)

5.1.4.2 *BC-1B: Non-residential warm air heater*

The information used in the environmental and economic analysis of the Base-Case for non-residential warm air heater is provided by stakeholders and completed with information from publicly available literature.

5.1.4.2.1 *Inputs in the production and distribution phase*

Four bills of materials of gas warm air heaters were received from stakeholders, but none of them was for non-residential warm air heaters. The average composition including packaging has been extrapolated following the same material shares as in residential warm air heaters and assuming a total weight of 325 kg, as presented in manufacturers' brochures of products with similar characteristics as the Base-Case. The composition of materials is presented in Table 5—11. As in the case of residential warm air heaters, no information was provided by manufacturers on the type and quantity of packaging materials. The project team assumed that the packaging is wood, but as this choice was not possible in EcoReport, it was modelled as cardboard.

Table 5—15: Bill of Materials of BC-1B (non-residential warm air heater)

	Material	Share (%)	Weight (kg)
Product	Steel	72.14	234.46
	Cast iron	0.50	1.63
	Other ferrous metals	0.00	0.00
	Non-ferrous metals	11.00	35.75
	Plastics	5.94	19.31
	Coatings	1.33	4.32
	Electronics	6.65	21.61
	Other materials	2.43	7.90
	Total weight	**100%**	**325**
Packaging	Plastics	4.17	1.92
	Cardboard	43.33	19.92
	Paper	0.00	0.00
	Other	52.50	24.16
	Total weight	**100%**	**46.00**
Sheetmetal scrap fraction		5%	
Total volume of product (m^3)		**1.82**	

5.1.4.2.2 *Inputs in the use phase*

The economic product life, use pattern and energy consumption of indirect-fired gas warm air heaters was provided by stakeholders. The average working hours per year and the calculation of energy consumption of central heating appliances were presented in section 5.1.3.

The distance covered by maintenance services during the product's entire life is estimated to be 90 km, following information found in the ENER Lot 1 preparatory study on boilers[11]. This corresponds to an average of 6 km per year for annual maintenance checks.

Table 5—16: Inputs in the use phase of non-residential warm air heater

Product life (years)	15	
Heating capacity (kW)	120	
Equivalent heating hours per year **(H_{HE})**	1,200	
Heat demand (kWh)	120,000	
Efficiency of temperature control (η_{temp})	90%	
Efficiency of the heat emission in the room (η_{em})	86%	
Jacket losses (kWh | %)	1,500	0.7%
Duct losses (kWh | %)	3,000	1.4%
Heat generation efficiency, GCV (η_{gen})	81%	
Influence of capacity controls in thermal efficiency ($\Delta\eta_{gen,ctr}$)	0	
Losses from pilot flame (Q_{pilot}) (kWh | %)	1,554	0.7%
Losses at start-up (Q_{start}) (kWh | %)	1,137	0.5 %
Heat energy consumed per year (kWh)	213,510	
Auxiliary energy consumed per year (kWh)	1,440	
Annual efficiency in primary energy (%)	55%	
No. of km by maintenance services over product-life (km)	90	

5.1.4.2.3 *Inputs in the end-of-life phase*

The same assumptions as for BC-1a were used for landfilling, reuse, recycling and incineration rates.

[11] VHK (2007) ENER Lot 1 preparatory study. Final Report for DG ENER of the European Commission.

Table 5—17: Inputs in the end-of-life phase of non-residential warm air heater

Landfill (fraction products not recovered)	5%
Re-use, recycling	
Plastics: Re-use, Closed Loop Recycling	0%
Plastics: Materials Recycling	87%
Plastics: Thermal Recycling	13%

5.1.4.2.4 *Economic inputs*

The market data, product price and user expenditure inputs are provided by stakeholders and shown in detail in the Task 2 report.

The electricity and gas rates for industrial consumers are calculated in Task 2 using data available from Eurostat for EU-27 in 2010. Average values for the EU-27 have been taken.

Table 5—18: Economic inputs of non-residential warm air heater

Annual sales 2010 (million units)	0.029
EU stock 2010 (million units)	0.45
Average product purchase price (€)	7,300
Installation/acquisition costs (€)	4,000
Fuel rate (gas) (€/GJ)	12.45
Electricity rate (€/kWh)	0.1599
Repair & maintenance costs (€ over life span)	10,125
Discount rate (interest minus inflation)	4.0%

5.1.4.3 BC-2: Single split heat pump

The information describing the Base-Case of single split heat pumps were provided by stakeholders and completed with information from other sources (including a number of studies that analyse the environmental performance of heat pumps).

5.1.4.3.1 *Inputs in the production and distribution phase*

Two bill of materials were received from stakeholders for single split heat pumps with a heating capacity around 16 kW. The average composition is presented in Table 5—19. This was taken as a basis for the single split heat pump Base-Case. The results of a sensitivity analysis will show later on that variations in the bill of materials (factor 0.5 to factor 2) do not make any major change in the results.

Table 5—19: Bill of Materials of BC-2 (single split heat pumps)

	Material	Share (%)	Weight (kg)
Product	Steel	24	32.86
	Cast iron	0	0
	Other ferrous metals	0	0
	Non-ferrous metals	4	5.83
	Plastics	36	48.31
	Coatings	0	0
	Electronics	2	2.92
	Other materials	34	45.68
	Total weight	**100%**	**135.60**
Packaging	Plastics	17.50	2.01
	Cardboard	60.50	6.96
	Paper	0.00	0.00
	Other	21.50	2.47
	Total weight	**100%**	**11.50**
Sheetmetal scrap fraction		5%	
Total volume of packaged product (m^3)		**0.77**	

5.1.4.3.2 *Inputs in the use phase*

As stated in Section 5.1.3, the working hours used for the Base-Case analysis are taken from the standard prEN 14825.

The economic product life and energy consumption of single split heat pumps in each working mode and part load conditions were provided by stakeholders.

The distance travelled by maintenance services during the product's entire life is estimated to be similar for BC-1 or 90 km. This corresponds to an average of 6 km per year for annual maintenance checks.

The inputs in the use phase of single split heat pumps are summarised in Table 5—20.

Table 5—20: Inputs in the use phase of single split heat pumps

Product life (years)		15
Heating capacity (kW)		16
Power inputs (kW)	P_{HE}: full load mode outdoor unit	4.79
	P_{HE}: full load mode indoor unit(s)	0.14
	P_{TO}: thermostat off mode outdoor+indoor	0.04
	P_{SB}: standby-mode	NA
	P_{OFF}: off-mode	0.04
	P_{CK}: crankcase heating mode	0.04
Working hours per year (hours)	H_{HE}: On-mode equivalent heating hours	1,400
	H_{TO}: Thermostat off mode	179
	H_{SB}: Standby-mode	0
	H_{OFF}: Off-mode	3,672
	H_{CK}: Crankcase heating mode	3,851
Efficiencies	COP (7°C/20°C) (EN 14511)	3.38
	COP (PhA) (-7°C/20°C)	2.39
	COP (PhB) (2°C/20°C)	2.82
	COP (PhC) (7°C/20°C)	3.38
	COP (PhD) (12°C/20°C)	3.50
	SCOP (prEN 14825)	2.40
Annual energy consumption (kWh)		8,522
No. of km by maintenance services over product life (km)		90

5.1.4.3.3 *Inputs in the end-of-life phase*

The estimate for refrigerant leakage during the use phase is included in the refrigerant emissions during the end-of-life in the EcoReport tool.

The refrigerant charge in heat pumps varies depending on the configuration of the system, as explained in Task 4. The Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee (RTOC) of the United Nations Environment Programme (UNEP) suggests a ratio of refrigerant charge of 0.3 kg of R404A per kW of heating capacity[13]. DEFRA suggested some rules of thumb for refrigeration systems in which as a rough estimation, the amount in kg of refrigerant charge is approximately equal to the motor capacity in kW of the compressor[12].

[12] Defra (2009) F-gas support information sheet GEN 5 – refrigerant quantity.

There is no clear agreement on the refrigerant leakage rates in heat pumps, and different figures can be found in literature - as pointed out by Johnson (2011)[13]:

- the figures provided by the stakeholders vary between 0% and 10% of the charge
- RTOC estimates the annual operating leak rate at 6% of rated charge
- the Technology and Assessment Panel (TEAP) of the Intergovernmental Panel on Climate Change (IPCC) proposes a leak rate of 4%-5% of the nominal charge per year[14]
- Frischknecht (1999)[15] estimates it at 8% per year
- DECC and Defra (2010)[16] give an estimate of 8.5% per year

Logbook data for Europe provided by stakeholders indicated an annual leakage rate between 1.1% to 1.8% for single split heat pumps.

The dumped refrigerant at the end-of-life of heat pumps is another controversial issue. IPCC TEAP[14] estimates that 60% of the charge rate is emitted at the end-of-life, whereas the RTOC of the UNEP estimates the end-of-life venting at 55% of the rated charge[13]. The end-of-life venting for both single split and VRF has been estimated at 15% of the rated charge. In this study, annual leakage rate and end-of-life emission, the figures provided by the stakeholders are used. Regarding the refrigerant charge, the figure provided from RTOC of the UNEP is used.

However, there is a slight difference with the figures of refrigerant charge presented in the ENTR Lot 6 preparatory study in the air conditioning part. A sensitivity analysis has been carried out to test the variability of the results depending on the different options explained in this section. The results are shown in section 5.7.2.

As explained in Task 4, the percentage in weight of the product destined to landfill is estimated in 5%, the materials recycling rate is 83% and the energy recovery rate is 12% (these data were provided by stakeholders). For its use in the EcoReport tool, the reuse, recycling and incineration rates have been recalculated for the plastic fraction. The recycling rate of the metal and miscellaneous fraction is fixed by the MEEuP at 95%.

[13] Johnson, E.P. (2011) Air-source heat pump carbon footprints : HFC impacts and comparison to other heat sources. Energy Policy, doi:10.1016/j.enpo.2010.12.009

[14] IPCC TEAP (2005) Refrigeration. Safeguarding the Ozone Layer and the Global Climate System.

[15] Frischknecht, R (1999) Umweltrelevanz natürlicher Kältemittel: Ökobilanzen von Wärmerpumpen und Kälteanlagen. Bundesamtes für Energie, Switzerland.

[16] DECC and Defra (2010) Guidelines to Defra/DECC's GHG Conversion Factors for Company Reporting.

Table 5—21: Inputs in the end-of-life phase of single split heat pumps

Refrigerant charge (kg)	4.80
Type of refrigerant	R410A
Fugitive refrigerant per year	1.44%
Dumped refrigerant at end-of-life	15%
Total fugitive and dumped refrigerant	36.6%
Landfill (fraction products not recovered)	5%
Re-use, recycling	
Plastics: Re-use, Closed Loop Recycling	0%
Plastics: Materials Recycling	87%
Plastics: Thermal Recycling	13%

5.1.4.3.4 *Economic inputs*

The market and economic data are taken from the Task 2 report of this study. The market analysis was based on the literature and information provided by the stakeholders. The electricity rates for industrial consumers have been calculated based on information available from Eurostat for EU-27 in 2010.

There is a slight difference between the energy rates used here and the ones used in the ENTR Lot 6 preparatory study on air conditioning. However, a sensitivity analysis on the energy prices is carried out as part of Task 8 of this preparatory study, in order to test the results depending on this variable.

The ENTR Lot 6 preparatory study also differs in the economic inputs of single split heat pumps regarding life cycle costs. The costs presented here much higher than in ENTR Lot 6. Purchase, installation and maintenance costs presented in Table 5—22 were provided by manufacturers.

Table 5—22: Inputs to economic analysis in EcoReport for BC-2 (single split heat pumps)

Annual sales 2010 (million units)	0.15
EU stock 2010 (million units)	1.53
Average product purchase price (€)	6,450
Installation/acquisition costs (€)	2,500
Electricity rate (€/kWh)	0.1599
Repair & maintenance costs (€ over life span)	6,000
Discount rate (interest minus inflation)	4.0%

5.1.4.4 *BC-3: VRF heat pump*

The information describing the Base-Case of VRF heat pumps was provided by stakeholders and completed with information from literature.

5.1.4.4.1 *Inputs in the production and distribution phase*

Five bills of materials were received from stakeholders for VRF heat pumps. Two of them are VRF systems around 16 kW of heating capacity, and three are for VRF systems around 30 kW, 100 kW and 400 kW of heating capacity.

The average composition of a heat pump with a cooling capacity of 55 kW is presented in Table 5—23. This has been taken as a basis for the Base-Case of VRF heat pumps.

Table 5—23: Bill of Materials of BC-3 (VRF heat pump)

	Material	Share (%)	Weight (kg)
Product	Steel	54.80%	322.35
	Cast iron	2.88%	16.96
	Other ferrous metals	1.89%	11.11
	Non ferrous metals	17.46%	102.7
	Plastics	9.93%	58.39
	Coatings	0.99%	5.81
	Electronics	4.39%	25.82
	Other materials	7.26%	42.69
	Total weight	**100%**	**588.22**
Packaging	Plastics	5.87	4.2
	Cardboard	77.76	55.6
	Paper	0.00	0
	Other	16.36	11.7
	Total weight	**100%**	**71.5**
Sheetmetal scrap fraction		5%	
Total volume of packaged product (m^3)		**4.96**	

5.1.4.4.2 *Inputs in the use phase*

The economic life and the energy consumption of VRF heat pumps in each working mode were provided by stakeholders. The use pattern and the distance covered by maintenance services are assumed to be the same as for single split heat pumps, as stated in Task 3 report. The inputs in the use phase of VRF heat pumps are summarised in Table 5—24.

Table 5—24: Inputs in the use phase of VRF heat pumps

Product life (years)		15
Heating capacity (kW)		55
Power inputs (kW)	P_{HE}: full load mode outdoor unit	13.82
	P_{HE}: full load mode indoor unit(s)	1.26
	P_{TO}: thermostat off mode outdoor+indoor	0.29
	P_{SB}: standby-mode	NA
	P_{OFF}: off-mode	0.29
	P_{CK}: crankcase heating mode	0.08
Working hours per year (hours)	H_{HE}: On-mode equivalent heating hours	1,400
	H_{TO}: Thermostat off mode	179
	H_{SB}: Standby-mode	0
	H_{OFF}: Off-mode	3,672
	H_{CK}: Crankcase heating mode	3,851
Efficiencies	COP (7°C/20°C) (EN 14511)	3.98
	COP (PhA) (-7°C/20°C)	3.04
	COP (PhB) (2°C/20°C)	3.47
	COP (PhC) (7°C/20°C)	3.98
	COP (PhD) (12°C/20°C)	4.44
	SCOP (prEN 14825)	2.93
Annual energy consumption (kWh)		20,085
No. of km by maintenance services over product life (km)		90

5.1.4.4.3 *Inputs in the end-of-life phase*

In order to model the end-of-life phase of VRF heat pumps, the same assumptions were used as for BC-2 (single split heat pumps).

The refrigerant charge was calculated as a ratio of 0.5 kg of refrigerant per kW of heating capacity. Logbook data for Europe provided by stakeholders, indicated an annual leakage rate of around 3.5% for VRF heat pumps.

The recycling practices in the end-of-life phase were taken from the stakeholders' inputs, as explained in Task 4. The same assumptions for BC-2 were used for landfill, reuse, recycling and incineration rates.

Table 5—25: Inputs in the end-of-life phase of VRF heat pumps

Refrigerant charge (kg)	22
Type of refrigerant	R410A
Fugitive refrigerant per year	3.5%
Dumped refrigerant at end-of-life	15%
Total fugitive and dumped refrigerant	68%
Landfill (fraction products not recovered)	5%
Re-use, recycling	
Plastics: Re-use, Closed Loop Recycling	0%
Plastics: Materials Recycling	97%
Plastics: Thermal Recycling	3%

5.1.4.4.4 *Economic inputs*

The market and economic data were gathered from the Task 2 report of this study. The electricity rates for industrial consumers were calculated based on information from Eurostat for EU-27 in 2010 (also explained in the Task 2 report).

As in the case of single split heat pumps, the life cycle costs of the Base-Case of VRF differs from the information used in the ENTR Lot 6 preparatory study. In this case, the deviation is much lower than in the case of single split.

The purchase, installation and maintenance costs presented in Table 5—26 were provided by manufacturers.

Table 5—26: Economic inputs VRF heat pumps

Annual sales 2010 (million units)	0.08
EU stock 2010 (million units)	0.56
Average product purchase price (€)	23,650
Installation/acquisition costs (€)	5,300
Electricity rate (€/kWh)	0.1599
Repair & maintenance costs (€ over life span)	18,000
Discount rate (interest minus inflation)	4.0%

5.2 Base-Case Environmental Impact Assessment

In the following sections the environmental impacts throughout all the life cycle stages of the Base-Cases are presented. These results were calculated using the EcoReport tool provided in the MEEuP methodology based on the inputs presented in the previous section. The MEEuP methodology tracks 17 environmental impact categories, classified in three groups:

- Resources and waste
  - Total energy (GER - gross energy requirement)
  - Electricity (in primary energy)
  - Water (process)
  - Water (cooling)
  - Waste, nor hazardous/landfill
  - Waste, hazardous/incinerated
- Emissions (air)
  - Greenhouse gases in GWP100
  - Ozone depletion, emissions
  - Acidification, emissions
  - Volatile organic compounds (VOC)
  - Persistent organic pollutants (POP)
  - Heavy metals into air
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Particulate matter (PM, dust)
- Emissions (water)
  - Heavy metals into water
  - Eutrophication
  - Persistent organic pollutants (POP)

This analysis of the environmental impacts allows the most significant environmental impacts to be determined. It will also be used as a reference when analysing the improvement potential of design options in Task 7.

5.2.1 BC-1A Residential warm air heater

The results of the environmental analysis of BC-1A are shown in Table 5—27 and in Figure 5-7. According to these, the material consumption during the production phase and the use phase are the most predominant aspects contributing to the environmental impacts from the product's entire life cycle.

Table 5—27: Life cycle impact (per unit) of BC-1A: residential warm air heater

Life Cycle phases -->		PRODUCTION			DISTRI-BUTION	USE	END-OF-LIFE			TOTAL
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	7,998	353	8,352	834	3,166,432	375	276	99	3,175,717
of which, electricity (in primary MJ)	MJ	3,591	212	3,803	2	51,304	0	16	-16	55,093
Water (process)	ltr	2,970	3	2,973	0	3,447	0	11	-11	6,410
Water (cooling)	ltr	1,208	99	1,307	0	136,723	0	89	-89	137,941
Waste, non-haz./ landfill	g	93,497	1,172	94,668	371	60,387	5,419	63	5,356	160,783
Waste, hazardous/ incinerated	g	3,623	0	3,623	7	1,218	668	10	658	5,506
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	494	20	513	51	174,473	28	8	19	175,056
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	3,333	85	3,418	153	63,405	60	18	42	67,018
Volatile Organic Compounds (VOC)	g	43	0	43	15	2,291	2	0	2	2,351
Persistent Organic Pollutants (POP)	ng i-Teq	797	5	802	2	344	37	0	37	1,185
Heavy Metals	mgNi eq.	592	11	604	19	932	107	0	107	1,662
PAHs	mgNi eq.	1,210	0	1,210	34	247	0	1	-1	1,490
Particulate Matter (PM, dust)	g	363	13	376	2,410	1,951	584	2	582	5,319
Emissions (Water)										
Heavy Metals	mg Hg/20	2,239	0	2,239	1	353	29	0	29	2,621
Eutrophication	g PO4	40	0	40	0	2	2	0	1	43
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

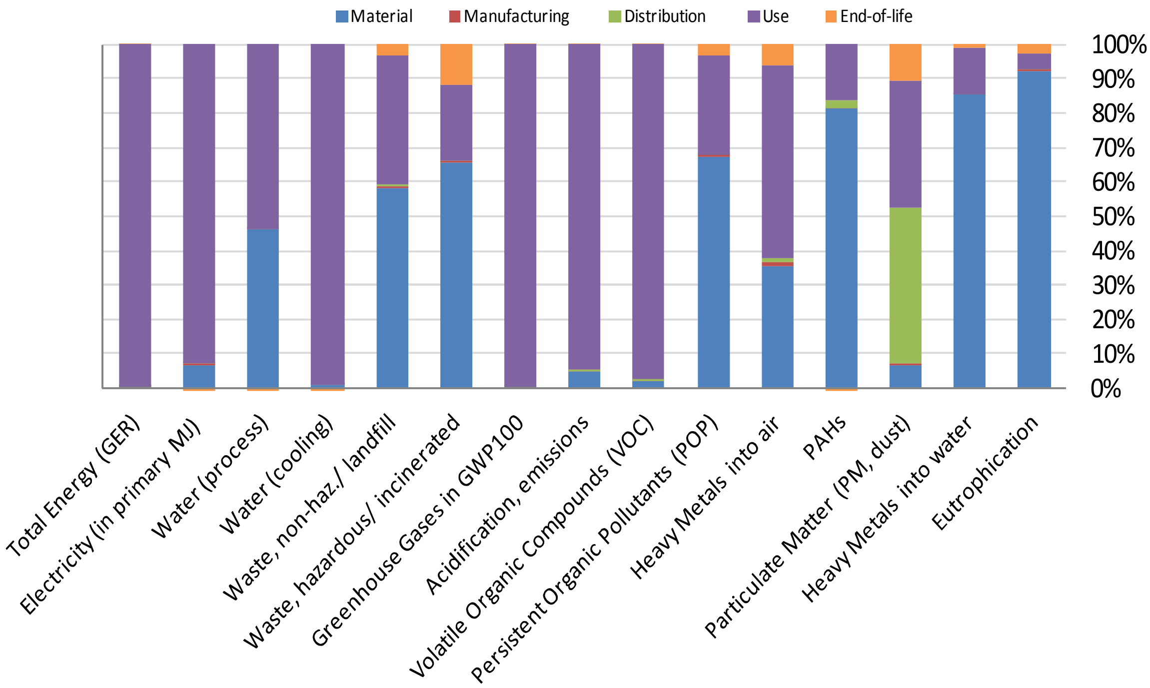


Figure 5-7: Distribution of the BC-1A's environmental impacts by life cycle phase

- Raw material extraction contributes with more than 50% of the overall environmental impacts for 6 out of 17 environmental impact categories:
  - Waste non hazardous 59%
  - Waste hazardous 66%
  - Persistent Organic pollutants 68%
  - PAH 81%
  - Heavy metals into water 85%
  - Eutrophication 92%

This is mainly due to the electronic components and the steel used in the product.

- The use phase contributes with more than 50% of the overall environmental impacts for 8 out of 17 environmental impact categories:
  - Total Energy (GER) ~100%
  - Electricity 93%
  - Water (process) 54%
  - Water (cooling) 99%
  - Greenhouse Gases in GWP100 100%
  - Acidification, emissions 95%
  - Volatile Organic Compounds (VOC) 97%
  - Heavy metals into air 56%

This is mainly because of the energy consumption in operation mode. The maintenance practices and other consumables are negligible.

- 45% of particulate matter emissions occur during distribution. However, it is necessary to point out that the assumptions in the distribution phase included in the MEEuP methodology assume an average transport in the EU combining truck, train, sea freight and air freight. This might not be the case for all the products represented by this Base-Case, but represent the average transport in the EU.
- The values for ozone depletion and persistent organic pollutants emitted to water are negligible.
- The manufacturing phase has very little contribution to the overall environmental impacts.
- The end-of-life phase contributes somewhat to hazardous and incinerated waste (12%), due to the disposal in landfill and recovery and recycling of plastic components. The end-of-life phase contributes also to particulate matter (11%).

5.2.2 BC-1B: Non-residential warm air heater

The results of the environmental analysis of BC-1B are shown in Table 5—27 and in Figure 5-8. According to these, the material consumption during the production phase and the use phase are the most predominant aspects contributing to the environmental impacts from the product's entire life cycle.

Table 5—28: Life cycle impact (per unit) of BC-1B: non-residential warm air heater

Life Cycle phases -->		PRODUCTION			DISTRI-BUTION	USE	END-OF-LIFE			TOTAL
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	32,234	1,433	33,667	834	14,204,303	1,573	1,185	388	14,239,193
of which, electricity (in primary MJ)	MJ	14,215	859	15,074	2	226,951	0	67	-67	241,960
Water (process)	ltr	11,870	13	11,883	0	15,239	0	44	-44	27,078
Water (cooling)	ltr	4,806	401	5,207	0	604,852	0	369	-369	609,690
Waste, non-haz./ landfill	g	369,846	4,745	374,591	371	266,708	22,800	260	22,540	664,210
Waste, hazardous/ incinerated	g	14,287	0	14,287	7	5,369	2,761	41	2,720	22,383
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	1,964	80	2,044	51	782,688	117	38	79	784,861
Ozone Depletion, emissions	mg R-11 eq.	Negligible								
Acidification, emissions	g SO_2 eq.	13,169	344	13,513	153	283,600	250	77	173	297,439
Volatile Organic Compounds (VOC)	g	171	0	171	15	10,267	8	1	8	10,461
Persistent Organic Pollutants (POP)	ng i-Teq	3,142	19	3,162	2	1,518	157	0	157	4,839
Heavy Metals	mgNi eq.	2,336	45	2,381	19	3,962	447	0	447	6,809
PAHs	mgNi eq.	4,772	0	4,773	34	933	0	4	-4	5,735
Particulate Matter (PM, dust)	g	1,431	53	1,484	2,410	5,968	2,444	7	2,436	12,298
Emissions (Water)										
Heavy Metals	mg Hg/20	8,827	0	8,827	1	1,551	121	0	121	10,500
Eutrophication	g PO_4	160	1	160	0	9	7	2	5	174
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

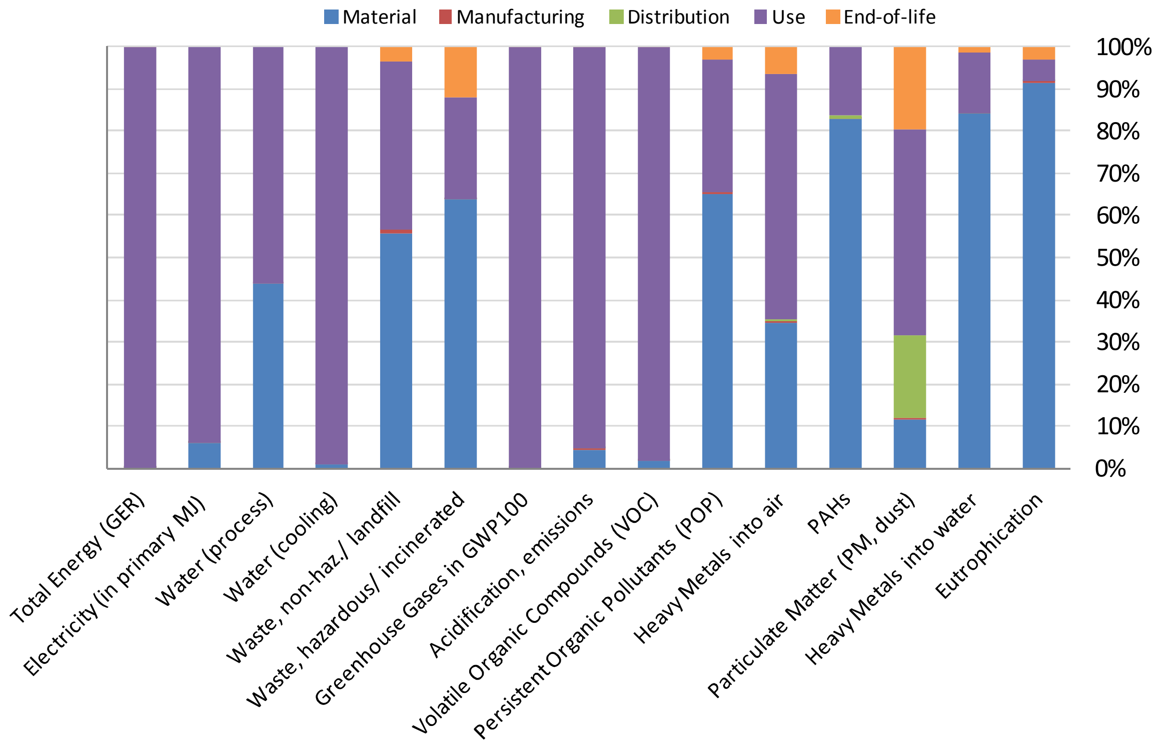


Figure 5-8: Distribution of the BC-1B's environmental impacts by life cycle phase

- Raw material extraction contributes with more than or close to 50% of the overall environmental impacts for 7 out of 17 environmental impact categories:
  - Water, process 44%
  - Waste, non hazardous/landfill 56%
  - Waste, hazardous/ incinerated 64%
  - Persistent Organic Pollutants (POP) 65%
  - PAHs 83%
  - Heavy metals into water 84%
  - Eutrophication 92%

This is mainly due to the electronic components and the steel used in the product.

- The use phase contributes with more than 50% of the overall environmental impacts for 6 out of 17 environmental impact categories:
  - Total Energy (GER) ~100%
  - Electricity 94%
  - Water (cooling) 99%
  - Greenhouse Gases in GWP100 ~100%
  - Acidification, emissions 95%
  - Volatile Organic Compounds (VOC) 98%

This is mainly because of the energy consumption in operation mode. The maintenance practices and other consumables are negligible.

- The distribution phase has only a small contribution to the overall environmental impacts. However, 20% of the particulate matter emissions over the whole life cycle are from the distribution phase. The values for ozone depletion and persistent organic pollutants emitted to water are negligible.
- The manufacturing phase has very little contribution to the overall environmental impacts.
- The end-of-life phase contributes significantly to hazardous or incinerated waste (12%) and particulate matter (20%).

BC-2: Single split heat pump

The results of the environmental analysis of BC-2 (single split heat pumps) are shown in Table 5—27 and in Figure 5-9. According to these, the use phase is the most predominant aspect contributing to the overall environmental impacts from the product's life cycle.

Table 5—29: Life cycle impact (per unit) of BC-2: single split heat pump

Life Cycle phases -->		PRODUCTION			DISTRI-BUTION	USE	END-OF-LIFE			TOTAL
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	8,576	2,115	10,691	907	1,342,478	1,213	2,507	-1,294	1,352,782
of which, electricity (in primary MJ)	MJ	2,820	1,273	4,093	2	1,342,195	1	156	-156	1,346,135
Water (process)	ltr	2,216	19	2,235	0	89,499	0	103	-103	91,631
Water (cooling)	ltr	2,307	600	2,907	0	3,579,108	0	862	-862	3,581,152
Waste, non-haz./ landfill	g	56,598	6,669	63,267	401	1,556,785	9,103	606	8,497	1,628,949
Waste, hazardous/ incinerated	g	2,134	0	2,134	8	30,949	6,442	95	6,346	39,437
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO_2 eq.	398	117	516	55	58,593	3,599	69	3,530	62,693
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO_2 eq.	2,215	506	2,721	166	345,649	224	154	69	348,605
Volatile Organic Compounds (VOC)	g	25	0	25	16	509	9	1	8	558
Persistent Organic Pollutants (POP)	ng i-Teq	446	3	449	2	8,802	63	0	63	9,315
Heavy Metals	mgNi eq.	329	7	336	20	23,076	325	0	325	23,758
PAHs	mgNi eq.	762	1	763	36	2,698	0	8	-8	3,489
Particulate Matter (PM, dust)	g	237	78	316	2,632	8,179	2,503	17	2,486	13,612
Emissions (Water)										
Heavy Metals	mg Hg/20	1,229	0	1,229	1	8,666	78	0	78	9,974
Eutrophication	g PO_4	24	1	25	0	42	4	4	1	67
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

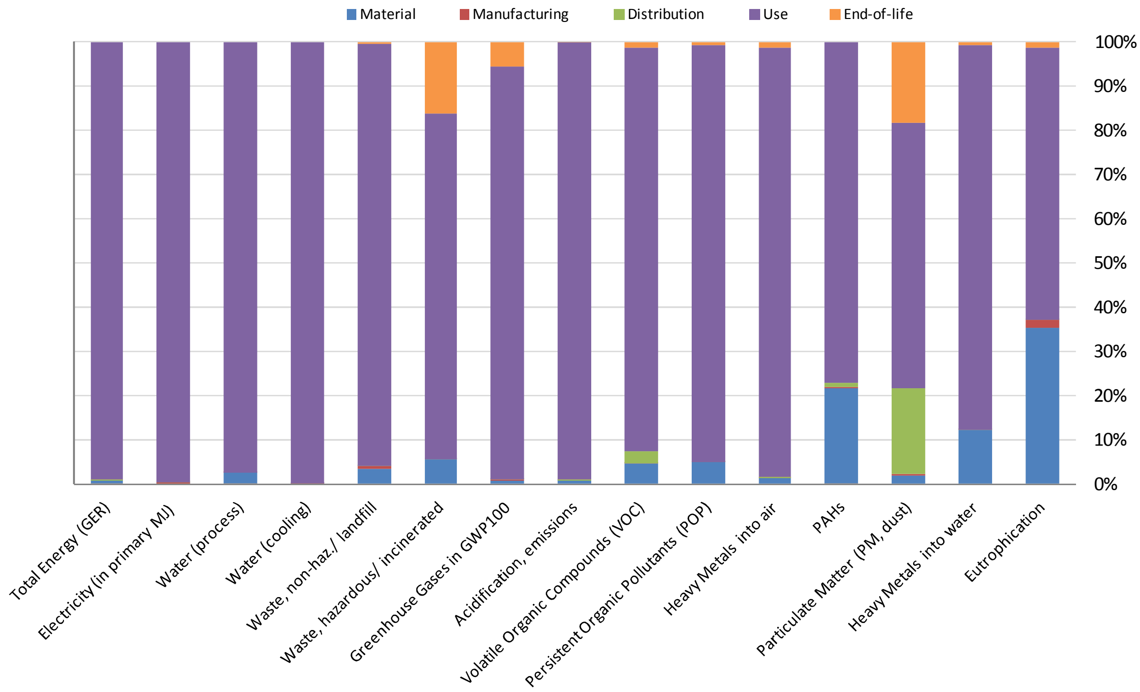


Figure 5-9: Distribution of the BC-2's environmental impacts by life cycle phase

- The use phase is clearly the dominant phase in 15 out of the 17 potential environmental impact categories calculated in EcoReport.

Total Energy (GER)	99%
Electricity	~100%
Water (process)	97.7%
Water (cooling)	~100%
Waste, non-haz/landfill	95.6%
Waste, hazardous/incinerated	78.5%
Greenhouse Gases in GWP100	93.5%
Acidification, emissions	99%
Volatile Organic Compounds (VOC)	91%
Persistent Organic Pollutants (POP)	94.5%
Heavy metals to air	97%
PAH	77%
Particulate Matter	60%
Heavy metals into water	87%
Eutrophication	62%

- The materials contribute to 22% of all the PAHs impacts as well as 35% of overall eutrophication impacts and 12% of overall heavy metals emissions to water. This is mainly due to the production of the electronic components and the steel in the product.
- The end-of-life phase contributes mostly to greenhouse gas emissions (5.7%), but also to particulate matter (18.4%). This is due to refrigerant emissions and the recovery and recycling of plastic components.
- The manufacturing phase has very little contribution to environmental impacts. The highest contribution is to eutrophication due to the plastics and metals included, but this 2%.
- The values for ozone depletion and persistent organic pollutants emitted to water are negligible.

In addition to the environmental analysis performed with the EcoReport, the Total Equivalent Warming Impact (TEWI) of the Base-Case is shown in Figure 5-10. The figure differentiates between the global warming potential caused by the electricity consumed (GWP indirect) and the emissions of the refrigerant used (GWP direct). The results show that the GWP of the refrigerant is around 5% of the Total Equivalent Warming Impact.
A sensitivity analysis on various parameters that influence this TEWI analysis has been carried out in section 5.7.2.

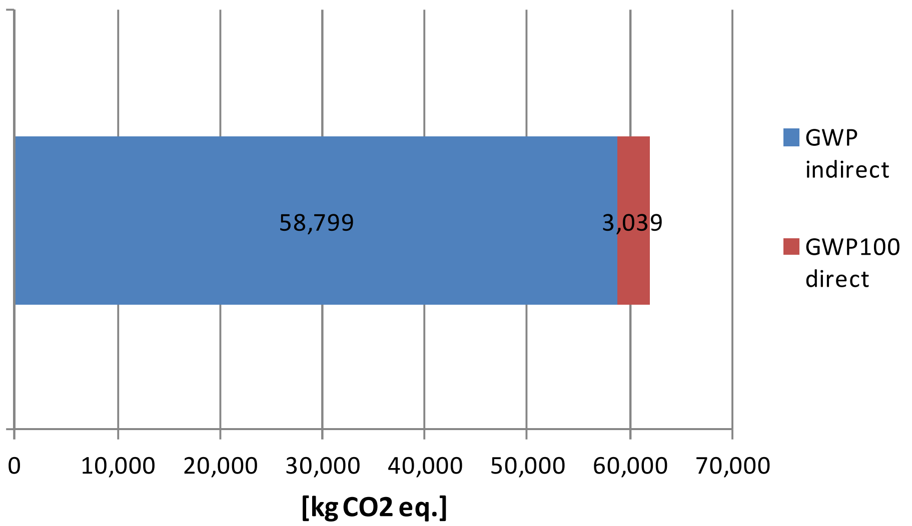


Figure 5-10: Total Equivalent Warming Impact at 100 years of BC-2: single split heat pump

5.2.3 BC-3: VRF heat pump

The results of the environmental analysis of BC-3 (VRF heat pump) are shown in Table 5—30 and in Figure 5-11. According to these, the use phase contributes to most of the overall environmental impacts from the product's life cycle.

Table 5—30: Life cycle impact (per unit) of BC-3: VRF heat pump

Life Cycle phases -->		PRODUCTION			DISTRI-BUTION	USE	END-OF-LIFE			TOTAL
		Material	Manuf.	Total			Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	55,395	4,704	60,098	2,984	3,164,213	2,762	3,542	-781	3,226,514
of which, electricity (in primary MJ)	MJ	18,027	2,819	20,845	7	3,163,604	1	248	-247	3,184,209
Water (process)	ltr	15,468	42	15,510	0	211,048	0	164	-164	226,394
Water (cooling)	ltr	9,201	1,316	10,518	0	8,435,825	0	1,366	-1,366	8,444,977
Waste, non-haz./ landfill	g	728,113	15,550	743,663	1,249	3,675,214	39,247	961	38,286	4,458,412
Waste, hazardous/ incinerated	g	17,261	0	17,261	25	73,067	2,117	151	1,965	92,318
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	3,236	262	3,498	177	138,101	29,874	78	29,796	171,571
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	21,092	1,129	22,222	540	814,813	476	205	272	837,846
Volatile Organic Compounds (VOC)	g	218	1	218	55	1,197	18	1	18	1,488
Persistent Organic Pollutants (POP)	ng i-Teq	4,739	61	4,800	7	20,783	270	0	270	25,860
Heavy Metals	mg Ni eq.	4,803	144	4,947	63	54,368	774	0	774	60,152
PAHs	mg Ni eq.	12,069	1	12,070	119	6,399	0	13	-13	18,575
Particulate Matter (PM, dust)	g	3,120	174	3,294	9,024	18,225	5,082	26	5,056	35,599
Emissions (Water)										
Heavy Metals	mg Hg/20	13,690	0	13,690	2	20,534	193	0	193	34,419
Eutrophication	g PO4	231	2	233	0	100	11	6	5	338
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

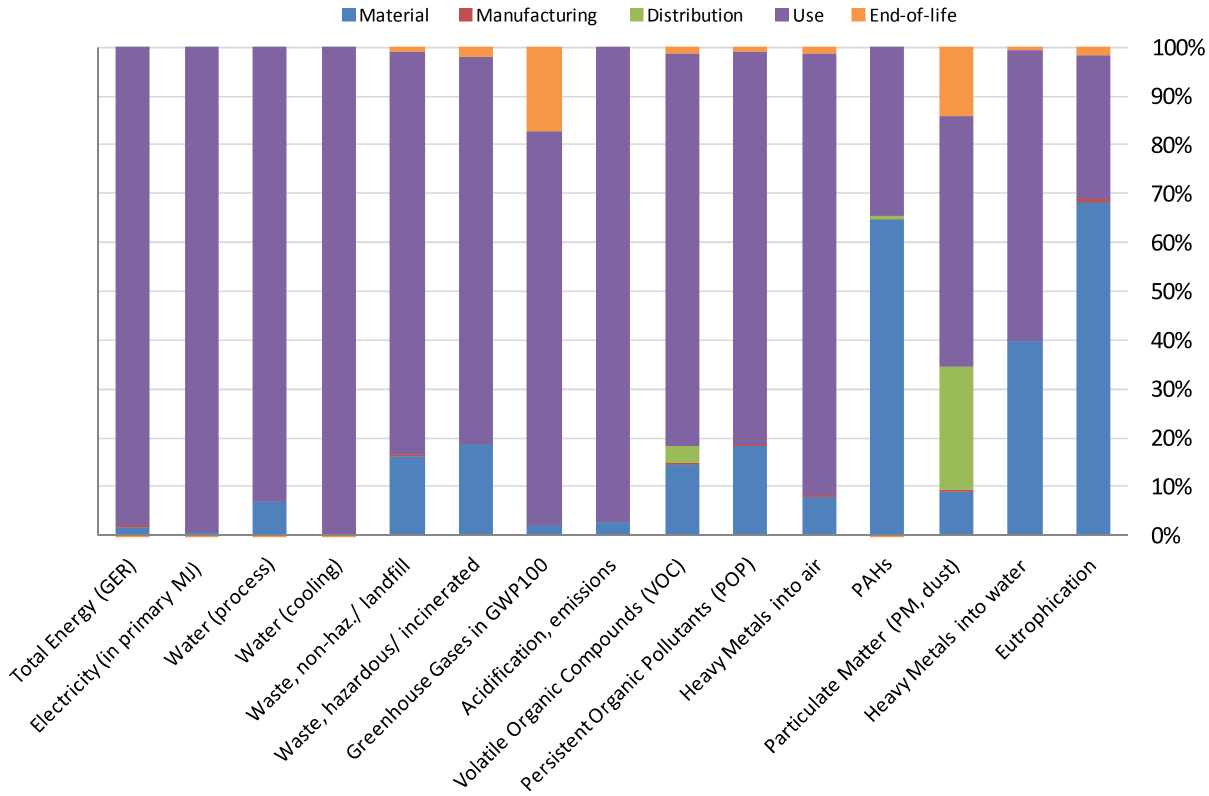


Figure 5-11: Distribution of the BC-3's environmental impacts by life cycle phase

- The most impacting phase is the use phase. It is the major contributor in 14 out of 17 environmental impact categories. This is mainly because of the high energy consumption in operation mode. Maintenance and other consumables are negligible.
  - Total Energy (GER) 98%
  - Electricity ~100%
  - Water (process) 93%
  - Water (cooling) ~100%
  - Waste, non-haz/landfill 82%
  - Waste, hazardous/incinerated 79%
  - Greenhouse Gases in GWP100 80%
  - Acidification, emissions 97%
  - Volatile Organic Compounds (VOC) 80.5%
  - Persistent Organic Pollutants (POP) 80%
  - Heavy metals to air 90%
  - PAH 35%
  - Particulate Matters (PM, dust) 51%
  - Heavy metals into water 75%

The material acquisition phase and the end-of-life phase also contribute to the appliance's environmental impacts.

- Raw material extraction contributes with more than 20% of the overall impacts for 3 out of 17 environmental impact categories:
  - PAHs 65%
  - Heavy Metals into water 40%
  - Eutrophication 68%
- The end-of-life contributes for 2 out of 17 environmental impact categories:
  - Particulate Matter (PM, dust) 14%
  - Greenhouse Gases in GWP100 17%
- The distribution phase contributes with 25% of the overall impacts of "particulate matter". Its second highest contribution is to Volatile Organic Compounds emissions, but it is a bit less than 4% .
- The manufacturing phase has very little contribution to environmental impacts. The highest contribution is to eutrophication due to the plastics and metals included, but this is less than 1%.

In addition to the calculations from the EcoReport tool, the Total Equivalent Warming Impact (TEWI) caused by the refrigerant (GWP direct) and by the electricity consumed (GWP indirect) was calculated for BC-3. The results, as can be seen in Figure 5-12, show that the GWP caused by the refrigerant is around 16% of the Total Equivalent Warming Impact.

A sensitivity analysis on various parameters that influence this TEWI analysis has been carried out in section 5.7.2.

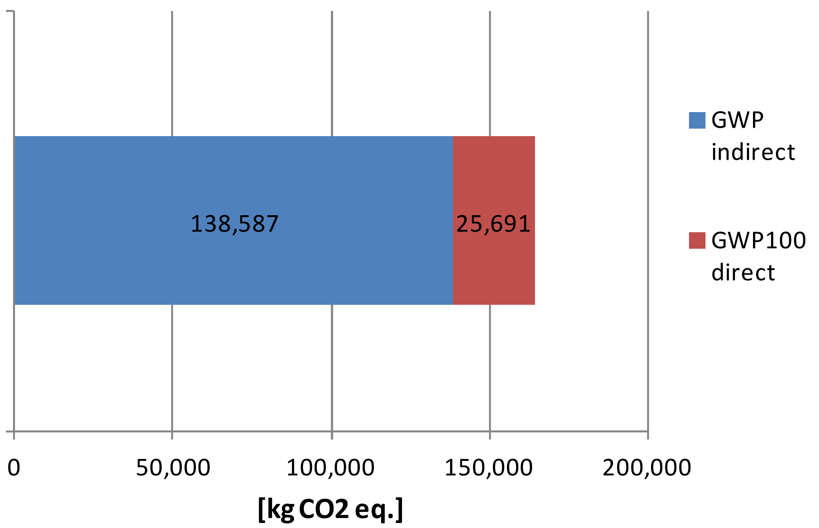


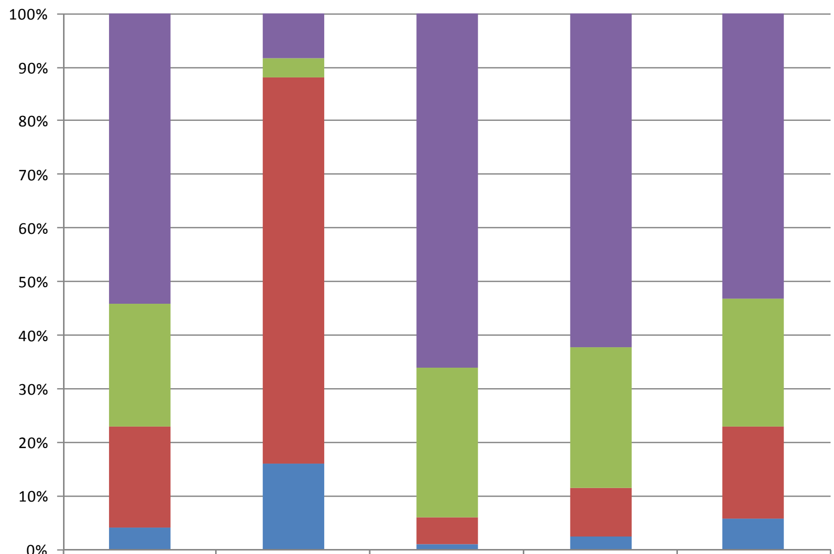
Figure 5-12: Total Equivalent Warming Impact at 100 years of BC-3: VRF heat pump

5.3 Other environmental impacts

Apart from the environmental impacts associated with energy consumption during the use phase and the materials consumption in the production phase, air-based central heating products can have other significant environmental impacts, such as emissions to air and noise emissions during the use phase.

The emissions to air are already included in the EcoReport analysis, and are divided in five categories: acidification emissions, volatile organic compounds, persistent organic pollutants, polycyclic aromatic hydrocarbons and particulate matter. Nitrogen oxides and carbon monoxide are not accounted for within the MEEuP methodology.

The emissions to air per year during the use phase of air-based central heating products are shown in Figure 5-13. Warm air heaters are especially important for VOC emissions, whereas the rest of the air emissions are mainly caused by heat pumps. However, these emissions are calculated from a life cycle perspective, so they include the emissions of energy production and transport, as well as other processes needed during the use phase of the products (e.g. maintenance practices). This life cycle approach helps the assessment of the environmental impacts of the products from a general point of view, but does not provide much detailed information on the specific impacts of emissions during the use phase. On the other hand, there is a lack of standardised data on emissions to air during the use of air-based central heating products. Without this, a deeper analysis of impacts is therefore not possible.



	g SO2 eq. Acidification, emissions	g Volatile Organic Compounds (VOC)	ng i-Teq Persistent Organic Pollutants (POP)	mg Ni eq. PAHs	g Particulate Matter (PM, dust)
BC-3: VRF heat pump	54,321	80	1,386	427	1,215
BC-2: Single split heat pump	23,043	34	587	180	545
BC-1B: Non-residential warm air heater	18,907	684	101	62	398
BC-1A: Residential warm air heater	4,227	153	23	16	130

Figure 5-13: Emissions to air of air-based central heating products during the use phase (per unit per year)

Regarding noise emissions, heat pumps manufacturers provide this kind of information in their commercial brochures and data sheets, as this is one of the important parameters for customers. The determination method of the noise levels is standardised for air conditioning heat pumps, as seen in Task 1. However, this is usually related to comfort rather than environmental impacts. As explained in Task 4, there is no relation between energy efficiency and noise emissions of heat pumps. The differences in noise levels between different products are only of a few dB. Furthermore, two different sources of noise can be differentiated in heat pumps: the outdoor unit(s) and the indoor unit(s). For single split heat pumps, both the outdoor and the indoor units noise levels are usually between 60 dB and 90 dB. For multi split and VRF heat pumps, the outdoor unit noise levels are between 60 dB and 90 dB, and the indoor units are usually quieter, with ranges between 60 and 85 dB. In all cases, the noise level is directly related to the heating capacity.

Figure 5-14 and Figure 5-15 below present the noise emissions for the outdoor and indoor units of VRF heat pumps placed in the EU market. The noise emissions data were collected from available brochures of major manufacturers. A relation between the heating capacity of the outdoor unit and sound emissions is evident, ranging between 65 dB and 85 dB for smallest and biggest units, respectively. On the other hand, looking at the indoor units, the noise emissions are not influenced by their capacity. The levels achieved are similar for most units, having a difference only of few dB across units of the same capacity. However, most units have more than one modes of operation hence, having a variation of noise emissions (minimum and maximum).

Figure 5-14: VRF outdoor units - Sound power levels as a function of heating capacity

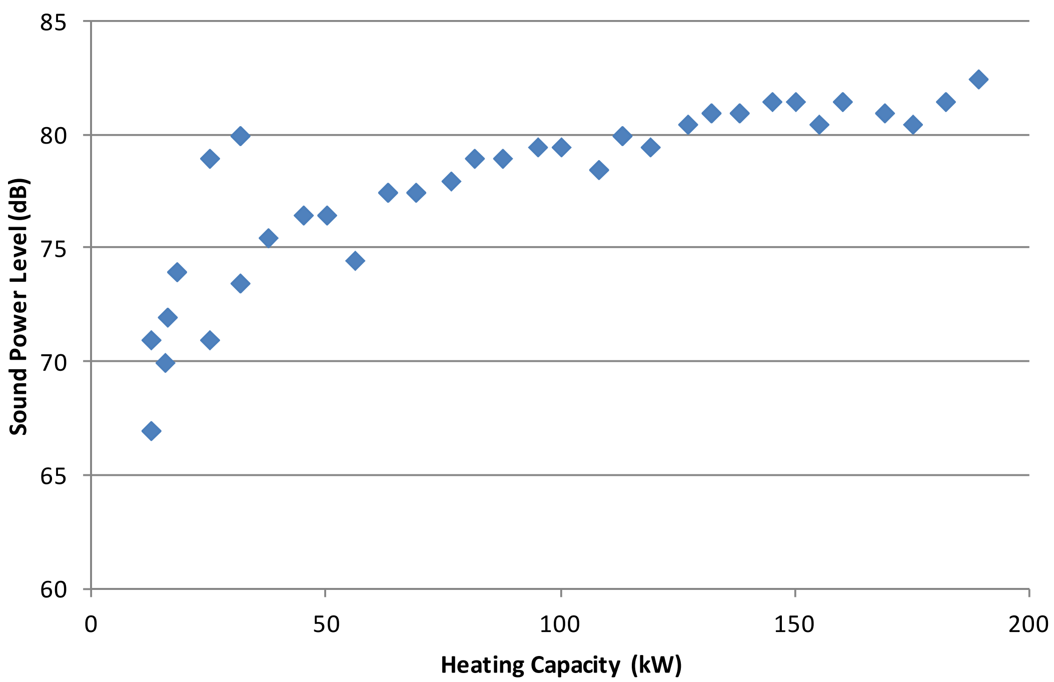
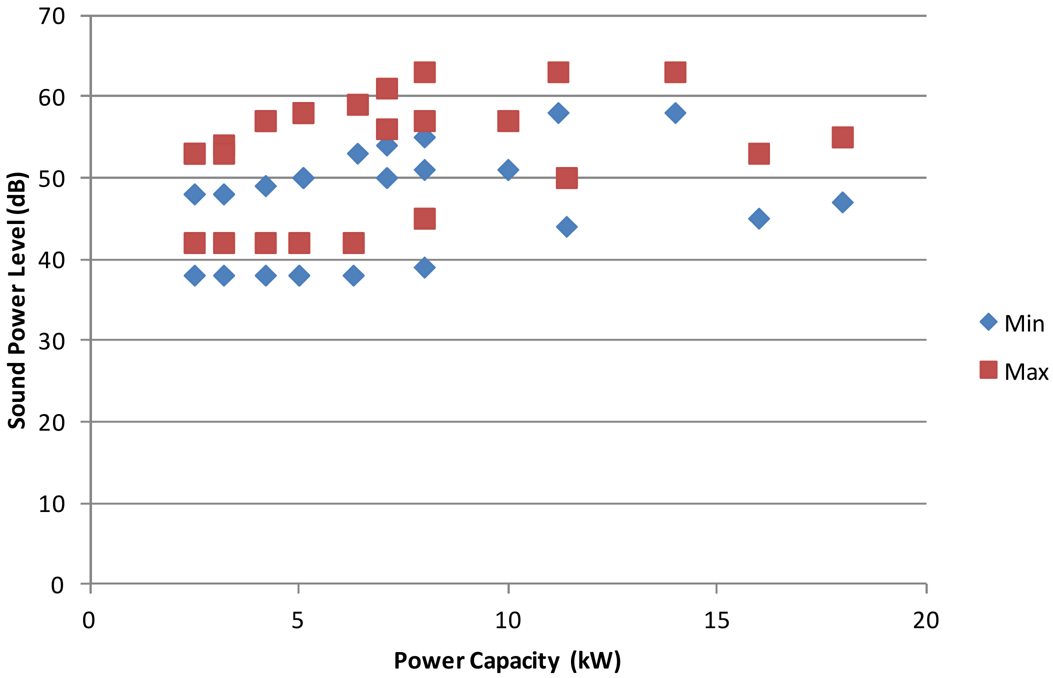


Figure 5-15: Sound power levels as a function of capacity of indoor units used in VRF systems



On the contrary, there is a lack of standardised methods for data provision of noise generation of warm air heaters. Some of the manufacturers include this information in their commercial brochures, but it does not seem to be general practice. The sound levels claimed by the manufacturers for the warm air heaters studied in this project are between 42 dB and 67 dB, and are directly related to the heating capacity of the heater. DIN EN 3744 can be used to assess the noise emissions for warm air heaters as this standard concerns the sound power level measurement for various machinery and equipment.

5.4 Base-Case Life Cycle Costs

This section presents the results of the Life Cycle Cost (LCC) analysis of the Base-Cases using the EcoReport tool. In this analysis, all the consumer expenditures throughout the life span of the product are accounted for (as shown in section 5.1.4), from the purchase and installation of the product to the maintenance needed and the running costs. In the following Tasks, this analysis will serve to compare the total expenditure of the different design options identified for each Base-Case.

The life cycle costs are calculated as follows:

$$LCC = PP + PWF * OE$$

Where PP is the purchase and installation price, OE is the operating expense and PWF is the present worth factor, calculated as follows:

$$PWF = \frac{1 - \frac{1}{(1+r)^N}}{r}$$

Where N is the product life in years and r is the discount rate specified in section 5.1.4.

5.4.1 BC-1A: Residential warm air heater

The results of the Life Cycle Cost analysis for BC-1A are presented in Table 5—31. The highest costs are gas costs during use phase (around 89%). Purchase cost and installation costs account for 1% each and maintenance costs means 8% of the total LCC. Electricity costs are 2% of the total consumer expenditure.

Table 5—31: Life Cycle Costs per product BC-1A

	LCC new product	
	Costs [€]	Share [%]
Product price	1,500	1%
Installation/ acquisition costs (if any)	1,200	1%
Fuel (gas, oil, wood)	31,623	89%
Electricity	633	2%
Repair & maintenance costs	2,780	8%
Total	**37,736**	100%

5.4.2 BC-1B: Non-residential warm air heater

The results of the Life Cycle Cost analysis for BC-1B are presented in Table 5—31. The highest costs are the gas costs (around 87%). The purchase costs and repair and maintenance costs account for 4% and 5% respectively of the total LCC, whereas installation costs and electricity signify around 2% each of the total costs throughout the life cycle.

Table 5—32: Life Cycle Costs per product BC-1B

	LCC new product	
	Costs [€]	Share [%]
Product price	7,300	4%
Installation/ acquisition costs (if any)	4,000	2%
Fuel (gas, oil, wood)	120,179	87%
Electricity	2,560	2%
Repair & maintenance costs	7,505	5%
Total	**141,544**	100%

5.4.3 BC-2: Single split heat pump

The results of the Life Cycle Cost analysis for BC-2 are presented in Table 5—33. The highest contributor to the total expenditure during the product life span is in this case the electricity (53%). The purchase cost means around 23% and maintenance costs account for 16%, whereas installation costs are 9% of the total LCC.

Table 5—33: Life Cycle Costs per product BC-2

	LCC new product (€)	
	Costs [€]	Share [%]
Product price	6,450	23%
Installation/ acquisition costs (if any)	2,500	9%
Electricity	15,150	53%
Repair & maintenance costs	4,447	16%
Total	**28,547**	**100%**

5.4.4 BC-3: VRF heat pump

The results of the Life Cycle Cost analysis for BC-3 are presented in Table 5—34. The electricity is the highest contributor to the total expenditure during the product life span (46%). The product price and installation costs, account together for 30% of the LCC. On the other hand, repair and maintenance costs are 17% of the total expenditure.

Table 5—34: Life Cycle Costs per product BC3

	LCC new product (€)	
	Costs [€]	Share [%]
Product price	23,650	30%
Installation/ acquisition costs (if any)	5,300	7%
Electricity	35,342	46%
Repair & maintenance costs	13,342	17%
Total	**78,000**	**100%**

5.5 EU totals

In this section, the environmental impact data and the Life Cycle Cost data are aggregated at the EU-27 level using stock and market data from Task 2. It is assumed that the entire installed stock in the EU-27 in 2010 is represented by the Base-Cases.

5.5.1 Life Cycle Environmental Impacts at EU-27 level

The aggregated results of the environmental impact per year of the EU stock of products are presented in Table 5—35. The total primary energy consumption per year of the stock of each of the four Base-Cases in 2010 in the EU-27 is between 85 and 427 PJ, and the greenhouse gas emissions per year are between 5 and 24 million t CO_2 eq.

Table 5—35: EU-27 total impact per year of the stock (2010) of the Base-Cases

		BC-1A: Residential warm air heater	BC-1B: Non-residential warm air heater	BC-2: Single split heat pump	BC-3: VRF heat pump	Total
Resources & Waste						
Total Energy (GER)	PJ	85	427	138	120	770
of which, electricity (in primary PJ)	PJ	1	7	137	119	265
Water (process)	mln. m3	0	1	9	8	19
Waste, non-haz./ landfill	kt	4	20	166	166	357
Waste, hazardous/ incinerated	kt	0	1	4	3	8
Emissions (Air)						
Greenhouse Gases in GWP100	mt CO2 eq.	5	24	6	6	41
Ozone Depletion, emissions	t R-11 eq.	negligible	negligible	Negligible	Negligible	Negligible
Acidification, emissions	kt SO2 eq.	2	9	36	31	78
Volatile Organic Compounds (VOC)	kt	0	0			0
Persistent Organic Pollutants (POP)	g i-Teq	0	0	1	1	2
Heavy Metals	ton Ni eq.	0	0	0	2	5
PAHs	ton Ni eq.	0	0	0	1	1
Particulate Matter (PM, dust)	kt	0	0	1	1	3
Emissions (Water)						
Heavy Metals	ton Hg/20	0	0	1	1	3
Eutrophication	kt PO4	0	0			
Persistent Organic Pollutants (POP)	g i-Teq	negligible	negligible	negligible	negligible	negligible

All selected BCs contribute significantly to energy consumption at the EU-27 level. Non-residential warm air heaters present higher energy consumption than residential warm air heaters and heat pumps, but the stock of heat pumps in the EU-27 presents a higher contribution to other environmental impacts such as waste production and acidification. A comparison between some environmental impacts of different central heating systems is presented in section 5.6.

The overall primary energy consumption of the total stock of all Base-Cases is around 770 PJ/year, and the GHG emissions are around 41 million tonnes of CO_2 eq.

5.5.2 Life Cycle Costs at EU-27 level

The aggregated results of the annual consumer expenditure per Base-Case in the EU-27 based on the year 2010 are presented in Table 5—36. This represents the total expenditure at EU level per year, assuming that the Base-Cases represent the entire installed stock in the EU-27.

For indirect-fired gas warm air heaters, the highest expenditure per year is the energy consumption during use (42%). The installation, repair and maintenance costs account together for 50% of the total costs. For both single split and VRF heat pumps, electricity represents the major part of the total expenditure at EU level.

Table 5—36: EU-27 total annual consumer expenditure (2010)

	Total annual consumer expenditure in EU-27 (million €)			
	BC-1A: Residential warm air heater	BC-1B: Non-residential warm air heater	BC-2: Single split heat pump	BC-3: VRF heat pump
Product price	14	212	979	1,873
Installation/ acquisition costs (if any)	11	116	380	420
Fuel (gas, oil, wood)	1,138	4,864	0	0
Electricity	23	104	2,090	1792
Repair & maintenance costs	100	304	614	670
Total	**1,285**	**5,599**	**4,062**	**4,754**

5.6 EU-27 total system impact

In this section, the total environmental impacts calculated for the Base-Cases at EU-27 level are compared with other results from similar studies.

The annual energy consumption in the use phase of the stock of all products covered within the ENER Lot 21 preparatory study is around 770 PJ. This is a relatively high energy consumption compared with the total space-heating sector in the EU.

The EU stock of products covered in other Ecodesign preparatory studies on space heating, i.e. ENER Lot 1, ENER Lot 10 and ENER Lot 15, consume 10,880 PJ (primary), 850 PJ and 1,700 PJ per year during the use phase respectively (See Table 5—37). These together make more than 18,862 PJ per year.

Table 5—37: Annual energy consumption and emissions of EU stock of space-heating products

	Geographical scope	Energy consumption per year (PJ)	Emissions Mt CO2 eq. per year	Emissions kt SO2 eq. per year
ENER Lot 1[17]	EU-25	10,880	630	500
ENER Lot 10[18]	EU-27	855	37	221
ENER Lot 15[19]	EU-27	1,699	36	347
ENER Lot 21	EU-27	770	41	78

The contribution to environmental impacts of ENER Lot 21 products is also significant compared to other space-heating products assessed in other Ecodesign preparatory studies as can be seen from Table 5—37. With ENER Lot 21 stock of products being responsible for the emission of 41 million tonnes CO_2eq per year, even though the units stocks are low, their contribution to the total GHG emissions of the space heating sector is considerable.

The EU stock of products covered within Lot 21 is lower than of other preparatory studies (see Task 2 report of this preparatory study). Thus, the relatively high energy consumption and environmental impact associated with ENER Lot 21 products demonstrate that it is pertinent to investigate whether their environmental performance can be improved. It is part of the following tasks of this preparatory study to assess the improvement potentials of the ENER Lot 21 products and the possible means to achieve them.

5.7 Validity of results

As there is considerably uncertainty of the reliability and accurateness of the inputs used in EcoReport, some of the assumptions made during the analysis of the Base-Cases were subject to a simple sensitivity analysis. This was done in order to check the validity of the results presented in relation to these variables.

The parameters tested in the sensitivity analysis are those associated with uncertainty, due to lack of data sources or considerable differences of values from different sources. These parameters are the amounts provided in the Bill of Materials; the refrigerant-related issues (emissions, time horizon of the GWP, equivalent working hours); and, the end-of-life practices.

5.7.1 Sensitivity analysis of the Bills of Materials

Because of the small number of Bill of Materials (BOM) received from the manufacturers, it seems relevant to test the variability of the results in relation with the BOM of the Base-Cases. To do so, the amounts of material used in the Base-Cases were divided and multiplied by a factor 2,

[17] VHK (2007) DG ENER Lot 1 preparatory study on CH-Boilers.
[18] ARMINES (2008) DG ENER Lot 10 preparatory study on residential air conditioning and ventilation.
[19] BIO Intelligence Service (2009) DG ENER Lot 15 preparatory study on solid fuel small combustion installations.

respectively. Table 5—38 shows the results of this sensitivity analysis on the environmental impacts of all BCs.

Table 5—38: Results of the sensitivity analysis of the Bill of Materials

	BC-1a BOM/2	BC-1a BOM*2	BC-1b BOM/2	BC-1b BOM*2	BC-2 BOM/2	BC-2 BOM*2	BC-3 BOM/2	BC-3 BOM*2
Other Resources & Waste								
Total Energy (GER)	0%	0%	0%	0%	0%	0%	-1%	2%
of which, electricity (in primary MJ)	-3%	7%	-5%	-3%	0%	0%	0%	1%
Water (process)	-23%	47%	-39%	-22%	-1%	2%	-3%	7%
Water (cooling)	0%	1%	-1%	0%	0%	0%	0%	0%
Waste, non-haz./ landfill	-31%	63%	-53%	-30%	-2%	4%	-9%	18%
Waste, hazardous/ incinerated	-39%	78%	-67%	-38%	-3%	6%	-7%	36%
Emissions (Air)								
Greenhouse Gases in GWP100	0%	0%	0%	0%	0%	1%	-1%	2%
Ozone Depletion, emissions								
Acidification, emissions	-3%	5%	-4%	-2%	0%	1%	-1%	3%
Volatile Organic Compounds (VOC)	-1%	2%	-2%	-1%	-2%	5%	-8%	16%
Persistent Organic Pollutants (POP)	-36%	71%	-60%	-34%	-3%	5%	-10%	20%
Heavy Metals	-22%	43%	-37%	-21%	-1%	2%	-5%	10%
PAHs	-41%	82%	-73%	-41%	-11%	22%	-33%	66%
Particulate Matter (PM, dust)	-9%	18%	-28%	-16%	-3%	5%	-11%	26%
Emissions (Water)								
Heavy Metals	-44%	87%	-75%	-42%	-6%	13%	-20%	41%
Eutrophication	-48%	96%	-84%	-48%	-13%	26%	-35%	73%

These results indicate that some impact categories are highly variable depending on the amount of materials reported for the production phase. These impact categories are water consumption, waste generation (hazardous and not hazardous), persistent organic pollutant emissions to air, heavy metals emissions (to air and to water), polycyclic aromatic hydrocarbons, particulate matter and eutrophication.

These impact categories were identified in the environmental analysis as the impact categories for which the production phase was significant. No other impact categories are affected in a high degree by the augmentation or reduction of the material consumption in the production phase.

5.7.2 Sensitivity analysis of the TEWI

The refrigerant emissions proved to have a relatively high importance in the Total Equivalent Warming Impact of the product (see section 5.2). However, there is high uncertainty regarding different parameters used for the calculation of the TEWI.

Several sources consulted offer different figures for refrigerant emissions during the use phase and end-of-life phase. The maximum and minimum values found in the literature were calculated in EcoReport in order to compare the results. The minimum values are 0% annual refrigerant leakage and 15% of dumped refrigerant in the end-of-life, and the maximum values are 8.5% of annual leakage and 60% dumped in the end-of-life (see section 5.1.4).

The amount of equivalent working hours for heat pumps also influences the TEWI results. At a higher work pattern, the indirect emissions are greater than the direct emissions. A similar use pattern as in the proposal of the regulation for central heating boilers (2,066 hours) is tested in this sensitivity analysis.

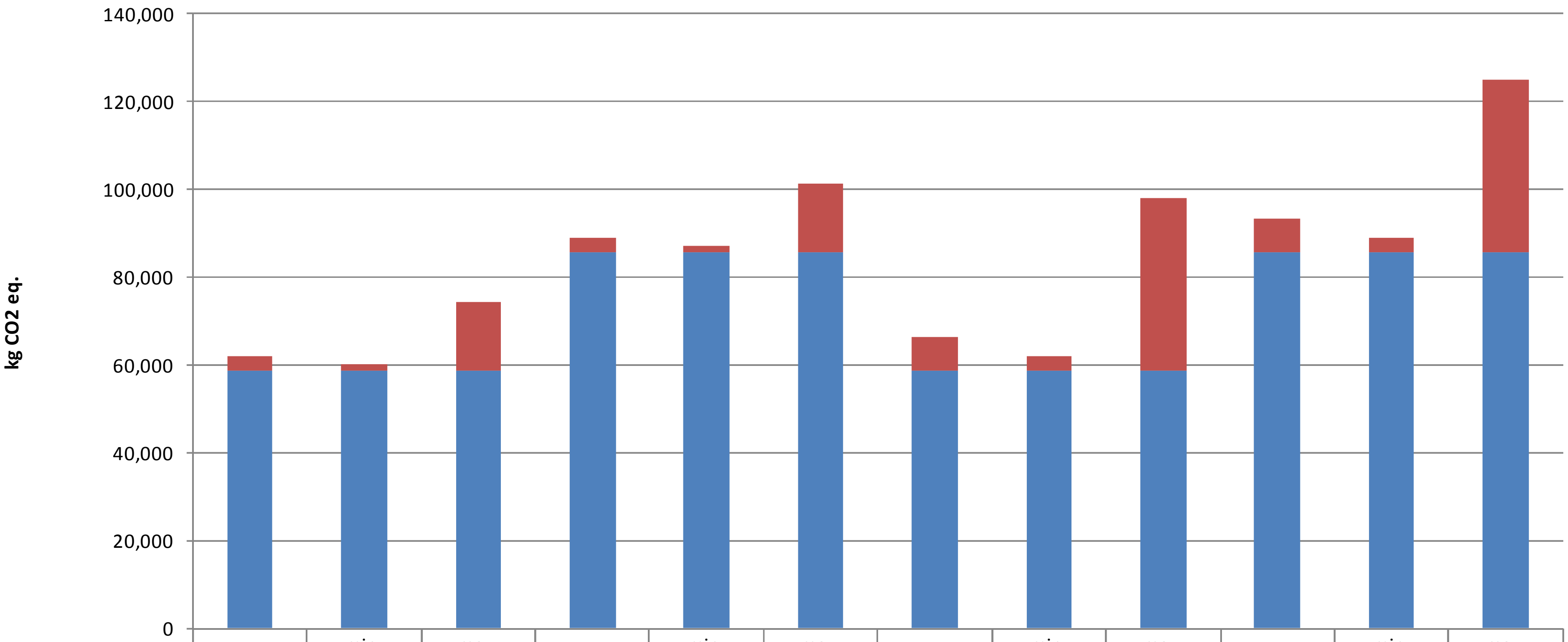
Finally, the GWP values proposed in the MEEuP methodology and used in the EcoReport tool refer to a 100 years horizon. The IPCC also provides GWP values for 20 years and 500 years, which gives the opportunity to analyse the impacts at other time scales. In the case of refrigerants, their lifetime in the atmosphere is relatively short, and the GWP values for 20 years and 100 years might be very different. In this sensitivity analysis, the following values for the refrigerant of the Base-Cases are tested:

5—39: Global Warming Potentials for R410A

	GWP 100 (MEEuP)[20]	GWP 20 (based on IPCC)
R410A	1,730	4,340

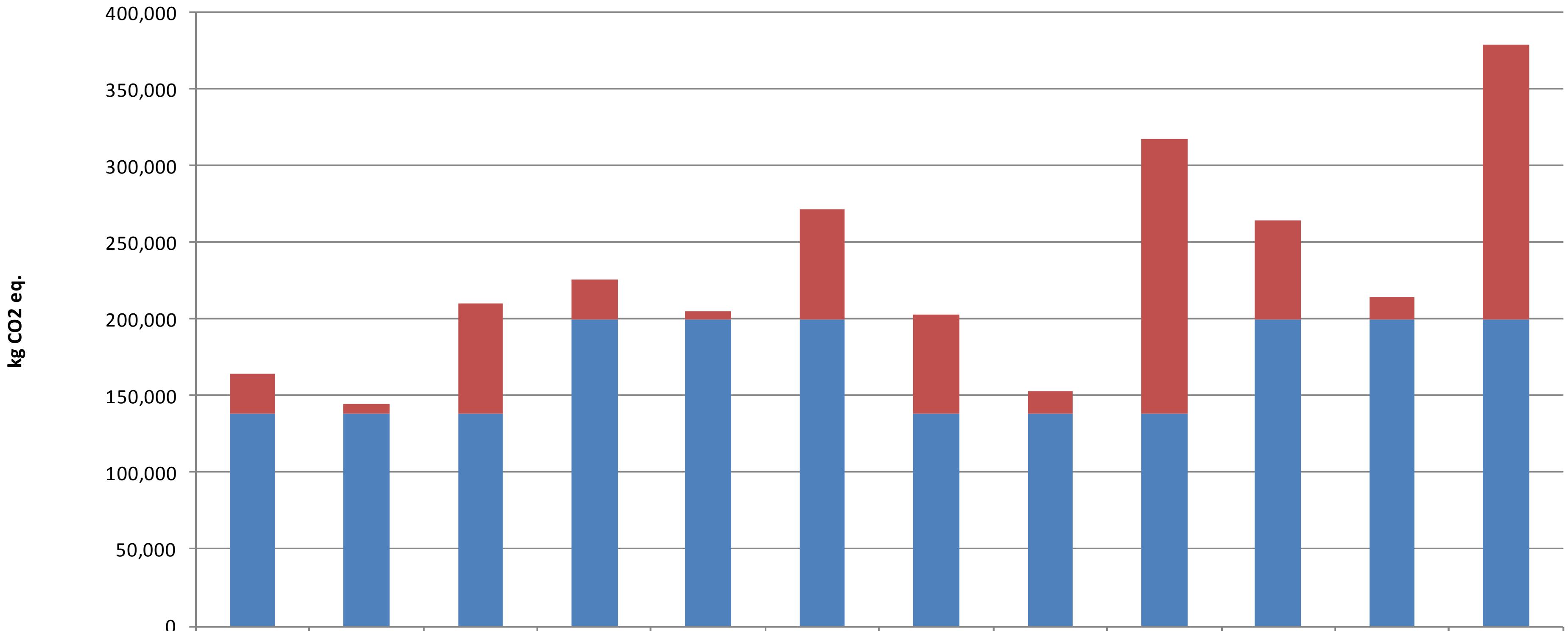
The results of this sensitivity analysis are shown in Figure 5-16 and Figure 5-17.

[20] The EcoReport tool and the MEEuP methodology set the GWP100 of R410A as 1,730. The IPCC published GWP100 values for the components of R410A (i.e. R32 and R125 at 50%) as 675 and 3,500, respectively. According to that, the GWP100 of R410A would be 2,088. For the sake of clarity, the value set in the MEEuP methodology has been kept in this preparatory study.



	BC2	min. emissions	max. emissions	BC2	min. emissions	max. emissions	BC2	min. emissions	max. emissions	BC2	min. emissions	max. emissions
	1,400 h			2,066 h			1,400 h			2,066 h		
	GWP 100 (MEEuP)						GWP 20 (based on IPCC)					
Direct emissions	3,039	1,246	15,570	3,039	1,246	15,570	7,625	3,125	39,060	7,625	3,125	39,060
Indirect emissions	58,799	58,799	58,799	85,815	85,815	85,815	58,799	58,799	58,799	85,815	85,815	85,815

Figure 5-16: Sensitivity analysis of the TEWI of BC2: refrigerant emissions, equivalent working hours and GWP time horizon



	GWP 100 (MEEuP)						GWP 20 (based on IPCC)					
	1,400 h			2,066 h			1,400 h			2,066 h		
	BC3	min. emissions	max. emissions	BC3	min. emissions	max. emissions	BC3	min. emissions	max. emissions	BC3	min. emissions	max. emissions
Direct emissions	25,691	5,709	71,363	25,691	5,709	71,363	64,449	14,322	179,025	64,449	14,322	179,025
Indirect emissions	138,587	138,587	138,587	199,858	199,858	199,858	138,587	138,587	138,587	199,858	199,858	199,858

Figure 5-17: Sensitivity analysis of the TEWI of BC3: refrigerant emissions, equivalent working hours and GWP time horizon

5.7.3 Sensitivity analysis of the end-of-life options

In the end-of-life phase, in order to check the variability of the results, the amount of product sent to landfill was calculated for the two alternative options presented in Task 4. The inputs provided by the stakeholders (i.e. 5% landfilling and 100% recycling rate); and the Municipal Solid Waste statistics (37% landfill, 23% material recycling, 17% other recycling, 16% energy recovery and 4% incineration).

For its use in the EcoReport tool, the reuse, recycling and incineration rates have been recalculated to sum up 100% of the plastic fraction. The values used for the Base-Cases, the maximum and minimum amounts are presented in Table 5—40.

Table 5—40: Landfill, recycling and incineration rates of air-based central heating products

	Base-Cases (WEEE statistics)	Landfill min (stakeholder's inputs)	Landfill max (MSW statistics)
Landfill (fraction products not recovered)	5%	5%	37%
Re-use, recycling			
Plastics: Re-use, Closed Loop Recycling	0%	0%	0%
Plastics: Materials Recycling	87*%	100%	66%
Plastics: Thermal Recycling	13*%	0%	34%

*recycling rate for VRF heat pumps is different, the values of 97% materials and 3% thermal recycling were provided by stakeholders

The results are presented in Table 5—41. The gas warm air heater Base-Cases were the most affected by the variation of the end-of-life options. The results of the analysis of Base-Cases for heat pumps vary considerably only in some impact categories, namely particulate matter and heavy metals into air and waste, hazardous/incinerated.

Table 5—41: Results of the sensitivity analysis of end-of-life options

	BC-1a landfill min	BC-1a landfill max	BC-1b landfill min	BC-1b landfill max	BC-2 landfill min	BC-2 landfill max	BC-3 landfill min	BC-3 landfill max
Other Resources & Waste								
Total Energy (GER)	0%	0%	0%	0%	0%	0%	0%	0%
of which, electricity (in primary MJ)	0%	0%	-5%	-5%	0%	0%	0%	0%
Water (process)	0%	0%	-33%	-33%	0%	0%	0%	0%
Water (cooling)	0%	0%	-1%	-1%	0%	0%	0%	0%
Waste, non-haz./ landfill	0%	22%	-45%	-40%	0%	4%	0%	6%
Waste, hazardous/ incinerated	-12%	20%	-60%	-53%	-16%	26%	-2%	24%
Emissions (Air)								
Greenhouse Gases in GWP100	0%	0%	0%	0%	0%	0%	0%	0%
Ozone Depletion, emissions								
Acidification, emissions	0%	0%	-3%	-3%	0%	0%	0%	0%
Volatile Organic Compounds (VOC)	0%	0%	-1%	-1%	0%	2%	0%	4%
Persistent Organic Pollutants (POP)	0%	20%	-52%	-47%	0%	4%	0%	7%
Heavy Metals	-1%	35%	-32%	-23%	0%	5%	0%	7%
PAHs	0%	0%	-63%	-63%	0%	0%	0%	0%
Particulate Matter (PM, dust)	-1%	48%	-24%	-3%	-3%	35%	0%	54%
Emissions (Water)								
Heavy Metals	0%	6%	-64%	-63%	0%	3%	0%	4%
Eutrophication	-1%	22%	-72%	-66%	-4%	29%	0%	22%

5.7.4 Conclusions of the sensitivity analysis

The sensitivity analysis carried out shows clearly that some of the assumptions taken in during the assessment of the Base-Cases have high importance on the final results of the environmental analysis. This is the case for the amount of raw materials extracted and for the refrigerant-related issues in heat pumps. We can draw the conclusion that it is of high importance the reliability of the values selected for these parameters, since they can influence significantly the overall results.

Only after confirming the validity of the inputs can we conclude that the parameter to focus on for improving the environmental performance of air-based central heating appliances is the energy consumed during the use phase. It proved to be the most important environmental aspect throughout the life cycle of air-based central heating appliances. In the case of warm air heaters, material consumption may also be considered as an important environmental aspect. It should therefore be investigated whether a good trade-off between improving the energy efficiency through increased insulation and reducing material consumption can be found.

There is special uncertainty in the TEWI analysis of heat pumps. The share of the direct emissions of refrigerants respect to the total warming impacts depends highly on the time horizon selected for the analysis and the leakage rate during the use phase and in the end-of-life.

5.8 Conclusions

This Task 5 report analysed the environmental impacts and economic costs of four Base-Cases that are thought to represent the air-based central heating products most relevant for proposing Ecodesign requirements. The selection of Base-Cases and subsequent analysis was based upon the market analysis presented in Task 2, the consumer behaviour and existing infrastructure described in Task 3 and the technical analysis of products carried out in Task 4. The Base-Cases were constructed as an "abstraction" of the average product in the EU market representing the wide range of products considered in this ENER Lot 21 preparatory study. The Base-Cases are used to estimate the environmental impacts of air-based central heating products in the EU.

The EcoReport results show that energy consumption during the use phase is the most important environmental aspect. Dumped refrigerant also has a significant impact on greenhouse gas emissions, especially for VRF heat pumps. The raw materials used in production also contribute significantly to environmental impacts for all the Base-Cases, especially warm air heaters. The manufacturing, distribution and end-of-life phases are less significant to the overall environmental impacts.

The results of the economic analysis are in line with the environmental impacts. Energy consumption (electricity or fuel) is the largest single component of the overall Life Cycle Costs. Purchase costs and maintenance costs also represent significant shares of the total consumer expenditure, but in all cases do not exceed more than 15% of the total LCC.

The environmental and economic analysis of the Base-Cases will serve as point of reference when evaluating the possible improvement potentials in Task 6 and the design options in Task 7. As most of the environmental impacts are caused by the energy consumption during the use phase, the improvement options will be focused mainly on this aspect. However, improvement options that can lead to a reduction of raw materials used and less emissions as well as less negative impacts of refrigerants will also be explored.

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