Bio Intelligence Service

European Commission DG ENTR

Preparatory Study for Eco-design Requirements of EuPs
[Contract N° S12.515749]

Lot 1

Refrigerating and freezing equipment:

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

Task 4: Technical analysis and assessment of Base Cases

Final report

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

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4. Technical analysis and assessment of Base Cases

4.1. INTRODUCTION

The objectives of Task 4 are to:

- build on the product definition set out in Task 1 by describing the technical function of refrigeration and the products in scope;
- assess environmental improvement areas; and
- describe the Environmental Impact Assessment and Life Cycle Cost analysis of the Base Cases (this analysis uses data gathered from Tasks 1, 2 and 3).

The refrigeration equipments identified in Task 1 are used by a wide range of users. Service cabinets, blast cabinets, and walk-in cold rooms are primarily used in restaurants, catering facilities, hotels, and supermarkets. Process chillers are more used for industrial and commercial processing. Remote condensing units used in a variety of applications, those covered in ENTR Lot 1 are mostly destined for commercial application.

Task 2 described product market figures, provided insight into the current market situation, trends and structure. Finally, economic data on manufacturing costs, consumer prices and rates was provided for use in Life Cycle Cost (LCC) calculations.

The results of Task 3 show that user behaviour could have a significant impact on the electricity consumption of refrigeration equipment through operational and maintenance practices.

Initial technical analysis data for dessert and beverage machines, water dispensers and ice machines are provided in Annex 4-1. A preliminary analysis suggested that their figures for stock numbers, energy consumption, and energy saving potential made them less of a priority in terms of potential improvement and energy consumption reduction across the EU, compared to the products selected for further analysis. These conclusions are discussed in Task 1 and data displayed in Annex 1-2.

4.2. THE VAPOUR-COMPRESSION CYCLE: HEAT TRANSFER AND EFFICIENCY

Refrigerators and freezers work on the principle of a reverse heat engine.

Figure 4-1 demonstrates that the refrigeration unit removes heat (Q1) from a low temperature source and then transfers heat (Q2) to a high temperature source using a certain amount of electrical energy input (E) for the purpose of cooling the cold region. Heat pumps do the same thing with the intent of heating the hot region.

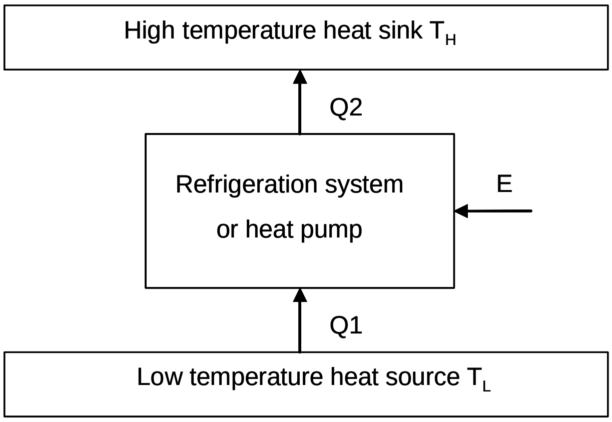

Figure 4-1: Principles of refrigeration systems

The efficiency of the refrigeration system is expressed by the COP (coefficient of performance) which is the ratio of the refrigeration effect (heat extracted) and the energy input required:

$$COP = \frac{Q1}{E}$$

The purpose of the refrigeration unit is to keep the low temperature heat source at the desired temperature T_L. Heat leakage from the surroundings to the low temperature heat source tends to increase this temperature. In order to keep the cold region at T_L a certain amount of heat Q1 has to be removed.

These heat transfers are made possible through the vapour compression refrigeration cycle, and as described in Task 1, almost all refrigerators and freezers in operation are based on this cycle. The main components in a vapour compression system are the compressor, the expansion valve and two heat exchangers referred to as evaporator and condenser. The components are connected to form a closed circuit, as shown in Figure 4-2. A volatile liquid, known as the working fluid or refrigerant, circulates through the four components.

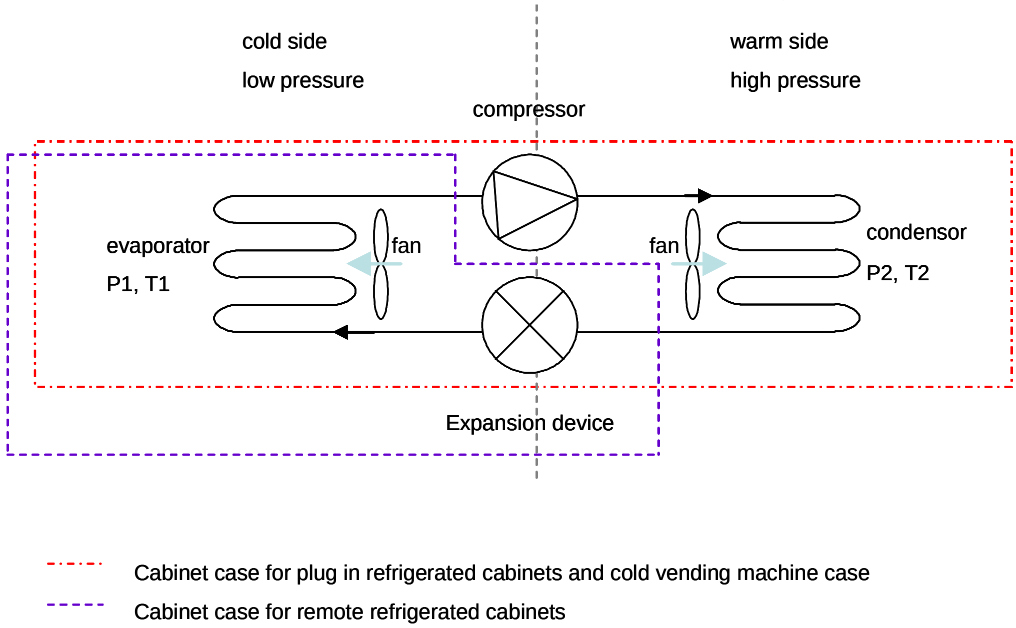

Figure 4-2: Schematic representation of the refrigeration cycle – Vapour compression system

As shown in Figure 4-2, the cycle starts with a low temperature (T1), low pressure (P1) mixture of liquid and vapour refrigerant entering the evaporator where it absorbs heat from the relatively warm air surrounding the evaporator. This heat transfer, corresponding to the refrigeration effect (Q1 in

Figure 4-1) boils the liquid refrigerant in the evaporator and this superheated vapour (the temperature of the refrigerant vapour is above its saturation temperature) is drawn in the compressor. Evaporator fans are used in order to increase the heat transfers.

The refrigerant is superheated to prevent the formation of liquid droplets in the compressor, which would affect its operation. The compressor compresses the refrigerant into a hot high pressure refrigerant vapour which is released in the condenser.

Within the condenser, the high pressure (P2 in Figure 4-2) refrigerant is condensed at high temperature (T2 in Figure 4-2) by heat transfer (Q2 in Figure 4-1to the relatively cool ambient surroundings. The condenser is often equipped with a condenser fan, used to increase the heat transfer. The condenser causes the vapour to cool down, condense into liquid and further sub-cool.

A liquid receiver at the exit of the condenser serves to accumulate the reserve liquid refrigerant, acting as a stock for off-peak operation, and to permit pumping down of the system. The receiver also serves as a seal against the entrance of gaseous refrigerant into the liquid line.

The refrigerant liquid then travels to the expansion device where it is reduced to a low pressure, and low temperature (T1). This pressure drop causes a small part of the refrigerant to boil off. The cooled liquid-vapour mixture then re-enters the evaporator to repeat the cycle.

4.3. REFRIGERANTS

The thermodynamic properties of the refrigerant can be plotted in a pressure-enthalpy chart, as shown in Figure 4-3. The blue curve represents the saturated liquid line (on the left) and the saturated vapour line (on the right) and limits the liquid domain, the vapour domain and the liquid-vapour domain of the refrigerant. The refrigeration cycle is represented in bold black.

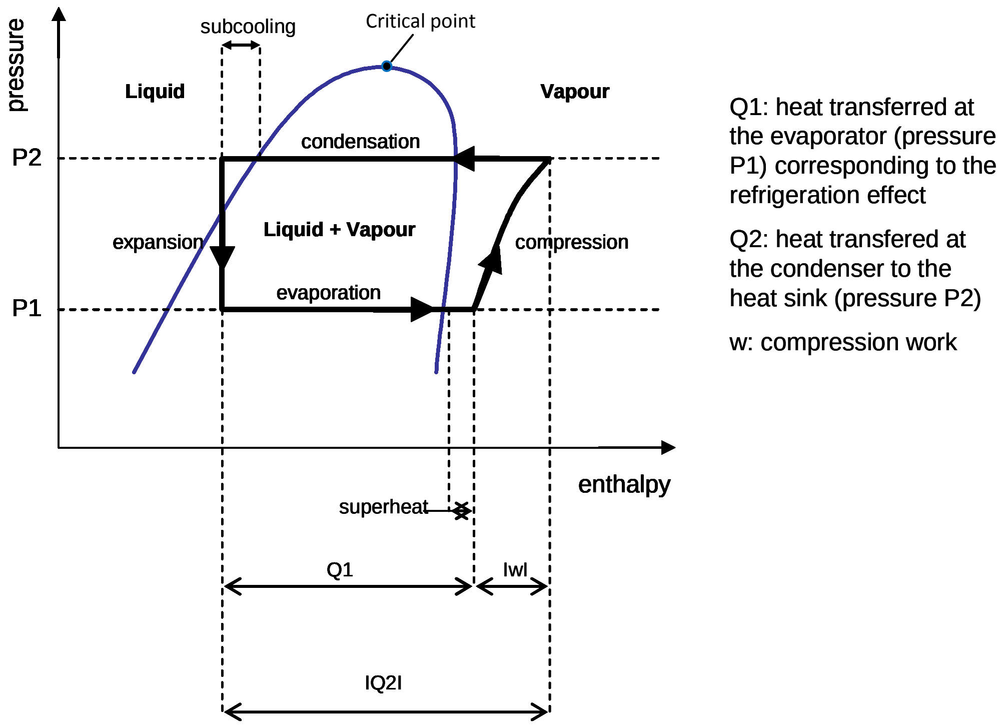

Figure 4-3: Pressure-Enthalpy chart of the vapour-compression refrigeration cycle

The right refrigerant selection is important for energy efficiency, as it can affect the energy consumption of the refrigeration equipment. The following thermodynamic properties of the refrigerant have significant impact on the heat transfer and therefore on the performance of the refrigeration system.

4.3.1. LATENT HEAT OF VAPORISATION

High latent heat[1] of vaporisation is desirable because the refrigerant mass flow rate per unit of refrigeration effect is reduced. When a high latent heat of vaporisation is combined with a low specific volume in the vapour state, the compressor work needed is reduced, allowing the use of smaller and more compact equipment.

[1] Latent heat refers to the amount of energy released or absorbed by a chemical substance during a change of state that occurs without changing its temperature, meaning a phase transition

4.3.2. Compression ratio

The compression ratio is the ratio of the absolute discharge pressure (P2 in Figure 4-2) to the absolute suction pressure (P1 in Figure 4-2). In the case of a system with reciprocating compressors, all factors being equal, the refrigerants with the lowest compression ratio are the most desirable. This results in low power consumption and high volumetric efficiency.

4.3.3. Specific heat of the refrigerant (both in liquid and vapour state)

High specific heat translates into good heat transfer properties. Increasing these factors will allow the use of a smaller charge of refrigerant.

Therefore, in regards to thermodynamic properties, the “best” refrigerant would have the following characteristics:

- *Low liquid viscosity*: improves heat transfer primarily in condenser;
- *Low vapour viscosity*: reduces single-phase and two-phase pressure drops;
- High liquid thermal conductivity: improves heat transfer in evaporator and condenser;
- *Low liquid density*: improves heat transfer in evaporator;
- *High vapour density*: improves heat transfer in condenser and reduces pressure drops;
- *High latent heat of vaporisation*: reduces evaporator and condenser pressure drops;
- *High liquid specific heat*: improves heat transfer in evaporator and condenser;
- *Low saturated temperature-pressure gradient*: reduces compression ratio and therefore compressor power consumption;
- *Volumic refrigerating effect (latent heat divided by specific volume)*: an important (but not absolute) indicator of the effect of refrigerant properties on the efficiency of a real refrigeration system.

Figure 4-4 shows the variation of some of the selected properties listed above with molecular mass of the fluid (based on mass fraction in the case of mixtures) for a lot of refrigerants, where the properties were calculated for 0°C using the Refprop database[2]. A limited number of common refrigerants are indicated. Refrigerants with a lower molecular mass such as ammonia (R 717) and propylene (R 1270) are shown to have favourable thermodynamic properties, thus higher efficiency. The desired thermodynamic properties are a boiling point below the target temperature, a high heat of vaporization, a moderate density in liquid form, a relatively high density in gaseous form, and a high critical temperature. However, R1270 is said to be a very unusual refrigerant in commercial refrigeration and it is not viable for general use[3].

[2] Lemmon et al, 2002

[3] Source: Defra

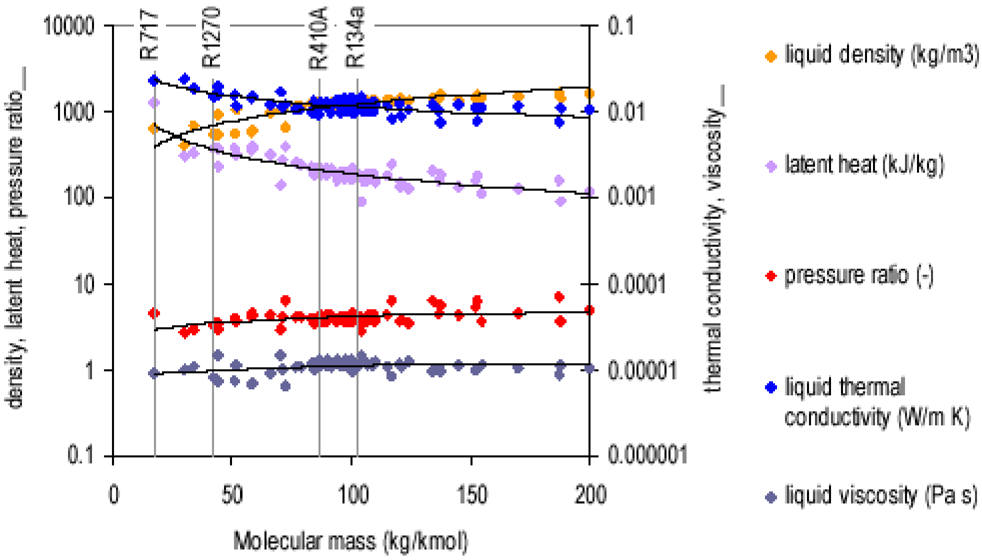

Figure 4-4: Variation of refrigerant thermodynamic properties[4]

Currently the main refrigerants used in the refrigeration sector are hydrofluorocarbons (HFCs) R134a and R404A Refrigeration equipment is also being adapted to also allow use of other refrigerants, such as hydrocarbons (HCs) isobutane (R600a) and propane (R290). Although HCs have a much reduced GWP, their disadvantage is flammability, in that sufficient leakage could lead to an explosive mix of gases if leakage occurs in enclosed spaces. Components such as electric motors[5] have been developed to avoid this occurring due to component sparking.

The use of other "natural" refrigerants is also being proposed as a means to reduce the direct environmental impacts of refrigeration systems (due to refrigerant leakage), as well as enabling energy savings through improved refrigeration system performance. However, such systems sometimes have drawbacks. Some alternative refrigerants are not efficient in particular conditions, for example high ambient temperatures for CO_2 (R-744) systems. Hence, they are more prevalent in specific countries, such as Denmark and Sweden. Besides that, the main drawback of R744 is the transcritical operation. Sensible heat rejection occurs above the critical point at constant pressure, resulting in gliding temperatures. Therefore, unlike subcritical systems, the refrigerant is not condensed by normal condensers or heat exchangers but cooled by gas coolers[6].

Other refrigerants have charge limitations due to safety requirements. However, alternatives already exist in the market, and future developments will diversify the variety of refrigerant choices.

However, the choice of the appropriate refrigerant is a compromise between its environmental, thermodynamic and safety properties. Environmental and safety data of several refrigerants used in refrigerated systems are presented in Task 5, including parameters such as flammability. A good comparison of environmental

[4] Reference: *BNCR37: Characteristics of refrigerants in relation to efficiency*, Market Transformation Programme *efficient-products.defra.gov.uk/spm/download/document/id/702*

[5] Source: Ebm-papst Landshut

[6] Colombo et al.: Case study R744: A transcritical system with heat recovery for a supermarket.

and efficiency properties can be done using TEWI (Total Equivalent Warming Impact) values. However, the safety information of refrigerants should follow the standards ANSI/ASHRAE 34[7], EN 378-1:2009 or ISO 817. The ANSI/ASHRAE standard has been suggested by manufacturers to classify refrigerants in terms of safety. However, it is not completely harmonised to the EU Directives, and some stakeholders suggested that it is too restrictive for most of the "natural" refrigerants.

These classifications and assessment of each type of refrigerant are further explained in the analysis of refrigerants in Task 5.

Some substances that can be used as refrigerants are also used as foaming agents in insulation materials in refrigeration products. A foaming agent is usually a surfactant that strengthens the foam, and some HFC blends are developed specifically for that function, as HFC-245fa. However, the environmental impacts of this HFC used as foaming agents are expected to be lower than the impacts caused by refrigerants, because they are not supposed to be emitted throughout leakages, and the quantity used in the products is lower, but no independent study has been found to prove this statement.

4.3.4. USE OF REFRIGERANTS

The global warming potential of refrigerants is characterised by the GWP indicator (global warming potential). Other alternatives exist, to avoid the use of HFCs, such as the use of hydrocarbon or carbon dioxide.

Experience has shown[8] that, in certain ambient conditions, refrigeration systems running with HC and carbon dioxide can achieve the same levels of efficiency as HFC based systems. For example, the coefficient of performance of compressors running with hydrocarbons is generally slightly better than compared to HFC systems due to better thermodynamic properties (particularly R290 and R1270, even though the latter is a very unusual refrigerant in commercial refrigeration). When comparing the GWP of systems running with different types of refrigerant, the global warming potential is often characterised by the TEWI, Total equivalent Warming Impact, which also takes into account the emissions of greenhouse gases due to the electricity consumption of the system.

These two environmental impacts (Global warming potential and Ozone depletion potential) are not only an issue if the refrigerant leaks or if the treatment is not appropriate at the end-of-life stage, but also during the production phase. Some of the key requirements to reduce environmental impacts are the reduction of refrigerant charges and the control during use.

The F-Gas Regulation EC 842/2006 requires the recovery of HFC refrigerants during service, and at end-of-life. It establishes standard inspection requirements and indirect and direct leakage measurements for refrigeration systems (among others).

These issues and others associated to refrigerants are further explained in Task 5.

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[7] No equivalent standard in the EU; the International Institute of Refrigeration recommended use of this standard

[8] Feedback from the Refrigerants, Naturally! initiative

4.3.5. End-of-life disposal

Plug-in refrigerators and freezers can be handled like household equipment. The RAL association, specialised in demanufacturing of refrigeration equipment containing CFCs, has been working on a certification for recycling plants which includes the following steps:

- Step 1: extraction of refrigerant.
- Step 2: extraction of the insulating foam and other components containing harmful substances.
- Step 3: separating, sorting and classification of the material obtained in step 1 and 2 and preparative steps needed to the re-use, and/or disposal of these materials.

After the treatment of harmful substances, the compressor, in the case of a plug in, is withdrawn and handled separately. The rest of the appliance is then ground in order to segregate ferrous and non-ferrous metals, along with plastics. The metallic part is removed with a magnet, and will be re-used in new products. About 85 % of materials (metals and plastics) included in the appliance are recycled. Moreover, about 10 % of materials (only plastics) are burned in order to recover the heat created, and only 5 % of plug in and remote equipment is thrown away in landfills.[9]

Concerning refrigerant end-of-life, data has been collected from different studies and from the EFCTC (European Fluorocarbon Technical Committee).

The F-Gas Regulation EC 842/2006 requires the recovery of HFC refrigerants during service, and at end-of-life. In addition, the WEEE directive requires end-of-life recovery and treatment of CFCs, HCFCs, HFCs or other gases that are ozone depleting or have a GWP higher than 15. EFCTC member companies offer recycling and destruction (typically incineration) schemes directly or via their distributors for HFC refrigerants. The HFC refrigerant currently returned to suppliers is relatively small and the percentage of recycled refrigerant returned to supply chain by HFC producers is small. Refrigerant recycling can extend the product's lifespan to 15 years.

Typically, the second hand refrigerant would be reclaimed and supplied to the same specifications as a virgin refrigerant. Recovery/recycling machines allow engineers to reuse HFC without returning them to the suppliers. Because refrigerants are simple to be treated locally, a significant proportion of the recovered refrigerant is treated in this way, although practice varies by country. EFCTC comments that it is expected that the WEEE directive will impact on the quantity of refrigerant recovered at end-of-life.

In plug-in products, the refrigerant charges are small (0.2 – 1 kg) but end-of-life recovery is almost non-existent[10].

[9] Estimations from manufacturers

[10] IPCC *Special Report on Safeguarding the Ozone Layer and the Global Climate System. Chapter 4 Refrigeration*. (2005)

4.4. PRODUCT INTERACTION WITH THE SYSTEM

This section discusses the interaction of individual products within their environment and system. For plug-in equipment all components are integrated in the product. In the case of plug-in products, the functional system consists of:

- the product itself;
- its surroundings; and
- the control system(s).

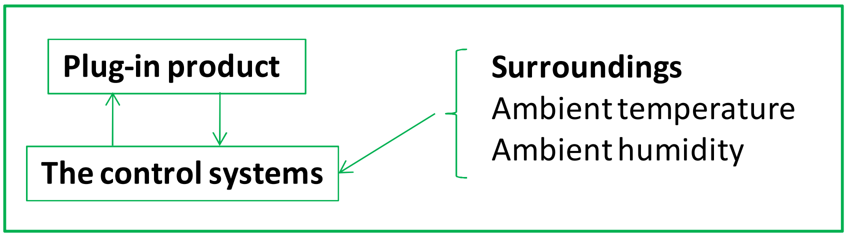

Figure 4-5: Functional system for plug in refrigeration appliances

Remote appliances are not used as stand-alone products, and they also interact with their surroundings as well as with the building's air conditioning and heating system. They receive refrigeration energy from a remote condensing unit, as shown below.

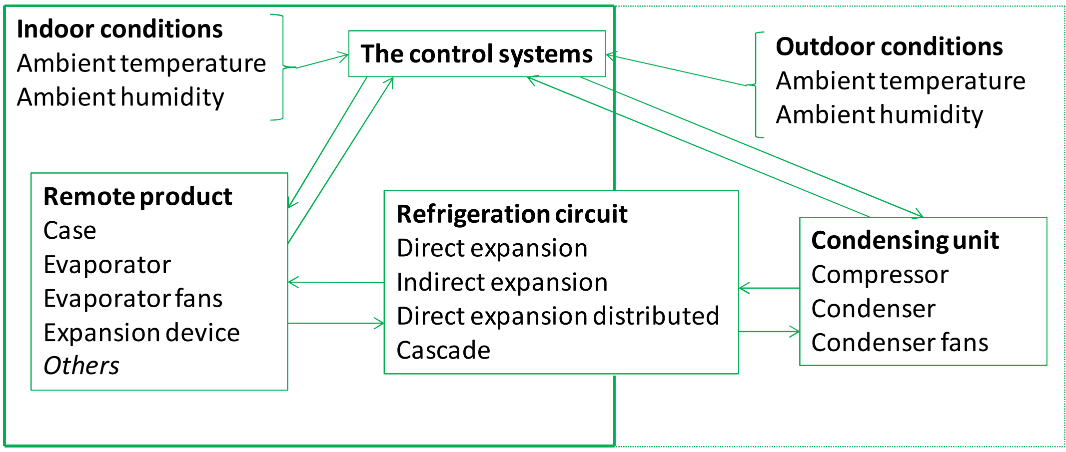

Figure 4-6: Functional system of remote refrigeration appliances

For remote appliances the evaporator, the refrigerant and the expansion device are the only components included in the equipment and the compressor and the condenser are located outside of the product. The functional system of remote products includes:

- the product itself (including accessories e.g. defrost heaters);
- the ambient surroundings of the product (e.g. temperature, humidity);
- the different regulating systems;
- other equipment linked to the same refrigeration system; and
- the refrigeration system (remote condensing unit), via the refrigerant piping circuit.

Large, central refrigeration systems (central plants, racks and packs) are discussed in a separate technical annex to this report.

4.5. FACTORS AFFECTING THE ENERGY CONSUMPTION

Energy consumption is mainly dependent on the hours of use, operation and ambient temperatures, capacity, and efficiency of a product's components. As these parameters are considered in the product analysis (the study compares products with the same functional unit), this section compares a range of different technical options that might affect energy efficiency or environmental performance of the products, including those factors that affect products with the same function, use patterns and capacity.

4.5.1. OPERATING TEMPERATURE

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	✓	✓	✓	✓

The refrigeration load which needs to be delivered by the compressor depends on the desired temperature inside the refrigeration appliance. The lower the operating temperature is, the higher the demand for cooling load, and the higher the electricity consumption. Moreover, defrost heaters used in cabinets and cold rooms working at low temperatures represent additional electricity consumption and an additional heat load within the equipment.

According to information provided by stakeholders, most of the characteristics of the products, including refrigerant used, except power input and energy consumption, are similar for low and medium temperature ranges. According to the opinion of some experts, the power input for those products operating at low temperatures is around 40% higher than the products for medium temperatures, and for the same cooling capacity, the product is around 20% bigger[11].

According to literature, typical differences between freezing and refrigerating service cabinets can be around two to three times higher. For blast cabinets, the extra energy consumption presented by freezing cycles, respect the same equipment chilling cycle, is estimated to be approximately 2.5 times higher. In remote condensing units and chillers, the increase in energy consumption of appliances working at low evaporating temperatures is around 1.7 times the consumption of medium temperature products.

4.5.2. OPERATION: PULL-DOWN OR STEADY-STATE REFRIGERATION

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	✓	✓	✓	✓

The refrigeration system of products will be designed to fit its operational requirements. One important distinction is that of pull-down cooling, compared to

[11] Source: Expert estimate

steady-state cooling for storage. A blast cabinet, for example, will have a powerful refrigeration system (considering its capacity), and requires this to rapidly bring down the temperature. However, a product designed to provide steady-state cooling will not perform well if required to rapidly "pull-down" temperature. In addition, a pull-down system will not perform efficiently if required to store produce at a steady temperature (as its refrigeration system is unnecessarily powerful for this task).

4.5.3. AMBIENT CONDITIONS

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	✓	✓	✓	✓

The temperature and humidity in which a product and its condensing unit are located affect the heat infiltration into the product housing (and hence increased heat load), the work required to remove the heat from the condenser (a reduced temperature difference between the condenser and air increases energy consumption, or lower ambient temperature increases heat transfer from condenser), and the frosting on the evaporator (potentially reducing heat transfer and increasing defrost duty).

As many of the product groups are located indoors, at relatively high temperature (e.g. in professional kitchens), remote condensing can take advantage of lower ambient temperatures outdoors.

Due to varying climates in EU, and varying indoor conditions where products are located, the performance of products may differ. Often equipment is designed to operate at a "worst case" scenario of high ambient temperature. If this occurs, then the product will effectively work at part load for a significant portion of the year (when "worst case" conditions are not met). However, standards for chillers and condensing units in particular do not take into account this requirement for most products to operate at part load, or operate at differing temperatures from the "norm". Hence, they may not accurately reflect real use.

According to members of the chillers and condensing unit industry, the machines do not work at full load more than 20% of their running time. The rest of the time, the machines can decrease their load to even less than 50%. Some stakeholders have mentioned that the average work capacity during a year could be 40% of the full load capacity, depending on environmental conditions and cooling requirements. This is the reason why the season and partial load conditions should be considered during the evaluation or testing of these machines.

4.5.4. LOCATION OF CONDENSING UNIT: REMOTE OR PLUG-IN

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓*	✓	✓	×	×

** Remote configuration for service cabinets is extremely rare in the market.*

The compressor and the condenser can either be integrated in the product (plug-in units) or located in a remote location (remote units). In the case of remote products, the condenser is often located on the rooftop or outside of the building where the product is used. Having more space around the condenser provides a better heat exchange with the environment.

Depending on the difference between internal and external ambient temperatures, the efficiency of remote compared to plug-in equipment can vary. Lower ambient temperatures increase the heat transfer from the condenser.

Based on the findings of the preparatory study to TREN Lot 12, and on qualitative analysis, it is estimated that plug-in products usually present higher energy consumption than remote products[12].

Other explanations for lower energy consumption of remote products could include:

- larger condensers can be used since there are less space restrictions than in plug-in units. As described in §4.6.5. , a large surface area of the condenser allows greater heat exchange. Remote products could alternatively use water-cooled or evaporative condensers, which both present higher efficiency than the smaller air-cooled condensers, used in plug-in units[13].
- in the case of remote central refrigeration systems, the cooling load of compressor is shared by the different refrigerant equipments connected to it, including the remote cabinet. This optimises the compressor duty cycles, thus reducing the power demand of the system.
- due to the fact that many of the products covered in ENTR Lot 1 are located in professional kitchens, where internal ambient temperatures are often high, remote systems may benefit from lower external ambient temperatures.

However, remote units (especially supermarket packs) are in some cases maintained at condensing temperatures higher than those that can be achieved in internal ambient temperatures typical of comfort conditions in a populated space.

In addition, while a refrigeration system served by a remote condensing unit has a net cooling effect on the internal environment, which may require supplementary heating, the opposite is true of integral units which provide a net heat gain to the internal environment. This is because all heat removed from the refrigerated space

[12] Source: Mark Ellis & Associates. *Minimum Energy Performance Standards for Commercial Refrigeration Cabinets*. EECA Energy efficiency and Conservation Authority, June 2003

[13] Source: UK Catering Equipment Suppliers Association (CESA) www.cesaenergy.org.uk/Refrigeration.asp

plus that of the heat-generating components located externally of the refrigerated space is rejected locally.

One significant trade-off of remote systems is the potential increase in refrigerant leakage, compared to plug-in units. As remote systems are installed on-site, the level of workmanship may not reach the same quality of that achieved in dedicated manufacturing lines used to produce plug-in units, hence there may be increased leaks due to faulty piping connections.

4.5.5. Condenser cooling: air-cooled, water-cooled or evaporative condensation

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	✓	✓	✓*	✓

*(water-cooled and evaporative for remote condensing and process chillers only)

Air-cooled condensers are most commonly used, and require a greater surface area compared to water-cooled units, but are not subject to freezing or water problems; however, they may eventually be subjected to air corrosion problems. Air-cooled condensers also generate noise due to the operation of the fans, which can be an issue if disturbing neighbouring residences in urban areas. According to the opinion of some experts, air-cooled process chillers generally consume between 10 and 30% more power than a water-cooled unit, as a wet surface will transfer heat better than a dry surface. Water-cooled chillers generally require cooling towers, including piping and energy-consuming pumps.

Water-cooled condensers can be relatively small compared to air-cooled, due to the better heat transfer properties of water compared to those of air. However, water may be scarce or chemically unsuited for condenser cooling use. In addition, water-cooled condensers are subject to additional cost and need for water, and are at risk of scale, fouling, freezing, corrosion if water is in contact with outside air (relevant for open or semi-open water circuit), potentially dangerous bacteria, and biofilms. However, in the case of dry-cooled water condensers, there is no contact between water and air.

Evaporation-cooled condensers use a mist of water in combination with air to improve the heat transfer. The performance of these systems is better than that of air-cooled, but less than water-cooled.

4.5.6. Design: packaged or bespoke

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
×	×	✓	✓	✓

This topic is related to installation, which can affect product efficiency. As with remote compared to plug-in products, packaged and bespoke products can have varying levels of build quality. Bespoke units are often field-erected, which may affect refrigerant leakage if pipework is poorly constructed. Packaged units constructed on production lines are considered on average to have a higher build quality, and hence are likely to have lower levels of refrigerant leakage.

However, packaged products can often be installed by non-experts, due to the refrigerant being pre-charged. This lack of expertise may lead to inaccurate set-up for the required use, leading to reduced efficiency and higher energy consumption.

4.5.7. Door (and drawer) configuration

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	✓	✓	×	×

The type, size and number of doors (and drawers for service cabinets only) are important criteria determining the performance of products. This is due to their impact on the spillage of cold air from the product to the external environment, and inflow of warmer external air into the product, and also the transmission of heat from the external environment through the door and round its edges.

For example, every time doors are opened in service cabinets, the cooling load demand increases, due to cold air spillage and heat transfer from the surroundings. Drawers and/or half-doors are often advertised as enabling energy savings because they allow reaching for items in the service cabinet without exposing the entire refrigerated volume to the ambient atmosphere (unlike single larger doors)[14].

However, at this stage, no data was found to support such a statement.

4.5.8. Internal layout

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	✓	✓	×	×

The products covered in ENTR Lot 1 use forced air cooling, with fans forcing the cold air from the evaporator throughout the internal volume to regulate temperature (as opposed to static cooling which uses natural convection). As shelves are used to hold items inside the products, the internal layout can significantly affect the airflow from the evaporator, and a poor design of the interior shelf configuration can therefore disrupt the flow of cooled air through the product, and reduce the overall performance.

[14] Source: Caterer and Hotel Keeper, 12 October 2006

4.5.9. ORIENTATION

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	×	×	×	×

Orientation could also affect the energy consumption of service cabinets, as different air-flow patterns are achieved from the inside of the cabinet to the outside of the cabinet. Depending on the cabinet's orientation (vertical, chest or horizontal), the air flow pattern is altered. This affects:

- the air flow inside the cabinet's insulated casing; and
- the quantity of cold spillage when opening the service cabinet.

The cold spillage can be different depending on the door configuration, with horizontal chest cabinets typically being less subject to such losses. However, no quantified data is available at this stage.

4.5.10. VAPOUR-COMPRESSION OR ABSORPTION

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
×	×	×	✓	×

Due to the refrigerant used and the refrigeration cycle, an absorption chiller is less efficient than a vapour compressor refrigeration cycle.

To operate absorption chillers a heat source such as steam or hot water is needed. This source can be generated by a boiler or waste heat can be used. In general, the cycle, where the heat source has higher temperature, is more efficient. However, there are some limitations due to technical issues as corrosion protection for example.

Due to these technical differences, and only to provide indicative figures, the recommended energy performance levels for *air-conditioning* chillers as per the US ASHRAE Standard 90.1-2007 are as follows:

Table 4-1: Performance levels for chillers used for air-conditioning according to ASHRAE 90.1-2007 table 6.8.1.C

Chiller	Capacity (RT – refrigeration ton)	COP	IPLV
Air cooled electrical	All	2.80	3.05
Air cooled w/o condenser	All	3.10	3.45
Water cooled Reciprocating	All	4.20	5.05
Water cool screw rotary and scroll	< 150 RT	4.45	5.20
	≥ 150 RT and < 300 RT	4.90	5.60
	≥ 300 RT	5.50	6.15
Water cool Centrifugal	< 150 RT	5.00	5.25
	≥ 150 RT and < 300 RT	5.55	5.90
	≥ 300 RT	6.10	6.40
Air cooled absorption single effect	All	0.60	
Water cooled absorption	All	0.7	
Absorption double effect indirect fired	All	1.00	1.05
Absorption double effect direct fired	All	1.00	1.00

*COP – Coefficient of Performance

*IPLV – Integrated Part Load Value

The absorption chiller has very low efficiency versus vapour compression cycle (3 to 6 times less efficient), however benefits from the fact that it does not use electricity to drive the refrigeration cycle. Electricity is a high value energy form (with its own inherent inefficiencies such as generation and transmission losses) and vapour compression exclusively requires electricity. Absorption chillers typically use low grade heat or waste heat to drive the refrigeration cycle, partially avoiding electricity use.

4.5.11. Individual or parallel compressor units

Relevance:

Service cabinets	Blast cabinets	Walk-in cold rooms	Process chillers	Remote condensing units
✓	××	✓	✓	✓

*remote condensing in for all the products

Using one compressor on several fixtures results in the greater efficiency of compressor motors, because they are larger. Besides, more heat can be captured from the equipment for heating the space or for heating water. The disadvantages of that product are as follows:

- the refrigeration load cannot be closely matched;
- starting and stopping larger compressors is harder;
- short cycling larger compressors may increase both electrical demand and consumption charges; and
- larger compressors are more sensitive to refrigeration load.

On the other hand, using parallel compressor units (to apply two or more compressors to a common suction header, a common discharge header and a common receiver) results in the potential for more effective load matching. Compressors are subsequently turned on or off in response to the changing load.

Other advantages are diversification, flexibility, higher efficiencies, lower operating costs and less compressor cycling. The drawback of this kind of system is that any leaks affect the entire compressor rack[15].

Although the use of parallel compressors is possible for bigger blast cabinets, those included within the scope do not commonly include this feature.

[15] Refrigeration & air conditioning technology Par William C. Whitman, William M. Johnson, John Tomczyk

4.6. COMPONENT TECHNICAL ANALYSIS

The performance of the refrigeration system depends on the components it includes. This section describes the different components found in refrigeration equipment.

4.6.1. ELECTRIC MOTORS

4.6.1.1 Characteristics

There are a variety of types and sizes of motors, depending on the application requirements. The power range of motors used in the refrigeration sector is mainly between 0.3 to 2,000kW and they are responsible for the 33% energy consumption used in the refrigerator sector[16], although for products in the scope of ENTR Lot 1, motors under 300W are often used.

- **Start-up type**

Single-phase induction motors require separate starting windings to assure proper start rotation and sufficient starting torque. The type of start-up differentiates the three main types of single phase induction motors, which include the shaded pole motor, the permanent split capacitor motor (PSC), and the electronically commutated permanent magnet motor (ECM).

- **Direct and alternating current**

Both DC (Direct Current) and AC (Alternative Current) electric motors can be used for refrigeration applications. Higher efficiency fan motors reduce energy consumption by requiring less electrical power to generate motor shaft output power; efficiency of the motor can be calculated in percentage, via dividing power output by power input. AC motors are in general simple and cheaper than equivalent DC machines, they do not have commutator, slip rings or brushes. The stator winding in connected to the AC source and the induction produces the currents in the rotor.

Motor controls are devices that monitor the speed of a fan motor (it can be two speeds or more). Therefore, they control its efficiency indirectly as well as energy efficiency. They are usually made out of several blocks of sensors and electronic circuits which physically modulate the power to modify speed.

- **Variable speed drive**

During the past several years, variable-speed-drive (VSD) for compressors and heat exchanger fans has become an option for manufacturers of refrigeration equipment. However, this option has not been commonly applied to some refrigeration equipment like blast cabinets due to their intensity of use. This type of equipment stops the blast chilling/freezing cycle when the food temperature is lower than a specific level. According to industry stakeholders, this option might have positive impacts in the energy consumption, but they are not currently applied to small machines like blast cabinets.

[16] Cold Hard Facts, prepared by Energy Strategies in association with Expert Group, 2007

DC motors allow modulating the frequency of the power input and thus the rotation frequency of the motor and are much easier to control than single phase AC motors, for which a current converter is needed.

Modulation of the VSD motor is achieved in two ways; through varying the frequency of the applied waveform to the motor windings, or varying the peak voltage of the waveform applied to the motor windings. These two parameters allow for control over the torque and speed of the motor at any operating condition.

Inverter systems control the rotational speed of an AC electric motor by controlling the frequency of the electrical power supplied to the motor and generally consist of an AC motor, a controller and an operator interface. The conversion losses from AC to DC and back can be up to 5% per step, even though these have been reduced significantly recently.

An example of a voltage varied waveform is given with the clipper. The clipper is a device that limits the voltage without affecting the rest of the waveform. It can be made of resistors, connection of diodes or transistors.

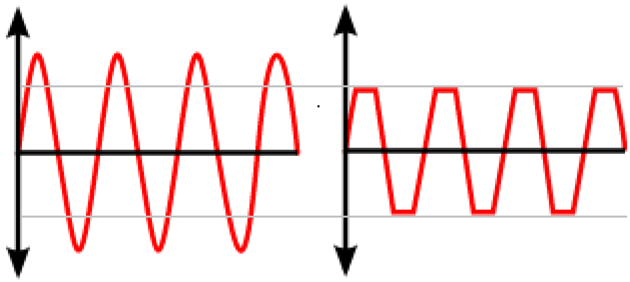

Figure 4-7: Voltage clipping mechanism demonstrated on a sine waveform

4.6.1.2 Shaded pole motor

The shaded-pole induction motor is a single-phase motor. In a shaded-pole motor, the starting windings are shaded by a copper loop. The interactions between the magnetic field generated by the shaded portion and that generated by the un-shaded portion induce rotation when the motor is powered. The imbalance between the shaded and un-shaded portions of the magnet remains throughout operation. As a result, shaded-pole motors used in commercial refrigeration applications, with low output power, are inefficient. Shaded-pole motors are, however, electrically simple and inexpensive.

4.6.1.3 Permanent split capacitor motor

In a PSC motor, a smaller, start-up winding is present in addition to the main winding. The start-up winding is electrically connected in parallel with the main winding and in series with a capacitor. At start-up, the interactions between the magnetic field generated by the start up winding and that generated by the main winding induce rotation. Because of the capacitor, however, the current to the start-up winding is cut off as the motor reaches steady state. Because of this, PSC motors are more energy efficient than their shaded-pole counterparts. Like shaded-pole motors, PSC motors are produced in large quantities and are relatively inexpensive[17].

These motors are more suitable for continuous use systems, since they cannot provide an initial "boost" and they have low torque (30 to 150% of the rated load). PSCs have lower starting currents than split-phase motors[18] (less than 200% of the rated full-load current). These are categorized as very good equipment for high cycle rate applications[19].

The advantages of PSCs are that:

- they are designed for high efficiency and high power factors at rated load;
- due to their increased efficiency compared to standard shaded pole motors, the PSCs used within a refrigerated enclosure release less heat, and therefore reduce the relative heat load that must subsequently be removed by the refrigeration system, reducing system energy consumption (see Figure 4-9); and
- they do not require a starting switch, which makes them more reliable.

The common applications for this equipment are: direct drive fans, blowers with low starting torque requirements and intermittent cycling applications with reversing requirements.

4.6.1.4 Electronically commutated permanent magnet motor

ECM is a high efficiency programmable brushless DC motor using a permanent magnet motor and an electronic speed controller. It is more energy-efficient than either shaded-pole or PSC motors, but ECM motors are more complex than either shaded pole or PSC motors, particularly for commercial refrigeration applications, because they are internally powered with DC power. In ECMs, the electromagnets do not move and the brush-system assembly normally used to invert the magnetic polarity is replaced by an electronic controller. A power supply is required to convert from AC line power to DC, and control electronics are required to handle the electronic commutation, i.e. switching the power to the motor windings in synchronization with motor rotation.

For this reason, ECM motors can weigh more than shaded pole or PSC motors, and they are more expensive. The cost of ECMs can be up to 2.5 times higher, and the high price of ECM technology for compressors makes it advantageous only for capacities over 10kW. This depends on the total price of the product and the energy savings provided[20]. They are still customised without suitable standards to allow a commodity market to develop. The mass production for specialised

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[17] Arthur D. Little Inc, Energy Savings Potential for Commercial Refrigeration Equipment, US DOE, 1996

[18] www.toolingu.com/definition-460240-34008-split-phase-motor.html: "A single-phase motor that consists of a running winding, starting winding, and centrifugal switch. The reactance difference in the windings creates separate phases, which produce the rotating magnetic field that starts the rotor".

[19] www.electricmotorwarehouse.com/plant_services.htm

[20] For example, for a remote condensing unit for commercial refrigeration below 10 kW, the use of an ECM in the compressor can increase the price of the product by 20%, and can achieve energy savings of up to 10%.

applications has lowered their cost[21] and they may become a common component in low-power compressors.

For example, ECM motors are used for compressors in small mobile cooling appliances. Although their numbers are low and price high, this provides evidence of the potential future applicability of this kind of motor to small compressors. These options are further investigated in Task 5.

In addition to direct energy savings achieved through their high efficiency, ECM motors used within a refrigerated enclosure release less heat, and therefore reduce the relative heat load that must subsequently be removed by the refrigeration system, further reducing system energy consumption (see Figure 4-8 and Figure 4-9). ECMs are also easier to control than single phase shaded-pole AC motors. Stakeholders have claimed that ECMs provide twice the life expectancy of small shaded-pole motors.

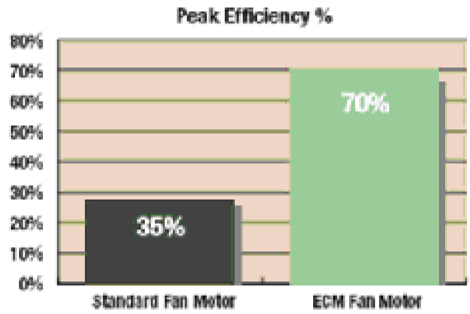


Figure 4-8: Comparison of the efficiency of two types of fan motors[22]

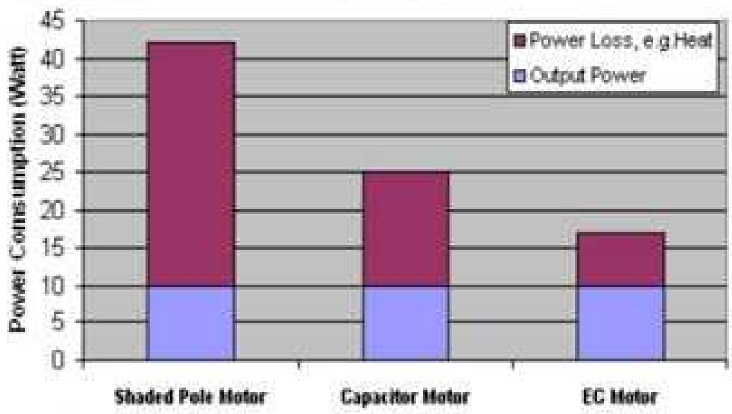


Figure 4-9: Comparison of the power consumption of types of fan motors[23]

4.6.1.1 Application in refrigeration products

Fans in the region of 10 to 20W typically use shaded pole motors, whereas fans above 40W normally use PSC motors; ECM motors are commonly available up to approximately 40W, with most in the range of 10 to 12W (these are increasingly used in refrigerated display and service cabinets due to significant potential to

[21] EUP TREN Lot 11 Motors Final Report. May 2008.

[22] Source: Puget Sound Energy

[23] Source: ebm-papst Landshut GmbH

reduce heat load, energy consumption and hence energy costs)[24]. Ranges of motor power typically used in the fans integrated in products covered by ENTR Lot 1 are described in Table 4-2.

Table 4-2: Electric fan motor power ranges, types, efficiencies and applications[25]

Electric motor power range (W)	Efficiency (%)	Typically used in the following product:
5-70 AC	20-30	Service cabinets, walk-in cold rooms
5-70 ECM DC	60-70	
70-770 AC	40-60	Blast cabinets, walk-in cold rooms, RCUs, chillers
70-770 ECM DC	90-95	
500-2,000 AC	75-85	
500-2,000 ECM DC	90-95	

Table 4-3 describes typical power ranges for motors used in different types of compressors.

Table 4-3: Electric motor sizes used in compressors[26]

Power range of motor (W)	Compressor type
190 – 22,500	Hermetic reciprocating
3,500 – 53,000	Hermetic scroll
1,800 – 90,000	Semi-Hermetic reciprocating
8,000 – 223,000	Open reciprocating
84,000 – 1,905,000	Open screw
84,000 – 1,905,000	Semi-hermetic screw

4.6.1.2 Performance

As described, efficient fan motors reduce energy consumption by requiring less electrical power to generate motor shaft output power. A further comparison of motor efficiencies is provided in Table 4-4.

[24] Source: Remco

[25] Adapted from: Mark Ellis, In from the cold – Strategies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealand

[26] Mark Ellis, In from the cold – Strategies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealand

Table 4-4: Efficiency data for types and power outputs of motors[27]

	SPM		PSC		ECM	
Power output (W)	Power input (W)	Thermal Efficiency (%)	Power input (W)	Thermal Efficiency (%)	Power input (W)	Thermal Efficiency (%)
373	-	-	530	70.38	450	82.89
249	-	-	370	67.30	304	81.91
125	329	37.99	202	61.88	155	80.65
50	-	-	90	55.56	65	76.92
37	110	33.64	70	52.86	49	75.51
25	100	25.00	51	49.02	33	75.76
20	90	22.22	42	47.62	27	74.07
15	75	20.00	33	45.45	20.5	73.17
9	53	16.98	21	42.86	12.5	72.00
6	40	15.00	15	40.00	8.5	70.59

From Table 4-4, a relationship between the efficiency of the motor and the power output can be set up as shown in Figure 4-10.

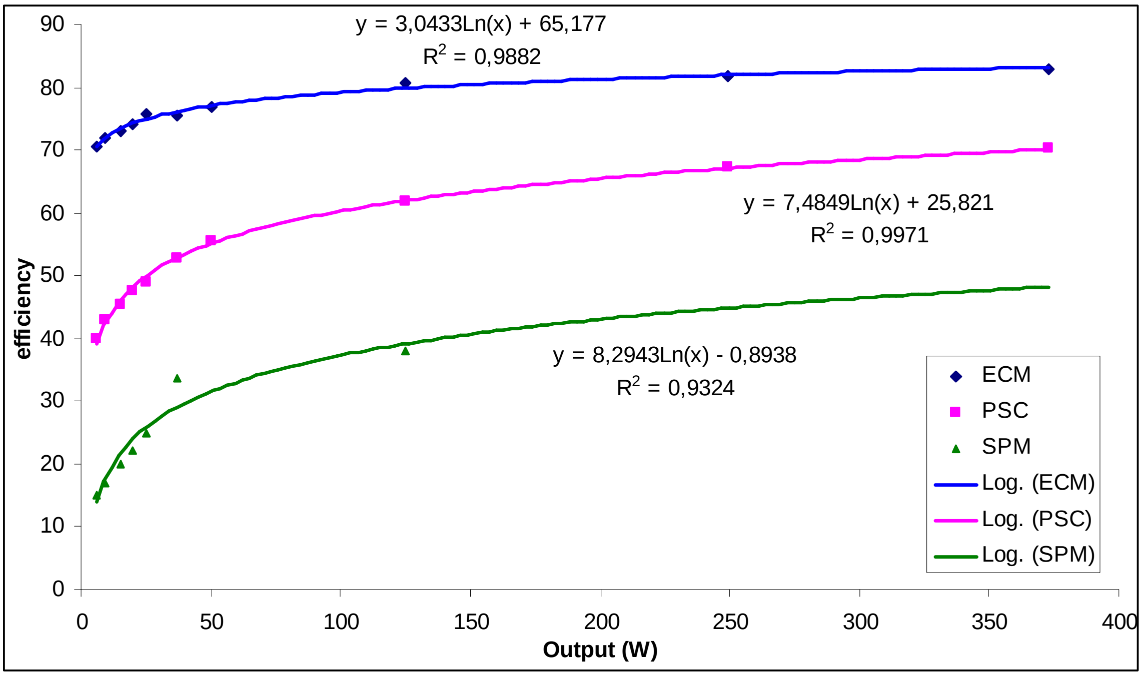


Figure 4-10: Comparison of the efficiency to power output of shaded pole (SPM), permanent split capacitor (PSC) and electronically commutated (ECM) motors

This demonstrates the significant difference in the efficiencies of the three motor technologies, and suggests that the rate of decline in efficiency of shaded pole and PSC motors is greater compared to that of ECM as fan power decreases from around 25W.

4.6.1.3 Regulation

CE marking for electric motors sold onto the EU market is managed through self-certification, hence testing is reliant on the manufacturer.

[27] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)

As discussed in Task 1, Ecodesign requirements for electric motors have been developed in the framework of the Ecodesign Directive 2009/125/EC based on the TREN Lot 11 preparatory study[28]. Minimum efficiency requirements have been established for electric motors in Commission Regulation (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors[29]. Electric motors used as external power source for semi-hermetic and open compressors are sold separately and thus are covered by the Commission Regulation (EC) No 640/2009 and are not analysed in the ENTR Lot 1 preparatory study. The regulation is, however, not applicable to electric motors completely integrated into other products, such as hermetic compressors, and only covers three-phase motors from upward of 750W (motors within the scope of ENTR Lot 1 are frequently single-phase and have low power input).

However, fans are under consideration for separate regulation, as discussed in Task 1, for powers from 125W upward, including those fans integrated into other products. This will therefore cover some of the fans integrated into products covered in ENTR Lot 1, but not those fans with power below 125W, which are often used for evaporator and condenser fan-coils.

Hence, a gap in current and foreseeable regulation exists for these small single-phase motors and fans incorporating them.

4.6.2. COMPRESSOR

The compressor receives the refrigerant coming from the evaporator, at low pressure and low temperature, compresses it, and pumps it on towards the condenser at high pressure and high temperature. The compressor efficiency is expressed in terms of Coefficient of Performance (COP), which is the ratio of the cooling load divided by the compressor power. This value can be compared to the cooling system's carnot efficiency (or COP carnot), which is the system's theoretical maximum possible COP. The COP carnot is defined as the evaporating temperature divided by the temperature difference between the evaporating and condensing temperatures, in K.

[28] TREN Lot 11 Website: www.ecomotors.org/

[29] COMMISSION REGULATION (EC) No 640/2009 of 22 July 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for electric motors

4.6.2.1 Types

Compressors can be divided into two categories according to the compression type: positive displacement compressors and dynamic compressors. In commercial refrigeration positive displacement compressors are used.

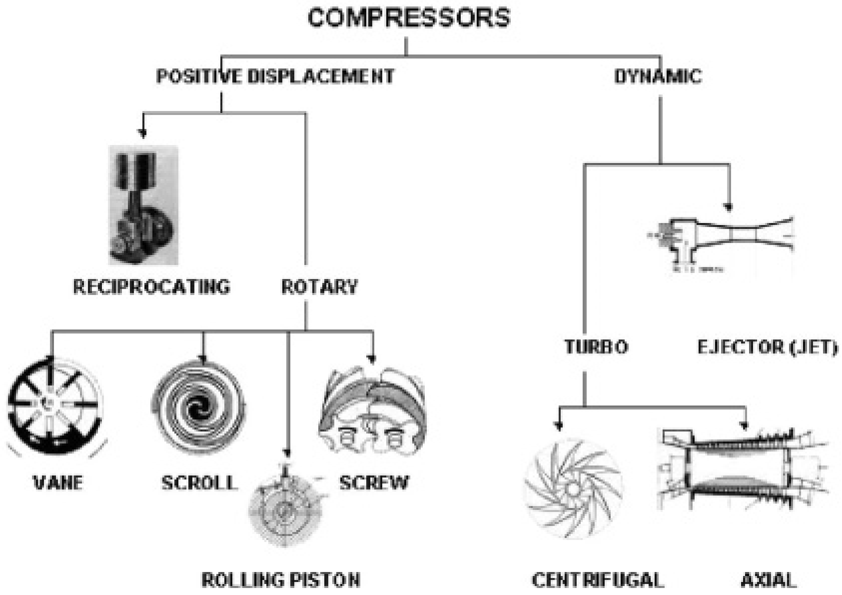


Figure 4-11: Types of compressors

- **Positive displacement compressors** confine successive volumes of refrigerant within a closed space in which the pressure of the fluid is increased by decreasing the volume in which the refrigerant is contained. Reciprocating, screw, and scroll are common positive displacement compressors.

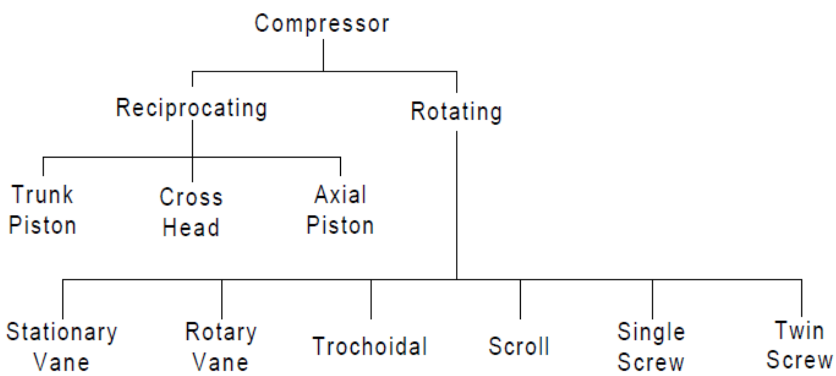


Figure 4-12: Classification of positive displacement compressors

- **Dynamic compressors** use rotating vanes or impellers to impart velocity and pressure to the refrigerant. Centrifugal compressors are the most popular compressors of this category. Other dynamic compressors include axial types; however these are not used in commercial refrigeration applications.

Another way to classify compressors is based on the motor configuration:

- In an **open compressor**, the compressor motor and the compressor are in separate casings. Such configuration allows easy access to the components for maintenance. However, this open architecture often results in refrigerant leaks. This type of configuration is only used in remote refrigeration systems. When ammonia is used as the refrigerant, an open compressor is the only solution because the refrigerant could have a corrosive effect on the copper contained inside the motor if sealed completely.

- In a **hermetic compressor**, the motor and compressor are located in a closed space, which allows tightness against refrigerant leakages. In this kind of compressor, the refrigerant is used to cool the motor. These compressors are mostly used for small and medium power ranges (less than 40 kW[30]).
- A **semi-hermetic compressor** has motor and compressor assembled together, with possible access to key parts such as valves and connecting rods. In comparison with open compressors, they have an improved tightness but it is not absolute as in hermetic compressors. As in the case of hermetic compressors, the refrigerant is used to cool the motor.

The main types of compressors used in commercial refrigeration equipment are hermetic reciprocating (piston) and scroll, with some screw compressors used in large machines. Rotary vane compressors are not used in commercial refrigeration equipment, this type of compressors is used mainly in air conditioning systems. Figure 4-13 shows the main compressors used in commercial refrigeration.

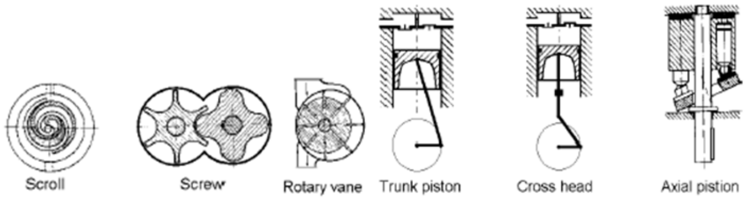


Figure 4-13: Types of compressors: scroll, screw, rotary vane and different reciprocating (piston)[31]

Reciprocating compressors are positive displacement compressors; an electric motor is driving the crank gear and moving pistons to compress and release the gas. Semi-hermetic reciprocating compressors are used in higher cooling capacities and can achieve higher efficiencies than hermetic reciprocating compressors

Table 4-5 provides power ranges typically available for different types of compressors.

[30] Source: Hydro Québec, Guide technique, systèmes de compression et de réfrigération, 1994

[31] Jürgen Süβ, Impact of refrigerant fluid properties on the compressor selection.

Table 4-5: Range of refrigeration power according to the type of compressor[32]

Type of compressor	Range of use
Reciprocating hermetic	Up to 60 kW
Reciprocating semi-hermetic	Up to 500 kW
Reciprocating open	Up to 1,200kW
Scroll	Up to 100 kW
Screw	20kW up to 1,200kW

NB: Several compressors with different cooling capacity can be set in parallel

However, it should be noted that these ranges are flexible (see **Figure 4-14**), and no reciprocating compressors with capacity higher than 200 kW have been found in the market. Besides that, the evaporating temperature is also important for the capacity needed in a compressor in order to be operative. For negative evaporating temperatures, i.e., hermetic reciprocating compressors are only used up to 5.7 kW, scroll compressors up to 10 kW and semi hermetic compressors can be used to achieve higher cooling capacities[33].

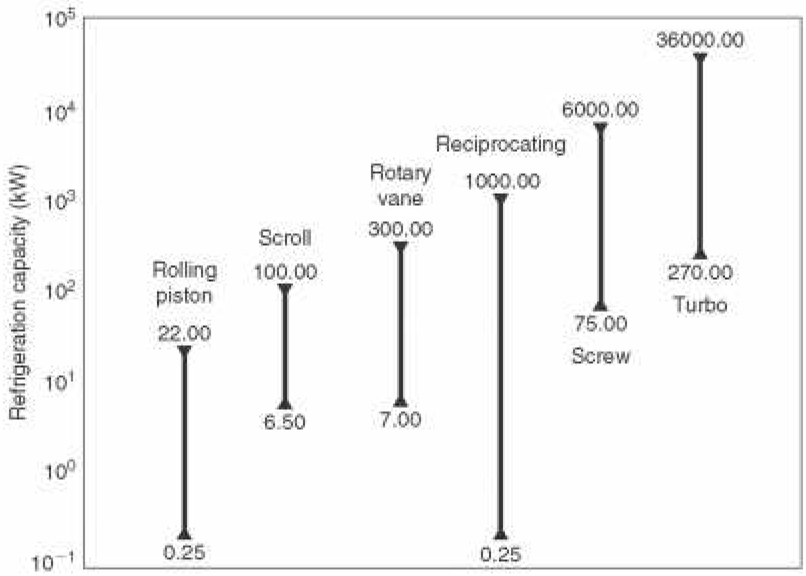


Figure 4-14: Approximate capacity ranges for compressors[34]

Most plug in refrigerated service cabinets and blast cabinets use hermetically sealed, electric motor driven compressor units with a reciprocating compressor. Open or semi-hermetic compressor units are commonly used for remote refrigeration systems. Figure 4-15 shows the internal elements of a typical hermetic reciprocating compressor.

[32] Reference: Direction générale des Technologies, de la Recherche et de l'Energie (DGTRE) du Ministère de la Région wallonne

[33] Source: Bitzer

[34] Source : Refrigers.com

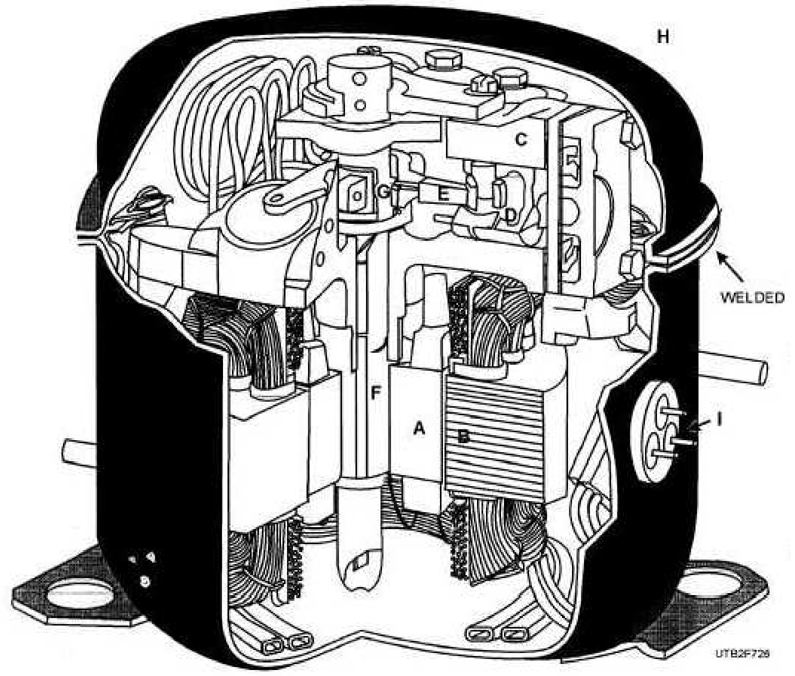


Figure 7-26.—Reciprocating hermetic compressor. (A) Motor rotor; (B) Motor stator; (C) Compressor cylinder; (D) Compressor piston; (E) Connecting rod; (F) crankshaft; (G) Crank throw; (H) Compressor shell (I) Glass sealed electrical connection.

Figure 4-15: Cutaway diagram of a hermetic reciprocating compressor

4.6.2.2 Characteristics

Table 4-6 gives an overview of the main characteristic values of compressors depending on the type of appliance (plug in compared to remote)[35]. The following data are assessed at the following rating points, including Suction Gas Temperature (SGT):

- low temperature: Evaporating -35 °C / Condensing +40 °C / SGT +20 °C / Subcooling 0 K;
- medium temperature: Evaporating -10 °C / Condensing +45 °C / SGT +20 °C / Subcooling 0 K.

Table 4-6: Overview of compressor characteristics

Type of Appliance	Feature	Range	
		LT	MT
Self-contained (R404A	Cooling capacity range	0.5 to 2.0 kW	0.8 to 4.0 kW
	Nom. COP Range	0.9 to 1.28	1.4 to 2.0
	Average COP	1.10	1.70
Remote (R404A)	Cooling capacity range	>3 kW	>8kW
	Nom. COP Rang	1.10 to 1.48	1.83 to 2.37
	Average COP	1.25	2.10

As can be seen in the table above, the COP is higher for medium temperatures which means that compressors perform better at these temperature ranges rather than at low temperatures. Moreover, capacity ranges affect performance of compressor and in general compressors are more efficient in bigger capacity ranges as well as in remote appliances. It has to be noted that differences between

35 Tested to standard EN12900

cooling capacity ranges for LT and MT appliances in this table might be due to dimensions of products (different net volumes) and so the cooling capacity ranges do not represent the energy consumption.

In typical screw compressor-based refrigeration systems, compressor lubricant may comprise on the order of 10% by weight of the compressed refrigerant gas discharged from the compressor and, despite the availability and use of 99.9% efficient oil separators, 0.1% of the lubricant available to a screw compressor is continuously carried out of the compressor-separator combination and into downstream components of the refrigeration system. The lubricant typically makes its way to the low-side of the refrigeration system and concentrates in the system evaporator.

The low-side of a refrigeration system is the portion of the system which is downstream of the system expansion valve but upstream of the compressor where relatively low pressures exist, while the high-side of the system is generally downstream of the compressor but upstream of the system expansion valve where pressures are relatively much higher.

Despite the high efficiency of the oil separators used in such systems, a compressor will lose a significant portion of its lubricant to the downstream components of the refrigeration system over time. Failure to return the oil to the compressor will ultimately result in compressor failure due to oil starvation.

In some screw compressor-based refrigeration systems, so-called passive oil return has been used to achieve the return of oil from the system evaporator to the compressor. Passive oil return utilises conditions which are inherent in the normal course of system operation, such as the velocity of suction gas, to carry or drive oil from the system evaporator back to the system compressor without the use of "active" components, such as mechanical or electromechanical pumps, float valves, electrical contacts, eductors or the like, which must be separately or proactively energized or controlled in operation.[36]

4.6.2.3 Performance

The compressor performance is affected by:

- the temperature lift (difference between evaporating and condensing temperatures);
- the properties of the refrigerant (e.g. centrifugal compressors are best suited for low evaporator pressures and refrigerants with large specific volumes at low pressure, on the other hand reciprocating compressors perform better over large pressure ranges and are better able to handle low specific volume refrigerants[37]).
- the temperature of the superheated suction vapour (achieved using a suction/liquid line heat exchanger). If superheat is not usefully obtained, the efficiency will be reduced because the specific volume of the suction gas will increase, reducing the mass flow and thus reducing the refrigerating capacity of the compressor for the same power consumption. In addition, if

[36] www.patentstorm.us/patents/5761914/description.html
[37] http://www.scribd.com/doc/22244125/vapour-compression-refrigeration

the temperature of the superheated suction vapour is too low liquid refrigerant may return to the compressor and damage it.

- the use of intercooler systems to pull down the temperature of the refrigerant before entering the compressor.

4.6.2.4 Selection

As described above, the efficiency of the compression process is influenced by the thermodynamic properties of the applied refrigerant. To obtain the maximum performance of a vapour compression process, a compressor design has to be selected so offers the best perspective to match the requirements given by the application and the selected refrigerant. One of the most important characteristics of the refrigerant are the pressure ratio at a given temperature (evaporating temperature of the application). A temperature increase or a pressures decrease of a refrigerant results in an increase of the specific volume and a reduction of the volumetric efficiency of the compressor, and should be minimized. When minimising the occurring pressure drop of the suction gas, compressors of the rotating type are favourable, since there is no need to re-expand clearance volume gas in this kind of machines[38]. Table 4-7 shows recommendations of compressor types for selected evaporating temperatures, cooling capacities and refrigerants.

Table 4-7: Recommendation of compressors for various refrigerants and applications[38]

	Application					
	Low temperature			Medium temperature		
	Compressor power input in kW			Compressor power input in kW		
Fluid	< 1	≤ 10	>10	< 2	≤ 20	> 20
R22, R134a	recip	recip	screw	recip, vane	recip	screw
R290	recip	recip	screw	recip	scroll	screw
R404A; R507	recip	recip	screw	recip	recip	screw
R407C	recip	recip	screw	vane, recip	recip	screw
R410A	recip	recip	screw	recip	recip	screw
R600a, R717	vane	vane	screw	vane	vane	screw
R744	recip	recip	recip	recip	recip	recip

The COP is mainly affected by the temperature lift (difference between evaporating and condensing temperatures). Figure 4-16 shows that for the same evaporating temperature, the lower the condensing temperature, the higher the COP. A decrease of +1°C in the temperature lift will involve an increase of the COP by 2 to 4 %.

38 Jürgen Süss, Bjarne Dindler Rasmussen, Arne Jakobsen. Impact of refrigerant fluid properties on the compressor selection.

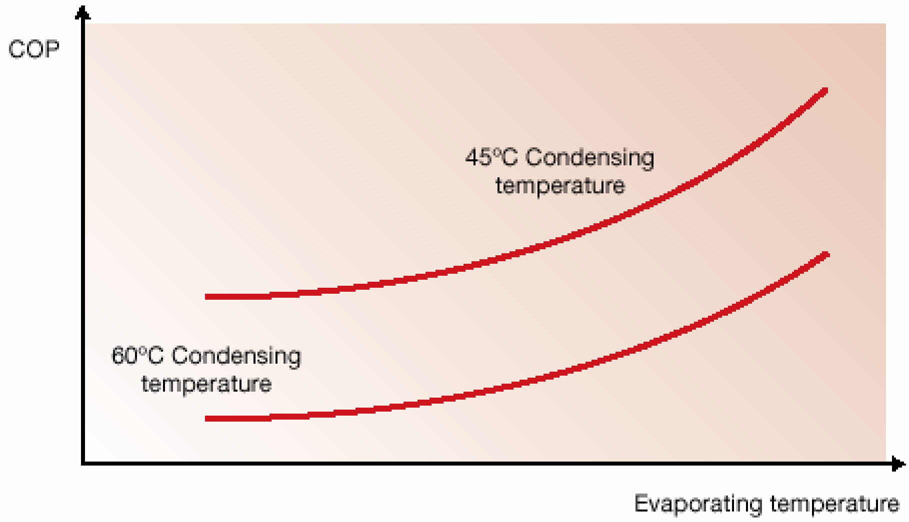


Figure 4-16: COP for a typical compressor according to the temperature lift[39]

However, each compressor technology has an optimum application range. The most efficient compressor for a specific application depends on parameters that are specific to that application (such as cooling capacity), and therefore this should be taken into account when assessing compressor technologies.

Table 4-8 below shows the average compressor type used for different cooling capacities, according to information provided by stakeholders. The drivers in this decision are mostly production, installation and running costs.

Table 4-8: Compressor types used by cooling capacity ranges

0kW-20kW	20kW-50kW	>50kW
• Reciprocating hermetic	• Reciprocating hermetic • Reciprocating semi-hermetic • Scroll • Screw	• Reciprocating semi-hermetic • Scroll • Screw

In general, the first technology for compressor application is reciprocating with an average COP of 2.5. Following this, scroll and screw compressors were introduced to achieve higher efficiency levels for refrigeration compressors since they use less power to rotate than pistons and cranks. For example, the scroll compressor can achieve up to 30% of efficiency improvement compared to reciprocating technology, if it is used at the workload and ambient conditions it was designed for. Scroll and screw compressors in principle offer more reliability than reciprocating compressors, if the oil system is designed and maintained properly, but under deviation on the working conditions, the energy performance of these types of compressors decreases more severely compared to reciprocating types. The market prices are around 25% higher for equivalent sizes of scroll type compressors compared to reciprocating type. The latest development – centrifugal compressor is generally more efficient than rotary vane screw and scroll types.[40]

[39] UK Energy Efficiency Best Practice Program. *Energy efficient refrigeration technology – the fundamentals,* Good Practice Guide n°280. Available at: www.cibse.org/pdfs/GPG280.pdf

[40] Mark Ellis & Associates, In from the cold – Strategies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealand, 2009

Moreover, the improved gas management as well as optimised motor matching to the specific compressor displacement and its application might improve the COP within existing technologies.

In medium temperature applications (i.e. between i.e. between 0°C and +4°C)[41], the COP of a scroll compressor is assumed to be higher than for a reciprocating compressor at operating conditions, assuming an annual average condensing temperature between +20°C and +30°C, which is representative of today's applications. For low temperature applications, standard scroll compressors show lower COPs. Therefore, the choice of the compressor depends mostly on average annual evaporator and condenser temperatures.

A compressor is chosen to supply enough power even during high cooling loads. However, most of the time, it does not operate at 100%. Therefore the compressor with the best COP under nominal conditions (with maximal cooling load) is not necessarily the best under real operation conditions.

The ideal choice of the compressor should depend mostly on average annual evaporator and condenser temperatures.

4.6.2.5 Control

Traditional compressor motors run multiple start-stop cycles in order to maintain the desired temperature. Compressor control can enable adaptation of the cooling capacity to changing operating conditions. Several control devices are available to optimise compressor operation to the cooling power required:

- **On/off control**: these controllers are applicable to a wide range of compressors and are the most common control type. They are simple in action and not very expensive. They activate or de-activate the equipment through readings taken from a probe (e.g. pressure drop). This technology seems to be the most common in the market.
- **Cylinders control:** in reciprocating compressors, the suction vapour is stopped from entering one or more cylinders, thus reducing the pumping rate of the compressor. This technology does not seem to be of general use in the market.
- **Step control:** used when several compressors are installed in parallel, one or more of the compressors can be deactivated to effectively achieve a partial load operation of the system. This is more effective than having one larger compressor working at low capacity. This technology, due to the high cost of having a second compressor, is only applied in condensing units of medium and high capacity, over 20kW-30kW.
- **Continuous compressor capacity control:** generally achieved through variable speed or similar technologies. The speed of the motor is adapted according to the cooling power required.
- **Digital modulation control:** a continuous capacity modulation technique specifically developed for scroll compressors. Digital modulation not only controls the speed of the compressor motor, but also the flux of the

[41] Source: Thermal evaluation of low and medium temperature refrigerated facilities. Phillip C. McMullan; TSI Thermo Scan Inspections; Indiana USA

refrigerant and other components of the condensing unit such as the expansion valve. This technology is claimed to achieve higher energy savings than variable speed motors in conditions of variable workload. However, if the system works at full load, most of the time the digital variable speed technology is not beneficial.

Without taking into account the price, the choice of the control depends on the type of compressor, and real-life operational conditions.

The common industry practice for larger remote refrigeration systems is to over-size design capacity in order to add a safety margin due to the potential risk issues resulting from insufficient capacity (e.g. during times of high ambient temperature for a given climate). Therefore, compressors in large refrigeration systems often work at part-load. It is estimated that compressors in refrigeration systems work at an average capacity of 70%-80% of the full load, with seasonal peak variations of 30%-40%. Within this scenario, a VSD compressor is more efficient, hence the most efficient architecture should be analysed and chosen regarding the overall performance of the system.

For compressors, VSD adaptation to load can reduce the refrigerant flow rate and consequently to operate at lower pressure ratio than at full capacity, improving the efficiency as compared to full capacity. A motor that modulates the compressor speed rather than switching on/off, adjusting it to the workload, also increases the reliability and durability of the compressor.

At full load, a VSD compressor is not as efficient as a comparable constant speed compressor because the variable-frequency drive increases power draw by 2% to 4%. In addition, for variable speed compressors integrating DC inverter systems, the efficiency of the compressor decreases because of the efficiency loss induced by the inverter, around 3 to 5%.

As 100% power is approached, the constant-speed compressor is more efficient than the VSD compressor. Therefore VSD compressors only allow energy savings when working under part load conditions. Generally, if a constant-speed compressor is expected to operate above 80% of its capacity, it is the more efficient choice. On the other hand, if the constant-speed compressor operates below 80% of its capacity, then replacing it with a VSD compressor will provide additional savings.

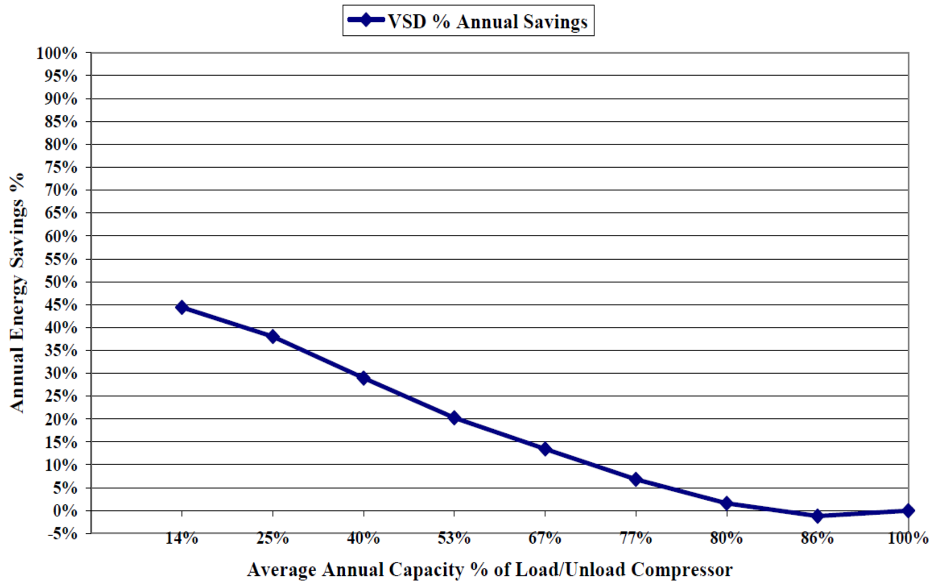


Figure 4-17: The annual savings percentage available by installing a 93 kW VSD compressor versus a 93 kW constant speed compressor[42]

Therefore, when the workload and air-on temperature are mostly constant during the year, variable speed controls do not achieve energy savings compared with on-off controls.

VSD compressors are well suited as trim compressors, working in parallel with 1 base load compressor. The base-load compressor operates at a constant-speed, at its maximum efficiency as required, while the trim VSD compressor would cycle on and off in order to match fluctuating system demand. However, these savings are only achievable in large capacity units, when the compressor rarely works at full capacity.

4.6.3. Expansion device

The expansion valve is a device used to control the refrigerant flow rate to match the amount of refrigerant being boiled off in the evaporator, adapt the cooling capacity to meet demand, and regulate the superheating of the refrigerant. The valve provides the flow resistance necessary to maintain a pressure drop in the system, separating the high pressure side (P2 in Figure 4-2) from the low pressure side (P1 in Figure 4-2).

Expansion devices used in refrigeration appliances are:

- capillary tubes (typically found in smaller refrigerating and freezing equipment) and orifice plates;
- thermostatic expansion valves (with balanced port for bi-flow applications); and
- electronic expansion valves (e.g. modulating or stepper technology).

[42] Chris E.Beals, *Unwinding the Spin on Variable Speed Drive Air Compressors*, Proceedings of the Twenty-Eighth Industrial Energy Technology Conference, New Orleans, LA, May 9-12, 2006

4.6.3.1 Capillary tube

The capillary tube is small diameter tubing that offers the restricted flow of the refrigerant. The pressure drop attained through the capillary depends upon its diameter and length. Capillary tubing is used for small refrigerating and air-conditioning systems. Overcharging can lead excessive high discharge pressures from the compressor, which leads to over loading of the compressor and the chances of refrigerant leakages from the system are also increased[43]. Capillary tubing is usually made of copper.

4.6.3.2 Thermostatic expansion valve

A typical thermostatic expansion valve (TEV) comprises a valve body, a stem connected to a spring and to a metal membrane, and a sensing system consisting of a bulb and a capillary tube which is partially filled with some refrigerant. The inside of the valve is in open contact with the evaporator but separated from the sensing system by the membrane. The bulb is placed in contact with the end of the evaporator. Above the membrane, the pressure corresponds to the evaporation temperature of the refrigerant in the bulb (bulb pressure) which itself corresponds to the temperature of the superheated refrigerant vapour.

A TEV is chosen according to the system's pressure drop and design evaporator cooling capacity adjusted with the subcooling to ensure the desired evaporating temperature and superheat is reached for a set condensing temperature. This type of valve is set to maintain approximately the same superheat at the end of the evaporator at all conditions. The mass flow of refrigerant through the evaporator will vary in response to the changes in the heat load sensed by the bulb. If the compressor is stopped, no superheat is sensed and the valve is closed.

A basic thermostatic expansion valve operates depending on three forces, demonstrated in Figure 4-18. These are:

- the closing force P_b;
- the spring pressure P_s; and
- the evaporator pressure P_1.

When the evaporator pressure increases while P_b remains the same, the valve closes. If the bulb pressure increases to the larger amount, the valve opens ($P_b > P_1+P_s$)

[43] www.brighthub.com/engineering/mechanical/articles/966.aspx

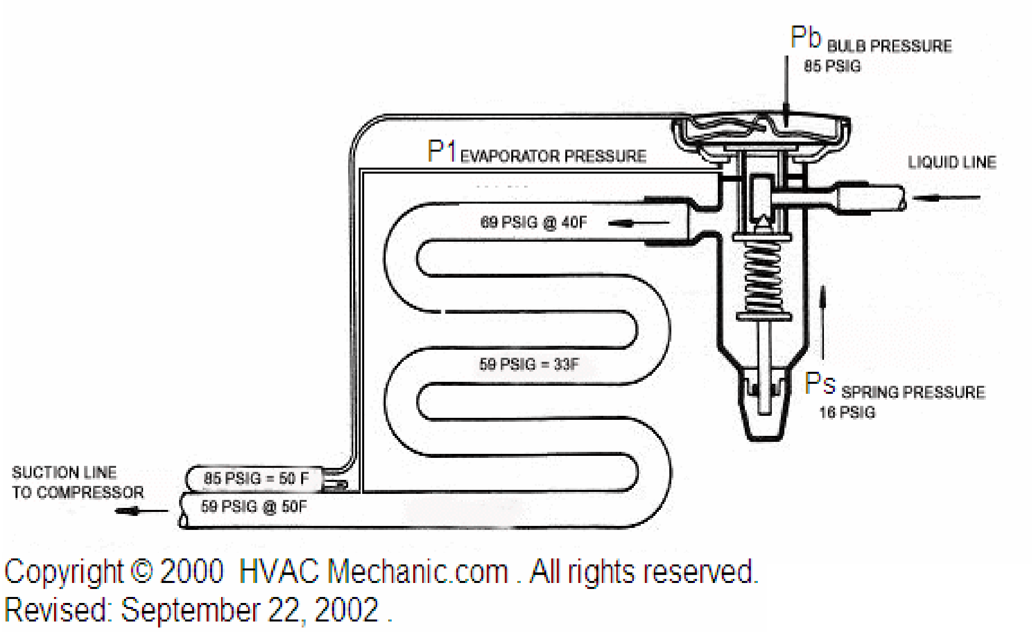


Figure 4-18: Example of a TEV[44]

4.6.3.3 Electronic expansion valve

Using an electronic expansion valve (EEV), it is possible to decrease the superheating of the evaporator, improving the refrigeration product's performance, as compared to the TEV. Moreover, it allows a better control of the temperature, which insures a better preservation of products under variable ambient conditions.

[44] Source: HVAC Mechanic - www.hvacmechanic.com/txv.htm

4.6.4. EVAPORATOR

Evaporation of the refrigerant occurs in the evaporator (i.e. heat exchanger). The vaporisation is maintained through the suction effect of the compressor on the refrigerant, keeping a low pressure in the evaporator. When the refrigerant evaporates, it removes heat from the surroundings of the evaporator. Typically, in refrigeration equipment, evaporators are immersed in the medium being cooled and close to the product being cooled.

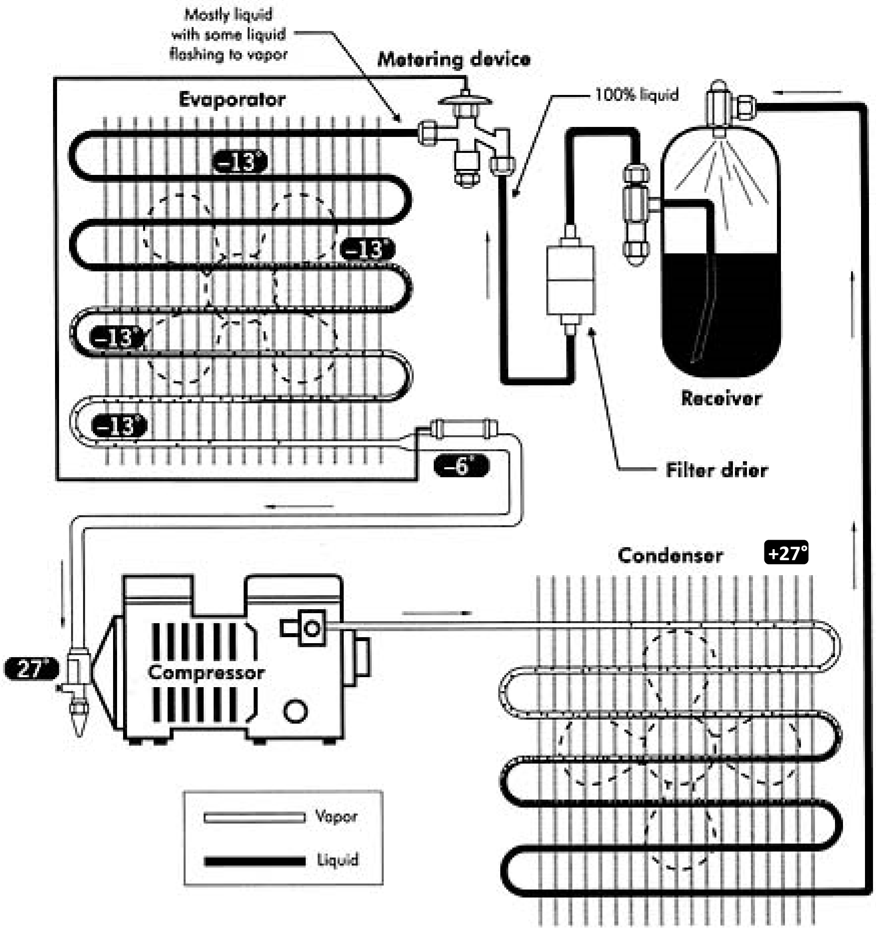


Figure 4-19: Illustration of common evaporator used for refrigeration

Before being transferred to the compressor, the vapour refrigerant can be heated over its evaporating temperature through use of a liquid suction heat exchanger (i.e. superheated by heat exchange with the liquid exiting the condenser) to prevent the transfer of liquid droplets in the compressor, which would impair its operation (see §4.6.6.).

4.6.4.1 Types

Air type evaporators are the most typically used in commercial refrigeration equipment. The difference is that the air evaporator wholly vaporizes the refrigerant before it reaches the suction line in the compressor. Flooded evaporators can be used in process chillers. In the case of flooded evaporators, to avoid liquid refrigerant getting into the compressor and damaging it, a receiver is added at the outlet of the evaporator. The vapour and liquid phases are separated; the vapour circulates through the compressor, and the liquid is reinserted into the evaporator. Thus, flooded evaporators are also called recirculation-type evaporators.

This type of evaporator has a heat transfer coefficient higher than an air evaporator, and is therefore more efficient. However, flooded evaporators are more expensive to operate (they require twice more refrigerant charge and create added cost for liquid/vapour separator as well as oil recovery method required), and ensuring that oil returns to the compressor is important to maintain its performance. Moreover, flooded evaporators are mainly used for large capacity applications due to their greater efficiency. One advantage of flooded evaporator coil is increased heat transfer capacity because areas of reduced heat transfer are smaller (boiling of refrigerant occurs over a greater area of the evaporator).

4.6.4.2 Characteristics

The evaporating temperature is one of the operation conditions of the refrigeration equipment which is determined according to the refrigerating effect needed. A high evaporating temperature is desirable. The density of the refrigerant suction vapour entering the compressor is a function of the evaporating pressure P1 (see Figure 4-2). The higher the vaporising pressure, the greater the density of the suction vapour. For a given volume of vapour handled by the compressor, a greater mass of refrigerant is drawn when the suction pressure is high (when the suction temperature is high). Q2 (see **Figure 4-1**) increases and the performance is improved.

The ARI 1200 2006 standard provides COP values for a typical reciprocating compressor used for remote refrigerated equipment. It is clearly visible, as shown in Figure 4-20, that the higher the Adjusted Dew Point[45], the higher the COP. The adjusted dew point temperature is defined in ANSI/AHRI 1200-2008 as being "lower than the actual Dew Point temperature (refrigerant vapour saturation temperature at a specified pressure) resulting from suction line pressure losses, equal to saturated suction temperature at the compressor".

[45] "Dew point" can relate to both evaporating temperature (suction dew point) and condensing temperature (discharge dew point) – the Dew Point temperatures differ due to the different pressures at evaporation and condensation.

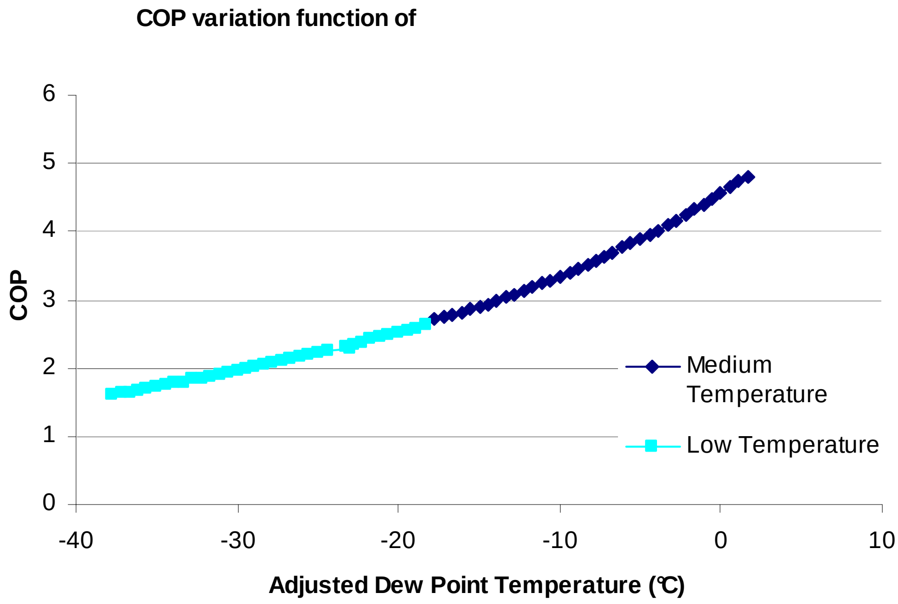


Figure 4-20: Influence of the evaporation temperature on the efficiency of the refrigeration cycle[46]

Q1 (i.e. the amount of heat transferred from within the refrigeration equipment to the refrigerant circulating in the evaporators) is also a function of the heat transfer properties at the evaporator. The heat transfer of an evaporator is related to the evaporator's heat exchange surface area and heat transfer coefficient.

The heat transfer coefficient is a function of the difference between the evaporating temperature of the refrigerant and the temperature of the evaporator's surroundings, the surface area of the evaporator's heat exchanger, the flow of refrigerant through the evaporator and the flow of air around the evaporator.

4.6.4.3 Performance

Fans are often used in order to increase the heat transfer (e.g. increase the flux and therefore the heat transfer coefficient). Evaporator fan motors in refrigeration systems commonly operate at constant speed; however, increasingly, manufacturers suggest the use of variable speed fan motors (i.e. two-speed fans) to allow reduced energy consumption when less refrigeration load is required.

A larger surface area increases a heat exchanger's heat transfer capacity; however, the flow of refrigerant through a larger evaporator must then be properly controlled to ensure its full use. Heat exchangers, used in both condenser and evaporator components, have undergone new developments in the field of micro-channel heat exchangers. These developments provide an opportunity to increase the active heat exchange surface area of air cooled heat exchangers, leading to a potential reduction of the dimensional footprint of the component (maintaining

[46] Source: ARI 1200 2006 standard. The COP values presented in the figure are based on an evaporator temperature and the Commercial Refrigerated Display Merchandiser or Storage Cabinet classification.

the same heat exchange capacity with smaller heat exchanger) or increased heat exchange capacity, using the same sized component. In addition, importantly, it also can reduce the refrigerant charge. This will be discussed further in Task 5 as a Best Available Technology.

4.6.5. CONDENSER

The condenser's function is to reject heat from the refrigeration-cycle to the ambient surroundings. The refrigerant vapour enters the condenser (i.e. heat exchanger) where it is cooled down by transferring its heat to a coolant fluid. This coolant fluid might be air, water, or a combination of both. Fins, wires, or plates may be fastened to condenser tubing to increase the surface area and the ability to dispose of the heat of condensation. Fans or pumps are commonly used to increase the flow of the condensing medium. Such enhancements increase the sub-cooling of the refrigerant, increase the rate of heat transfer, and decrease the overall size of the condenser.

4.6.5.1 Types

The types of condensers used in refrigeration appliances[47] are:

- air cooled (using ambient air);
- water cooled using either groundwater, cooling tower, river, or mains water (although this should be discouraged to consumption of mains water); and
- evaporative-cooled (using ambient air and re-circulated water).

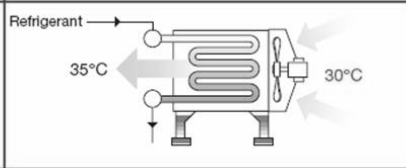
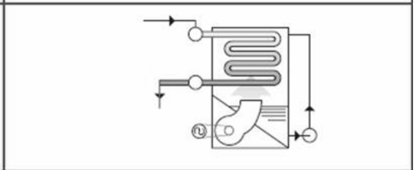
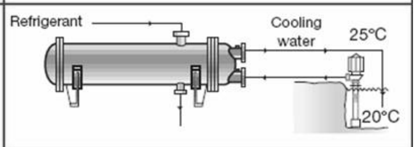
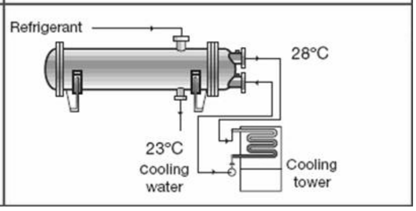
All three types of condensers mentioned above have specific energy needs because of the components used, including:

- fan power for air-cooled condensers;
- circulating pump power (and in some cases cooling tower components) for water-cooled condensers; and
- both fan and pump power for evaporative condensers.

A typical air cooled condenser uses propeller type fans to draw the surrounding air over a finned-tube heat transfer surface (a large surface is required to compensate the relatively poor heat transfer characteristics of air) and increase the heat transfer coefficient. This is the major cause of noise problems connected to the air-cooled condenser use.

[47] Source: Energy Efficiency Best Practice Programme UK (2000). *Energy efficient refrigeration technology – the fundamentals. Good Practice Guide* 280.

Table 4-9: Illustration of Common type of condensers[48]

CONDENSER TYPE	DIAGRAMMATIC ARRANGEMENT
AIR-COOLED	
EVAPORATIVE	
SHELL AND TUBE WATER-COOLED (supplied from a river)[2]	
SHELL AND TUBE WATER-COOLED (supplied from a cooling tower)	

4.6.5.2 Characteristics

As in the case of evaporators, the amount of heat transferred at the condenser, and therefore the energy consumption of the overall refrigeration system, depends on:

- the temperature difference between the inside and the outside of the condenser (i.e. between the refrigerant and the cooling medium);
- the size of the condenser (a larger surface area will enable an increased amount of heat to be transferred); and
- the flow of the fluids in contact of the condenser.

Therefore, the condensing temperature of the refrigerant has an impact on the system's efficiency and should be kept as low as possible to ensure low energy consumption. When T2 (see Figure 4-2) increases, Q1 (see

Figure 4-1) decreases. Typically, a +1°C increase in condensing temperature can lead to a 2 to 4% increase in energy use by the refrigeration system. Thus, keeping the condenser temperature difference as small as possible, it is ensured that the system condensing temperature is as low as possible, which leads to the lowest energy consumption and best COP for given ambient and load conditions.

The purpose of condenser capacity control is to maintain system condensing temperatures artificially high to ensure a sufficient pressure differential is available to enable flow through expansion valves. All other factors being equal, increasing the condensing temperature increases the compression ratio and reduces the

[48] Source: Energy Efficiency Best Practice Programme UK. Energy efficient refrigeration technology – the fundamentals. Good Practice Guide 280. 2000

volumetric efficiency and the isentropic efficiency of the compressor. As a result, the total efficiency of the compressor decreases. Since the saved fan power is almost always outweighed by increased compressor power consumption, the technique is inherently inefficient and should be avoided where possible.

In condensers with condensation inside the tubes and no receiver, the amount of refrigerant can be controlled so that the last section of the heat exchanger acts as a subcooler. In air cooled condensers, the subcooling section is placed on the air inlet side.

4.6.5.3 Performance

To ensure effective operation of the condenser, good maintenance practice is required (i.e. regular cleaning) to prevent debris from blocking the airflow and hence limiting the heat transfer.

As for evaporator fans, condenser fans can be controlled to reduce their energy consumption. Most condenser fans use constant speed motors, however, variable speed motors or two-speed fans, allowing reduced electricity consumption when less refrigeration load is required, can also be used. However, reduced fan speed and hence air flow over the condenser needs to be considered in light of the fact that larger air flows will help keep head pressure (compressor exit pressure) down, reduce power consumption, and contribute to a long service life of the compressor. For on/off systems, some of the condenser fans might be switched off at lower load, and if so, some of the condenser coil will not be being ventilated, hence some efficiency will be wasted. Variable speed fans do not need to stop when the flow is reduced (if there are several, they can each be slowed), hence the whole surface of the heat exchanger will have air blown over it. However, as discussed in §4.6.5.2, this technique of condenser control is considered to be inadvisable as it is unlikely to reduce overall energy consumption.

Water has better heat transfer properties than air; therefore, water-cooled and evaporative-cooled condensers are typically more efficient than the air-cooled ones. In the case of water-cooled and evaporative condensers, pumps can be used to improve the heat transfer, and in this case the power input of the machine will increase.

Evaporative condensers have even better efficiency than water-cooled ones, since they reduce the water pumping need. They also result in a lower heat sink temperature, which allows a lower head pressure or a smaller condenser. Choosing an evaporative condenser instead of commonly used air cooled condensers can lead to 8.2% reduction in electricity consumption[49]. However, compared to conventional condensers, these products have a higher capital cost (from 40 €/kW cooling capacity to 80 €/kW cooling capacity for air-conditioning equipment[50]), and require more maintenance and water consumption. In addition, their use has been cautioned in relation to the potential growth of Legionella bacteria and subsequent health concerns[51]. They are therefore rarely used in certain countries (e.g. the UK).

[49] Walker D.H., Van D.B. *Analysis of Advanced, Low-Charge Refrigeration Systems for Supermarkets.* Oak Ridge National Laboratory.

[50] Davis Energy Group (1998). *Evaluation of residential evaporative condensers in PG&E service territory*. California – USA

[51] Source: http://www.osha.gov/dts/osta/otm/legionnaires/cool_evap.html

Because of the lack of space, plug-in refrigerated appliances use an air cooled condenser. In the case of remote products, water cooled or evaporative condensers are commonly used.

Good ventilation, as discussed above, will help keep head pressure (compressor exit pressure) down, reduce power consumption, and contribute to a long service life for the compressor. Further, a simple way to reduce the condensing temperature of the refrigeration system is to use an electronic expansion valve, which allows reduction of condensing temperature.

Developments in heat exchanger technology, as discussed above in the evaporator section, could either decrease the dimensional footprint of condensers, while maintaining similar heat exchange capacity, or increase the energy efficiency of a condenser with a heat exchanger of equal size, through increased active heat exchange.

4.6.6. Pumps

Pumps are sometimes used within process chiller systems, and as discussed in Task 1 are being currently considered for regulation under Directive 2009/125/EC. Please see Task 1 for more details.

Electric pumps covered are single stage end suction, vertical multistage and submersible multistage pumps. In commercial and industry refrigeration sector, especially in chillers, single stage end suction and vertical multistage pumps might be used. Three categories of single stage end suction water pumps are included: end suction own bearing (ESOB); end suction close coupled (ESCC); end suction close coupled in-line (ESCCi). For smaller installations, circulators could also be used.

Following is the specification according to working document of these two types of pumps:

Table 4-10: Water pumps used in the refrigeration sector considered for regulation under the Eco-design directive in the future[52]

Single stage end suction water pumps	Vertical multistage (MS) water pumps
Operating temperature between -10 and +120°C	Operating temperature between -10 and +120°C
Single suction, single impeller	Vertical multistage pumps in in-line and ring section design
All efficiencies based on full (untrimmed) impeller	Efficiency is measured and judged on the basis of a 3 stage pump

Some further explanations on these terms are:

- Stage: the quantity of impellers within the equipment to develop the head (pressure). When they are more than one (multistage), they work in series.

[52] Working document on possible eco-design requirements for single stage end suction, vertical multistage and submersible multistage pumps

- Impeller: the rotor inside the equipment which increases the pressure of the fluid.
- Efficiency: ratio of the power imparted on the fluid (by the pump) and the power supplied to drive the equipment.

Table 4-11: Total annual energy consumption for different types of pumps[53]

Pump type	Total annual energy consumption (kWh pa)
End suction close coupled (s)	7,291
End suction close coupled (l)	32,610
End suction in line close coupled (s)	10,906
End suction in line closed coupled (l)	53,325
End suction own bearings pump (s)	8,631
End suction own bearings pump (l)	32,588
Submersible multistage (s)	2,141
Submersible multistage (l)	4,956
Multistage pump (s)	3,074
Multistage pump (big)	1,356

(S): small (l): large

The potential improvements for pumps were presented in TREN Lot 11. Below is a summarising list of the possible improvements for these equipments:

- end suction own bearings pumps:
  - hydraulic design: improving the geometry by replacing cast impellers;
  - surface friction of the impeller: eliminating surface roughness by using coats of smooth resins;
  - surface friction of the casing (same case as for the impeller);
  - leakage: increasing shaft diameter, using harder materials for wear rings, using a large conical housing for the seal to avoid the bleeding of water, among others.
- end suction close coupled pumps:
  - hydraulic design: improving the geometry by replacing cast impellers;
  - surface friction of the impeller: eliminating surface roughness by using coats of smooth resins;
  - surface friction of the casing: same case as for the impeller;
  - leakage: using harder materials for wear rings, using a large conical housing for the seal to avoid the bleeding of water, among others.

[53] Source: BIO Intelligence Service. *Appendix 6 : Lot11 – Water pumps (in commercial buildings, drinking water pumping, food industry, agriculture)*. 2008

- vertical multistage pumps:
  - hydraulic design: increasing the number of stage and its width can increase the efficiency;
  - leakage: using harder materials for wear rings.
- positive displacement pumps (rotary, reciprocating, and open): no improvements identified.
- using intelligent controls in centrifugal pumps.
- using optimal specific speed motors, thanks to the implementation of electronic controls.
- Variable Speed Drivers pumps can provide up to 50% of energy savings by adjusting the flow to meet actual system requirements. The percentage of equipments currently sold with this characteristic is as follows:
  - end suction own bearing: 4%;
  - end suction close coupled: 5%;
  - end suction close coupled in line: 30%;
  - multistage water: 8%; and
  - multistage submergible: 1%.

In process chiller systems, depending of the complexity of the cooled water circuit, a single circuit (primary circuit) for the chiller and a secondary circuit for the customer are used. Due to poor installation, the actual performance of the water pumping system might be as much as 28 to 56% lower than the performance claimed by the manufacturer.[54]

4.6.7. LIQUID SUCTION HEAT EXCHANGER

Liquid suction heat exchangers are commonly used in refrigeration systems to ensure the right operation of the system and increase its performance. Figure 4-21 shows the refrigeration cycle including a liquid suction heat exchanger, which allows exchange of energy between the cool gaseous refrigerant leaving the evaporator and warm liquid refrigerant exiting the condenser.

[54] M. Merchat, *Mesure des performances énérgétique des systémes de refroidissement*, 2009

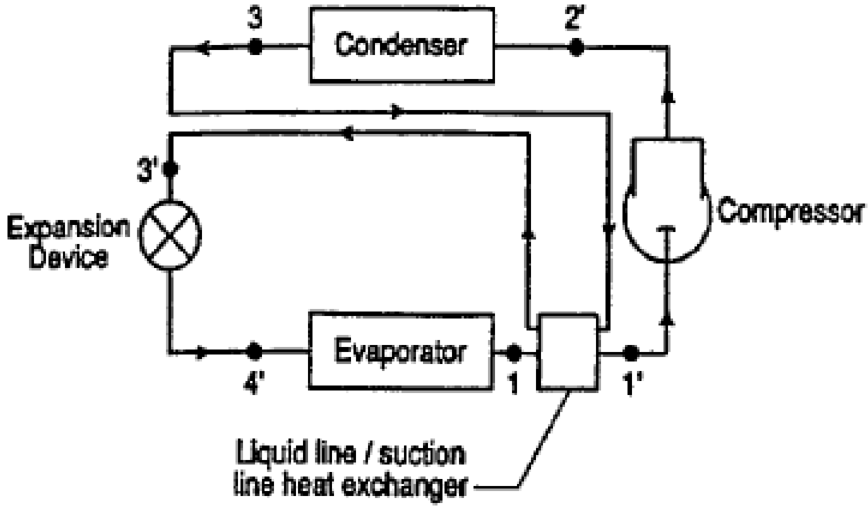


Figure 4-21: Schematic representation of refrigeration cycle with a liquid suction heat exchanger

ASHRAE[55] states that liquid suction heat exchangers are effective in:

- increasing the system performance;
- subcooling liquid refrigerant to prevent flash gas formation at inlets to expansion devices; and
- fully evaporating any residual liquid that may remain in the liquid-suction prior to reaching the compressor (which might damage it).

Liquid has been known to destroy compressors by snapping connecting rods and crankshafts. It is stated that liquid slugging is the direct cause of 20% of the mechanical failures in the compressor[56]. In addition, reciprocating compressors (more than other types of compressors) have been shown to be particularly vulnerable to liquid slugging[57].

However, liquid-suction heat exchangers could increase the temperature and volume of the refrigerant entering the compressor, causing a decrease in the refrigerant density and compressor volumetric efficiency.

[55] ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

[56] Stouppe, D. and Lau, T. Air conditioning and refrigeration equipment failures. *National Engineer*, 93:14–17 (1989).

[57] Liu, Z. and Soedel, W. A mathematical model for simulating liquid and vapor two-phase compression processes and investigating slugging problems in compressors. *HVAC+R Research Journal*, 1(2):99–109 (1995).

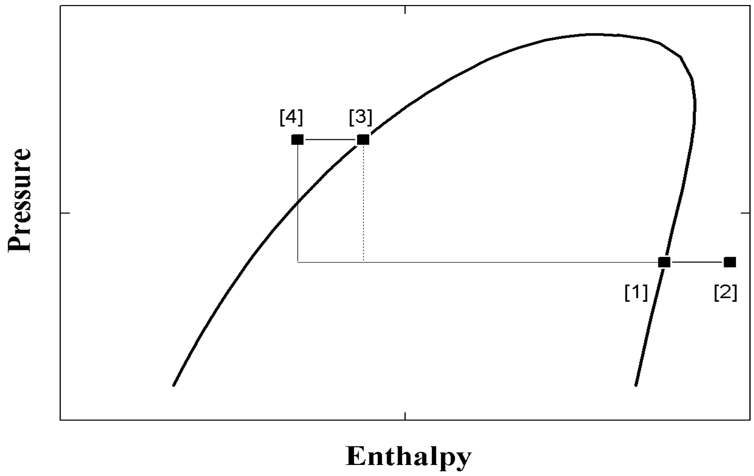


Figure 4-22: Pressure- Enthalpy diagram showing effect of an liquid-suction heat exchange[58]

When a liquid-suction heat exchanger is employed, the refrigerant entering the compressor (state 2) has been superheated by heat exchange with the liquid exiting the condenser which causes the liquid to enter the expansion device in a subcooled state (state 4). However, pressure drop issues always occur in the heat exchangers.

The choice of installing a liquid suction heat exchanger is a compromise, and depends on the temperature lift (difference between condensing and evaporating temperatures) of the system and the refrigerant used. As can be seen in the figure below, it is detrimental to system performance in systems using R717 (ammonia) as refrigerant since they are characterised as very high temperature substances.

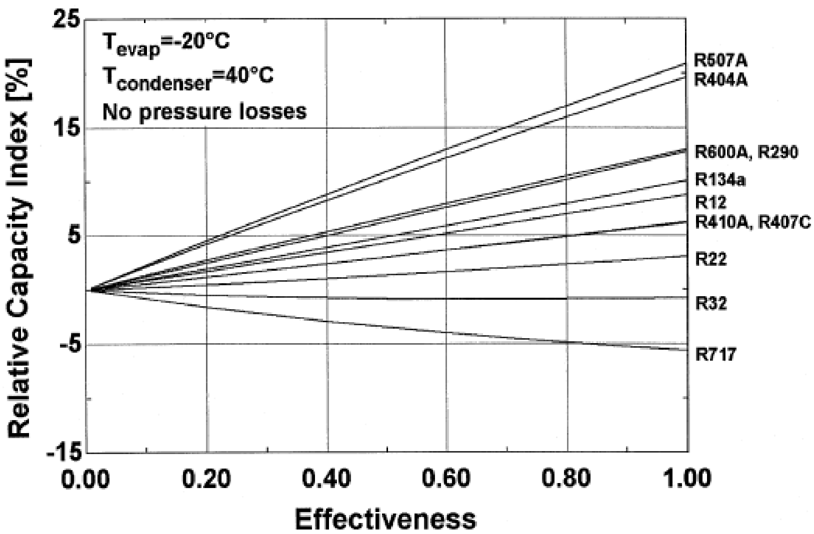


Figure 4-23: Relative capacity (and relative system COP) index as a function of liquid-suction heat exchanger effectiveness[59] for various refrigerants at -20°C evaporating temperature and +40°C condensing temperature[60]

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[58] S. A. Klein, D. T. Reindl, and K. Brownell, *Refrigeration System Performance using Liquid-Suction Heat Exchanger,* 2000

4.6.8. LIQUID RECEIVER

For proper operation of the expansion valve, all the refrigerant on the high pressure side must be in liquid phase. To ensure this, the refrigerant should, if possible, be subcooled a few degrees at the exit of the condenser. If the refrigerant is not subcooled, pressure drops in the tubes, and height differences between the condenser and the expansion valve, may cause formation of vapour bubbles. A liquid receiver is therefore placed between the condenser and the expansion valve. During operation, the receiver is partially filled with refrigerant liquid and as the outlet is placed in the bottom, only the liquid phase can leave the receiver.

A liquid receiver is used in all refrigeration systems except in those using a capillary tube expansion device technology (capillary tube expansion devices can be found in smaller refrigerating and freezing equipment such as plug-in service cabinets, dessert and beverage machines, ice-makers) and the main functions of this component are to:

- hold a reserve of refrigerant to ensure there is always refrigerant available with a change in the evaporator load; and
- in some cases, hold the whole refrigerant charge during pump-down operation (purge).

The liquid receiver gives stability to the overall efficiency of the refrigeration system. Subcooling occurring in the condenser is lost when the liquid enters the receiver and flashes to the saturated state, lowering the pressure slightly. It needs to be further subcooled downstream of the receiver to prevent vapour bubbles being present at the TEV. Some types of condensers also operate as receivers.

4.6.9. PIPING SYSTEM

Copper or steel pipes are used to link the different components. The piping system is designed and installed to:

- minimise pressure drops and ensure the difference between the condensing and evaporating pressures is as low as possible to maintain efficiency;
- avoid refrigerant leakages; and
- allow oil return to the compressor by maintaining high velocity of the refrigerant (in the case of vapour-compression cycles), as discussed in §4.6.1.

Insulation is required on the suction line.

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[59] The term "effectiveness" should be understood in relation to degrees of superheat; efficiency improvements of 20% cannot be achieved on R404a systems by using a heat exchangeras this would require an infinitely large heat exchanger – what might be possible is a heat exchanger with an effectiveness of 25%, superheating the suction vapour by 15K, providing an efficiency improvement of 5%.

[60] S. A. Klein, D. T. Reindl, and K. Brownell, *Refrigeration System Performance using Liquid-Suction Heat Exchanger,* 2000

4.6.10. INSULATED ENCLOSURE

Insulation reduces heat transmission (hence reduces heat load) from the ambient environment, through the equipment enclosure, into the refrigerated storage space. Wall losses[61] can be reduced by improved insulation, leading to reduced head load which in turn requires a refrigeration system with smaller cooling capacity, and hence can lead to reduced energy consumption of the equipment.

There are various materials used as insulation, but predominantly in refrigeration equipment this is polyurethane (PUR) or polyisocyanurate (PIR) foam. A blowing agent is used to foam these materials to create a cell. Both the material used for insulation and the blowing agent should therefore have low thermal conductivity.

Refrigerants, when used for blowing agents, can increase the direct emissions of refrigeration equipment as the gas permeates out of the foam structure, as the insulation degrades during life. The environmental impacts of HFCs are encouraging refrigeration equipment manufacturers to identify other, more “eco-friendly” blowing agents. In EU production, use of HFC as blowing agent involves less than 10%[62] of the insulation produced. Besides HFCs, cyclopentane, isopentane, CO_2, water and HFOs have also been used; however, the thermal conductivity of such blowing agents is higher than that of HFCs. Therefore, this does not lead to a reduction of energy consumption but will help in reducing environmental impacts such as Global Warming Potential (GWP). Manufacturers can use a higher insulation thickness to compensate for the energy loss.

Various insulating materials and ranges of thermal conductivities (and ranges of thicknesses required to provide U value of between 0.1 and 0.2 $W/m^2.K$) are presented in the figure below.

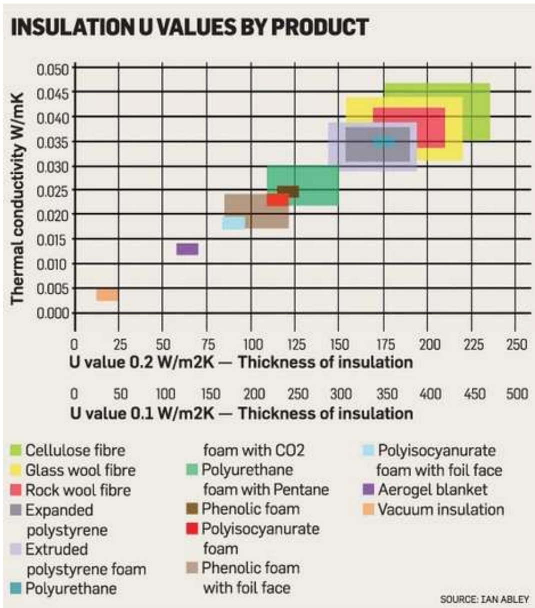

Figure 4-24: Insulation properties[63]

[61] Wall looses refers to heat gain from surroundings of service cabinets

[62] Source: ISOPA

[63] Source: Birch, A., *Vacuum insulation panels promise a thinner future*, 08/05/2009 www.bdonline.co.uk/buildings/technical/vacuum-insulation-panels-promise-a-thinner-future/3140081.article

4.6.11. Anti-condensation heater

Anti-condensation heaters can be used in refrigeration appliances with doors to heat the area around the door seal of the appliance to prevent condensation, and consists of an electrical resistance coil heater or other system of heating such as hot refrigerant gas from the compressor.

For example, service cabinets can include an anti-condensation heater to prevent moisture from forming on the outside of the refrigerator during hot, humid weather. Moisture could lead to ice build-up on door gaskets, "sweating" where temperatures at the product skin fall below dew point, and to fogging in the case of glass doors or windows.

4.6.12. Defrosting

Service cabinets, blast cabinets and walk-in cold rooms are mostly used in catering facilities (e.g. kitchens, bakeries) where ambient humidity is high (around 60 %).

When in contact with the evaporator, the moisture condenses and freezes. A layer of frost forms on the outside of the evaporator, acting as an insulator and hindering the heat exchange with the air (that needs to be cooled). This results in poor energy efficiency. Regular defrost prevents ice build-up. Different types of defrost methods exist: defrost through compressor shutdown, electric defrost and hot or cool gas defrost.

4.6.12.1 Compressor shutdown

In the case of defrost through compressor shutdown, the flow of refrigerant liquid in circulation inside the evaporator is temporarily stopped but the ventilators are kept in operation. The evaporator heats up, melting the ice, and the water resulting from defrost is drained and collected in the defrost water tray. The water from defrosting is then either evaporated within the appliance's storage volume (using an evaporator pan) or drained externally (drain line).

Defrost cycles are set automatically[64] and stop when the evaporator surface temperature rises to above 0°C, at which point no frost remains. The evaporator is then fed with refrigerant liquid and the vapour compression cycle can restart. However, this defrost method is only acceptable for chilled refrigerated equipment, and cannot be operated in the case of freezers because it would increase the refrigerated space temperature to above that required for food preservation.

4.6.12.2 Electric

One common defrost method used to reduce the duration of the ice melting is the electric defrost, through the use of heating filaments. They consist of heaters that are fixed near the evaporator (defrost coil which is integrated to the evaporator coil) and that are switched on to accelerate defrost. During this process the refrigerant supply is switched off and the ventilators are kept in operation to blow

[64] The defrost operation can be automatic (no end-user action is required to initiate and stop the defrost), semi-automatic (automatic defrost with manual removal of the defrost water, or defrost initiated by the end-user which then stops automatically), or manual (the defrost is initiated and stopped by the end-user).

warmed air on to the evaporator. A few minutes are then needed to achieve the complete melting of the ice. However, higher electricity consumption is needed for the resistances and defrosting brings heat to the refrigerated storage space that needs to be taken out.

4.6.12.3 Hot or cool gas

Hot or cool gas defrost are potentially efficient methods, although they require additional piping (implying higher risks of refrigerant leakages) and maintenance. Hot gas defrost uses the hot discharge (high pressure) gas directly from the compressor piped to the evaporator. Cool gas defrost involves the circulation of gas from the liquid receiver with a control valve to begin and end the defrost cycle. The cool or hot gas condenses in the evaporator, releasing heat which melts the ice from the evaporator coils.

The merits claimed for cool gas defrost are that there is less temperature shock to the piping and evaporators compared to hot gas defrost. During this operation, the fans are switched off to prevent water carry-over from the coils. The refrigerant leaving the evaporator is piped back to the liquid manifold of the compressor pack for distribution to other refrigeration equipment connected to the system.

4.6.13. CONTROL SYSTEMS

Control systems can be used to manage refrigeration systems, and these control systems have been developed to adapt certain physical parameters of a refrigeration system in order to maximise energy efficiency. For example, control systems can increase system efficiency through algorithms that regulate the activation of compressor(s), variation of fan speed, and an electronic valve function, as described in the component sections above, hence reducing the system's energy consumption.

Particularly when the efficiency of the "best available component" is high, the application of an intelligent control algorithm can enable greater energy savings, for example self-adaptive evaporating and condensing temperature, self-adapting defrost control, or connection to a building management system, with pro-active alarm management to provide warning of malfunctions or breakdowns.

4.7. PRODUCT TECHNICAL ANALYSIS

This section describes the functionality of the products, their components, the factors affecting their energy consumption and "average" technical parameters. The table below describes the components typically included in each of the five product groups.

Table 4-12: Components included in product groups

	Service cabinet	Blast cabinet	Walk-in cold room	Process chiller	Remote condensing unit
Compressor	Y	Y	Y	Y	Y
Condenser coil	Y	Y	Y	Y	Y
Condenser fan	Y	Y	Y	Y	Y
Evaporator coil	Y	Y	Y	Y	N
Evaporator fan	Y	Y	Y	Y	N
Insulation	Y	Y	Y	Sometimes on piping and in housing	Sometimes in housing if outdoors
Anti-condensation	Sometimes	N	Sometimes	N	N
Defrost	Y	Y*	Y	N	N
Door	Y	Y	Y	N	N
Lighting	Sometimes	N	Y	N	N
Glass	Sometimes	N	Sometimes	N	N
Other	-	-	-	-	-

Y: included in product

N: not included in product

**Only equipment including freezing mode*

4.7.1. SERVICE CABINETS

4.7.1.1 Product description at component level

Preliminary analysis shows the typical service cabinet will be a single-door, vertical plug-in model, of net internal volume around 450 litres, providing a storage temperature range of around +2°C for refrigeration or -18°C for freezing. Figure 4-25 provides the technical drawing for a 2-door plug-in vertical service cabinet.

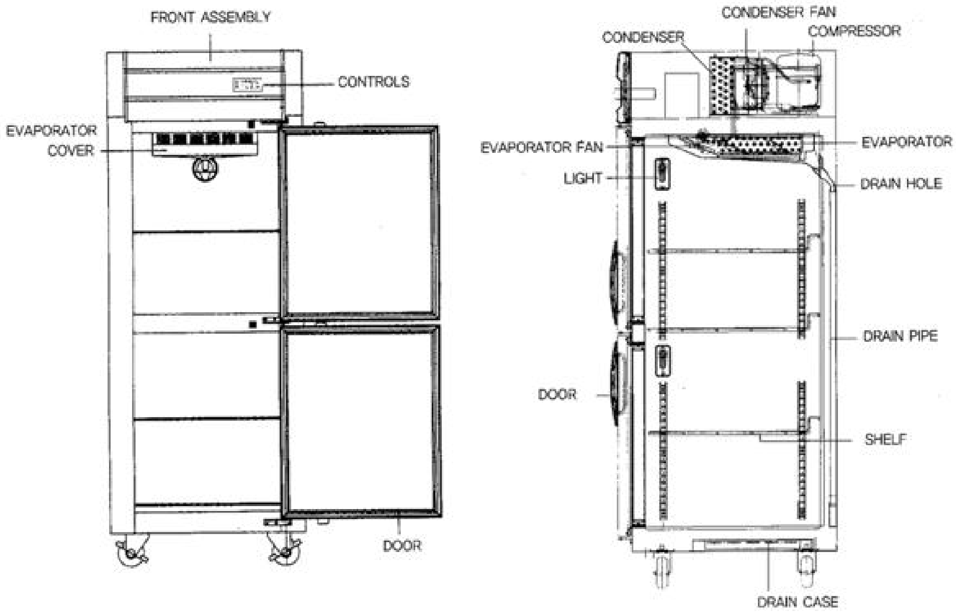

Figure 4-25: Service cabinet and major components

The refrigeration system is usually located at the top of the unit to keep the refrigeration components away from spills and dust and to allow easy access for maintenance. The evaporator is located inside the cabinet housing, at the top.

- **Compressor**

The compressor used within average service cabinet is a hermetic reciprocating one with the capacity of 351W and power of 320W. The weight of the compressor is usually between 10 to 14 kg.

In plug-in freezing appliances, the compressor's electricity consumption may represent around 70% of the overall energy consumption and 60% for refrigeration remote appliances[65].

An increase of the compressor efficiency (e.g. by reducing suction and discharge gas pressure losses, mechanical losses (frictions), and electrical losses (motor) can reduce the total electricity consumption of a cabinet by around 12%[65].

Advanced control technologies to enable variable speed drive[65] can reduce the total electricity consumption of service cabinets by 10 to 15%. At the moment,

[65] Source: Arthur D. Little Inc, Energy Savings Potential for Commercial Refrigeration Equipment, US DOE, 1996 and MARK ELLIS & Associates, Self-Contained Commercial Refrigeration, Australian Greenhouse Office, 2000 and MARK ELLIS & Associates, Remote Commercial Refrigeration, Australian Greenhouse Office, 2000

such control devices are typically not present in plug-in service cabinets, but can be found in the compressors of refrigeration systems for remote service cabinets. However, as explained before, this energy saving varies depending on the workload and ambient conditions.

It has to be noted that the above-mentioned figures are referenced as for year 1996 and the updating feedback from the stakeholders indicate that potential improvement for compressor can only be 5% by 2020.

- **Expansion device**

The average expansion valve type is a capillary tube, while remote condensing will use a thermostatic expansion valve (remote service cabinets are considered to be rarely purchased). The thermostatic expansion valve can have an impact on the remote cabinet's energy efficiency by allowing the control of the flow of refrigerant into the evaporator in order to vary system capacity to meet demand (enabled savings around 5 to 10%[66]).

- **Evaporator**

Typical service cabinets include one or several evaporator fans to ensure air circulation and an even temperature distribution. Evaporator used in the average service cabinet uses 1 fan with the 200mm diameter and the blade at the 28° angle. The face area of the evaporator is 240cm^2 and the air flow is around 240m^3 per hour. The fan motor type is the axial sucking and the fan wattage is equal to 5W. The total weight of the evaporating module is 1 kg.

The motors driving the fans can represent between 5 and 10% of the total electricity consumption, at design conditions, of service cabinets for freezer and refrigerators respectively[65].

For service cabinets, potential improvement of the evaporator fan motor could lead to 2 to 5% of total electricity savings.

- **Condenser**

Plug-in refrigerated service cabinets commonly use air-cooled condensers located at the top or bottom of the cabinet. The average air-cooled condenser module consists of 1 fan with the 254mm diameter and the blade at the 22° angle. The face area of the condenser is 730cm^2 and the air flow is around 600m^3 per hour. The fan motor type is the axial sucking and the fan wattage is equal to 10W. The total weight of the condensing module is 1.5 kg.

Remote service cabinets might use either water-cooled or evaporative condensers, although remote condensation for service cabinets is very rarely used.

Typically, condenser fans represent about 10% of the service cabinet's total energy consumption.

Variable speed or two-speed fan motors can provide energy savings of around 3%[65]. However, if these variable speed fan motors prevent the condensing temperature from falling, this could reduce the system efficiency and increase the energy consumption. In the majority of cases controlling condenser fan speed results in a net loss of COP. However, there is an optimum condensing

[66] Source: BIO intelligence Service, Ecodesign Preparatory Study Lot 12 on commercial refrigerating equipment, DG TREN, 2007

temperature for supermarket packs (about +21°C) when the condenser capacity is achieved through high power fans rather than surface area[67].

- **Controls**

The average service cabinet does not necessarily have an anti-condenser heater, but is equipped with a defrost system. The electric defrost has a direct energy consumption that can represent around 6% of the overall energy consumption of freezing appliances[65]. Defrost drip trays are used to drain away or re-evaporate water resulting from defrosting[68].

Energy savings between 14 and 20%[69] can be achieved through a control device which enables to avoid the continuous operation of anti-condensation heaters (either timer or humidity sensor-based controls).

- **Refrigerant**

The standard choice of refrigerant for service cabinets is R-134a. The usual amount employed of this refrigerant varies from 220 to 400g[70], but can be greater[71]. However, HCs such as R290 and R600a are already being used in equipment[72].

Stakeholder comments suggested that the use of some HCs as refrigerants can save up to 5% more energy than the use of other refrigerants.

- **Housing and insulation**

The door is made of stainless steel and the housing is insulated using 60 mm thick polyurethane (PUR) panels[73], with the blowing agent commonly being HFC or HC[74]. Different door configurations are available on the market; these configurations range from the number of doors to the position of the door itself. The gasket seals the contact area between door and the inside of the service cabinet and contributes to its proper insulation.

Increase of insulation thickness can lead to around 2% reduction of total service cabinet electricity consumption[75] however, either internal space will decrease or external dimension will increase. Therefore, a balance between these factors is necessary in order to reduce overall energy consumption and maintain the service cabinet desired dimensions.

In a small number of models (estimated at 1 to 2%[76]), a transparent door may be used in place of a solid door. The U value of a foamed (solid) door might for example be 0.274 $W/m^2.K$, while for a glass door this may be 1.1 $W/m^2.K$ or more.

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67 Source: Defra

68 Source: Friginox, Gram

69 Source: APS Utility service www.aps.com/main/services/business/WaysToSave/BusWaysToSave_59.html

70 Source: UNEP. *Report of the Refrigeration, Air Conditioning and Heat Pumps Techinical Options Committee*. Montreal Protocol On Substances that Deplete the Ozone Layer, January 2007

71 Stakeholder feedback

72 http://www.fosterrefrigerator.co.uk/default.asp?p=45

73 Source : Gram

74 Source: Foster

75 Source: Arthur D. Little Inc, *Energy Savings Potential for Commercial Refrigeration Equipment*, US DOE, 1996 and MARK ELLIS & Associates, *Self-Contained Commercial Refrigeration*, Australian Greenhouse Office, 2000 and MARK ELLIS & Associates, *Remote Commercial Refrigeration*, Australian Greenhouse Office, 2000

76 Source: Foster, Gram, Infrico

In service cabinets with solid doors, the duty cycle of the lighting system can vary from 0.5 to 1 hour per day, depending on how long the cabinet is open every day. With such duty cycles the electricity consumption for lighting represents less than 0.5% of the total electricity consumption of service cabinets[65]. These values can vary depending on the service cabinet's design: some glass door cabinets might have the lights on even if the door is closed.

A service cabinet might include 1 or 2 incandescent light bulbs (around 25 W) inside the cabinet which operate when the door is opened. Efficient lighting systems may provide electricity savings; however, these are expected to be negligible (considering the low share of electricity consumed by the lighting system).

4.7.1.2 Component use pattern, energy consumption and saving potential

The table below describes two products' component use patterns and energy consumption.

Table 4-13: Average working hours of components and their energy consumption for plug in service cabinets

Component	Model 1[77]		Model 2[78]	
	Average Energy consumption per day (kWh)	Hours per day (h/d)	Average Energy consumption per day (kWh)	Hours per day (h/d)
Compressor	0.35	10	1.1	5.3
Evaporator fans	0.12	11	0.1	10
Condenser fans	0.02	17.5	0.08	5.3
Anti-condensation heaters	0.06	4	0.24	4
Defrost	N.A	3	0.02	2
Lights	0.02	0.3	N.A	N.A.
Control	N.A.	N.A	0.05	24
TOTAL	0.57	-	1.59	-

N.A.: Not Available (i.e. no data provided)

The data in Table 4-14, based on literature and stakeholder feedback, summarises for each component the percentage of total energy consumption of the service cabinet, the energy saving potential of the component and the energy saving for the overall product.

[77] Reference: Mark Ellis & Associates, *National Appliance and Equipment Energy Efficiency Program, Analysis of Potential for Minimum Energy Performance Standards for Self-Contained Commercial Refrigeration, Final Draft Report March 8th, 2000.* Available at <www.energyrating.gov.au/library/pubs/tech-sccommrf2000.pdf>. (24/11/2006)

[78] Source: stakeholder

Table 4-14: Service cabinet component energy consumption and improvement potential

Component	% TEC	% improvement potential for component	% improvement potential for product
Evaporator fans	5-10	50-70*	2-5
Compressor	60-70	5-21	3-15
Condenser fans	10	50-70	0.5-0.7
Expansion device	N.A.	-	5-10
Lighting	≤0.5	N.A.	N.A.
Defrost	6	N.A.	N.A.
Anti-condensation heaters	N.A.	-	14-20
Insulation	-	-	2**
TOTAL	**96.5**	**-**	**39.6-76.2**

N.A.: Not Available (i.e. no data has been found)
-: no energy consumed by component
**By replacing shaded pole motor by an electrical commutated motor*
***Thicker insulation will reduce the energy savings achieved through other components*

The total improvement potential suggested here must be seen as overstating the potential savings, as some component improvements will overlap, but the figures compare roughly with an overall estimate provided by stakeholders of 33% energy efficiency achievable for plug-in service cabinets in the year 2020.

As described in Task 2, the product use pattern corresponds to 8760 hours/year – the product is left on constantly.

4.7.2. Blast cabinets

4.7.2.1 Product description at component level

Preliminary analysis shows that the typical blast cabinet will be a single-door, plug-in model, with a capacity of around 12kg, providing a chilling cycle from +70°C to +3°C in 90 minutes. Figure 4-26 provides a technical drawing for a typical plug-in blast cabinet.

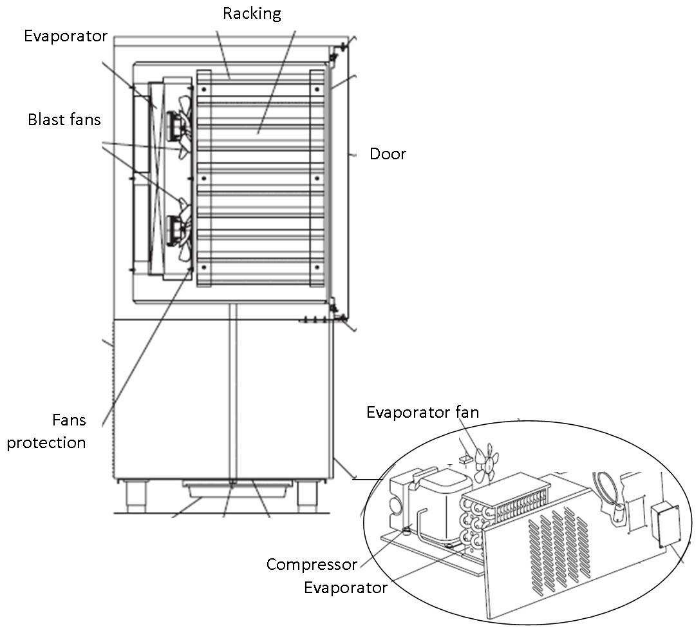

Figure 4-26 Typical plug-in blast cabinet and major components[79]

In blast cabinets, the refrigeration system is usually located at the bottom of the unit. The evaporator is usually located inside the cabinet housing, at the top. The average model for blast cabinets is assumed to be around 5-6 GN 1/1 trays (20kg of foodstuff capacity in chilling cycle). The average roll-in model has a capacity of two 30 kg trolleys (60kg). Stakeholder feedback and sales data indicate that blast cabinets use a vapour compression cycle and are mainly used for chilling (however the same product can often also be used for freezing). Roll-in and pass-through equipment comprise a small share of the market (accounting for 15%). However, their energy consumption can reach up to 1.15 times that of a cabinet of similar capacity in the same cycle type.

- **Compressor**

The compressor used within average blast cabinet is a hermetic reciprocating one with the capacity of 969W and power of 813W. The weight of the compressor is usually between 10 to 14 kg.

The compressor is normally located at the bottom of the blast cabinet (see Figure 4-26). As in all vapour-compression based refrigerating equipment, this component is estimated to represent a significant share of the total electricity consumption of blast cabinets (60-80%).

[79] Cervino 10 Spare Diagram and Spare List

Expansion device

The function of the expansion device, and its role on the overall energy efficiency, is described in §4.3.4. and §4.4.1.1.

Evaporator

Evaporator used in the average blast cabinet uses 1 fan with the 254mm diameter and the blade at the 34° angle. The face area of the evaporator is $1470cm^2$ and the air flow is around $1400m^3$ per hour. The fan motor type is axial sucking and the fan wattage is equal to 160W. The total weight of the evaporating module is 2 kg.

Fans are estimated to represent around 30% of the total electricity consumption of blast cabinets. Typical blast cooling devices include one or several evaporator fans in order to provide a rapid cooling process, responding to the need of increased heat removal from the foodstuff inside the equipment in a very short period of time, having high energy consumption as a consequence. The motors of these fans also generate heat that increases the load and hence the energy consumption of the blast cooling device.

Condenser

The condenser module consists of 1 fan with the 230mm diameter and the blade at the 34° angle. The face area of the condenser is $1000cm^2$ and the air flow is around $710m^3$ per hour. The fan motor type is axial sucking and the fan wattage is equal to 34W. The total weight of the condensing module is 2.5 kg.

Plug-in blast cabinets commonly use air-cooled condensers located at the bottom of the cabinet (see Figure 4-26). Due to a higher cooling load, blast cabinet condensers are bigger than those used in service cabinets.

In the case of remote blast cabinets, the condenser is not located within the cabinet itself and it can therefore be either air-cooled, water-cooled, or be attached to an evaporative condenser.

Controls

The function of an electric defrost system expansion device, and its role on the overall energy efficiency, is described in §4.3.4. and §4.4.1.1.

Refrigerant

For the different capacities of these equipments, different refrigerants are used. Machines with a capacity equal to 50kW or less usually operate with HFC (as R404A or R134a) in the EU.

As with service cabinets, HCs can also be used. However, there is a trade-off in that they are highly flammable, such as is the case for R290 and R1270. Other alternatives such as the R245fa (pentafluoropropane) are in development.

For the range between 50kW to 200kW, it is possible to use ammonia instead, while for larger capacities freezers ammonia is preferred because of its energy efficiency and reduced direct emissions impacts through leakage. Machines in this capacity range are not common in the market.

In recent years, there has been an increment on the use of R-744 (carbon dioxide), mainly responding to the advantage of running the systems at lower temperatures due to the high suction pressure[80].

- **Housing and insulation**

The function of insulated walls, casing and gasket, and their role on the overall energy efficiency is similar to that of service cabinets, as described in §4.4.1.1.

Doors in blast cooling devices are not opened during the blast cooling process. Instead, doors are opened at the beginning and at the end of the process.

4.7.2.2 Component energy consumption, use pattern and saving potential

Data on blast cabinet component use pattern, obtained from a blast cabinet manufacture, is presented below. As described in Task 2, the use pattern of 5 cycles per day, 220 days per year has been estimated based on comments from stakeholders and it only applies to chilling functioning. Stakeholders also have mentioned that the energy consumption for similar equipment would vary according to the efficiency of these, reaching the same temperature in different time, hence the use of the components is not standardised.

Table 4-15: Average working hours of components and energy consumption for plug-in chilling cycle blast cabinets

Component	Model 1	
	Average energy consumption per day (kWh)	Hours per day (h/d)
Compressor	1.3**	2.7-3
Evaporator fans	0.64	3
Condenser fans	0.4	2.7-3
Anti-condensation heaters	0.06	2.7-3
Defrost*	3.15	0.3
Lights[1]	0.006	0.3
Heated probe	0.02	0.01

**Applicable only to freezing equipment*
***Per cycle*
[1]Normally optional

The data in the table below, based on literature and stakeholder feedback, summarises for each component the percentage of total energy consumption of the appliance, the energy saving potential of the component and the energy saving for the overall product. Reductions in total electricity consumption are estimated to be possible through the use of traditional options to improve vapour-compression based equipment: with the use of high-efficiency motors in condenser fans and compressors, and thicker insulation.

[80] Source: UNEP. *Report of the Refirgeration, Air Conditioning and Heat Pumps Techinical Options Committee*. Montreal Protocol On Substances that Deplete the Ozone Layer, Januayr 2007

Table 4-16: Blast cabinet component energy consumption and improvement potential

Blast cabinets			
Component	**% of total energy consumption of the appliance**	**Improvement potential (in % of the energy consumption of the component)**	**Improvement potential (in % of total energy consumption of the appliance)**
Evaporator fans (motor)	15-30	2-5	0.1-0.5
Compressors (motor)	60-80	16-21	11-18
Condenser fans (motor)	10	3	0.3
Expansion device	-	-	5-10
Electric defrost (freezers only)	6	N.A.	-
Insulated walls	-	-	10-30*
TOTAL	**100**	**-**	**26.4-58.8**

N.A.: Not Available (i.e. no data has been found)
-: no energy consumed by component
** Approximated – thicker insulation will reduce the energy savings achieved through other components*

The total improvement potential suggested here compares with an overall estimate of 33% energy efficiency achievable for plug-in blast cabinets in the year 2025, provided by stakeholders, although some component improvements will overlap.

4.7.3. WALK-IN COLD ROOMS

4.7.3.1 Product description at component level

Preliminary analysis shows that typical walk-in cold rooms rely on compression technology. Sales data indicates that walk-in cold rooms are both plug-in (45%), and remote, with some remote connected to packaged condensing units and others to central refrigeration plants.

- **Compressor**

The compressor used within the average walk-in cold room is assumed to be hermetic and reciprocating with capacity of 560 W and total weight of 20 kg. The compressor is the component with the highest electricity consumption (it may represent over 50% of the overall energy consumption)[81].

Hermetic compressors can be used for duties of up to around 7kW, depending on temperature and pipe run. Semi-hermetic and scroll can be used above this, with scrolls being used up to around 15 to 20kW, and with semi hermetic being more commonly used in larger systems. Scrolls can only really be used high temperature applications from around 5kW, and semi-hermetic from around 2.5kW. Regarding applicability of digital scroll compressors stakeholders stated that these are only available on sizes from around 5 to 14kW on high temperature systems and from 5 kW up to 7.5kW on low temperature systems. There is a general trend toward hermetic compressors[82].

- **Expansion device**

Using expansion valves with better control (i.e. electronic expansion valves) is estimated to lead to overall electricity savings of up to 18% for remote walk-in refrigerators[81], as they would enable floating head pressure.

- **Evaporator**

The average evaporator weight is 2.4kg with the fan wattage of 12W.

The evaporator is located inside the walk-in cold room, at the top of the product. The function of the evaporator, and its role in the overall energy efficiency of walk-in cold rooms is the same as described in §4.6.4.

Typical walk-in cold rooms include one or several evaporator fans to increase the heat transfer coefficient and achieve an optimal circulation of refrigerated air inside the insulated area. The motors driving the fans can represent around 10 and 17%[81] of the total electricity consumption of walk-in cold rooms for refrigerators and freezers respectively.

For walk-in cold rooms, the potential improvement of the evaporator fan motors could lead to a 7 to 8% reduction on overall energy consumption. Further reduction could be achieved through evaporator fan control using a variable speed drive (around 4% reduction) [81].

[81] Source: Arthur D. Little Inc, Energy Savings Potential for Commercial Refrigeration Equipment, US DOE, 1996

[82] Source: GR Scott, Foster

The positioning of the evaporator is also important. They tend to be located at the centre/rear of the room. In smaller rooms, this may encroach on and reduce internal storage space. Ideally, through better design, the evaporator should be located outside the enclosure or in the centre of the room (although this may have an impact on drainpipe positioning) to maximise storage.

- **Condenser**

The average condenser weight is 3.5kg with the fan wattage of 20.4W.

The function of the condenser in walk-in cold rooms is the same as in refrigeration equipment already described in §4.6.5.

Plug-in walk-in cold rooms typically use fan assisted air-cooled condensers. In the case of remote walk-in cold rooms, water-cooled or evaporative condensers might be used.

Typically, condenser fans represent about 13 and 20% of the walk-in cold room's total electricity consumption for freezing equipment, and refrigerating equipment respectively. Condenser fan motor controls using variable speed drive can be used in order to achieve up to 7% and 2% of energy consumption reduction for freezer and refrigerated walk-in cold rooms respectively[81].

- **Controls**

Just as in service cabinets, anti-condensation systems (used to avoid damage of the door gaskets) have a direct impact on electricity consumption, not only by their power demand but also because they represent an extra source of heat to be absorbed by the refrigeration system.

Frost can alter the heat exchange process at the evaporator and reduce the energy efficiency of the walk-in cold room. Defrost devices can be used to heat the walk-in freezer evaporator coils at regular intervals to avoid frost build-up. The electric defrost electricity consumption can represent around 3% of the overall energy consumption of freezing appliances.

Defrost systems can be controlled, eliminating unnecessary defrost cycles. The most efficient controls are on-demand types. They start the defrost cycle depending on the temperature or pressure drop across the evaporator or by measuring frost accumulation and sensing humidity[83]. However, these are not commonly used in walk-in cold rooms[84]. Stakeholders estimate that the use of efficient defrost systems could allow savings around 1 to 2%.

- **Refrigerant**

For storage temperatures between -4°C to +6°C the typical refrigerants employed are often R-134a and R-404a. For lower temperature requirements, the refrigerant used is typically R-404a. There are also packaged refrigeration units using R290 available on the market[85], and CO_2 is also being used for cold rooms in catering facilities[86].

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[83] Source: Mark Ellis, *Startegies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealan*, 2009

[84] Source: Defra

[85] Zanotti 'uniblock'

[86] CCS Refrigeration and Iglu Cold System. Source: Shecco

◆ **Housing and insulation**[87]

Insulating enclosure

Insulation panels are the main components of the insulated enclosure. The function of the insulated panels is similar to that discussed for service cabinets (§4.7.1.1). By increasing insulation thickness, energy savings are estimated to be achievable[88].

Panels are normally formed in a "sandwich" style, with a central portion of insulating material (either foamed into place or as a slab) between two sheets of metal (acting as a thermal break) and with an external finish (can be a variety of materials).

Every producer may have different typical sizes according to their production and panels' shape; for one producer, a typical panel size may be 1200x2000x60mm, but for another producer it may be 800x1800x80mm, depending on how the producers' developed the design of its products. Typical sizes of panels are in the region of 2.3m high, by 1.2m width for smaller walk-in cold rooms. There are many thicknesses, with 80mm stated as common for higher temperature applications (>0°C) and 100mm for low temperatures (≤0°C). Predominantly thicknesses are manufactured at 60mm, 80mm, 100mm and 120mm, but many other thicknesses are used (from 50mm to 200mm).

Self-supporting panels have maximum spans, which limit the size of self supporting rooms (constructed without the support of an additional frame); ceiling panels are no longer self supporting when cold room dimension is such that it requires two or more panels to cover the whole ceiling span. In this case it is necessary to use external or internal supporting systems. For example, 80mm thick panels' ceiling spans are approximately 4500mm max (and 6400mm high). 100mm thick panels can have a ceiling span of 6000mm (and 9100mm high). External or internal supporting systems are studied on a case by case basis, to best fit the cold room requirements (the conditions under which it will be used), and characteristics of the building in which the cold room is to be assembled, hence may be required for smaller rooms in certain cases.

Wall and ceiling panels are usually identical, while floor panels have a typical anti-slip finish and may have specific internal reinforcement to withstand the supported or transiting loads. Floor panels are made of several layers:

- An external layer: metal sheet (the same as wall and ceiling panels)
- The core material: there are several types of floor panels, which every producer may make in different ways. The core material is PUR but on the internal side there may be reinforcement, such as a chipboard panel glued to the internal side metal sheet.
- An internal layer (the side which is walked upon): a metal sheet, which is specifically used only for floor panels (usually have an anti-slip finish).

[87] Source: Fermod, GR Scott, Assofoodtec (IT)
[88] Source: Arthur D. Little Inc, *Energy Savings Potential for Commercial Refrigeration Equipment*, US DOE, 1996 and MARK ELLIS & Associates, *Self-Contained Commercial Refrigeration*, Australian Greenhouse Office, 2000 and MARK ELLIS & Associates, *Remote Commercial Refrigeration*, Australian Greenhouse Office, 2000

Some producers may replace the internal metal sheet with other materials, such as phenolic plywood

Examples displaying the different layers:

- Phenolic plywood, then PUR/PIR, then a metal sheet.
- Metal sheet with anti slip finish paint, chipboard, PUR/PIR, metal sheet.
- For small cold rooms, extruded polystyrene might be used as a layer in the floor panel.

Insulation panels are typically PUR and have a λ value of between 0.02 and 0.023 W/m.K[89]. Table 4-17 below shows the typical thicknesses available currently on the market according to the application temperatures ranges.

Table 4-17: Typical thicknesses and estimated U-values of insulation panels for walk-in cold rooms[90]

Walk in cold room panel thickness (mm)	U-value (λ = 0.023 W/m.K) (W/m².K)	Walk-in cold room storage temperature (°C)
60	0.38	≥ 5
75	0.31	≥ -5
(Freezer) 75 < mm < 100	0.31 < U < 0.23	≥ -25
(Freezer) 100 < mm < 150	0.23 < U < 0.15	≥ -45

Figure 4-27 below provides other examples of the range of thicknesses and λ values of insulation panels available on the market.

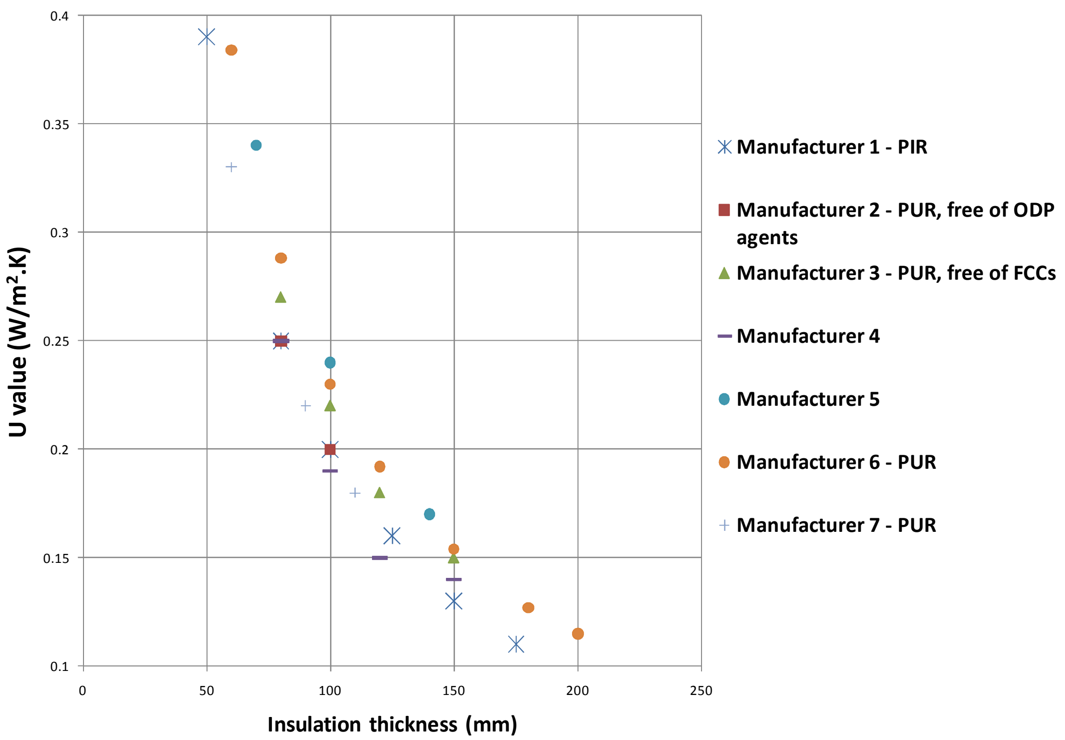

Figure 4-27: Thicknesses and U values of insulating panels available on the market

89 Source: GR Scott, INCOLD

90 www.dragon-enterprise.com/cold-room/polyurethane-insulation-panel.htm

Ambient infiltration is affected by the method of fastening the insulation panels together. “Cam-lock” type mechanisms are commonly used to improve seals (compared to the less effective angled or butted type joints) and hence reduce air infiltration from the (usually) warm and humid external ambient into the refrigerated space, reducing load on the refrigeration system and defrost frequency.

Pressure relief valves are also used; if not correctly sized, internal and external pressures can affect the room.

<u>Entrances to the storage space</u>

The door’s effect on the energy consumption of walk-in cold rooms is significant, although the quality, design and user behaviour have a greater impact. Nevertheless, in walk-in cold rooms, doors can be closed while an end-user is collecting cooled items within the room to maintain the integrity of the insulating enclosure and reduce infiltration of ambient air. Panels and doors can be manufactured by the same company, but sometimes are not. For example, some smaller producers may not be equipped to produce doors.

Strip door curtains and automatic door closers can help to further reduce infiltration of air. Strip door curtains are more commonly used, and are rows of overlapping clear flexible strips, often fabricated from PVC, which are hung over the opening of a walk-in refrigerator or freezer. They allow passage into and out of the refrigerated space while reducing ambient air infiltration when the door is open. However, these can be an annoyance to operators and considered by some to be a hygiene problem.

Hinged doors are the most common and popular (estimated at 70% of the market[91]), particularly on small cold rooms, but sliding doors are also available. An average door is estimated as having dimensions of 800x1900mm high.

“Slam-faced doors”, also known as “plant-on doors”, are positioned on the outside and overlap the door opening. This method is generally preferred as it is easy to fit and overcomes problems of mis-alignment of door openings. “Flush and semi rebated doors” are less popular, but tend to be higher quality. They are more difficult to fit on site, as levels need to be exact and panels need to be plumb, otherwise doors will not fit. Any future settlement would also cause a problem. With cam-locked units, the door frame is manufactured as part of a panel when foamed. To save materials the flush type can also be cut from the main panel itself, which may cause problems if not sealed effectively.

Sliding doors are usually manual but can be easily automated. They are common even in small walk in cold rooms and have the advantage of being suitable where a hinged door would encroach on walkways or were access is generally restricted. Usually they are fitted with a manual track, which relies on the operator physically closing the door.

Doors in walk-in cold rooms can have security systems in order to avoid users getting locked inside the insulated compartment. Manual operation is available should the need arise, access is available in a variety of ways such as push buttons, pull cords, radars, radio control, etc.

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[91] Source: GR Scott

Types of doors include:

- Doors cut from a panel: in this case the door leaf is cut from a typical insulation panel (equipped with adequate reinforcement metal plates, to fix ancillaries) and the remaining part of the panel will form the door frame.

- Doors with frame: the door leaf is directly foamed in a specific production line, completed with its aluminium profiles (gaskets and ancillaries are however usually added after door leaf is foamed). In this case the door frame is prepared separately using PVC profiles, usually internally reinforced with a steel tube or other material.

Door insulation if therefore sometimes the same as wall panels, but other materials are also used:

- Aluminium profiles for door leaf.
- Metal sheets (pre-painted).
- Gaskets made of PVC or other material.
- PVC (usually internally reinforced) or other material for door frame.

Typical insulation properties[92] for doors (the worst case has been assessed for these and worst data are quoted) cut from a panel are:

- Hinged door (60mm thick) = 0,65W/m^{2}K
- Sliding door (60mm thick) = 0,80W/m^{2}K

Typical insulation properties for doors with a frame:

- Hinged door (68mm thick) = 1,16W/m^{2}K
- Sliding door (68mm thick) = 1,15W/m^{2}K

Gaskets play an extremely important role by creating an insulated seal around the door. Depending on the intended working temperature of the cold room, doors are also equipped with a heating cable around the frame to avoid the build-up of ice and freezing of the gasket.

<u>Transparent sections</u>

Some walk-in cold rooms incorporate glass sections on their doors or wall panels (estimated market share of 1 to 5%[93]). Normally, the way windows are installed in cold room walls is the same as a glazed section may be installed on a door; usually doors' glazed sections are smaller than windows on a wall panel[94]. Entirely transparent doors may be available on request, however normally transparent doors producers are not cold room producers.

Insulated glass typically has a U value of 2.9 W/m^2.K.

<u>Lighting</u>

[92] Source: Assofoodtec
[93] Source: GR Scott, Smeva
[94] Source: Incold

Historically, typical walk-in cold rooms include incandescent (estimate of approximately 200W) lighting or fluorescent lighting[81]. Its duty cycle can vary from 12 to 14 hours per day, depending on end-user behaviour. With such use, the electricity consumption for lighting represents less than 3% of the total electricity consumption of walk-in cold rooms. Efficient lighting systems may provide electricity savings. However, these are expected to be low; around 1% reduction of the overall energy consumption of the walk-in cold room[81]. Lighting is designed according to customer specifications; a standard value for lighting in working environments is regulated by EN 12464-1:2004.

4.7.3.2 Component energy consumption, use pattern and saving potential

The data in the table below, based on literature and stakeholder feedback, summarises for each component the percentage of total energy consumption of the appliance, the energy saving potential of the component and the energy saving for the overall product.

Table 4-18: Walk-in cold room component energy consumption and improvement potential

Component	% of total energy consumption of the appliance	Improvement potential (in % of the energy consumption of the component)	Improvement potential (in % of total energy consumption of the appliance)
Evaporator fans (motor)	10-17	7-8	0.7-1.4
Compressors (motor)	57	16-21	8-10
Condenser fans (motor)	13-20	2-7	0.3-1.4
Expansion device	-	-	18
Lighting	2	1	<0.1
Electric defrost (freezers only)	3	1-2	<0.1
Thicker insulation	-	-	10-30*
Door	-	-	N.A.
Anti-condensation system	N.A	N.A	N.A
TOTAL	**93**	**-**	**37-60.8**

N.A.: Not Available (i.e. no data has been found)
-: no energy consumed by component
**Approximated – thicker insulation will reduce of energy savings achieved through other components*

The total improvement potential suggested here compares with an overall estimate of 39% energy efficiency achievable for plug-in walk-in cold rooms in the year 2020, provided by stakeholders, although some component improvements will overlap.

As described in Task 2, the product use pattern corresponds to 8760 hours/year – the product is left on constantly.

4.7.4. PROCESS CHILLERS

4.7.4.1 Product description at component level

Process chillers are refrigerating products, therefore, depending on the technology used, they include the refrigeration components described for either the vapour-compression or absorption technologies. Absorption technology is discussed further in Task 5, in §5.3.2. (this technology is not used widely in EU). The average model for process chiller working at medium temperature was suggested by the industry to present approximately 260kW of cooling capacity. According to different stakeholders[95] the average chiller capacity could be 220kW. The latter will not be considered as the average in the scope of ENTR Lot 1.

In order to reach low and medium temperatures, the water used in the chiller is mixed with Ethylene glycol or propylene glycol. The efficiency of the equipment will decrease with the increase of the concentration of this substance. Another factor affecting the efficiency corresponds to the differential of temperature. The Base Case would provide a cooling capacity about 45% higher if used to cool pure water at +7°C.

- **Compressor**

Process chillers can easily be classified depending on the kind of compressor used: centrifugal, screw, scroll and reciprocating. The choice depends mainly on the cooling capacity range and operating conditions.

According to the answers in the second questionnaire, the average process chiller is also equipped with semi-hermetic screw compressors.

- **Expansion device**

According to the answers in the second questionnaire, the average process chiller for low temperatures would be equipped with an electronic expansion valve (EXV). However, later feedback received from manufacturers suggested that the average chiller in the EU market is not likely to include electronic expansion valve.

- **Evaporator**

According to the answers in the second questionnaire, the average process chiller uses a direct expansion system.

The evaporator technologies used in packaged chillers are: shell and tube heat exchanger, braze plate heat exchanger, tubular heat exchangers where the water can be outside the heat transfer tube. These technologies will be discussed in Task 5.

Shell and tube[96] evaporator type is the most commonly used for larger chillers.

- **Condenser**

According to the answers in the second questionnaire, the average process chiller for low temperatures is water-cooled. Air-cooled process chillers are generally

[95] Defra study
[96] A type of evaporator involving a nest of tubes within a baffled shell

used in applications where the additional heat they discharge is not a factor. They require less maintenance than water-cooled units and eliminate the need for a cooling tower and condensed water pump. They generally consume approximately 10% more power than a water-cooled unit as a wet surface will transfer heat better than a dry surface. For example, according to ASHRAE Standard 90.1-200, for compression technology, similar capacity chillers using water-cooled condensers should have EER[97] around 50% higher than those using air-cooled condensers. For absorption technology, similar capacity chillers using water-cooled condensers should have EER around 400 higher than those using air-cooled condensers. However, in ASHRAE the energy of water cooled condenser pumps is not taken in account.

The technologies used for water cooled condenser are: tube in tube, brazed plate heat exchanger or tubular heat exchanger with the water inside the heat transfer tube and semi-welded (the water needs to be cooled either in a cooling tower, or in a dry cooler).

For air cooled condenser, the technology widely used is the coil type refrigerant inside the tube. As emerging technology, the micro-channel heat exchanger has been introduced.

There is a size limitation for packaged air-cooled process chiller of between 1500 to 1800 kW cooling capacity. For bigger capacity, water-cooled is usually used.

- **Pump**

Stakeholders have mentioned that this is not normally included in the packaged equipment, but can be required to drive the water through the cooling system in water-cooled models.

Also, in some models, a condenser pump interlock is included to prevent refrigerant pressure falling too far during the off cycle, thus providing energy savings via pump shutdown. Depending of the complexity of the cooled water circuit, a single circuit (primary circuit) for the chiller and a secondary circuit for the customer are used. Due to poor installation, the actual performance of the water pumping system might be as much as 28 to 56% lower than the performance claimed by the manufacturer.[98]

- **Controls**

The control system of a process chiller should provide motor protection, avoid high pressure, loss of refrigerant, loss of water flow, freeze protection and low refrigerant pressure. Controls shall include motor switch, electricity switch in case of failure, chilled water set-point adjustment, operation indicators (temperatures and pressures), among others features.

- **Refrigerant**[99]

The refrigerant used in chillers has a strong relation with the type compressor employed.

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[97] Energy Efficiency Ratio (EER) - a ratio of the cooling capacity in Btu/h to the power input values in watts at any given set of Rating Conditions expressed in Btu/(W·h)

[98] M. Merchat, *Mesure des performances énérgétique des systémes de refroidissement*, 2009

[99] Source: UNEP. *Report of the Refirgeration, Air Conditioning and Heat Pumps Techinical Options Committee*. Montreal Protocol On Substances that Deplete the Ozone Layer, Januayr 2007

- Chillers equipped with positive displacement compressors:

Screw chillers initially employed R-22 (mid-1980s). The trend of recent years has been substituting this refrigerant for R-134a. In Europe, especially in northern countries, an increase on higher pressure R-410A chillers has been evidenced over the past years. Scroll chillers refrigerants features R-134a, R-410A and R-407C. In countries where R-22 has been phased out by regulations due to the Montreal Protocol, the use of R-407C has increased. For the new scroll chillers, R-410A is being used. R-744 is being used by several manufacturers all over the world; however, it is not yet common[100].

Prior the Montreal Protocol, smaller reciprocating chillers were using R-22 and R-12, being the first one the most preferred. The bigger reciprocating chillers were offered with R-22 as well. After the advent of Montreal Protocol, the refrigerant choice has shifted almost completely to R407C, and in a small extent to R-134a, R-290 (propane) or R-1270 (propylene). For water-cooled chillers it is possible to use ammonia as refrigerant, but these units are smaller compared to fluorocarbon ones.

- Chillers equipped with centrifugal compressors:

Prior to 1993, this kind of chillers was offered with R-11, R-113, R-12, R-114, R-500, and R-22 refrigerants, being the R-11 by far the most common due to its efficiency. After 1993, as consequence of the Montreal Protocol, production of CFCs or CFCs containing refrigerants was ended in developed countries. From this date, CFC-11 was replaced by R-123, while R-12 and R-500 were substituted by R-134a. The capacities for centrifugal chillers related to the used refrigerant are shown in table below)

Table 4-19: Centrifugal chillers refrigerants capacity

Refrigerant	Capacity range (kW)
R-11	350 – 10,000
R-12	700 – 11,000
R-500	3,500 – 5,000
R-22	2,500 – 35,000
R-123	700 – 15,000
R-134a	210 – 30,000
R-245fa	2,600 – 9,200
R-744	*No limits identified*

◆ **Housing**

This component is not relevant to all process chillers. Some incorporate a housing to protect from the environment, while giving a support to fans in the case of air-cooled. Normally, water-cooled chillers do not use housing.

4.7.4.2 Component energy consumption, use pattern and saving potential

The data in the table below, based on literature and stakeholder feedback, summarises for each component the percentage of total energy consumption of the appliance, the energy saving potential of the component and the energy saving for the overall product.

[100] Source: ECOS

According to feedback from stakeholders, the average chiller works at 80% load. Information on Base Case component working hours has not been provided.

Table 4-20: Process chiller component energy consumption and improvement potential

Component	% of total energy consumption of the appliance	Improvement potential (in % of the energy consumption of the component)	Improvement potential (in % of total energy consumption of the appliance)
Evaporator (pumps)	8.5 to 12.2	7 to 8	0.7 to 1.4
Compressor	63	16 to 21	10 to 13
Condenser fans	15.5	2 to 7	0.3 to 1.4
Expansion device	N.A.	-	N.A.
TOTAL	**100**	**-**	**Approx. 15**

N.A.: Not Available (i.e. no data has been found)
-: no energy consumed by component
[1]Tipically not included in the equipment

The improvement factors are also linked with the selection and the energy management of the pumps for example. The total improvement potential suggested here compares with an overall estimate of 30% energy efficiency achievable for packaged process chillers in the year 2020, provided by stakeholders, but this includes potential improvements such as floating head pressure, which the component analysis above does not.

As described in Task 2, the use pattern corresponds to 4,380 hours/year (365 days/year, 12hrs/day). This use pattern considers equipment working in industrial processes. Stakeholders has expressed that the use pattern for appliances working in refrigeration would be “on” during 24 hours per day and 365 days per year, working at 80% load.

4.7.5. Remote condensing units (RCUs)

4.7.5.1 Product description at component level

As shown in Task 2, the most commonly used RCUs are air cooled and consist of a compressor, condenser coil, fan, motors, refrigerant reservoir, and operating controls. Most of the condensing units have cooling capacities between 3-20 kW and capacities higher than 100 kW are only used for large systems.

- **Compressor**

The compressor most commonly used within the equipment is a reciprocating-type, hermetically sealed, with rubber vibration isolators. The motor is an on-off type and includes start capacitor, relay, and contactor.

The main factor affecting the energy consumption levels of the compressors is the differences between individual compressor units and parallel compressor units.

Variable speed drives for compressors allow for greater flexibility in meeting part refrigeration loads. Moreover switching from electric motors to engine-driven open compressors may also achieve savings.

- **Condenser**

The average condenser coil used in remote condensing units is made of a seamless copper tube and aluminium fin coil. The condenser fan is made of aluminium.

Moreover, three types of condensers might be used in the RCU: air-cooled, water-cooled or evaporative condensers.

Air-cooled condenser fans and water-cooled condenser pumps may provide opportunities to reduce energy consumption. Increased heat exchanger size, mini-channel heat exchangers and variable condensing temperatures can also achieve energy savings.

- **Controls**

In the average equipment, the controls to switch on and off the compressor when it is not needed are mechanical thermostats with no energy consumption in stand-by mode. Electronic thermostats are used in compressors with VSD technology, or condensing units with parallel compressors, with 1-2 W of power input.

- **Refrigerant**

Remote condensing units normally use R-404A as refrigerant in Europe. In some cases, R-507A or R-410A are employed as well. R-134a is also used, but R-404A is the leading choice because of the lower cost of the condensing units to obtain the same cooling capacity[101]. Market penetration of low-GWP condensing units in developed countries is 1-2% for CO2 and 3-5% for R290. Condensing units are the most difficult equipment to use low-GWP refrigerants because the market is driven by cost. CO_2, ammonia and hydrocarbons have been tested and applied, but

[101] Source: UNEP. *Report of the Refirgeration, Air Conditioning and Heat Pumps Techinical Options Committee*. Montreal Protocol On Substances that Deplete the Ozone Layer, May 2010

the number of these in the market is low. New designs emerged using ammonia, even for small condensing units[102].

- **Housing**

Packaged condensing units are constructed within metal or plastic housings for protection from dust and weather. Units located outdoors require better insulation for protection from water, whereas in indoor units insulation is not that important. In both cases the interior of the condensing unit has to be easily accessible for installers or technicians, in order to facilitate the maintenance of the components.

4.7.5.2 Component energy consumption, use pattern and saving potential

The data in the table below, based on literature and stakeholder feedback, summarises for each component the percentage of total energy consumption of the appliance, the energy saving potential of the component and the energy saving for the overall product.

Table 4-21: Remote condensing unit component energy consumption and improvement potential

Component	% of total energy consumption of the appliance	Improvement potential (in % of the energy consumption of the component)	Improvement potential (in % of total energy consumption of the appliance)
Compressor	90	16-21	11-18
Condenser fans/pump (motor)	10	2-7	0.2-2.1
TOTAL	**100**	**-**	**11.9-20.1**

N.A.: Not Available (i.e. no data has been found)
-: no energy consumed by component

The total improvement potential suggested here compares with an overall estimate of 23% energy efficiency achievable for remote condensing units in the year 2020, provided by stakeholders.

As described in Task 2, the use of the condensing unit depends on the product it is connected to, hence could vary from 1,650 for a blast cabinet to 8,760 for a walk-in cold room). The industry standard for the duty cycle is 16h/day, according to information provided by stakeholders. This means 5840h/year.

[102] Sanden Corporation (Japan). Source : Shecco

4.7.6. SUMMARY

This section described the average product parameters, Base Case technical specifications and an analysis of improvement potential by component. The Base Cases were selected as the most representative models on the market.

The calculated and stakeholder estimates for saving potentials for the product groups are described in the table below, and apart from the figures for process chillers, these are approximately equivalent (the saving potentials calculated through components do not take into account potential overlaps – e.g. improved insulation will reduce savings achieved though other components – therefore are over-estimated).

Table 4-22: Comparison of energy saving potentials

Type of equipment	Calculated potential energy savings by component (%)	Stakeholder estimates of potential energy savings in 2020 (%)
Service cabinets	39.6-76.2	25-33
Blast cabinets	26.4-58.8	21-33
Walk-in cold rooms	37-60.8	31-39
Process chillers	15	30
Remote condensing units	11.9-20.1	23

4.8. BASE CASE TECHNICAL SPECIFICATIONS

For each product group, the Base Case used for the environmental analysis is represented by one or two weighted Base Cases, calculated using the market shares of the different configurations and various assumptions on relative energy consumption, material quantities and other factors, as described below. This leads to an abstract model, not comparable to any specific product in the market, but useful as a statistical tool to calculate overall market impacts. The characteristics described below for these weighted Base Cases are those essential for the EcoReport assessment.

These weighted Base Cases have been developed from one or two sub-Base Cases (details provided in Annex 4-1), and these sub-Base Cases are comparable to the most common product configuration on the market, with differentiation of low, medium or high temperature, where necessary. The sub-Base Cases are necessary, in order to have real product characteristics from which to extrapolate the weighted models, and also to compare against BAT in the following Tasks.

However, for the environmental impact assessment and the EU stock energy savings calculations, the weighted Base Cases will be used. A sensitivity analyses for each weighted Base Case was undertaken, and the results of these are presented in §4.10.

4.8.1. SERVICE CABINETS

For the case of service cabinets, two weighted Base Cases have been developed corresponding to the different operation temperature (medium and low temperature). The details of the real model on which some of the Base Case specifications are based are provided in Annex 4-1, §4.14.

Assumptions used are as follows:

- energy consumption based on 450 litre net internal volume[103] model, climate class 4, M-package temperature class M1, extrapolated as shown in Table 4-23[104].
- AEC of LT product assumed to be HT multiplied by 2.5, and LT materials in the product are assumed to be equal to that of HT multiplied by 1.1.
- a market weighted AEC was then calculated, using the market shares as described in Table 4-23, for the high-temperature refrigerator and another for low-temperature freezer.
- price of HT model assumed to be €1,000[105], and €1,100 for LT.
- on average, the lifetime and distribution volume is assumed to be equal to that of the 450 litre net internal volume model described above.

[103] Calculated according to EN 441 method

[104] Stakeholder comments that AEC for an "average" M1 product should be around 2000 kWh/year. Source: Electrolux, Foster, Gram

[105] Source : Defra, Foster

- products are assumed to be 100% plug-in type (remote represent less than 2% of the market) and refrigerator-freezers are not included (also represent less than 2% of market).
- refrigerant R134a used in HT, charge 300g, and R404A used in LT, charge 400g.
- refrigerant leakage is estimated to be 1% per annum, and loss at end-of-life 100% of remaining refrigerant in the circuit. The sensitivity of the control instrumentation normally used at the end of the production line is set at 3%, hence the worst-case leakage rate is below this. During the life no recharge of refrigerant is planned (this would be considered as a product failure and would influence directly the service call rate, i.e. quality index, of the product[106]. Total lifetime leakage is therefore estimated to be 100% of original charge.
- installation cost is zero.
- maintenance and repair cost is 10% of the weighted Base Case price.

Table 4-23: Estimated energy consumption weighting factors for service cabinets

Configuration	Operation temperature	Model type: door numbers	Estimated average internal volume (litres)*	Market share (%)	Assumptions	Average AEC of Base Case sub-categories (kWh)
Vertical	Refrigerator	1	450	34.30	2,000 kWh per annum consumption (Provided by stakeholders)	2,000
		2	900	14.70	Consumption per litre is 0.8x that of 1-door vertical refrigerator	3,200
	Freezer	1	450	14.70	Consumption per litre is 2.5x that of 1-door vertical refrigerator	5,000
		2	900	6.30	Consumption per litre is 0.95x that of 1-door vertical freezer	9,500
Horizontal	Refrigerator	1	150	10.15	Consumption per litre is 1.35x that of 1-door vertical refrigerator	900
		2+	200	10.15	Consumption per litre is 0.8x 1-door horizontal refrigerator	960
	Freezer	1	100	4.35	Consumption per litre is 1.05x that of 1-door vertical freezer	1,167
		2+	200	4.35	Consumption per litre is 0.95x 1-door horizontal freezer	2,217
Chest	Freezer	1	400	1.00	Consumption per litre is 0.8x that of 1-door vertical freezer	3,556

**Calculated according to EN 441 method*

[106] Source: Electrolux

In Table 4-24 below, the main characteristics selected for the weighted service cabinet Base Cases are presented.

Table 4-24: Characteristics of the service cabinet weighted Base Cases

Product characteristics	Weighted Base Case MT	Weighted Base Case LT
Test standard	EN 441	EN 441
Functional unit:	Litre of net volume at +5°C	Litre of net volume at -18°C
AEC [kWh/year]:	2,000	5,000
Price (ex VAT) [€]:	1,000	1,100
Lifetime [years]:	8.5	8.5
Weight of product [kg]:	114	125.4
Shipping volume [m^3] :	1.5	1.5
Refrigerant:	R134a	R404A
Refrigerant charge [g]:	300	400
Refrigerant leakage [% per annum]:	1	1

4.8.2. BLAST CABINETS

For the case of blast cabinets, a single weighted Base Case has been developed corresponding to the different types of equipment (chilling, freezing and chilling/freezing) and the different configuration (reach-in, roll-in and pass-through). The technical specifications of the real model on which this is based are provided in Annex 4-1, §4.15. Assumptions used for the weighted blast cabinet Base Case are as follows:

- The weighting was done considering all configuration: roll-in, reach-in and pass-through.
- Remote units are considered to be 15% of the total market, the rest plug-in.
- Market distribution considered for all categories as per Task 2.
- Materials proportions and weights used were not weighted for all categories of the stock. Instead, the material proportion used is the equivalent to the most commonly sold equipment in the EU (20kg capacity reach-in).
- Use pattern varies for chilling equipment (440 90-minute cycles per year), freezing (220 240-minute cycles per year) and combined models (220 90-minute cycles plus 220 240-minute cycles per year). The weighted Base Case use pattern is an abstract figure, calculated by weighting the assumed used patterns of all product types by their respective market shares.
- The energy consumption per category is based on the assumed factors as shown on the table below.

Table 4-25: Estimated energy consumption weighting factors for blast cabinets

Configuration	Operation temperature	Size	Location of condensing unit	Market share (%)	Assumptions	Average AEC of Base Case sub-categories (kWh/year)
Reach-in	Chilling	Small R	Plug-in	1.91	0.60 energy cons. as reached-in medium (Base)	528
		Medium R	Plug-in	4.21	(Base)	880

Configuration	Operation temperature	Size	Location of condensing unit	Market share (%)	Assumptions	Average AEC of Base Case sub-categories (kWh/year)
		Large R	Plug-in	0.77	2.40 energy cons. as reached-in medium (Base)	2,112
		Extra-large R	Remote	0.77	3.8 energy cons. as reached-in medium (Base)	3,344
	Freezing	Small	Plug-in	0.26	2.5 energy cons. as reached-in small (Base)	660
		Medium	Plug-in	0.43	2.5 energy cons. as reached-in medium (Base)	1,100
		Large	Plug-in	0.09	2.5 energy cons. as reached-in large (Base)	2,640
		Extra-large	Remote	0.09	2.5 energy cons. as reached-in extra-large (Base)	4,180
	Chilling / Freezing*	Small	Plug-in	22.95	Aggregate energy cons. from chilling and freezing cycles*	924
		Medium	Plug-in	38.25	Aggregate energy cons. from chilling and freezing cycles*	1,540
		Large	Plug-in	7.65	Aggregate energy cons. from chilling and freezing cycles*	3,696
		Extra-large	Remote	7.65	Aggregate energy cons. from chilling and freezing cycles*	5,852
Roll-in (trolley)	Chilling	Small	Plug-in	0.06	1.15 energy consumption of cabinet of similar capacity	4,148
		Medium	Remote	0.03	1.15 energy consumption of cabinet of similar capacity	6,219
		Large	Remote	0.02	1.15 energy consumption of cabinet of similar capacity	10,102
	Freezing	Small	Plug-in	0.06	2.5*1.15 times energy consumption of cabinet of similar cap.	5,185
		Medium	Remote	0.03	2.5*1.15 times energy consumption of cabinet of similar cap.	7,774
		Large	Remote	0.01	2.5*1.15 times energy consumption of cabinet of similar cap.	12,628
	Chilling/ Freezing*	Small	Plug-in	5.88	Aggregate energy cons. from chilling and freezing cycles*	7,259
		Medium	Remote	2.94	Aggregate energy cons. from chilling and freezing cycles*	10,883
		Large	Remote	0.98	Aggregate energy cons. from chilling and freezing cycles*	17,679
Pass-through	Chilling	Small	Plug-in	0.03	1.15 energy consumption of cabinet of similar	4,148

Configuration	Operation temperature	Size	Location of condensing unit	Market share (%)	Assumptions	Average AEC of Base Case sub-categories (kWh/year)
					capacity	
		Medium	Remote	0.01	1.15 energy consumption of cabinet of similar capacity	6,219
		Large	Remote	0.01	1.15 energy consumption of cabinet of similar capacity	10,102
	Freezing	Small	Plug-in	0.03	2.5*1.15 times energy consumption of cabinet of similar cap.	5,185
		Medium	Remote	0.02	2.5*1.15 times energy consumption of cabinet of similar cap.	7,774
		Large	Remote	0.01	2.5*1.15 times energy consumption of cabinet of similar cap.	12,628
	Chilling/ Freezing*	Small	Plug-in	2.94	Aggregate energy cons. from chilling and freezing cycles*	7,259
		Medium	Remote	1.47	Aggregate energy cons. from chilling and freezing cycles*	10,883
		Large	Remote	0.49	Aggregate energy cons. from chilling and freezing cycles*	17,679

*User behaviour corresponds to 1chilling cycle of 90min + 1 freezing cycle of 240min

The factors presented in the table were provided by the industry. The factor of 1.25 for the relation between remote and plug-in cabinets was revised by stakeholders (Asskuhl, Friginox, Foster, 2010), providing a new factor of 1:1. This is due to the distance between the cabinet and condensing unit decreasing the efficiency, compensating the positive effect achieved by the lower temperature outside the kitchen.

- The annual foodstuff processing capacity is the total amount of kilograms of foodstuff that can be processed, and has been calculated using the assumed use patterns for each product type, then weighted according to the market proportions, to find an average. The calculated value corresponds to 16,197 kg/year.
- Expected refrigerant charge is approximately 100 g of refrigerant per 1 kg of foodstuff to be refrigerated. This has been calculated using average charges for each product type, which were then weighted according to their market distribution.
- Refrigerant leakage was calculated considering the proportion between plug-in and remote equipment, assumed to have leakage rates of 5% and 12% respectively. The End-of-Life dumped refrigerant percentage was weighted considering 50% for remote equipment and 100% for plug-in[107]. As result the end-of-life dumped refrigerant is 82%.

[107] Source: ECOS, 2010

- On average, lifetime, distribution volume and price assumed to be equal to that of a 20 kg capacity model.
- Installation cost is zero.
- Repair cost is 10% of price.
- The blast cabinet is only considered to work during the blast cycles, either chilling or freezing. As expressed in Task 1, storage mode is not the main function of this equipment.

In the table below, the main characteristics selected for the weighted service cabinet Base Cases are presented.

Table 4-26: Technical characteristics of weighted blast cabinet Base Case

Product characteristics	Base Case
Functional unit:	1kWh/1 kg of foodstuff (referred to material proposed by NF AC D 40-003)
AEC [kWh/year]:	3,031
Use pattern:	5.5 hour/day, 220 days/year, in different cycles types
Price (ex VAT) [€]:	6,400
Lifetime [years]:	8.5
Shipping volume [m^3] :	1.17
Weight of product [kg]:	120
Refrigerant:	R404A
Refrigerant charge [g]:	2,800
Refrigerant leakage [% per annum]:	7

4.8.3. WALK-IN COLD ROOMS

For walk-in cold rooms, a single weighted Base Case has been developed covering chilling and freezing products, and the different sizes. Assumptions used for the weighted blast cabinet Base Case are as follows:

- Due to no current measurement standard for walk-in cold rooms and no information provided on annual electricity consumption, AEC is based on UK MTP assumptions, and is weighted across the whole market, including low and medium temperatures (market data in Task 2), based on the average size of 25m^3 internal net volume and weighted AEC of 12,155 kWh.

Table 4-27: Estimated energy consumption weighting factors for walk-in-cold room

Size	Operation temperature	MTP estimated market proportion	MTP estimated average cooling load (kW)	MTP estimated average COP	MTP estimated average AEC of sub-categories (kWh)	Estimated average net internal volume (m^3)
Small (up to 20m^3)	Chiller	44.49%	1.4	1.84	6,665	12
	Freezer	22.54%	1.3	1.32	8,627	12
Medium (20m^3 to 100m^3)	Chiller	23.36%	4.5	2.41	16,357	40
	Freezer	8.10%	4.58	1.47	27,293	40
Large (100m^3 to 400m^3)	Chiller	1.13%	18	2.66	59,278	300
	Freezer	0.48%	19	1.47	113,224	300

- The room is assumed to be factory-built, with a packaged refrigeration unit.
- On average, refrigerant charge, lifetime, distribution volume and price assumed to be equal to that of the 25m^3 internal volume model.
- Refrigerant charge is an approximated average, which takes into account the difference between plug-in and remote charge sizes through weighting (assuming the market is split 45% plug-in and 55% remote).
- Refrigerant leakage was calculated considering the proportion between plug-in and remote equipment, assumed to have leakage rates of 5% and 12% respectively[115] per annum, and loss at end-of-life of 100% of the refrigerant in the circuit for plug-in and 50% for remote units Annual refrigerant leakage is therefore estimated to be 9%, while end-of-life is estimated as 73% - total lifetime leakage is therefore estimated to be 163% of original charge.
- Installation cost is 20% of price.
- Maintenance and repair cost is 10% of price.

In the table below, the technical characteristics selected for the walk-in cold room Base Case are presented.

Table 4-28: Characteristic of the walk-in cold room weighted Base Case

Product characteristics	Base Case
Functional unit:	m^3 of net internal volume
AEC [kWh/year]:	12,155
Price (ex VAT) [€]:	8,800
Lifetime [years]:	10
Shipping volume [m^3] :	15 (flat-packed)
Weight of product [kg]:	1,000
Refrigerant:	R404A
Refrigerant charge [g]:	3,000
Refrigerant leakage [% per annum]:	9

Further technical specifications of this estimated average chilling model are provided in Annex 4-1, §4.16.

4.8.4. Process chillers

For the case of process chillers, two weighted Base Cases have been developed corresponding to the different operation temperature (medium and low temperature). The technical specifications of the real model on which this is based are provided in Annex 4-1, §4.15. Assumptions used are as follows:

- the machines considered to generate the analysis are packaged ones.
- the condensing unit is integrated and condenser is water-cooled. There is more evidence and technical specifications available regarding this model type.
- the annual energy consumption was weighted considering the typical use pattern, relative energy consumption of different product types, as shown

in Table 4-29, the capacities of the equipment and their market shares. It was assumed that the compressor works during 80% of the cycle.

- the shipping volume was not weighted. Instead, the volume of the most commonly sold equipment was used for each temperature range.
- the consumption ratio between the different equipment types are shown in the Table 4-29. These factors are based on equipment evaluation expressed by the industry. Therefore, the conditions of evaluation are included in the factors, e.g. the difference of inlet temperature between water- and air- cooled chillers.

Table 4-29: Estimated energy consumption weighting factors for chillers

Type of equipment	Relative energy consumption
Low-temperature	2.5*X
Medium-temperature	X
Small low-temperature	Y
Medium low-temperature	4.6*Y
Large low-temperature	8.33*Y
Extra-large low-temperature	16*Y
Small medium-temperature	Y
Medium medium-temperature	4.6*Y
Large medium-temperature	8.33*Y
Extra-large medium-temperature	16*Y
Air-cooled	1.15*Z
Water-cooled	Z

- the equivalent cooling capacity of the equipment was calculated based on the annual consumption corresponding to the different product types and material weights and proportions extrapolated from the BOM of a similar product. The calculated weighted cooling capacity is 266kW for both temperature ranges. This weighted cooling capacity is determined using the average energy consumption per cooling capacity as in Table 4-30**.**
- the energy consumption per category is based on assumed factors shown on the Table 4-30. After revision of the factors by stakeholders, the original proportion between water- and air-cooled chillers (1:1.4) was reduced to 1:1.15 as an average of the possible European values (1:1 and 1:1.3), for energy consumption (Table 4-29). The calculation is based on market information considering the common cooling capacities and power inputs.

Table 4-30: Estimated energy consumption weighting factors for process chillers

Operation temperature	Size	Typical capacity (kW)	Cooling system	Market share (%)	Estimated factor	Average AEC of Base Case sub-categories (kWh) (-8°C/-15°C outlet temp./ 30°C)	Typical COP
Medium	Small	50	Air cooled	80	1.15*X	90,494	1.94
			Water cooled	20	X	78,690	2.23
	Medium	250	Air cooled	75	1.15*4.6*X	405,334	2.16
			Water cooled	25	4.6*X	352,465	2.49
	Large	500	Air cooled	70	1.15*8.3*X	779,009	2.25
			Water cooled	30	8.3*X	677,399	2.59
	Extra-large	1000	Air cooled	60	1.15*16*X	1,442,204	2.43
			Water cooled	40	16*X	1,254,090	2.79
Low	Small	50	Air cooled	80	1.15*Y	126,692	1.38
			Water cooled	20	Y	110,167	1.59
	Medium	250	Air cooled	70	1.15*4.6*Y	567,468	1.54
			Water cooled	30	4.6*Y	493,451	1.78
	Large	500	Air cooled	70	1.15*8.3*Y	1,090,612	1.61
			Water cooled	30	8.3*Y	948,359	1.85
	Extra-large	1000	Air cooled	60	1.15*16*Y	2,019,085	1.74
			Water cooled	40	16*Y	1,755,726	2.00

- the estimated power input corresponds to 120 and 168kW for medium and low temperature respectively.
- the estimation of COP was based on the equivalent cooling capacity and the weighted power input. The average COP for medium temperature water-cooled chillers is 2.21, while for low temperature is 1.58.
- the outlet evaporator operation temperature is -8°C in the range from -12°C to +3°C (medium temperature), and -15°C in the range of -25°C to -8°C (low temperature).
- the equipment works with ethylene glycol solution at 30%. It has been mentioned by stakeholders that the use of propylene glycol is more suitable for foodstuff refrigeration. However, within the scope of the study, chillers are meant for use in general industrial processes. The presence of additive to the water increases the requirements of power input, as the viscosity of the liquid increases.

- based on information from catalogues, there is a charge of 0.35kg of refrigerant per kW of cooling capacity. This ratio was used to determine the refrigerant charge of the two weighted Base Cases.
- price presented corresponds to around €200 per kW of cooling capacity for medium temperature and around €250 for low temperature.
- on average, lifetime and distribution volume are assumed to be equal to that of a 260 kW cooling capacity model.
- installation cost 10% of price.
- repair cost is assumed to be a 10% of the purchase product price. This cost could be increased depending on the type of refrigerant used due to safety conditions.
- the environmental conditions change according to the type of equipment. Water-cooled chillers have inlet water at 30°C, while for air-cooled is normally evaluated at 35°C inlet air. This difference is considered within the conversion factor (1.15) provided by the industry, expressed in Table 4-29 and Table 4-30.

The characteristics selected for these two are presented in the Table 4-31.

Table 4-31: Characteristics of weighted process chiller Base Cases

Product characteristics	Weighted Base Case MT	Weighted Base Case LT
Functional unit:	1 kW cooling capacity to reach -8°C at +30°C water temperature	1 kW cooling capacity to reach -25°C at +30°C water temperature
Cooling capacity (kW):	266	266
AEC [kWh/year]:	420,946	587,659
Use pattern:	12 hour/day, 365 days/year	12 hour/day, 365 days/year
Price (ex VAT) [€]:	55,000	70,000
Lifetime [years]:	15	15
Shipping volume [m^3] :	11.6	13.9
Weight of product [kg]:	2,667	3,067
Refrigerant:	R134a	R404A
Refrigerant charge [g]:	90	90
Refrigerant leakage [% per annum]:	1	1

4.8.5. Remote condensing units

For the case of remote condensing units, two weighted Base Cases have been developed corresponding to the different operation temperature (medium and low temperature). The technical specifications of the real models on which these are based are provided in Annex 4.1, §4.18. Assumptions used are as follows:

- the stock figures used for the EcoReport are slightly different from those shown in Task 2, in order to avoid the double counting of energy consumption of condensing units connected to service cabinets, blast cabinets, or walk-in cold rooms. From the overall stock figures for remote condensing units found in Task 2, the proportion number of products connected to a remote unit has been subtracted, remaining the stock of condensing units connected to other type of refrigeration equipment.

- market shares of the different configurations shown in Task 2, §2.4.4.5 and annex 2.9 are used in order to weight the annual energy consumption, coefficient of performance, price and refrigerant charge. Table 4-74 provided in Annex 4.1, §4.18. shows the weighting factors explained above, together with the Average Energy Consumption and the Average COP of the different configurations.
- material weights and proportions extrapolated from the sub Base Case (most common product in the market). A sensitivity analysis has been carried out to compare changes if material quantities vary (see results in §4.10.5.3).
- the material of the LT Base Case equals that of MT, increased by 20%.
- energy consumption for the Base Case model for medium temperature presented in Annex 4.1, §4.18. has been provided by stakeholders.
- energy consumption of remote condensing units with twin compressors or more is estimated to be 10% lower than remote condensing units with a single compressor, and represents 5% of the market.
- a temperature ratio[108] of 1.78 was used to calculate the increase in AEC of Low Temperature remote condensing units compared to Medium Temperature machines.
- condensing units using scroll, rotary vane and screw compressors are estimated to have annual energy consumption 10% lower than equivalent condensing units with hermetic reciprocating compressors. However, rotary vane compressors are not used in commercial refrigeration equipment. and are not taken into account.
- condensing units with 2-speed or VSD compressor are estimated to have energy consumption 10% lower than condensing units with on/off compressor
- water-cooled condensing units have been estimated to have energy consumption 5% lower than air-cooled condensing units
- lifetime, distribution volume and repair and maintenance costs are assumed to be equal to that of the Base Case model (most common product in the market). Installation and repair costs are 10% of price of the Base Case.
- the estimated COP values have been calculated by applying to the power input the same savings as in the AEC, and assuming that the cooling capacity is the same. Energy savings related to partial load and seasonal variations (variable speed drive, parallel compressors, floating head pressure) cannot be reflected in the COP tested at one point (EN 13215), and are not included in these calculations.

[108] (ambient temp- medium target temp)/(ambient temp- low target temp); (32-(-10))/(32-(-35)) = 1.78; LT = MT*1.78

The technical characteristics selected for the remote condensing unit weighted Base Case are shown in the following table.

Table 4-32: Characteristics of the remote condensing unit weighted Base Cases

Product characteristics	Weighted Base Case MT	Weighted Base Case LT
Test standard:	EN 13215:2000	EN 13215:2000
Functional unit:	1 kW of cooling capacity at evaporation temperature -10°C and ambient temperature +32°C	1 kW of cooling capacity at evaporation temperature -35°C and ambient temperature +32°C
AEC [kWh/year]:	31,270	50,106
COP*:	1.9	1.0
Price [€]:	6,627	7,933
Shipping volume [m^3]:	0.70	0.84
Weight of product [kg]:	117	213
Refrigerant:	R404A	R404A
Refrigerant charge [kg]:	11	11
Refrigerant annual leakage [% per annum]:	15	15
Lifetime [years]:	8	8

** COP: cooling capacity (kW) divided by the power input (kW). Although COP is not required as an EcoReport input, it is included for information.*

4.9. INPUTS FOR BASE CASE ASSESSMENT

This section describes the information required as input for the EcoReport tool, to assess the life cycle environmental impacts of the products.

4.9.1. LIFECYCLE STAGES

Production phase

The percentage of each material for the different products was provided by stakeholders through BOMs. The BOM obtained for selected products and components is presented in annex 4-2.

The scrap production during sheet metal manufacturing was considered as 5% for all products.

Distribution phase

The distribution phase in the EcoReport tool is represented by the product type and volume of the packaging. In general packaging consists of plastic, cardboard and a wood palette used to facilitate the transport of the product. This contribution of materials was assumed for all Base Cases.

Use phase

In this section, the annual energy and resources consumption that can be measured for the product and the direct emissions during product life are discussed. The electrical energy consumption and the direct emissions related to refrigerant use are considered.

End of life phase

Very little commercial or industrial refrigeration equipment is found in refrigerator recycling plants in EU (less than 1 %). The most common end of life route is dismantling of the cabinet, and recycling of the raw material through specific recycling companies, or via the original manufacturers. The cost is assumed to represent around 1% of the total cost purchase. According to manufacturers, resale of used products has been decreasing, and nowadays it represents less than 1% of appliances.

Refrigerant leakage rates

The estimation of the refrigerant leakage rates is shown in Table 4-33 below. An annual leakage rate between 1% and 7% has been estimated for plug-in products and between 12% and 15% for remote configurations. In order to carry out the environmental impact assessment on average products representative of the market, these values have been weighted following the market shares shown in Task 2 (also shown in the weighting assumptions in §4.8. above).

These leakage values have been multiplied by the number of years of life of the products to obtain the overall refrigerant emissions during their lifetime. The refrigerant emissions during the end of life phase have been estimated in 50% for remote condensing units and chillers[109], and between 73% and 100% for service

[109] Source: ECOS, Shecco

cabinets, blast cabinets and walk-in cold rooms. This was summed up to the fugitive refrigerant during the use phase, to provide a final total lifecycle leakage figure (this can in some cases exceed 100%, where it is assumed that the product has been recharged with refrigerant during its life).

Table 4-33: Leakage rates estimations for Base Cases analysis

Annual refrigerant leakage rates						
		Service cabinets	Blast cabinets	Walk-in cold rooms	Industrial process chillers	Remote condensing units
Refrigeration roadmap study (UK)		<1% plug-in	<1% plug-in	<1% plug-in	<1% plug-in	10%-20%
BIO estimation before 2nd SHM		1%	1%	1%	1%	1%
SH comments in 2nd SHM		10%-12%	10%-12%	10%-12%	10%-12%	15%
BIO used in sub-Base Cases	Plug-in	1%	5%	5%	1%	-
	Remote	12%	12%	12%	1%	15%
BIO used in weighted Base Cases		6%	7%	9%	1%	15%

4.9.2. DATA INPUTS SUMMARY

			SC HT	SC LT	BC	WICR	CH MT	CH LT	RCU MT	RCU LT
	Number of BOMs forming Base Case		3	Based on HT	1	Partial	1	Based on MT	partial	Based on MT
MANUFACTURING	Bulk Plastics		6.15%	6.15%	0.96%	3.58%	0.05%	0.05%	2.18%	2.18%
	TecPlastics		9.48%	9.48%	6.79%	6.10%	0.16%	0.16%	0.04%	0.04%
	Ferro		63.66%	63.66%	72.71%	81.37%	63.44%	63.44%	86.68%	86.68%
	Non-ferro		6.42%	6.42%	8.67%	2.84%	24.74%	24.74%	3.29%	3.29%
	Coating		4.95%	4.95%	0.00%	3.50%	10.46%	10.46%	0.62%	0.62%
	Electronics		0.54%	0.54%	1.63%	0.00%	0.01%	0.01%	0.00%	0.00%
	Misc.		8.79%	8.79%	9.24%	2.60%	1.14%	1.14%	7.19%	7.19%
	Total weight	g	141,390	155,529	116,330	1,003,755	2,667,000	3,067,050	138,211	165,853
	Sheetmetal Scrap		5%	5%	5%	5%	25%	5%	5%	5%
DISTRIBUTION	Volume of packaged final product	in m3	1.5	1.5	1	15	12	14	1	1
USE PHASE	Product Life	years	8.5	8.5	8.5	10	15	15	8	8
	On-mode: Consumption per hour, cycle, setting, etc.	kWh	2,000	5,000	3,031	12,155	420,946	587,659	31,270	50,106
	On-mode: No. Of hours, cycles, settings, etc. / year	#	1	1	1	1	1	1	1	1
	Percentage of fugitive refrigerant		1%	1%	6%	9%	12%	12%	15%	15%
DISPOSAL & RECYCLING	Refrigerant in the product		R134a	R404A	R404A	R404A	R134a	R404A	R404A	R404A
	Refrigerant in the product	g	300	400	2,800	3,000	100,000	100,000	11,100	11,100
	Percentage of dumped refrigerant at end of life*		92%	92%	5%	73%	5%	5%	5%	5%
	Percentage of fugitive & dumped refrigerant		100%	100%	142%	163%	65%	65%	170%	170%
	Landfill (fraction products not recovered)		5%	5%	5%	5%	5%	5%	5%	5%
	Plastics: Re-use, Closed Loop Recycling		1%	1%	1%	1%	1%	1%	1%	1%
	Plastics: Materials Recycling		9%	9%	9%	9%	9%	9%	9%	9%
	Plastics: Thermal Recycling		90%	90%	90%	90%	90%	90%	90%	90%
ECONOMIC & MARKET DATA	Product Life	years	8.5	8.5	8.5	10	15	15	8	8
	Annual sales	mln. Units/year	0.2782108	0.1192332	0.173655	0.088289	0.00327925	0.002576552	0.455817	0.113954
	EU Stock	mln. Units	2.2821141	0.9780489	1.33119685	1.521659	0.04531997	0.035608545	3.93535448	0.98383862
	Product price	Euro/unit	1,000	1,100	6,400	8,800	55,000	70,000	6,627	7,933
	Installation/acquisition costs	Euro/ unit	0	0	0	1,760	5,500	7,000	662	793
	Electricity rate	Euro/kWh	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	Repair & maintenance costs	Euro/ unit	100	100	640	880	5,500	7,000	525	742
	Discount rate	(interest minus inflation)	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%	4.0%
	Overall Improvement Ratio STOCK vs. NEW, Use Phase		1.17	1.17	1.02	1.03	1.07	1.07	1.03	1.03

*According to stakeholders, the actual end-of-life refrigerant percentage dumped might reach up to 100%, not following the WEEE Directive.

4.10. BASE CASE ENVIRONMENTAL AND ECONOMIC IMPACT ASSESSMENT

All the data presented in the section above where used to calculate environmental impacts. The results of the EcoReport impact assessment for each product group category are given below. The charts shown in this section correspond to the environmental impact generated during the life cycle of the product. Some impacts are represented in negative values in the charts representing the generation instead of the consumption, e.g. negative impact in energy represents energy production.

4.10.1. SERVICE CABINETS

The impacts of the service cabinet Base Cases are presented below.

Table 4-34: Environmental assessment results per HT PRODUCT from EcoReport for service cabinets

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	11443	2451	**13894**	**2087**	**178639**	1836	1488	**347**	**194968**
of which, electricity (in primary MJ)	MJ	2069	1464	**3534**	**4**	**178535**	0	8	**-8**	**182065**
Water (process)	ltr	6202	22	**6223**	**0**	**11962**	0	6	**-6**	**18180**
Water (cooling)	ltr	8270	679	**8950**	**0**	**476089**	0	46	**-46**	**484993**
Waste, non-haz./ landfill	g	185389	8382	**193771**	**1033**	**208898**	8674	33	**8641**	**412343**
Waste, hazardous/ incinerated	g	926	0	**926**	**21**	**4122**	19890	5	**19885**	**24954**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	773	137	**910**	**125**	**7799**	530	105	**424**	**9257**
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	5303	590	**5893**	**383**	**46023**	274	135	**139**	**52436**
Volatile Organic Compounds (VOC)	g	24	1	**25**	**31**	**67**	5	2	**3**	**127**
Persistent Organic Pollutants (POP)	ng i-Teq	1572	53	**1624**	**6**	**1186**	60	0	**60**	**2877**
Heavy Metals	mg Ni eq.	8916	124	**9040**	**52**	**3153**	503	0	**503**	**12748**
PAHs	mg Ni eq.	957	0	**958**	**69**	**361**	0	0	**0**	**1387**
Particulate Matter (PM, dust)	g	917	91	**1008**	**5129**	**992**	2381	3	**2378**	**9506**
Emissions (Water)										
Heavy Metals	mg Hg/20	5992	0	**5992**	**2**	**1211**	153	0	**153**	**7358**
Eutrophication	g PO4	255	1	**256**	**0**	**8**	9	0	**9**	**273**
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Table 4-35: Environmental assessment results per LT PRODUCT from EcoReport for service cabinets

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	12587	2696	**15284**	**2087**	**446403**	2019	1637	**382**	**464156**
of which, electricity (in primary MJ)	MJ	2276	1611	**3887**	**4**	**446289**	0	9	**-9**	**450171**
Water (process)	ltr	6822	24	**6846**	**0**	**29818**	0	6	**-6**	**36658**
Water (cooling)	ltr	9097	747	**9845**	**0**	**1190098**	0	51	**-51**	**1199892**
Waste, non-haz./ landfill	g	203928	9220	**213148**	**1033**	**519533**	9541	36	**9505**	**743219**
Waste, hazardous/ incinerated	g	1019	0	**1019**	**21**	**10293**	21879	6	**21874**	**33206**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	850	150	**1001**	**125**	**19484**	1676	116	**1561**	**22170**
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	5833	649	**6482**	**383**	**114974**	301	149	**153**	**121991**
Volatile Organic Compounds (VOC)	g	26	1	**27**	**31**	**168**	6	2	**4**	**230**
Persistent Organic Pollutants (POP)	ng i-Teq	1729	58	**1787**	**6**	**2943**	66	0	**66**	**4802**
Heavy Metals	mg Ni eq.	9808	136	**9944**	**52**	**7755**	553	0	**553**	**18305**
PAHs	mg Ni eq.	1053	0	**1053**	**69**	**890**	0	1	**-1**	**2012**
Particulate Matter (PM, dust)	g	1009	100	**1108**	**5129**	**2465**	2619	3	**2616**	**11318**
Emissions (Water)										
Heavy Metals	mg Hg/20	6591	0	**6591**	**2**	**2943**	168	0	**168**	**9705**
Eutrophication	g PO4	281	1	**282**	**0**	**17**	10	0	**9**	**308**
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Table 4-36: Impact of the service cabinets per functional unit per year

Impact indicator	Impact per litre of capacity at +5°C per year	Impact per litre of capacity at -18°C per year
Total Energy (GER) (MJ)	50.97	121.35
of which, electricity (in primary MJ)	47.60	117.69
Use-phase electricity consumption (kWh)	4.85	11.56
Water (process) (ltr)	4.75	9.58
Waste, non-haz./ landfill (g)	107.80	194.31
Waste, hazardous/ incinerated (g)	6.52	8.68
Greenhouse Gases in GWP100 (kg CO2 eq.)	2.42	5.80
Acidification, emissions (g SO2 eq.)	13.71	31.89
Volatile Organic Compounds (VOC) (g)	0.03	0.06
Persistent Organic Pollutants (POP) (ng i-Teq)	0.75	1.26
Heavy Metals (mg Ni eq.)	3.33	4.79
PAHs (mg Ni eq.)	0.36	0.53
Particulate Matter (PM, dust) (g)	2.49	2.96
Heavy Metals (mg Hg/20)	1.92	2.54
Eutrophication (g PO4)	0.07	0.08

The environmental impacts of the blast cabinets at different life phases are represented below. Use phase and production material are the two phases with the biggest impact. Almost 100% of the electricity consumed during the life-time of this equipment is related to the use-phase, which in terms of Total Energy becomes around 92% for HT and 96% for LT.

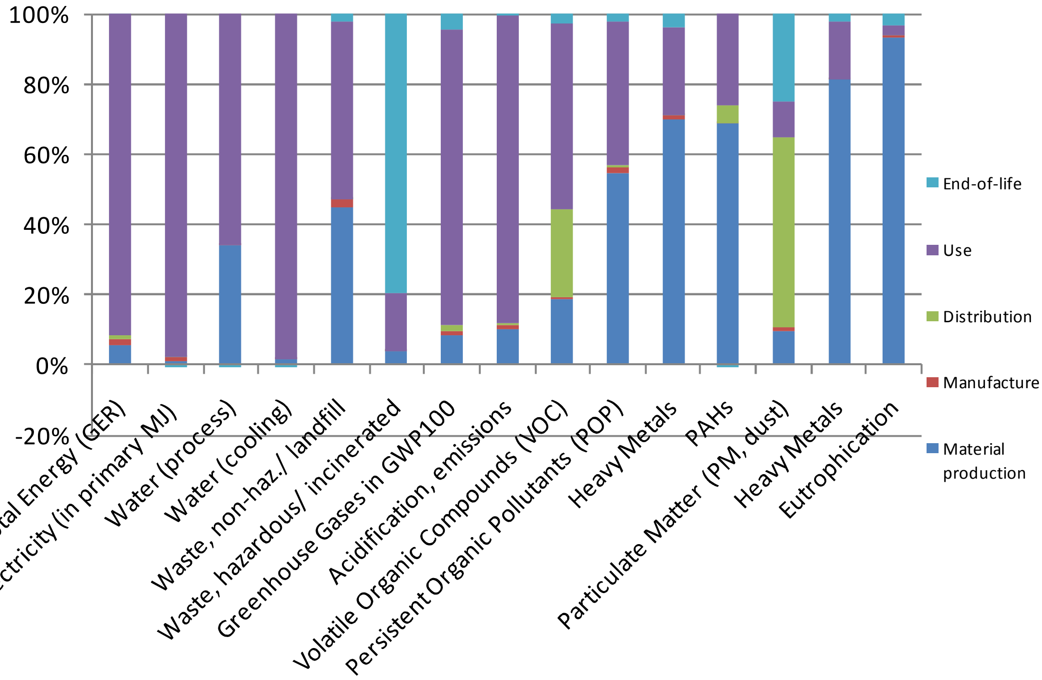

Figure 4-28: EcoReport results for HT service cabinets – impacts per lifecycle stage

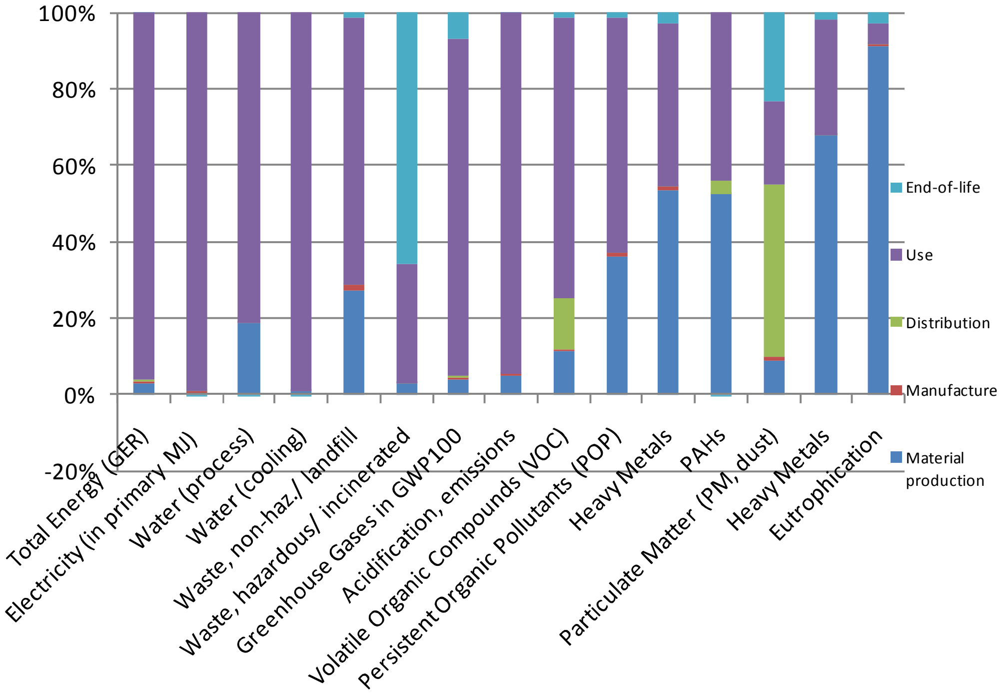

Figure 4-29: EcoReport results for LT service cabinets – impacts per lifecycle stage

When taking into account the GER (Gross Energy Requirement) as a reference for the environmental impacts, the results show that the use phase is the most important (Figure 4-30). Besides, it is important to note that the end of-life phase provides GER with the thermal recovery of some parts of the service cabinet.

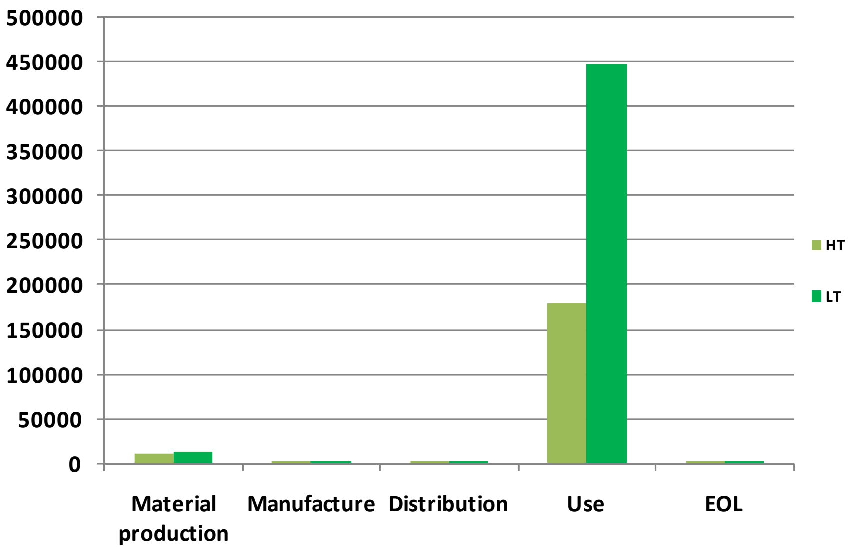

Figure 4-30: GER related to each phase of the life cycle of service cabinet (MJ)

Greenhouse Gases warming potential of service cabinet is mainly due to the use phase. The production of the electricity involves the combustion of fossil fuels and consequently emissions of carbon dioxide.

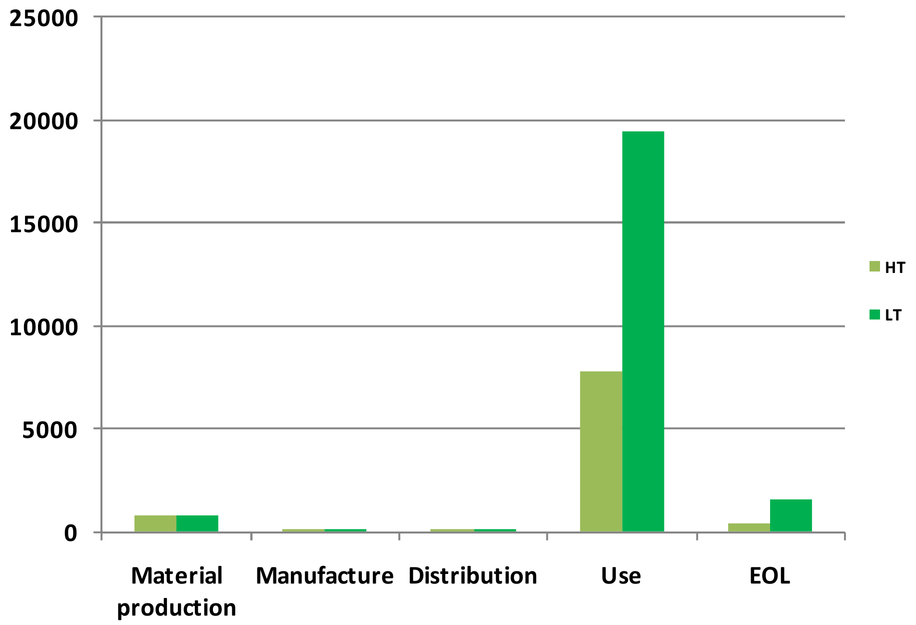

Figure 4-31: GWP related to each phase of the life cycle of service cabinet (kg CO2 eq.)

The direct and indirect greenhouse gasses emissions comparison is shown below. The higher GWP for LT products is due to the use of R404A in place of R134a.

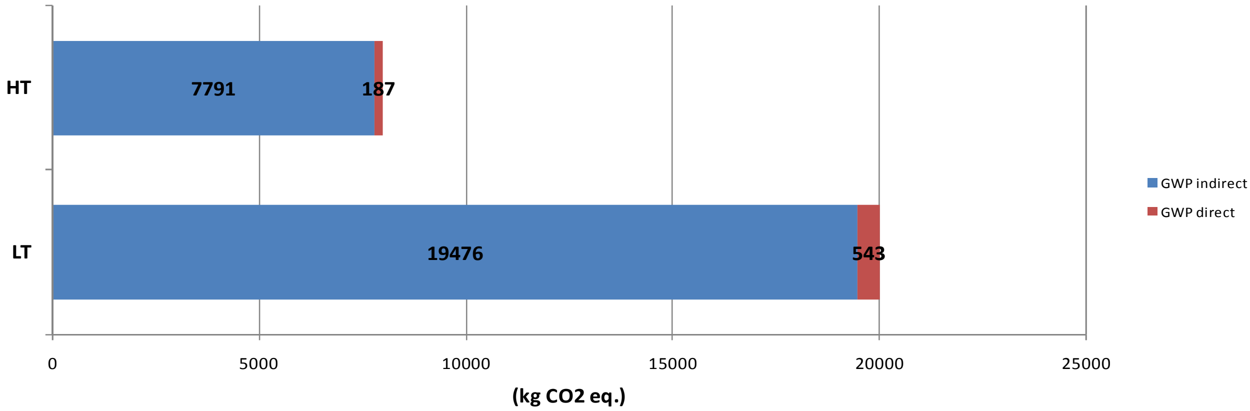

Figure 4-32 Life cycle Total Equivalent Warming Impact (TEWI) of service cabinet Base Case, per product over lifetime

Other impacts

- The process water used in the production phase is necessary in production of polyurethane used as an isolation of the service cabinet. Second process using significant amount of process water is production of steel. The water used during use phase is related to the electricity consumption.
- Concerning environmental impact on non-hazardous waste during the production phase, it is mainly due to materials as steel and copper. The use phase impacts are in similar proportions to electricity consumption.
- The high relative impact on hazardous waste during the End-of-Life phase is associated with incineration of plastics/PWB which are not being reused

or recycled. The use phase impact is connected to the electricity consumption.

- Emissions related to eutrophication mainly occur during production phase due to the coating. Heavy metals emissions to the air are due mainly to production of ferrite, and to water through the production of polyurethane used as an insulation of the service cabinet.
- The high amount of acidification emissions resulting from the use phase are correlated to electricity consumption.
- Relating to Persistent Organic Pollutants, impact during use phase again comes from the electricity consumption. The impact caused by the production phase is related to production of steel.
- Volatile Organic Compounds are mainly emitted during the use phase due to the electricity consumption. Distribution phase is the second source of emissions, because VOCs are usually related to so called mobile sources.
- Distribution phase is mainly responsible for emissions of Particulate Matter to the air. It is due to the transport. End-of-Life contribution is caused by incineration of plastics/PWB which are not being reused or recycled.
- Emissions of PAHs through production phase are related to the production of plastics (7-HI-PS) used as an inner cabinet lining. These materials are responsible for about half of the emissions.

4.10.1.1 Life Cycle Costs

The EcoReport provides the following results for the LCC. For HT and LT, the electricity costs represent a major share of the LCC (61% HT and 78% LT) followed by the product purchase cost (36% HT and 20% LT).

Table 4-37: Life Cycle Costs per product and total annual expenditure (2008) in the EU

	HT - LCC new product (€)	LT - LCC new product (€)	Total annual consumer expenditure in EU25 (mln €)
Product price	1000	1100	409
Installation/ acquisition costs	0	0	0
Electricity	1701	4252	1327
Repair & maintenance costs	83	83	38
Total	2784	5436	1775

4.10.1.2 EU Totals

As presented in this section, the service cabinet consumes a large amount of electricity, produced in general by burning fossil fuel that emits CO_2 (carbon dioxide) into the atmosphere. By simply consuming energy over its life cycle, it contributes to climate change.

A second environmental issue is the use of refrigerant, which also highly contributes to climate change. Poorly designed, badly maintained installations or refrigeration units abandoned at the end of their life without recovering or recycling the refrigerant fluid can lead to emissions into the atmosphere. These emissions are known as direct effects. Regulations such as the WEEE directive seek to avoid this, but implementation has been described as variable (please see Task 3 discussion on end-of-life). Therefore is it assumed that significant amounts of refrigerant are released through leakage and at end-of-life.

Table 4-38: EU Total Impact of STOCK of Service Cabinet in 2008

		TOTAL	PRODUCTION			DISTRIBUTION	USE	END-OF-LIFE		
			Material	Manuf.	Total			Disposal	Recycl.	Total
Other Resources & Waste										
Total Energy (GER)	PJ	122.87	4.68	1.00	5.69	0.83	116.21	0.75	0.61	0.14
Total use-phase electricity consumption	TWh	11.20	-	-	-	-	-	-	-	-
Water (process)	mln. m3	10.32	2.54	0.01	2.55	0.00	7.77	0.00	0.00	0.00
Water (cooling)	mln. m3	313.41	3.39	0.28	3.66	0.00	309.77	0.00	0.02	-0.02
Waste, non-haz./ landfill	kt	218.83	75.89	3.43	79.32	0.41	135.56	3.55	0.01	3.54
Waste, hazardous/ incinerated	kt	11.21	0.38	0.00	0.38	0.01	2.68	8.14	0.00	8.14
Emissions (Air)										
Greenhouse Gases in GWP100	mt CO2 eq.	5.80	0.32	0.06	0.37	0.05	5.07	0.35	0.04	0.30
Ozone Depletion, emissions	t R-11 eq.	0.00	negligable	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acidification, emissions	kt SO2 eq.	32.56	2.17	0.24	2.41	0.15	29.94	0.11	0.06	0.06
Volatile Organic Compounds (VOC)	kt	0.07	0.01	0.00	0.01	0.01	0.04	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	g i-Teq	1.46	0.64	0.02	0.67	0.00	0.77	0.02	0.00	0.02
Heavy Metals	ton Ni eq.	5.96	3.65	0.05	3.70	0.02	2.03	0.21	0.00	0.21
PAHs	ton Ni eq.	0.65	0.39	0.00	0.39	0.03	0.23	0.00	0.00	0.00
Particulate Matter (PM, dust)	kt	4.07	0.38	0.04	0.41	2.04	0.64	0.97	0.00	0.97
Emissions (Water)										
Heavy Metals	ton Hg/20	3.29	2.45	0.00	2.45	0.00	0.78	0.06	0.00	0.06
Eutrophication	kt PO4	0.11	0.10	0.00	0.10	0.00	0.00	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	g i-Teq	0.00	negligable	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The EU wide impact of such products in 2008 is estimated at a total energy consumption of approximately 123 PJ and GWP of 6 mt CO_2 eq.

4.10.1.3 Sensitivity analysis

A sensitivity analysis was performed to assess the change in environmental impacts when production material quantities are increased by +20% and +50%.

Table 4-39: Production material sensitivity analysis – change in total stock impacts

Impact Category	units	Base Case material +20%		Base Case material +50%	
		Absolute increase over Base Case	% increase over Base Case	Absolute increase over Base Case	% increase over Base Case
Total Energy (GER)	PJ	0.801	1.83%	2.003	4.57%
of which, electricity (in primary PJ)	PJ	0.198	0.49%	0.496	1.23%
Water (process)	mln. m3	0.350	8.01%	0.875	20.03%
Water (cooling)	mln. m3	0.501	0.47%	1.253	1.17%
Waste, non-haz./ landfill	kt	11.384	11.08%	28.461	27.71%
Waste, hazardous/ incinerated	kt	1.159	17.28%	2.896	43.21%
Greenhouse Gases in GWP100	mt CO2 eq.	0.053	2.57%	0.132	6.41%
Ozone Depletion, emissions	t R-11 eq.	0.000	-	0.000	-
Acidification, emissions	kt SO2 eq.	0.339	2.85%	0.848	7.12%
Volatile Organic Compounds (VOC)	kt	0.002	5.00%	0.004	12.51%
Persistent Organic Pollutants (POP)	g i-Teq	0.095	12.93%	0.237	32.33%
Heavy Metals	ton Ni eq.	0.537	15.92%	1.342	39.80%
PAHs	ton Ni eq.	0.054	14.72%	0.135	36.80%
Particulate Matter (PM, dust)	kt	0.189	7.30%	0.473	18.26%
Heavy Metals	ton Hg/20	0.346	17.44%	0.864	43.60%
Eutrophication	kt PO4	0.015	19.68%	0.037	49.20%
Persistent Organic Pollutants (POP)	g i-Teq	0.000	-	0.000	-

Table 4-40: Production material sensitivity analysis – change in impacts across lifecycle phases

	units	Base Case material +20%				Base Case material +50%			
		Production	Distribution	Use	End of life	Production	Distribution	Use	End of life
Other Resources & Waste		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Energy (GER)	MJ	1.73%	-0.03%	-1.74%	0.04%	4.20%	-0.07%	-4.23%	0.11%
of which, electricity (in primary MJ)	MJ	0.53%	0.00%	-0.53%	0.00%	1.32%	0.00%	-1.32%	0.00%
Water (process)	ltr	4.47%	0.00%	-4.47%	0.00%	10.00%	0.00%	-9.99%	-0.01%
Water (cooling)	ltr	0.51%	0.00%	-0.50%	0.00%	1.26%	0.00%	-1.25%	-0.01%
Waste, non-haz./ landfill	g	4.13%	-0.03%	-4.28%	0.18%	8.92%	-0.07%	-9.25%	0.40%
Waste, hazardous/ incinerated	g	0.08%	-0.01%	-1.81%	1.74%	0.17%	-0.03%	-3.70%	3.56%
Greenhouse Gases in GWP100	kg CO2 eq.	2.26%	-0.05%	-2.21%	0.00%	5.43%	-0.12%	-5.31%	0.01%
Ozone Depletion, emissions	mg R-11 eq.	n.a.				n.a.			
Acidification, emissions	g SO2 eq.	2.49%	-0.03%	-2.52%	0.06%	5.95%	-0.07%	-6.02%	0.14%
Volatile Organic Compounds (VOC)	g	3.23%	-1.47%	-2.19%	0.43%	7.51%	-3.43%	-5.09%	1.00%
Persistent Organic Pollutants (POP)	ng i-Teq	3.70%	-0.03%	-3.81%	0.14%	7.86%	-0.06%	-8.09%	0.29%
Heavy Metals	mg Ni eq.	2.44%	-0.06%	-2.51%	0.14%	5.04%	-0.13%	-5.19%	0.28%
PAHs	mg Ni eq.	3.19%	-0.71%	-2.48%	0.00%	6.67%	-1.48%	-5.19%	0.00%

Particulate Matter (PM, dust)	g	1.29%	-3.82%	-0.50%	3.04%	2.92%	-8.66%	-1.13%	6.88%
Heavy Metals	mg Hg/20	1.67%	0.00%	-1.71%	0.04%	3.41%	-0.01%	-3.49%	0.09%
Eutrophication	g PO4	0.23%	0.00%	-0.23%	0.01%	0.45%	0.00%	-0.46%	0.02%
Persistent Organic Pollutants (POP)	ng i-Teq	n.a.				n.a.			

Based on the sensitivity analysis for refrigerant charge, it is possible to conclude that this parameter do not have a significant impact over the lifetime of the product (see figure below).

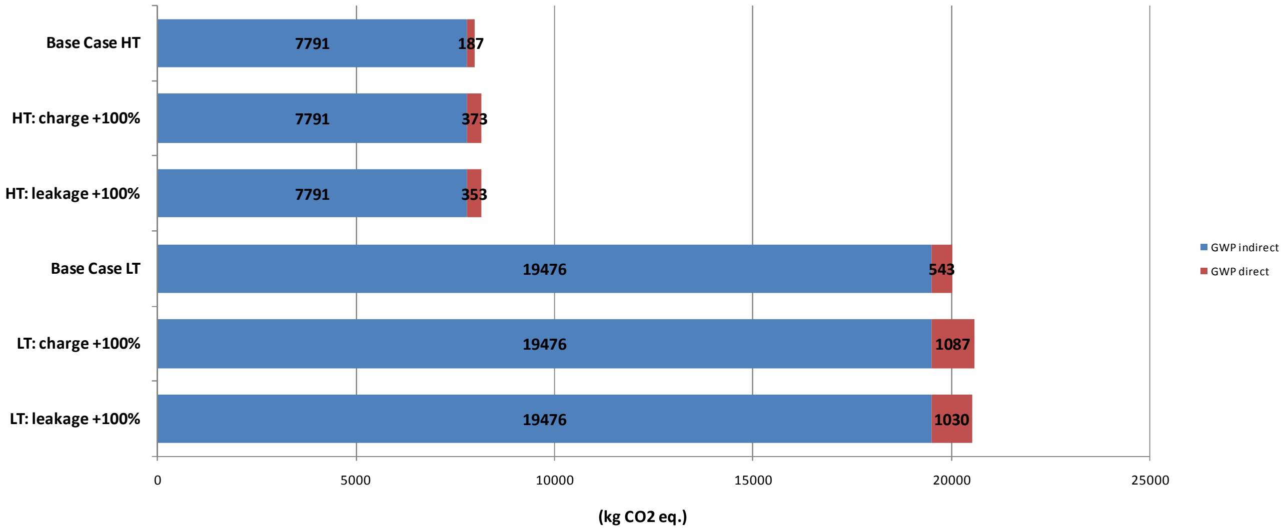

Figure 4-33: Sensitivity analysis Life cycle Total Equivalent Warming Impact (TEWI) of service cabinet Base Cases, per product over lifetime

4.10.2. BLAST CABINETS

The impacts of the blast cabinet Base Case are presented below.

Table 4-41: Environmental assessment results per PRODUCT from EcoReport for blast cabinets Base Case

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	7119	1979	**9099**	**3883**	**272482**	1000	817	**183**	**285646**
of which, electricity (in primary MJ)	MJ	1183	1070	**2253**	**3**	**272414**	0	90	**-90**	**274579**
Water (process)	ltr	4802	33	**4835**	**0**	**18208**	0	81	**-81**	**22962**
Water (cooling)	ltr	3007	546	**3553**	**0**	**726412**	0	35	**-35**	**729930**
aste, non-haz./ landfill	g	175268	6396	**181665**	**1800**	**317639**	7134	265	**6868**	**507972**
Waste, hazardous/ incinerated	g	3123	7	**3130**	**36**	**6308**	8868	100	**8768**	**18242**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	535	113	647	297	11893	5841	57	5784	18622
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	4378	504	4882	1019	70190	149	129	19	76110
Volatile Organic Compounds (VOC)	g	18	5	23	52	103	3	2	1	179
Persistent Organic Pollutants (POP)	ng i-Teq	1318	48	1366	10	1799	49	1	48	3224
Heavy Metals	mg Ni eq.	7629	114	7743	92	4751	277	11	266	12851
PAHs	mg Ni eq.	607	4	611	62	543	0	9	-9	1207
Particulate Matter (PM, dust)	g	695	89	784	1308	1506	1296	5	1291	4889
Emissions (Water)										
Heavy Metals	mg Hg/20	4842	1	4842	3	1805	83	50	33	6683

Eutrophication	g PO4	170	2	172	0	10	5	1	4	186
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Table 4-42: Impact of the blast cabinets per functional unit per year (considering weighted contribution of kg of foodstuff processed in one year=220 business day)

Impact indicator	Impact per kg of foodstuff at cycle temperature per year
Total Energy (GER) (MJ)	2.06
of which, electricity (in primary MJ)	1.98
electricity (kWh)	0.19
Water (process) (Ltr)	0.17
Waste, non-haz./ landfill (g)	3.67
Waste, hazardous/ incinerated (g)	0.13
Greenhouse Gases in GWP100 (kg CO2 eq.)	0.20
Acidification, emissions (g SO2 eq.)	0.55
Volatile Organic Compounds (VOC) (g)	0.00
Persistent Organic Pollutants (POP) (ng i-Teq)	0.02
Heavy Metals (mg Ni eq.)	0.09
PAHs (mg Ni eq.)	0.01
Particulate Matter (PM, dust) (g)	0.04
Heavy Metals (mg Hg/20)	0.05
Eutrophication (g PO4)	0.00

The environmental impacts of the blast cabinets at different life phases are represented in Figure 4-34. Use phase and production material are the two phases with the biggest impact. About 99% of the electricity consumed during the life-time of this equipment is related to the use-phase, which in terms of Total Energy becomes around 95%.

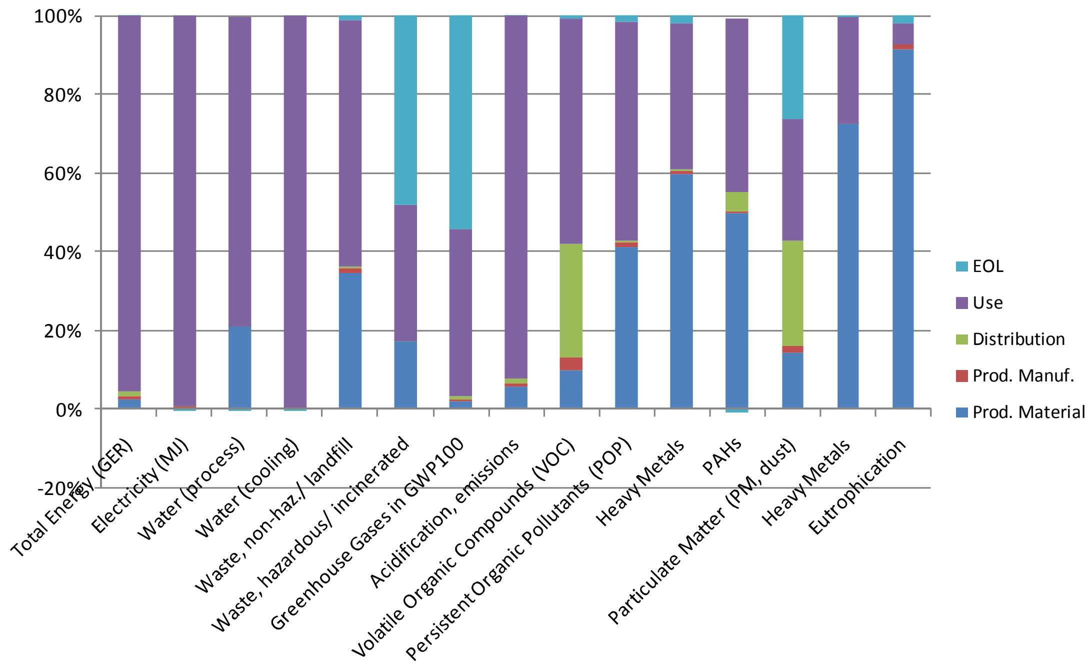

Figure 4-34: EcoReport LCA analysis results for blast cabinets – impacts per lifecycle stage

When taking into account the GER (Gross Energy Requirement) as a reference for the environmental impacts, the results show that the use phase is the most important. It is responsible of 95% of the GER required during the whole life cycle. The production phase is the second stage, representing around 4% of the GER over product lifetime. The distribution and end-of-life phase are negligible. Besides, it is important to note that the end of-life phase provides GER with the thermal recovery of some parts of the blast cabinet.

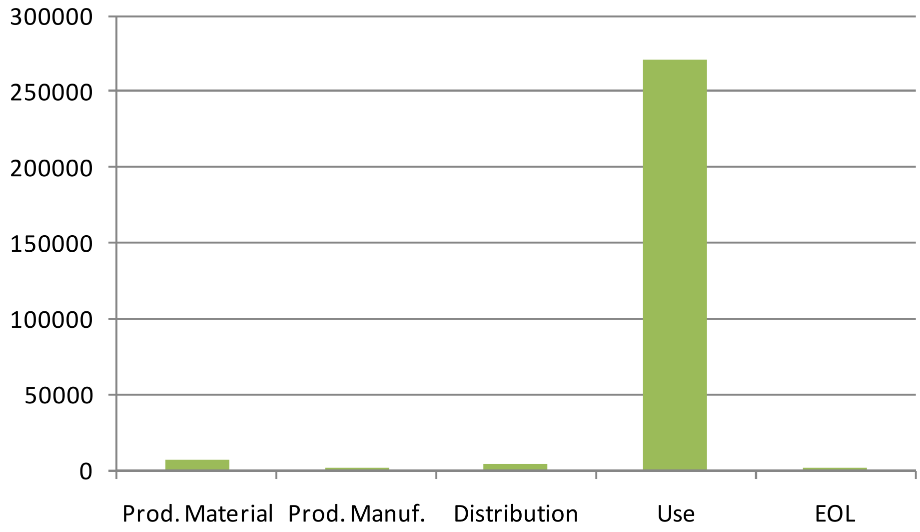

Figure 4-35: GER related to each phase of the life cycle of blast cabinet (MJ)

Greenhouse Gases warming of blast cabinets is mainly due to the end-of-life phase, closely followed by the use phase. The high percentage of dumped refrigerant contributes to this. The electricity production involves the combustion of fossil fuels and consequently emissions of carbon dioxide.

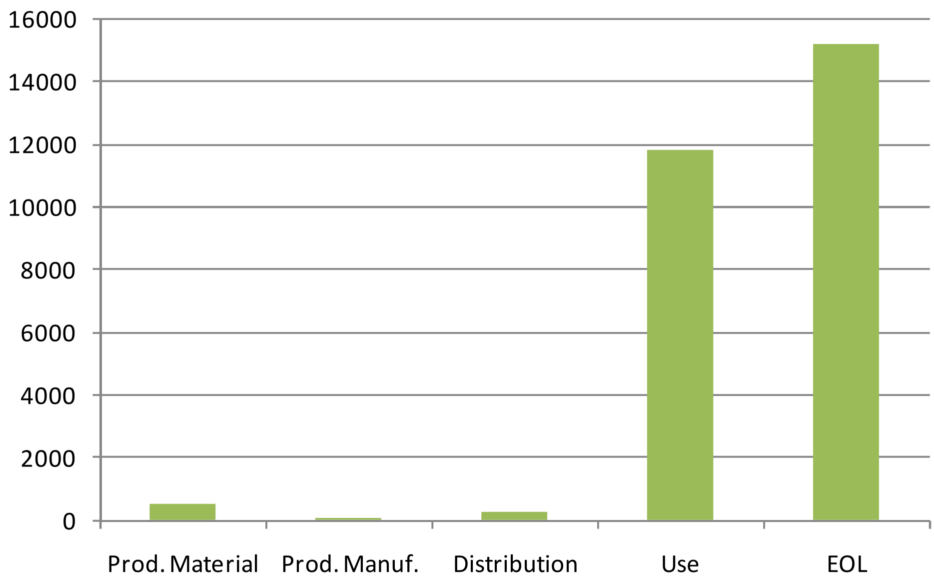

Figure 4-36: GWP related to each phase of the life cycle of blast cabinet (kg CO2 eq.)

The direct and indirect greenhouse gasses emissions comparison is shown below:

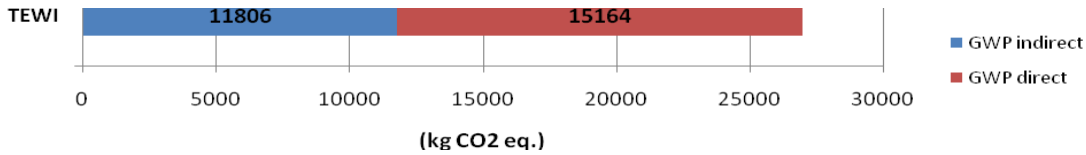

Figure 4-37: Life cycle Total Equivalent Warming Impact (TEWI) of blast cabinet Base Case, per product over lifetime

Other impacts

- the process water used in the production phase is necessary in the production of steel as well as the polyurethane foam used to isolate the blast cabinet. The water used during use phase is related to the electricity consumption (see Annex).
- concerning the environmental impact of non-hazardous waste during the production phase, it is mainly due to materials as steel and copper. The use phase impacts are higher due to electricity consumption (see Annex).
- the high relative impact of hazardous waste during the End-of-Life phase is associated with incineration of plastics/PWB which are not being reused or recycled, and dumped refrigerant. The use phase impact is connected to the electricity consumption. In the production phase, emissions of hazardous waste are due to PWB included in the electronic parts (see Annex).
- the high amount of acidification emissions resulting from the use phase are correlated to electricity consumption.
- relating to Persistent Organic Pollutants, their impact during the use phase again comes from the electricity consumption. The impact caused by the production phase is related to production of ferrous metals.
- Volatile Organic Compounds are mainly emitted during the use phase due to the electricity consumption. The use phase is the largest source of emissions.
- heavy metal emissions to the air from the use phase are smaller to use phase electricity production, indicating that heavy metal emissions for this phase are associated with the electricity production. Emissions occurred during the production phase are related to production of stainless coil used in the housing of the cabinet.
- emissions of PAHs through the production phase are related to the production of ferrous metals. These materials are responsible for about half of the emissions. Use phase emissions are correlated to energy consumption.
- following the use phase, the distribution phase is mainly responsible for emissions of Particulate Matter to the air with the end-of-life phase. It is due to the transport. The end-of-life contribution is caused by incineration of plastics/PWBs which are not being reused or recycled, and dumped refrigerant.

- emissions to water tackled by the EcoReport tool are heavy metals and eutrophication. Concerning emissions of heavy metals through the production phase, half of this impact is due to production of steel used in housing of the blast cabinet. Use phase emissions are again related to electricity consumption.
- emissions related to eutrophication mainly occur during the production phase due to polyurethane insulation foam and steel materials.

4.10.2.1 Life Cycle Costs

The EcoReport provides the following results for the LCC. The electricity costs represent around half of the share of the product price.

Table 4-43: Life Cycle Costs per product and Total annual expenditure (2008) in the EU-27

Blast Cabinet	LCC new product		total annual consumer expenditure in EU25	
Item				
Product price	6,400	€	1,111	mln.€
Installation/ acquisition costs (if any)	0	0		0
Fuel (gas, oil, wood)	0	€	0	mln.€
Electricity	2,578	€	494	mln.€
Water	0	€	0	mln.€
Aux. 1: None	0	€	0	mln.€
Aux. 2 :None	0	€	0	mln.€
Aux. 3: None	0	€	0	mln.€
Repair & maintenance costs	534	€	100	mln.€
Total	**9,512**	€	**1,705**	mln.€

4.10.2.2 EU Totals

As presented in section above, the blast cabinet consumes a large amount of electricity, produced in general by burning fossil fuel that emits CO_2 (carbon dioxide) into the atmosphere. By the simple fact of consuming energy over its life cycle, it contributes to climate change.

Table 4-44: EU Total Impact of STOCK of Blast Cabinet in 2008

Life Cycle phases -->		PRODUCTION			DISTRI-BUTION	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**			Disposal debet	Recycl. credit	**Total**	
Other Resources & Waste										
Total Energy (GER)	PJ	1	0	2	1	43	0	0	0	46
of which, electricity (in primary PJ)	PJ	0	0	0	0	43	0	0	0	44
Water (process)	mln. m3	1	0	1	0	3	0	0	0	4
Water (cooling)	mln. m3	1	0	1	0	115	0	0	0	116
Waste, non-haz./ landfill	kt	30	1	32	0	50	1	0	1	83
Waste, hazardous/ incinerated	kt	1	0	1	0	1	2	0	2	3
Emissions (Air)										
Greenhouse Gases in GWP100	mt CO2 eq.	0	0	0	0	2	3	0	3	5
Ozone Depletion, emissions	t R-11 eq.	negligible								
Acidification, emissions	kt SO2 eq.	1	0	1	0	11	0	0	0	12
Volatile Organic Compounds (VOC)	kt	0	0	0	0	0	0	0	0	0
Persistent Organic Pollutants (POP)	g i-Teq	0	0	0	0	0	0	0	0	1
Heavy Metals	ton Ni eq.	1	0	1	0	1	0	0	0	2
PAHs	ton Ni eq.	0	0	0	0	0	0	0	0	0
Particulate Matter (PM, dust)	kt	0	0	0	0	0	0	0	0	1
Emissions (Water)										
Heavy Metals	ton Hg/20	1	0	1	0	0	0	0	0	1
Eutrophication	kt PO4	0	0	0	0	0	0	0	0	0
Persistent Organic Pollutants (POP)	g i-Teq	negligible								

The EU wide impact of such products in 2008 is estimated to a total energy consumption of 116 PJ and to a GWP of 6 mt CO_2 eq.

4.10.2.3 Sensitivity analysis

A sensitivity analysis was performed to assess the change in environmental impacts when production material quantities are increased by +20% and +50%.

Table 4-45: Production material sensitivity analysis – change in total stock impacts

Impact Category	units	Base Case material +20%		Base Case material +50%	
		Absolute increase over Base Case	% increase over Base Case	Absolute increase over Base Case	% increase over Base Case
Total Energy (GER)	PJ	0.325	0.71%	0.813	1.79%
of which, electricity (in primary PJ)	PJ	0.076	0.17%	0.190	0.43%
Water (process)	mln. m3	0.167	4.49%	0.417	11.22%
Water (cooling)	mln. m3	0.123	0.11%	0.308	0.27%
Waste, non-haz./ landfill	kt	6.606	7.92%	16.515	19.79%
Waste, hazardous/ incinerated	kt	0.414	13.48%	1.036	33.70%
Greenhouse Gases in GWP100	mt CO2 eq.	0.023	0.50%	0.058	1.24%
Ozone Depletion, emissions	t R-11 eq.	0.000	-	0.000	-
Acidification, emissions	kt SO2 eq.	0.172	1.41%	0.429	3.53%
Volatile Organic Compounds (VOC)	kt	0.001	2.87%	0.002	7.19%
Persistent Organic Pollutants (POP)	g i-Teq	0.050	9.30%	0.124	23.25%
Heavy Metals	ton Ni eq.	0.281	12.99%	0.702	32.47%
PAHs	ton Ni eq.	0.021	10.47%	0.053	26.18%
Particulate Matter (PM, dust)	kt	0.072	8.75%	0.181	21.88%
Heavy Metals	ton Hg/20	0.171	15.08%	0.427	37.69%
Eutrophication	kt PO4	0.006	19.17%	0.015	47.92%
Persistent Organic Pollutants (POP)	g i-Teq	0.000	-	0.000	-

Table 4-46: Production material sensitivity analysis – change in impacts across lifecycle phases

		Base Case material +20%				Base Case material +50%			
	units	Production	Distribution	Use	End of life	Production	Distribution	Use	End of life
Other Resources & Waste		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Energy (GER)	MJ	0.62%	-0.01%	-0.62%	0.01%	1.53%	-0.02%	-1.53%	0.03%
of which, electricity (in primary MJ)	MJ	0.16%	0.00%	-0.16%	-0.01%	0.41%	0.00%	-0.39%	-0.02%
Water (process)	ltr	3.21%	0.00%	-3.16%	-0.05%	7.56%	0.00%	-7.44%	-0.13%
Water (cooling)	ltr	0.10%	0.00%	-0.10%	0.00%	0.24%	0.00%	-0.24%	0.00%
Waste, non-haz./ landfill	g	4.17%	-0.02%	-4.30%	0.16%	9.43%	-0.06%	-9.73%	0.36%
Waste, hazardous/ incinerated	g	1.05%	-0.02%	-3.96%	2.93%	2.23%	-0.05%	-8.43%	6.25%
Greenhouse Gases in GWP100	kg CO2 eq.	0.45%	-0.01%	-0.20%	-0.25%	1.12%	-0.01%	-0.49%	-0.61%
Ozone Depletion, emissions	mg R-11 eq.	n.a.				n.a.			
Acidification, emissions	g SO2 eq.	1.19%	-0.02%	-1.18%	0.00%	2.92%	-0.04%	-2.89%	0.01%
Volatile Organic Compounds (VOC)	g	2.17%	-0.78%	-1.51%	0.11%	5.22%	-1.87%	-3.62%	0.27%
Persistent Organic Pollutants (POP)	ng i-Teq	4.34%	-0.03%	-4.47%	0.15%	9.66%	-0.06%	-9.95%	0.34%
Heavy Metals	mg Ni eq.	3.96%	-0.08%	-4.02%	0.14%	8.48%	-0.17%	-8.60%	0.29%
PAHs	mg Ni eq.	4.56%	-0.48%	-4.02%	-0.07%	10.03 %	-1.05%	-8.83%	-0.15%
Particulate Matter (PM, dust)	g	1.70%	-2.11%	-2.38%	2.79%	3.79%	-4.72%	-5.33%	6.25%
Heavy Metals	mg Hg/20	3.31%	-0.01%	-3.33%	0.02%	6.94%	-0.01%	-6.98%	0.05%
Eutrophication	g PO4	0.70%	0.00%	-0.71%	0.02%	1.41%	-0.01%	-1.43%	0.03%
Persistent Organic Pollutants (POP)	ng i-Teq	n.a.				n.a.			

Based on the sensitivity analysis for refrigerant charge, it is possible to conclude that this parameter does have a significant impact over the lifetime of the product (see figure below). Therefore, alternative refrigerants with lower GWP should be considered.

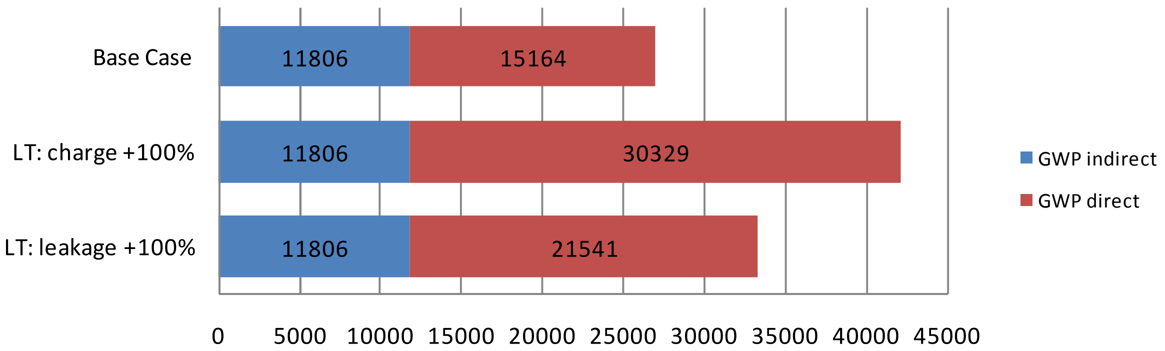

Figure 4-38: Sensitivity analysis Life cycle Total Equivalent Warming Impact (TEWI) of blast cabinet Base Case, per product over lifetime increasing in 50% and 100% refrigerant charge

4.10.3. WALK-IN COLD ROOMS

The impacts of the walk-in cold room Base Case are presented below.

Table 4-47: Environmental assessment results per PRODUCT from EcoReport for walk-in cold rooms

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	157748	16862	**174610**	**20407**	**1278003**	9379	7063	**2316**	**1475336**
of which, electricity (in primary MJ)	MJ	99088	10057	**109145**	**43**	**1277349**	0	37	**-37**	**1386499**

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	**BUTION**		Disposal	Recycl.	**Total**	
Water (process)	ltr	62772	148	**62920**	**0**	**85713**	0	24	**-24**	**148609**
Water (cooling)	ltr	87971	4649	**92620**	**0**	**3404278**	0	204	**-204**	**3496695**
Waste, non-haz./ landfill	g	1884380	58659	**1943039**	**9865**	**1499178**	61559	144	**61415**	**3513497**
Waste, hazardous/ incinerated	g	3257	2	**3259**	**196**	**29441**	87476	23	**87453**	**120350**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	9760	941	**10701**	**1205**	**55802**	19350	501	**18849**	**86557**
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	104658		4063	**108721**	**3717**	**329723**	1396	643	**753**
Volatile Organic Compounds (VOC)	g	226	5	**230**	**312**	**483**	28	9	**19**	**1045**
Persistent Organic Pollutants (POP)	ng i-Teq	22777	440	**23216**	**56**	**8597**	426	0	**426**	**32296**
Heavy Metals	mg Ni eq.	786269	1030	**787299**	**501**	**29769**	2592	0	**2592**	**820161**
PAHs	mg Ni eq.	4785	2	**4786**	**668**	**2562**	0	2	**-2**	**8014**
Particulate Matter (PM, dust)	g	8448	625	**9073**	**51286**	**7110**	12170	14	**12156**	**79625**
Emissions (Water)										
Heavy Metals	mg Hg/20	69615	1	**69616**	**16**	**8925**	782	0	**782**	**79338**
Eutrophication	g PO4	5112	7	**5119**	**0**	**90**	45	1	**44**	**5254**
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								
Other Resources & Waste								debet	credit	

Table 4-48: Impact of the walk-in cold rooms per functional unit per year

Impact indicator	impact per m3 of storage volume at storage temperature
Total Energy (GER) (MJ)	5901.34
of which, electricity (in primary MJ)	5546.00
Use-phase electricity consumption (kWh)	562.03
Water (process) (ltr)	594.43
Waste, non-haz./ landfill (g)	14053.99
Waste, hazardous/ incinerated (g)	481.40
Greenhouse Gases in GWP100 (kg CO2 eq.)	346.23
Acidification, emissions (g SO2 eq.)	1771.66
Volatile Organic Compounds (VOC) (g)	4.18
Persistent Organic Pollutants (POP) (ng i-Teq)	129.18
Heavy Metals (mg Ni eq.)	3280.65
PAHs (mg Ni eq.)	32.06
Particulate Matter (PM, dust) (g)	318.50
Heavy Metals (mg Hg/20)	317.35
Eutrophication (g PO4)	21.02

The environmental impacts of the blast cabinets at different life phases are represented below. Use phase and production material are the two phases with the biggest impact. The majority of the electricity consumed during the life-time of this equipment is related to the use-phase, which in terms of Total Energy becomes around 87%.

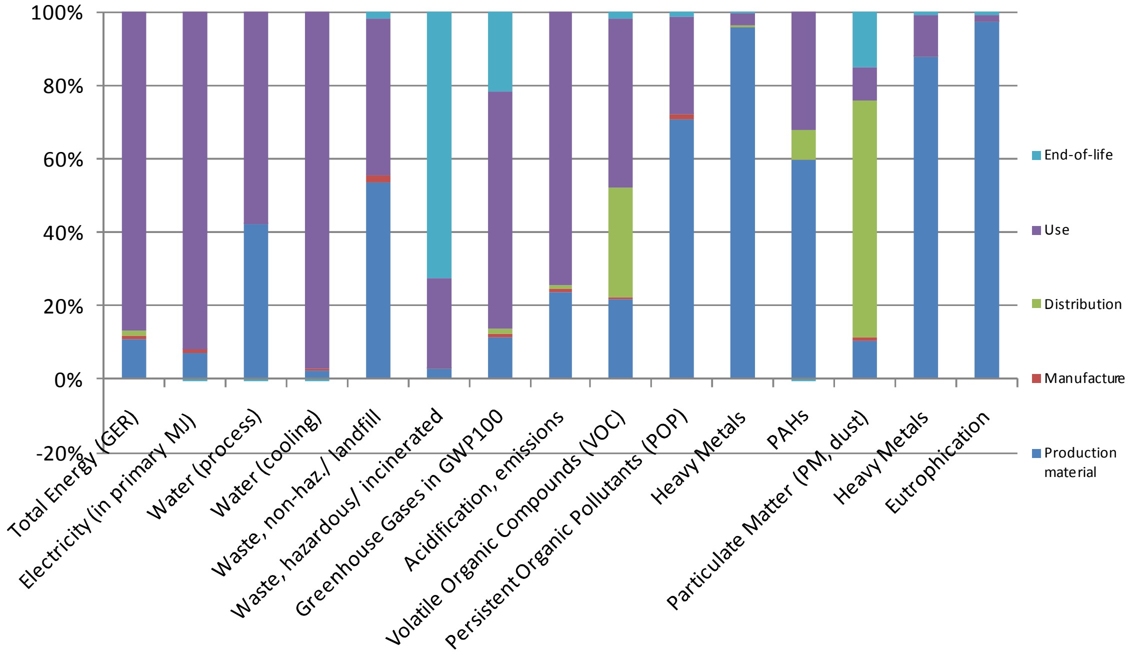

Figure 4-39: EcoReport results for walk-in cold rooms – impacts per lifecycle stage

When taking into account the GER (Gross Energy Requirement) as a reference for the environmental impacts, the results show that the use phase is the most important during the whole life cycle. It is important to note that the end of-life phase provides GER with the thermal recovery of some parts of the walk-in cold room.

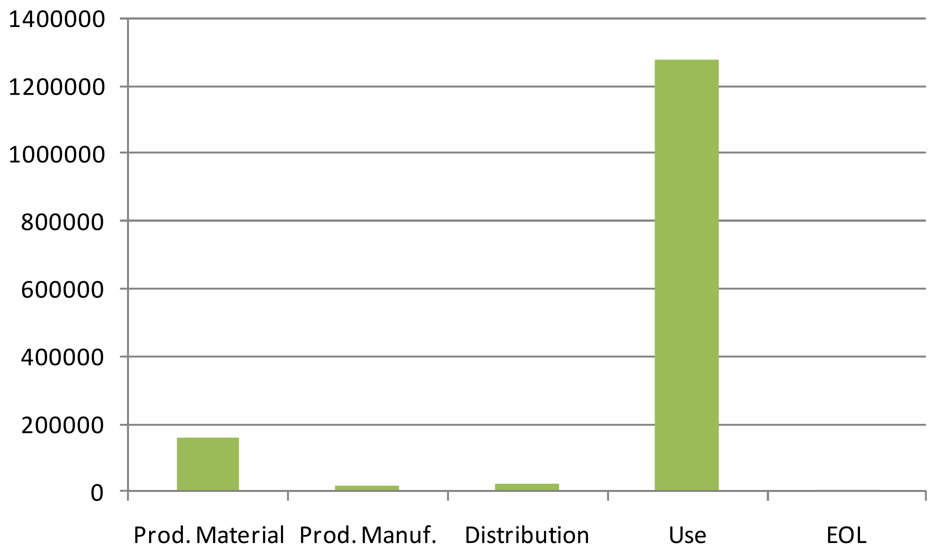

Figure 4-40: GER related to each phase of the life cycle of walk-in cold room (MJ)

Greenhouse Gases warming potential of service cabinet is mainly due to the use phase. The production of the electricity involves the combustion of fossil fuels and consequently emissions of carbon dioxide.

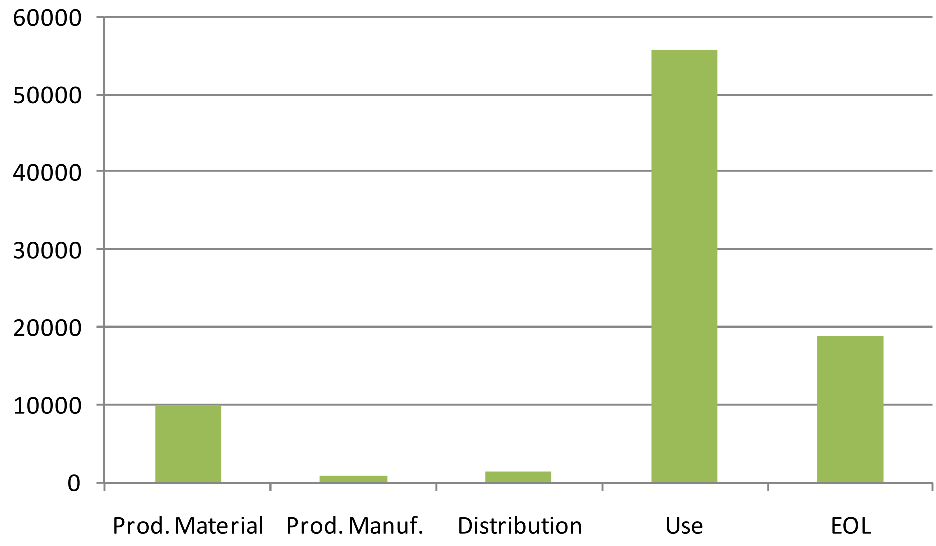

Figure 4-41: GWP related to each phase of the life cycle of walk-in cold room (kg CO2 eq.)

The direct and indirect greenhouse gasses emissions comparison is shown below:

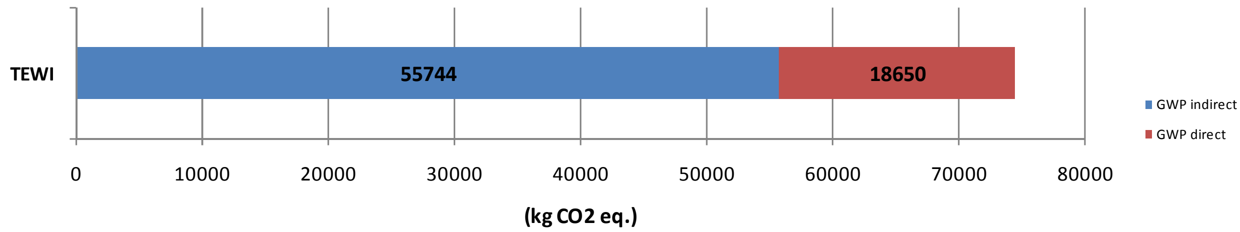

Figure 4-42 Life cycle Total Equivalent Warming Impact (TEWI) of walk-in cold room Base Case, per product over lifetime

Other impacts

- Extraction of material to produce coating and insulation has significant impacts, leading to almost 100% of eutrophication and release of heavy metals, and the majority of POPs and VOCs. Emissions related to eutrophication mainly occur during production phase due to coating made out of copper, nickel and chromium.
- The process water used in the production phase is necessary in production of production of steel. The water used during use phase is related to the electricity consumption.
- Concerning environmental impact on non-hazardous waste during the production phase, it is mainly due to materials as steel and copper. The use phase impacts are in similar proportions to electricity consumption.
- The high relative impact on hazardous waste during the End-of-Life phase is associated with incineration of plastics/PWB which are not being reused or recycled. The use phase impact is connected to the electricity consumption.

- Greenhouse Gases warming potential of walk-in cold room is mainly due to the use phase. The production of the electricity involves the combustion of fossil fuels and consequently emissions of carbon dioxide.
- The high amount of acidification emissions resulting from the use phase are correlated to electricity consumption.
- Relating to Persistent Organic Pollutants, impact during use phase again comes from the electricity consumption. The impact caused by the production phase is related to production of coating with materials as cooper, nickel and chromium.
- Volatile Organic Compounds are mainly emitted during the use phase due to the electricity consumption. Distribution phase is the second source of emissions, because VOCs are usually related to so called mobile sources.
- Heavy metals emissions to the air from use phase are in similar proportion to use phase electricity production, indicating that HM emissions for this phase are associated with the electricity production. Emissions occurred during production phase are related to use of materials as chromium, nickel and copper in the shell of the walk-in cold room.
- Emissions of PAHs through production phase are related to the production of plastics (5-PS) used as an inner cabinet lining. These materials are responsible for more than half of the emissions.
- Distribution phase is mainly responsible for emissions of Particulate Matter to the air. It is due to the transport. End-of-Life contribution is caused by incineration of plastics/PWB which are not being reused or recycled. Use phase is related to energy consumption.

4.10.3.1 Life Cycle Costs

The EcoReport provides the following results for the LCC. The electricity costs represent a major share of the LCC (51%) followed by the product purchase cost (38%).

Table 4-49: Life Cycle Costs per product and Total annual expenditure (2008) in the EU

Walk-in cold room	**LCC new product**			
Item				
Product price	8800	€	777	mln.€
Installation/ acquisition costs (if any)	1760	€	155	mln.€
Fuel (gas, oil, wood)	0	€	0	mln.€
Electricity	11830	€	2286	mln.€
Water	0	€	0	mln.€
Aux. 1: None	0	€	0	mln.€
Aux. 2 :None	0	€	0	mln.€
Aux. 3: None	0	€	0	mln.€
Repair & maintenance costs	714	€	134	mln.€
Total	**23104**	€	**3352**	mln.€

4.10.3.2 EU Totals

As presented in this section, the walk-in cold room consumes a large amount of electricity, produced in general by burning fossil fuel that emits CO_2 (carbon dioxide) into the atmosphere. By the simple fact of consuming energy over its life cycle, it contributes to climate change.

A second environmental issue is the use of refrigerant, which also highly contributes to climate change.

Table 4-50: EU Total Impact of STOCK of walk-in cold rooms

		TOTAL	PRODUCTION			DISTRIBUTION	USE	END-OF-LIFE		
			Material	Manuf.	Total			Disposal	Recycl.	Total
Other Resources & Waste										
Total Energy (GER)	**PJ**	217.72	13.93	1.49	15.42	1.80	200.30	0.83	0.62	0.20
Total use-phase electricity consumption	**TWh**	19.98	-	-	-	-	-	-	-	-
Water (process)	**mln. m3**	18.99	5.54	0.01	5.56	0.00	13.43	0.00	0.00	0.00
Water (cooling)	**mln. m3**	541.71	7.77	0.41	8.18	0.00	533.56	0.00	0.02	-0.02
Waste, non-haz./ landfill	**kt**	412.81	166.37	5.18	171.55	0.87	234.97	5.43	0.01	5.42
Waste, hazardous/ incinerated	**kt**	12.64	0.29	0.00	0.29	0.02	4.61	7.72	0.00	7.72
Emissions (Air)										
Greenhouse Gases in GWP100	**mt CO2 eq.**	11.46	0.86	0.08	0.94	0.11	8.75	1.71	0.04	1.66
Ozone Depletion, emissions	**t R-11 eq.**	0.00	negligible	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acidification, emissions	**kt SO2 eq.**	61.67	9.24	0.36	9.60	0.33	51.68	0.12	0.06	0.07
Volatile Organic Compounds (VOC)	**kt**	0.13	0.02	0.00	0.02	0.03	0.08	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	**g i-Teq**	3.44	2.01	0.04	2.05	0.00	1.35	0.04	0.00	0.04
Heavy Metals	**ton Ni eq.**	74.45	69.42	0.09	69.51	0.04	4.67	0.23	0.00	0.23
PAHs	**ton Ni eq.**	0.88	0.42	0.00	0.42	0.06	0.40	0.00	0.00	0.00
Particulate Matter (PM, dust)	**kt**	7.52	0.75	0.06	0.80	4.53	1.11	1.07	0.00	1.07
Emissions (Water)		0.00								
Heavy Metals	**ton Hg/20**	7.62	6.15	0.00	6.15	0.00	1.40	0.07	0.00	0.07
Eutrophication	**kt PO4**	0.47	0.45	0.00	0.45	0.00	0.01	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	**g i-Teq**	0.00	negligible	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The EU wide impact of such products in 2008 is estimated to a total energy consumption of 218 PJ and to a GWP of 11 mt CO_2 eq.

4.10.3.3 Sensitivity analysis

A sensitivity analysis was performed to assess the change in environmental impacts when production material quantities are increased by +20% and +50%.

Table 4-51: Production material sensitivity analysis – change in total stock impacts

Impact Category	units	Base Case material +20%		Base Case material +50%	
		Absolute increase over Base Case	% increase over Base Case	Absolute increase over Base Case	% increase over Base Case
Total Energy (GER)	PJ	3.390	1.56%	8.211	3.77%
of which, electricity (in primary PJ)	PJ	2.047	0.98%	5.010	2.39%
Water (process)	mln. m3	1.130	5.95%	2.826	14.88%
Water (cooling)	mln. m3	1.661	0.31%	4.152	0.77%
Waste, non-haz./ landfill	kt	39.177	9.49%	93.975	22.76%
Waste, hazardous/ incinerated	kt	1.604	12.69%	4.008	31.71%
Greenhouse Gases in GWP100	mt CO2 eq.	0.210	1.95%	0.507	4.71%
Ozone Depletion, emissions	t R-11 eq.	0.000	-	0.000	-
Acidification, emissions	kt SO2 eq.	2.030	3.29%	4.997	8.10%
Volatile Organic Compounds (VOC)	kt	0.006	4.80%	0.013	10.47%
Persistent Organic Pollutants (POP)	g i-Teq	0.614	17.86%	1.299	37.76%
Heavy Metals	ton Ni eq.	14.639	19.66%	36.042	48.41%
PAHs	ton Ni eq.	0.086	9.75%	0.215	24.37%
Particulate Matter (PM, dust)	kt	0.387	5.15%	0.956	12.71%
Heavy Metals	ton Hg/20	1.265	16.61%	3.162	41.53%
Eutrophication	kt PO4	0.093	19.74%	0.232	49.34%
Persistent Organic Pollutants (POP)	g i-Teq	0.000	-	0.000	-

Table 4-52: Production material sensitivity analysis – change in impacts across lifecycle phases

		Base Case material +20%				Base Case material +50%			
	units	Production	Distribution	Use	End of life	Production	Distribution	Use	End of life
Other Resources & Waste		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Energy (GER)	MJ	2.16%	-0.03%	-2.16%	0.03%	5.06%	-0.08%	-5.04%	0.06%
of which, electricity (in primary MJ)	MJ	1.49%	0.00%	-1.49%	0.00%	3.56%	0.00%	-3.56%	0.00%
Water (process)	ltr	4.47%	0.00%	-4.46%	0.00%	9.99%	0.00%	-9.98%	0.00%
Water (cooling)	ltr	0.51%	0.00%	-0.51%	0.00%	1.27%	0.00%	-1.27%	0.00%
Waste, non-haz./ landfill	g	4.56%	-0.03%	-4.65%	0.12%	9.44%	-0.06%	-9.64%	0.27%
Waste, hazardous/ incinerated	g	0.12%	-0.02%	-3.20%	3.10%	0.25%	-0.04%	-6.69%	6.48%
Greenhouse Gases in GWP100	kg CO2 eq.	2.44%	-0.04%	-2.03%	-0.36%	5.65%	-0.10%	-4.72%	-0.83%
Ozone Depletion, emissions	mg R-11 eq.	n.a.				n.a.			
Acidification, emissions	g SO2 eq.	3.62%	-0.04%	-3.60%	0.02%	8.31%	-0.09%	-8.27%	0.06%
Volatile Organic Compounds (VOC)	g	4.34%	-1.82%	-2.76%	0.23%	8.73%	-3.70%	-5.61%	0.58%
Persistent Organic Pollutants (POP)	ng i-Teq	4.56%	-0.03%	-4.52%	-0.02%	8.00%	-0.05%	-7.98%	0.04%
Heavy Metals	mg Ni eq.	0.45%	-0.01%	-0.44%	0.00%	0.89%	-0.02%	-0.87%	0.00%
PAHs	mg Ni eq.	4.24%	-0.90%	-3.34%	0.00%	9.12%	-1.93%	-7.18%	0.00%
Particulate Matter (PM, dust)	g	1.69%	-3.35%	-0.44%	2.10%	3.80%	-7.68%	-1.01%	4.90%
Heavy Metals	mg Hg/20	1.55%	0.00%	-1.56%	0.02%	3.15%	-0.01%	-3.18%	0.04%
Eutrophication	g PO4	0.12%	0.00%	-0.12%	0.00%	0.24%	0.00%	-0.25%	0.00%
Persistent Organic Pollutants (POP)	ng i-Teq	n.a.				n.a.			

Based on the sensitivity analysis for refrigerant charge, it is possible to conclude that this parameter has a significant impact over the lifetime of the product (see figure below).

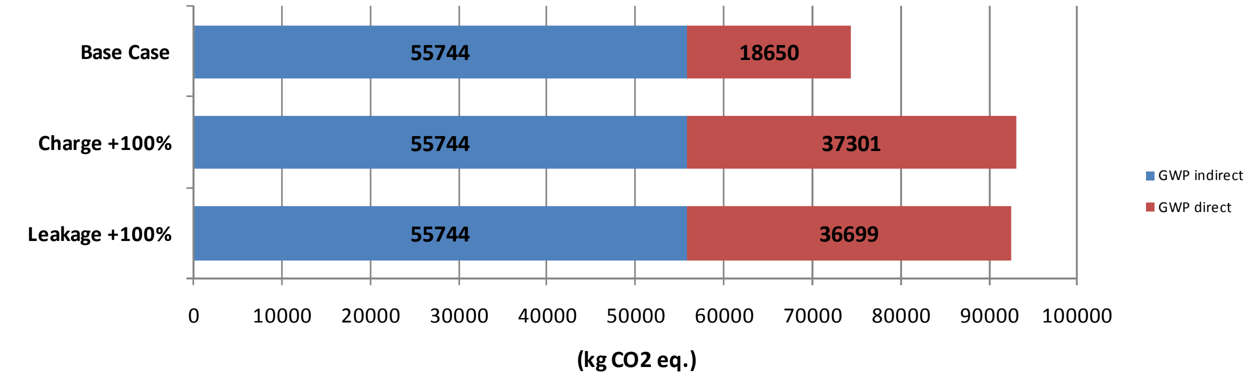

Figure 4-43: Sensitivity analysis Life cycle Total Equivalent Warming Impact (TEWI) of walk-in cold room Base Case, per product over lifetime

4.10.4. PROCESS CHILLER

The impacts of the process chiller Base Cases are presented below.

Table 4-53: Environmental assessment results per MT PRODUCT from EcoReport for process chiller

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	164794	18280	183074	15793	66300777	9448	13028	-3579	66496064
of which, electricity (in primary MJ)	MJ	30935	10538	41472	33	66299361	0	2	-2	66340864
Water (process)	ltr	38441	144	38584	0	4420316	0	1	-1	4458898
Water (cooling)	ltr	115475	4500	119975	0	176798389	0	12	-12	176918353
Waste, non-haz./ landfill	g	3775958	86265	3862224	7641	76908488	163481	8	163473	80941825
aste, hazardous/ incinerated	g	5788	12	5800	152	1527780	4960	1	4958	1538691
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	10240	1042	11282	933	2893362	85790	971	84819	2990396
Ozone Depletion, emissions	mg R-11 eq.									negligible
Acidification, emissions	g SO2 eq.	71676	4520	76196	2877	17072741	1384	1217	167	17151981
Volatile Organic Compounds (VOC)	g	453	19	472	241	24975	39	17	22	25710
Persistent Organic Pollutants (POP)	ng i-Teq	35440	2188	37628	43	434938	1125	0	1125	473734
Heavy Metals	mg Ni eq.	116645	5125	121770	388	1138658	2757	0	2757	1263573
PAHs	mg Ni eq.	2480	2	2481	517	130635	0	0	0	133632
Particulate Matter (PM, dust)	g	21886	689	22575	39661	364870	12299	21	12278	439385
Emissions (Water)										
Heavy Metals	mg Hg/20	43361	3	43364	12	427910	785	0	785	472071
Eutrophication	g PO4	3911	7	3918	0	2078	45	0	45	6040
Persistent Organic Pollutants (POP)	ng i-Teq					negligible				

Table 4-54: Environmental assessment results per LT PRODUCT from EcoReport for process chiller

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Total	
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	188214	18783	206997	18950	92558294	10866	14192	-3327	92780915
of which, electricity (in primary MJ)	MJ	35380	11200	46581	40	92556690	0	2	-2	92603308
Water (process)	ltr	41734	165	41899	0	6170834	0	2	-2	6212731
Water (cooling)	ltr	132797	5175	137972	0	246817978	0	13	-13	#######
Waste, non-haz./ landfill	g	4340158	65523	4405681	9163	107357747	188003	9	187994	111960584
Waste, hazardous/ incinerated	g	6645	3	6648	182	2132834	5703	1	5702	2145366
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	11758	1049	12806	1119	4039230	248721	1057	247664	4300819
Ozone Depletion, emissions	mg R-11 eq.									negligible
Acidification, emissions	g SO2 eq.	82265	4527	86792	3452	23834096	1592	1326	266	23924606
Volatile Organic Compounds (VOC)	g	515	5	520	290	34864	44	18	26	35700
Persistent Organic Pollutants (POP)	ng i-Teq	40755	503	41258	52	607080	1294	0	1294	649684
Heavy Metals	mg Ni eq.	134138	1179	135317	465	1589269	3171	0	3171	1728222
PAHs	mg Ni eq.	2851	0	2852	620	182365	0	1	-1	185837
Particulate Matter (PM, dust)	g	25115	696	25811	47616	509317	14144	23	14121	596866
Emissions (Water)										
Heavy Metals	mg Hg/20	49864	1	49865	14	597274	903	0	903	648056
Eutrophication	g PO4	4326	8	4334	0	2889	52	0	52	7274
Persistent Organic Pollutants (POP)	ng i-Teq					negligible				

Table 4-55: Impact of chillers per functional unit per year

Impact indicator	Impact per kW of capacity at -8°C per year	Impact per kW of capacity at -25°C per year
Total Energy (GER) (MJ)	14,775.6	20,676.0
of which, electricity (in primary MJ)	14,741.1	20,636.4
electricity (kWh)	1,403.9	1,965.4
Water (process) (ltr)	990.8	1,384.5
Waste, non-haz./ landfill (g)	17,985.4	24,950.1
Waste, hazardous/ incinerated (g)	341.9	478.1
Greenhouse Gases in GWP100 (kg CO2 eq.)	664.5	958.4
Acidification, emissions (g SO2 eq.)	3,811.2	5,331.5
Volatile Organic Compounds (VOC) (g)	5.7	8.0
Persistent Organic Pollutants (POP) (ng i-Teq)	105.3	144.8
Heavy Metals (mg Ni eq.)	280.8	385.1
PAHs (mg Ni eq.)	29.7	41.4
Particulate Matter (PM, dust) (g)	97.6	133.0
Heavy Metals (mg Hg/20)	104.9	144.4
Eutrophication (g PO4)	1.3	1.6

The figure below describes the proportions of the impacts caused during the various lifecycle stages of the product.

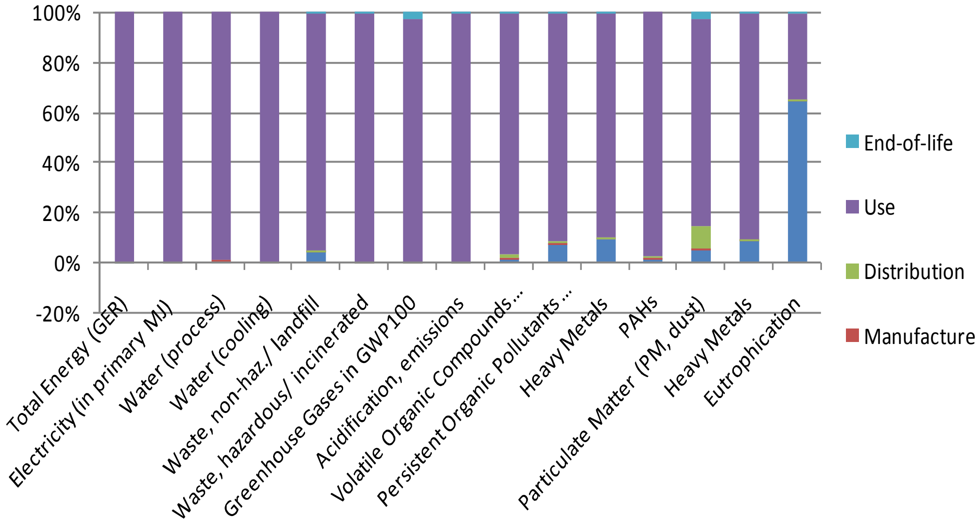

Figure 4-44 EcoReport LCA analysis results for MT chillers – impacts per lifecycle stage

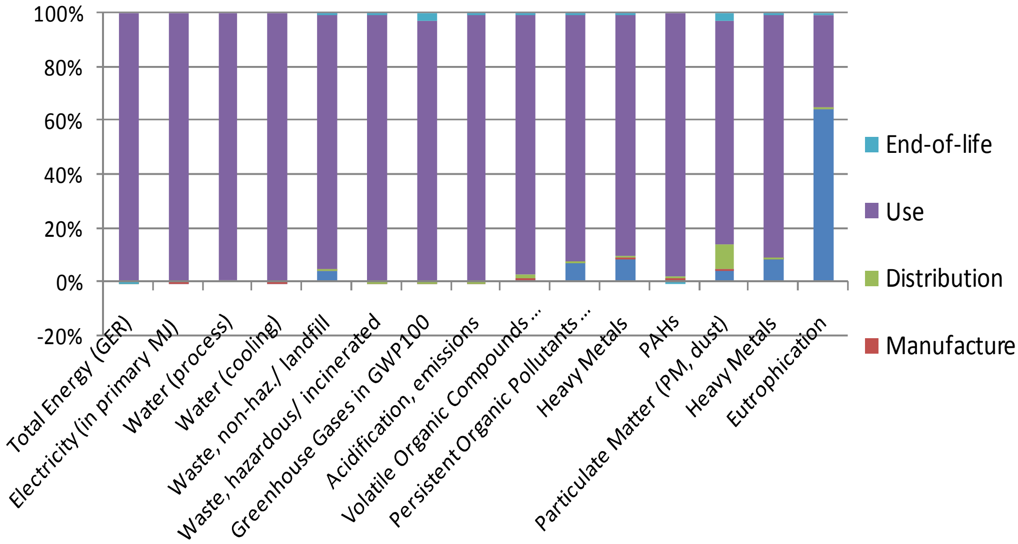

Figure 4-45 EcoReport LCA analysis results for LT chillers – impacts per lifecycle stage

When taking into account the GER (Gross Energy Requirement) as a reference for the environmental impacts, the results show that the use phase is the most important. It is responsible of fewer than 100% of the GER required during the whole life cycle. The production phase is the second stage, representing around 0.3% of the GER over product lifetime. The distribution and end-of-life phase are negligible. Besides, it is important to note that the end of-life phase provides GER with the thermal recovery of some parts of the packaged process chiller.

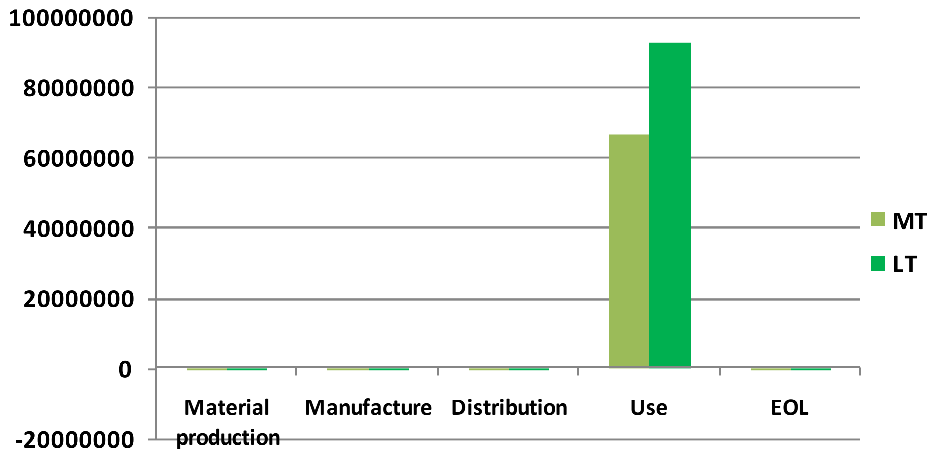

Figure 4-46: GER related to each phase of the life cycle of chiller (MJ)

Greenhouse Gases warming potential of chiller is mainly due to the use phase. The production of the electricity involves the combustion of fossil fuels and consequently emissions of carbon dioxide.

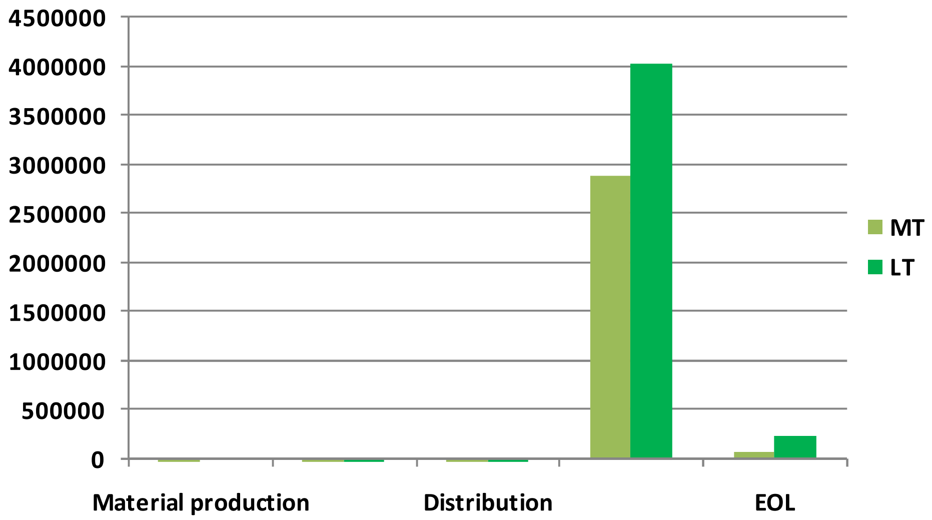

Figure 4-47: GWP related to each phase of the life cycle of chiller (kg CO2 eq.)

The direct and indirect greenhouse gasses emissions comparison is shown below. The higher GWP for LT products is due to the use of R404A in place of R134a.

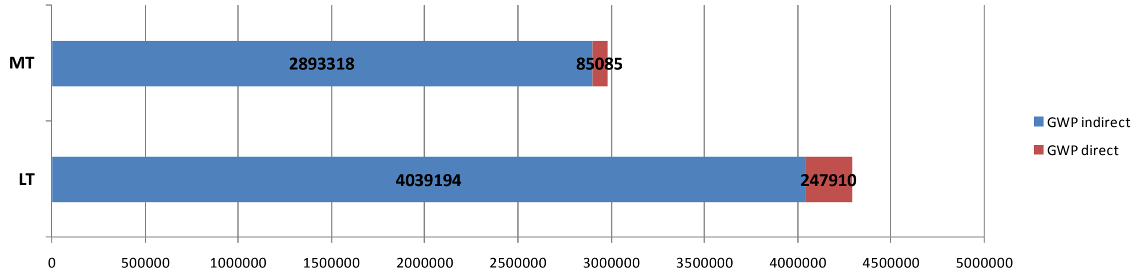

Figure 4-48: Life cycle Total Equivalent Warming Impact (TEWI) of chillers, per product over lifetime

Other impacts

- The process water used in the production phase is necessary in production mainly of steel elements included in chiller. The water used during use phase is related to the electricity consumption.
- Concerning environmental impact on non-hazardous waste during the production phase, it is mainly due to materials as steel and copper. The use phase impacts are in similar proportions to electricity consumption.
- The impact on hazardous waste during the use phase impact is connected to the electricity consumption. Other life phases are negligible.
- The high amount of acidification emissions resulting from the use phase are correlated to electricity consumption.
- Relating to Persistent Organic Pollutants, impact during use phase again comes from the electricity consumption. The impact caused by the production phase is related to production of ferrous metals.
- Volatile Organic Compounds are mainly emitted during the use phase due to the electricity consumption. Production phase emissions are related to the pre-coating coil material.
- Heavy metals emissions to the air from use phase are in similar proportion to use phase electricity production, indicating that HM emissions for this phase are associated with the electricity production. Emissions occurred during production phase are related to production of stainless coil.
- Emissions of PAHs through production phase are related to the production of ferrous metals. Use phase emissions are correlated to energy consumption.
- Following the use phase, the production phase is mainly responsible for emissions of Particulate Matter to the air (due to ferrous materials). End-of-Life contribution is caused by incineration of plastics/PWB which are not being reused or recycled.
- Emissions to water tackled by EcoReport tool are heavy metals and eutrophisation. Concerning emissions of heavy metals through production phase, half of this impact is due to production of steel and other ferrous metals. Use phase emissions are again related to electricity consumption.

- Emissions related to eutrophication mainly occur during production phase due to ferrous materials.

4.10.4.1 Life Cycle Costs

The EcoReport provides the following results for the LCC. The electricity costs represent the biggest share of the LCC (around 89 %), followed by price of the product.

Table 4-56: Life Cycle Costs per product and Total annual expenditure (2008) in the EU-27

	MT – LCC new product (€)	LT – LCC new product (€)	Total annual consumer expenditure in EU25 (mln €)
Product price	55,000	70,000	361
Installation/acquisition costs	5,500	7,000	36
Electricity	561,628	784,058	5,136
Repair and maintenance costs	4,077	5,189	33
Total	626,205	866,246	5,566

4.10.4.2 EU Totals

As presented in section above, the chiller consumes a large amount of electricity, produced in general by burning fossil fuel that emits CO_2 (carbon dioxide) into the atmosphere. By the simple fact of consuming energy over its life cycle, it contributes to climate change.

Table 4-57: EU Total Impact of STOCK of process chillers in 2008

		TOTAL	PRODUCTION			DISTRIBUTION	USE	END-OF-LIFE		
			Material	Manuf.	Total			Disposal	Recycl.	Total
Other Resources & Waste										
Total Energy (GER)	**PJ**	451	1.03	0.11	1.13	0.10	449.44	0.06	0.08	-0.02
of which, electricity	**TWh**	43	0.02	0.01	0.02	0.00	42.80	0.00	0.00	0.00
Water (process)	**mln. m3**	30	0.23	0.00	0.23	0.00	29.96	0.00	0.00	0.00
Water (cooling)	**mln. m3**	1199	0.72	0.03	0.75	0.00	1198.49	0.00	0.00	0.00
Waste, non-haz./ landfill	**kt**	546	23.56	0.45	24.02	0.05	521.33	1.02	0.00	1.02
Waste, hazardous/ incinerated	**kt**	10	0.04	0.00	0.04	0.00	10.36	0.03	0.00	0.03
Emissions (Air)										
Greenhouse Gases in GWP100	**mt CO2 eq.**	21	0.06	0.01	0.07	0.01	19.61	0.92	0.01	0.92
Ozone Depletion, emissions	**t R-11 eq.**	0	negligable	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acidification, emissions	**kt SO2 eq.**	116	0.45	0.03	0.47	0.02	115.73	0.01	0.01	0.00
Volatile Organic Compounds (VOC)	**kt**	0	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	**g i-Teq**	3	0.22	0.01	0.23	0.00	2.95	0.01	0.00	0.01
Heavy Metals	**ton Ni eq.**	8	0.73	0.02	0.75	0.00	7.72	0.02	0.00	0.02
PAHs	**ton Ni eq.**	1	0.02	0.00	0.02	0.00	0.89	0.00	0.00	0.00
Particulate Matter (PM, dust)	**kt**	3	0.14	0.00	0.14	0.25	2.47	0.08	0.00	0.08
Emissions (Water)										
Heavy Metals	**ton Hg/20**	3	0.27	0.00	0.27	0.00	2.90	0.00	0.00	0.00
Eutrophication	**kt PO4**	0	0.02	0.00	0.02	0.00	0.01	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	**g i-Teq**	0	negligable							

The EU wide impact of such products in 2008 is estimated to a total energy consumption of approximately 451 PJ and to a GWP of 21 mt CO_2 eq.

4.10.4.3 Sensitivity analysis

A sensitivity analysis was performed to assess the change in environmental impacts when production material quantities are increased by +20% and +50%.

Table 4-58: Production material sensitivity analysis – change in total stock impacts

Impact Category	units	Base Case material +20%		Base Case material +50%	
		Absolute increase over Base Case	% increase over Base Case	Absolute increase over Base Case	% increase over Base Case
Total Energy (GER)	PJ	0.119	0.07%	0.297	0.17%
of which, electricity (in primary PJ)	PJ	0.027	0.02%	0.069	0.04%
Water (process)	mln. m3	0.026	0.22%	0.064	0.55%
Water (cooling)	mln. m3	0.079	0.02%	0.199	0.04%
Waste, non-haz./ landfill	kt	2.665	1.26%	6.663	3.15%
Waste, hazardous/ incinerated	kt	0.007	0.18%	0.018	0.45%
Greenhouse Gases in GWP100	mt CO2 eq.	0.007	0.09%	0.018	0.23%
Ozone Depletion, emissions	t R-11 eq.	0.000	-	0.000	-
Acidification, emissions	kt SO2 eq.	0.051	0.11%	0.126	0.29%
Volatile Organic Compounds (VOC)	kt	0.000	0.49%	0.001	1.22%
Persistent Organic Pollutants (POP)	g i-Teq	0.026	2.05%	0.064	5.13%
Heavy Metals	ton Ni eq.	0.082	2.46%	0.206	6.15%
PAHs	ton Ni eq.	0.002	0.47%	0.004	1.18%
Particulate Matter (PM, dust)	kt	0.023	1.94%	0.058	4.85%
Heavy Metals	ton Hg/20	0.029	2.34%	0.073	5.85%
Eutrophication	kt PO4	0.003	14.27%	0.007	35.68%
Persistent Organic Pollutants (POP)	g i-Teq	0.000	-	0.000	-

Table 4-59: Production material sensitivity analysis – change in impacts across lifecycle phases

	units	Base Case material +20%				Base Case material +50%			
		Productio	Distributio	Use	End of life	Production	Distributio	Use	End of life
Other Resources & Waste		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Total Energy (GER)	MJ	0.07%	0.00%	-0.07%	0.00%	0.17%	0.00%	-0.17%	0.00%
of which, electricity (in primary	MJ	0.02%	0.00%	-0.02%	0.00%	0.04%	0.00%	-0.04%	0.00%
Water (process)	ltr	0.21%	0.00%	-0.21%	0.00%	0.53%	0.00%	-0.53%	0.00%
Water (cooling)	ltr	0.02%	0.00%	-0.02%	0.00%	0.04%	0.00%	-0.04%	0.00%
Waste, non-haz./ landfill	g	1.09%	0.00%	-1.14%	0.05%	2.68%	0.00%	-2.80%	0.11%
Waste, hazardous/ incinerated	g	0.09%	0.00%	-0.17%	0.08%	0.23%	0.00%	-0.43%	0.20%
Greenhouse Gases in GWP100	kg CO2 eq.	0.09%	0.00%	-0.09%	-0.01%	0.23%	0.00%	-0.22%	-0.01%
Ozone Depletion, emissions	mg R-11	n.a.				n.a.			
Acidification, emissions	g SO2 eq.	0.11%	0.00%	-0.11%	0.00%	0.28%	0.00%	-0.28%	0.00%
Volatile Organic Compounds	g	0.44%	-0.01%	-0.46%	0.02%	1.10%	-0.01%	-1.14%	0.05%
Persistent Organic Pollutants	ng i-Teq	1.72%	0.00%	-1.77%	0.05%	4.17%	0.00%	-4.29%	0.12%
Heavy Metals	mg Ni eq.	2.02%	0.00%	-2.06%	0.05%	4.87%	0.00%	-4.98%	0.11%
PAHs	mg Ni eq.	0.45%	0.00%	-0.45%	0.00%	1.12%	-0.01%	-1.11%	0.00%
Particulate Matter (PM, dust)	g	1.09%	-0.20%	-1.49%	0.60%	2.66%	-0.50%	-3.61%	1.45%
Heavy Metals	mg Hg/20	1.94%	0.00%	-1.98%	0.04%	4.70%	0.00%	-4.78%	0.09%
Eutrophication	g PO4	3.52%	0.00%	-3.56%	0.04%	7.42%	0.00%	-7.51%	0.08%
Persistent Organic Pollutants	ng i-Teq	n.a.				n.a.			

Based on the sensitivity analysis for refrigerant charge, it is possible to conclude that this parameter do not have a big impact over the lifetime of the product (see figure below).

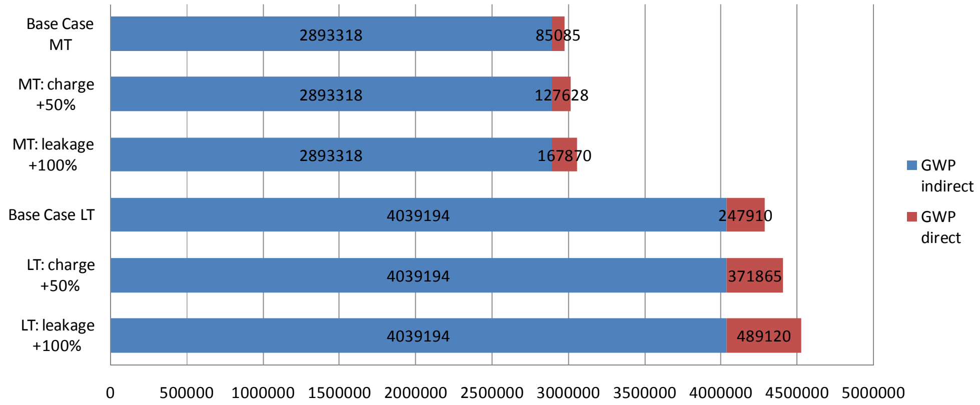

Figure 4-49: Sensitivity analysis Life cycle Total Equivalent Warming Impact (TEWI) of chiller Base Case, per product over lifetime increasing in 50% and 100% refrigerant charge

4.10.5. REMOTE CONDENSING UNIT

The impacts of the remote condensing unit Base Cases are presented below.

Table 4-60: Environmental assessment results per MT PRODUCT from EcoReport for remote condensing unit

Life Cycle phases -->		PRODUCTION			DISTRIBUTION	USE	EOL			TOTAL
Other Resources & Waste		Prod. Material	Prod. Manuf.	Total	Distribution	Use	Disposal	Recycl.	EOL	
Total Energy (GER)	MJ	5,253	1,778	7,031	825	2,626,752	659	188	471	2,635,079
of which, electricity (in primary MJ)	MJ	362	1,058	1,421	2	2,626,696	0	1	-1	2,628,117
electricity (in kWh)	kWh	34	101	135	0	250,161	0	0	0	250,297
Water (process)	ltr	1,049	16	1,065	0	175,123	0	1	-1	176,187
Water (cooling)	ltr	792	487	1,279	0	7,004,497	0	6	-6	7,005,769
Waste, non-haz./ landfill	g	274,686	6,305	280,991	368	3,048,298	8,473	5	8,468	3,338,125
Waste, hazardous/ incinerated	g	28	0	28	7	60,527	2,753	1	2,752	63,314
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	400	99	499	50	114,632	72,019	13	72,006	187,187
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	2,047	429	2,476	151	676,395	97	17	80	679,103
Volatile Organic Compounds (VOC)	g	18	1	19	14	989	2	0	2	1,025
Persistent Organic Pollutants (POP)	ng i-Teq	3,186	55	3,241	2	17,249	58	0	58	20,551
Heavy Metals	mg Ni eq.	1,408	130	1,538	19	45,079	188	0	188	46,824
PAHs	mg Ni eq.	191	0	191	33	5,177	0	0	0	5,401
Particulate Matter (PM, dust)	g	516	66	581	2,382	14,453	857	0	857	18,273
Emissions (Water)										
Heavy Metals	mg Hg/20	393	0	394	1	16,940	55	0	55	17,389
Eutrophication	g PO4	17	1	18	0	81	3	0	3	102
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Table 4-61: Environmental assessment results per LT PRODUCT from EcoReport for remote condensing unit

Life Cycle phases -->		PRODUCTION			DISTRIBUTIO N	USE	EOL			TOTAL
Other Resources & Waste		Prod. Material	Prod. Manuf.	Total	Distribution	Use	Dispos al	Recyc l.	EOL	
Total Energy (GER)	MJ	6,304	2,133	8,437	980	4,208,965	791	226	566	4,218,948
of which, electricity (in primary MJ)	MJ	435	1,270	1,705	2	4,208,898	0	1	-1	4,210,603
electricity (in kWh)	kWh	41	121	162	0	400,847	0	0	0	401,010

Water (process)	ltr	1,259	19	1,278	0	280,605	0	1	-1	281,882
Water (cooling)	ltr	950	585	1,535	0	11,223,698	0	8	-8	11,225,225
Waste, non-haz./ landfill	g	329,623	7,566	337,190	431	4,883,330	10,167	5	10,162	5,231,113
Waste, hazardous/ incinerated	g	33	0	34	9	96,985	3,304	1	3,303	100,330
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	479	119	599	59	183,679	72,029	16	72,013	256,350
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	2,456	515	2,971	179	1,083,817	117	20	96	1,087,063
Volatile Organic Compounds (VOC)	g	22	1	23	17	1,585	3	0	3	1,628
Persistent Organic Pollutants (POP)	ng i-Teq	3,823	67	3,890	2	27,626	70	0	70	31,588
Heavy Metals	mg Ni eq.	1,689	156	1,845	22	72,227	226	0	226	74,320
PAHs	mg Ni eq.	229	0	229	39	8,294	0	0	0	8,562
Particulate Matter (PM, dust)	g	619	79	698	2,859	23,156	1,029	0	1,028	27,740
Emissions (Water)										
Heavy Metals	mg Hg/20	472	0	472	1	27,142	66	0	66	27,681
Eutrophication	g PO4	21	1	22	0	130	4	0	4	155
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Table 4-62: Impact of remote condensing units per functional unit per year

Impact indicator	Impact per kW cooling capacity per year for MT	Impact per kW cooling capacity per year for LT
Total Energy (GER)	45,850	90,660
of which, electricity (in primary MJ)	45,729	90,481
electricity (in kWh)	4,355	8,617
Water (process)	3,066	6,057
Water (cooling)	121,899	241,216
Waste, non-haz./ landfill	58,083	112,410
Waste, hazardous/ incinerated	1,102	2,156
Greenhouse Gases in GWP100	3,257	5,509
Ozone Depletion, emissions	0	0
Acidification, emissions	11,816	23,360
Volatile Organic Compounds (VOC)	18	35
Persistent Organic Pollutants (POP)	358	679
Heavy Metals	815	1,597
PAHs	94	184
Particulate Matter (PM, dust)	318	596
Heavy Metals	303	595
Eutrophication	2	3
Persistent Organic Pollutants (POP)	0	0

When taking into account the GER (Gross Energy Requirement) as a reference for the environmental impacts, the results show that the use phase is the most important. It is responsible of 99.5% of the GER required during the whole life cycle. The production phase is the second stage, representing 0.4%. The distribution and end-of-life phase are negligible. The figure below describes the proportions of the impacts caused during the various lifecycle stages of the product.

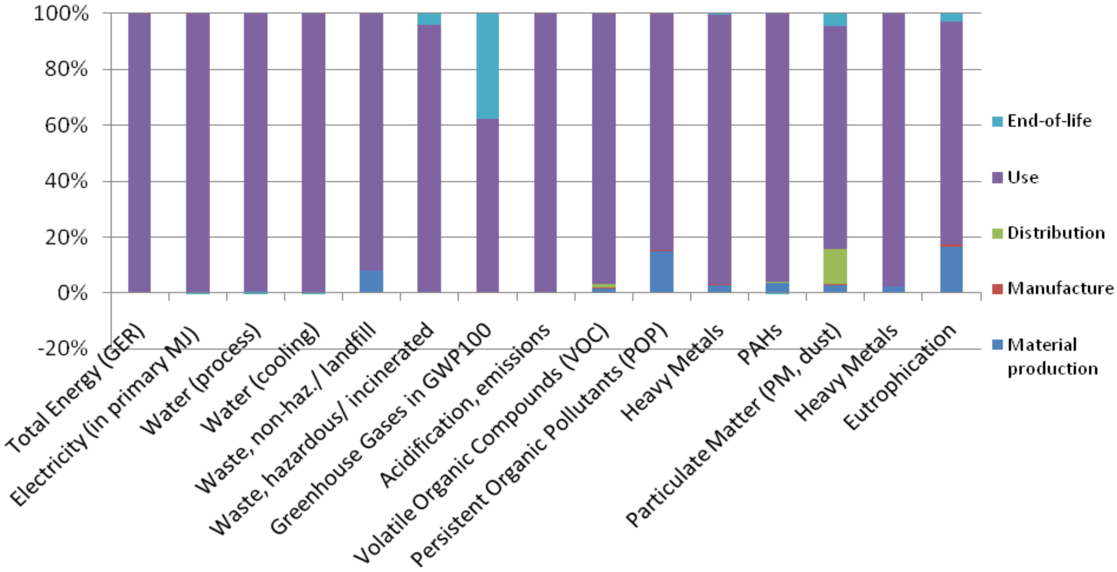

Figure 4-50 EcoReport LCA analysis results for MT remote condensing units

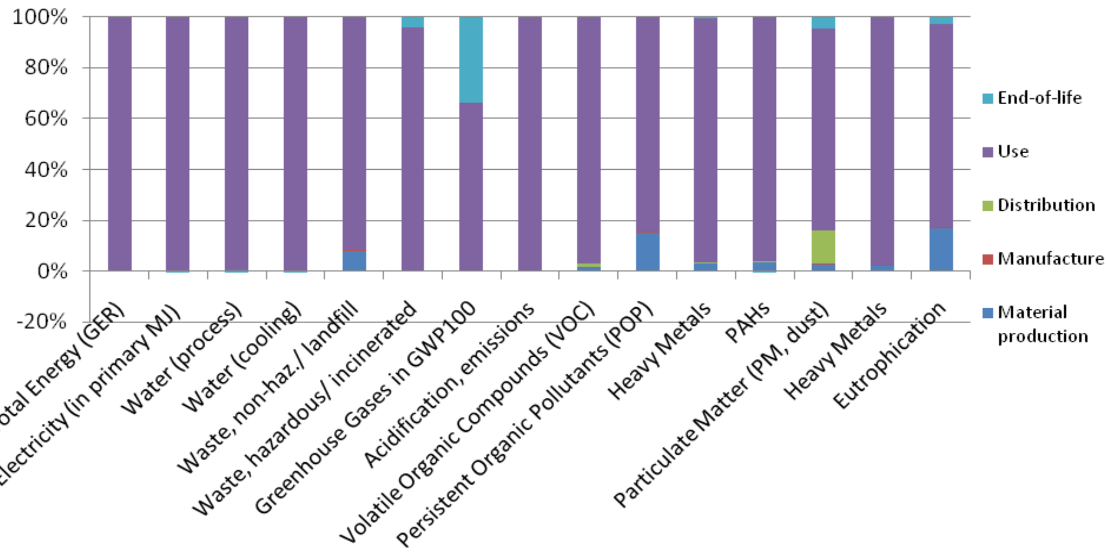

Figure 4-51 EcoReport LCA analysis results for LT remote condensing units

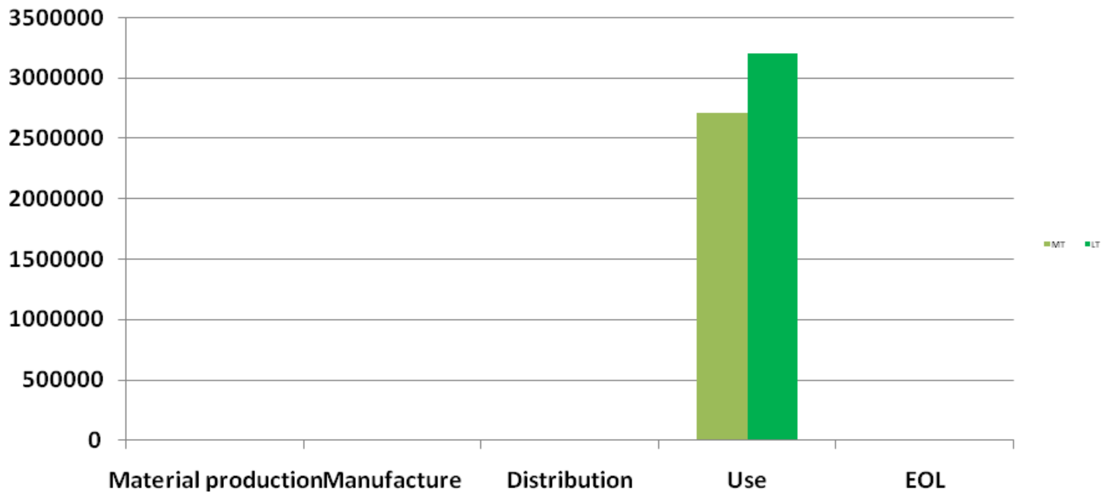

Figure 4-52: GER related to each phase of the life cycle of condensing unit (MJ)

The process water used in the production and manufacturing phase is necessary in production mainly of ferrous metals included in condensing unit. The water used during use phase is related to the electricity consumption.

Concerning environmental impact on non-hazardous waste during the production phase, it is mainly due to materials as steel and copper. The use phase impacts are in similar proportions to electricity consumption.

The impact on hazardous waste during the use phase impact is connected to the electricity consumption. The End-of-Life emissions are related to incineration of plastics

Greenhouse Gases warming potential of condensing unit is mainly due to the use phase. The production of the electricity involves the combustion of fossil fuels and consequently emissions of carbon dioxide.

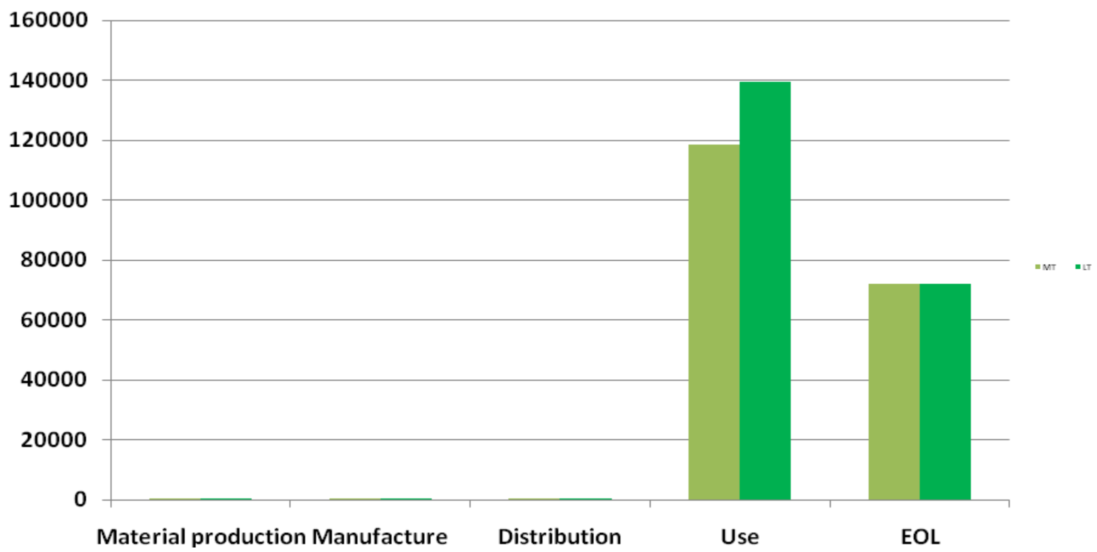

Figure 4-53: GWP related to each phase of the life cycle of condensing unit (kg CO2 eq.)

The direct and indirect greenhouse gasses emissions comparison is shown below. The refrigerant used is R404A, with a high GWP value, and the estimated leakage is 15% per year and 50% at the end–of-life. A change to a low GWP refrigerant and leakage reduction would drive to a lower direct environmental impact.

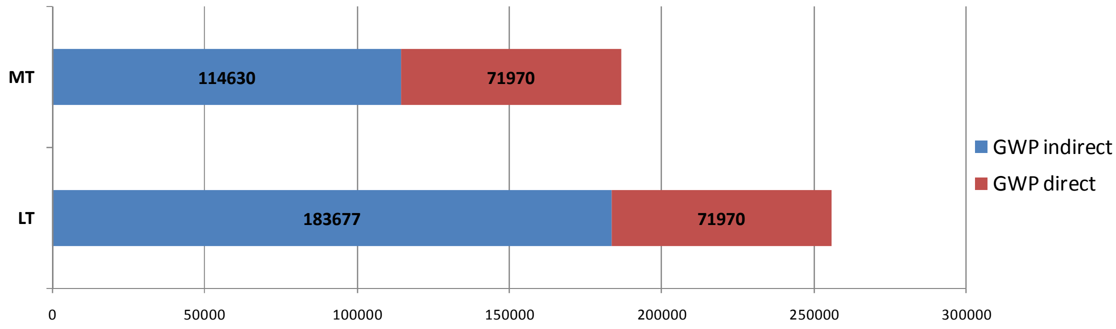

Figure 4-54: Life cycle Total Equivalent Warming Impact (TEWI) of remote condening unit Base Case, per product over lifetime

Other impacts

- The high amount of acidification emissions resulting from the use phase are correlated to electricity consumption.
- Relating to Persistent Organic Pollutants, impact during use phase again comes from the electricity consumption. The impact caused by the production phase is related to production of ferrous metals.
- Volatile Organic Compounds are mainly emitted during the use phase due to the electricity consumption. Production phase emissions are related to the pre-coating coil material and distribution phase is correlated to so called mobile sources.
- Heavy metals emissions to the air from use phase are in similar proportion to use phase electricity production, indicating that HM emissions for this phase are associated with the electricity production. Emissions occurred during production phase are related to production of steel used for chassis of appliance.
- Emissions of PAHs through production phase are related to the production of ferrous metals. Use phase emissions are correlated to energy consumption.
- Following the use phase, the distribution phase is mainly responsible for emissions of Particulate Matter to the air. End-of-Life contribution is caused by incineration of plastics which are not being reused or recycled.
- Emissions to water tackled by EcoReport tool are heavy metals and eutrophisation. Concerning emissions of heavy metals through production phase, this impact is due to production of steel and other ferrous metals. Use phase emissions are again related to electricity consumption.
- Emissions related to eutrophication occurring during production phase are due to ferrous materials production. However, use phase is dominant part.

4.10.5.1 Life Cycle Costs

The EcoReport provides the following results for the LCC. The electricity costs represent the biggest share of the LCC (84 % of the total annual consumer expenditure), followed by price of the product (13%).

Table 4-63: Life Cycle Costs per product and Total annual expenditure (2008) in the EU-27

	MT-LCC new product (€)	LT-LCC new product (€)	total annual consumer expenditure in EU25 (mln.€)
Product price	6,627	7,933	3,925
Installation/ acquisition costs (if any)	663	793	392
Electricity	25,264	40,482	21,303
Repair & maintenance costs	558	668	424
Total	33,111	49,875	26,044

4.10.5.2 EU Totals

As presented in section above, the condensing unit consumes a large amount of electricity, produced in general by burning fossil fuel that emits CO_2 (carbon dioxide) into the atmosphere. By the simple fact of consuming energy over its life cycle, it contributes to climate change.

Table 4-64: EU Total Impact of STOCK of Remote Condensing Units in 2008

		TOTAL	PRODUCTION			DISTRIBUTION	USE	END-OF-LIFE		
			Material	Manuf.	Total			Disposal	Recycl.	Total
Other Resources & Waste										
Total Energy (GER)	**PJ**	1,868.99	3.11	1.05	4.17	0.49	1,864.06	0.39	0.11	0.28
Water (process)	**mln. m3**	124.91	0.62	0.01	0.63	0.00	124.27	0.00	0.00	0.00
Water (cooling)	**mln. m3**	4,971.47	0.47	0.29	0.76	0.00	4,970.71	0.00	0.00	0.00
Waste, non-haz./ landfill	**kt**	2,334.81	162.77	3.74	166.50	0.22	2,163.07	5.02	0.00	5.02
Waste, hazardous/ incinerated	**kt**	44.60	0.02	0.00	0.02	0.00	42.95	1.63	0.00	1.63
Emissions (Air)										
Greenhouse Gases in GWP100	**mt CO2 eq.**	122.70	0.24	0.06	0.30	0.03	81.35	41.04	0.01	41.03
Ozone Depletion, emissions	**t R-11 eq.**	0.00	negligable	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Acidification, emissions	**kt SO2 eq.**	481.60	1.21	0.25	1.47	0.09	480.00	0.06	0.01	0.05
Volatile Organic Compounds (VOC)	**kt**	0.72	0.01	0.00	0.01	0.01	0.70	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	**g i-Teq**	14.20	1.89	0.03	1.92	0.00	12.24	0.03	0.00	0.03
Heavy Metals	**ton Ni eq.**	33.02	0.83	0.08	0.91	0.01	31.99	0.11	0.00	0.11
PAHs	**ton Ni eq.**	3.81	0.11	0.00	0.11	0.02	3.67	0.00	0.00	0.00
Particulate Matter (PM, dust)	**kt**	12.52	0.31	0.04	0.34	1.41	10.26	0.51	0.00	0.51
Emissions (Water)										
Heavy Metals	**ton Hg/20**	12.29	0.23	0.00	0.23	0.00	12.02	0.03	0.00	0.03
Eutrophication	**kt PO4**	0.07	0.01	0.00	0.01	0.00	0.06	0.00	0.00	0.00
Persistent Organic Pollutants (POP)	**g i-Teq**	0.00	negligable	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The EU wide impact of such products in 2008 is estimated to a total energy consumption of approximately 1,869 PJ and to a GWP of 123 mt CO2 eq.

4.10.5.3 Sensitivity analysis

A sensitivity analysis was performed to assess the change in environmental impacts when production material quantities are increased by +20% and +50%.

Table 4-65: Production material sensitivity analysis – change in total stock impacts

Impact Category	units	Base Case material +20%		Base Case material +50%	
		Absolute increase over Base Case	% increase over Base Case	Absolute increase over Base Case	% increase over Base Case
Total Energy (GER)	PJ	0.990	0.12%	2.357	0.28%
of which, electricity (in primary PJ)	PJ	0.173	0.02%	0.432	0.05%
Water (process)	mln. m3	0.129	0.23%	0.321	0.56%
Water (cooling)	mln. m3	0.155	0.01%	0.387	0.02%
Waste, non-haz./ landfill	kt	35.235	3.03%	88.036	7.57%
Waste, hazardous/ incinerated	kt	0.336	1.58%	0.836	3.93%
Greenhouse Gases in GWP100	mt CO2 eq.	0.070	0.10%	0.167	0.24%
Ozone Depletion, emissions	t R-11 eq.	0.000	-	0.000	-
Acidification, emissions	kt SO2 eq.	0.325	0.15%	0.791	0.36%
Volatile Organic Compounds (VOC)	kt	0.004	1.17%	0.008	2.28%
Persistent Organic Pollutants (POP)	g i-Teq	0.402	5.29%	1.004	13.23%
Heavy Metals	ton Ni eq.	0.211	1.35%	0.526	3.36%
PAHs	ton Ni eq.	0.026	1.45%	0.061	3.37%
Particulate Matter (PM, dust)	kt	0.413	5.81%	0.674	9.48%
Heavy Metals	ton Hg/20	0.055	0.95%	0.136	2.36%
Eutrophication	kt PO4	0.003	6.59%	0.006	16.06%
Persistent Organic Pollutants (POP)	g i-Teq	0.000	-	0.000	-

Table 4-66: Production material sensitivity analysis – change in impacts across lifecycle phases

		Base Case material +20%				Base Case material +50%			
	units	Production	Distribution	Use	End of life	Production	Distribution	Use	End of life
Other Resources & Waste		0.00%	0.00%	0.00%	0.00 %	0.00%	0.00%	0.00%	0.00%
Total Energy (GER)	MJ	0.09%	0.01%	-0.10%	0.01 %	0.22%	0.01%	-0.24%	0.01%
of which, electricity (in primary MJ)	MJ	0.02%	0.00%	-0.02%	0.00 %	0.04%	0.00%	-0.04%	0.00%
Water (process)	ltr	0.20%	0.00%	-0.19%	0.00 %	0.48%	0.00%	-0.48%	0.00%
Water (cooling)	ltr	0.01%	0.00%	-0.01%	0.00 %	0.01%	0.00%	-0.01%	0.00%
Waste, non-haz./ landfill	g	2.20%	0.00%	-2.27%	0.07 %	5.29%	0.00%	-5.45%	0.16%
Waste, hazardous/ incinerated	g	0.01%	0.00%	-1.29%	1.27 %	0.03%	0.00%	-3.14%	3.10%
Greenhouse Gases in GWP100	kg CO2 eq.	0.08%	0.01%	-0.05%	-0.03 %	0.20%	0.01%	-0.13%	-0.08%
Ozone Depletion, emissions	mg R-11 eq.	n.a.				n.a.			
Acidification, emissions	g SO2 eq.	0.12%	0.01%	-0.13%	0.00 %	0.30%	0.01%	-0.31%	0.01%
Volatile Organic Compounds (VOC)	g	0.55%	0.35%	-0.96%	0.06	1.38%	0.32%	-1.86%	0.16%

		Base Case material +20%				Base Case material +50%			
	units	Production	Distribution	Use	End of life	Production	Distribution	Use	End of life
					%				
Persistent Organic Pollutants (POP)	ng i-Teq	3.39%	0.00%	-3.46%	0.06 %	7.94%	0.00%	-8.08%	0.14%
Heavy Metals	mg Ni eq.	0.98%	0.01%	-1.10%	0.12 %	2.40%	0.01%	-2.70%	0.29%
PAHs	mg Ni eq.	1.04%	0.14%	-1.18%	0.00 %	2.58%	0.12%	-2.69%	0.00%
Particulate Matter (PM, dust)	g	0.63%	1.92%	-3.48%	0.93 %	1.72%	1.23%	-5.49%	2.53%
Heavy Metals	mg Hg/20	0.69%	0.00%	-0.79%	0.10 %	1.71%	0.00%	-1.95%	0.24%
Eutrophication	g PO4	3.36%	0.00%	-3.94%	0.58 %	7.54%	0.00%	-8.89%	1.35%
Persistent Organic Pollutants (POP)	ng i-Teq	n.a.				n.a.			

Based on the sensitivity analysis for refrigerant charge, it is possible to conclude that this parameter has a significant impact over the lifetime of the product (see figure below). Therefore, refrigerant charge reduction, refrigerant leakage prevention and the use of low GWP refrigerants would lower the direct environmental impact of remote condensing units.

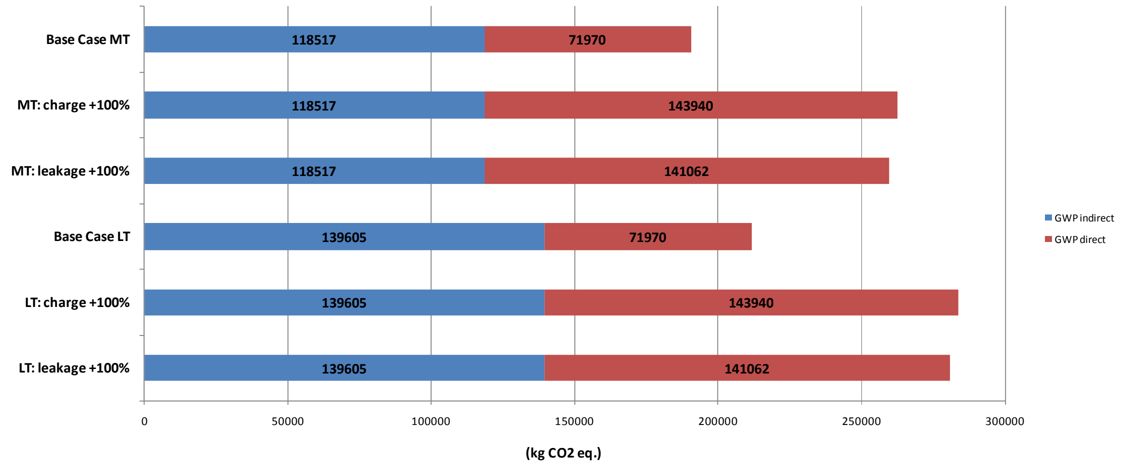

Figure 4-55 Sensitivity analysis Life cycle Total Equivalent Warming Impact (TEWI) of remote condensing unit Base Case, per product over lifetime increasing in 100% refrigerant charge and leakage rates

4.11. SUMMARY OF ENVIRONMENTAL IMPACTS

The following table describes relevant eco-design indicators for the environmental impacts across the range of products covered in the scope of ENTR Lot 1.

Table 4-67: Eco-design indicators for ENTR Lot 1 product groups per functional unit per year of life

Impact indicator	Unit	Service cabinets HT	Service cabinets LT	Blast cabinets	Walk-in cold rooms	Chillers MT	Chillers LT	Remote condensing units MT	Remote condensing units LT
		Impact per litre net volume at +5°C	Impact per litre net volume at -18°C	Impact per kg of foodstuff (referred to material proposed by NF AC D 40-003)	Impact per m^3 of net volume at +2°C	Impact per kW cooling capacity to reach -10°C at +30°C /+35°C cond. inlet temperature	Impact per kW cooling capacity to reach -18°C at +30°C/ +35°C cond. inlet temperature	Impact per kW cooling capacity at -10°C evap. temp; +32°C ambient temp.	Impact per kW cooling capacity at -10°C evap. temp; +32°C ambient temp.
Total Energy (GER)	MJ	50.97	121.35	2.06	5,901.34	14,775.55	20,675.99	45,850	90,660
of which, electricity (in primary MJ)	MJ	47.60	117.69	1.98	5,546.00	14,741.07	20,636.41	45,729	90,481
electricity (in kWh)	kWh	4.53	11.21	0.19	528.19	1403.91	1965.37	4,355	8,617
Water (process)	ltr	4.75	9.58	0.17	594.43	990.78	1,384.49	3,066	6,057
Water (cooling)	ltr	126.80	313.70	3.67	13,986.78	39,311.60	55,033.49	121,899	241,216
Waste, non-haz./ landfill	g	107.80	194.31	0.13	14,053.99	17,985.43	24,950.13	58,083	112,410
Waste, hazardous/ incinerated	g	6.52	8.68	0.20	481.40	341.90	478.09	1,102	2,156
Greenhouse Gases in GWP100	kg CO2 eq.	2.42	5.80	0.55	346.23	664.47	958.43	3,257	5,509
Ozone Depletion, emissions	mg R-11 eq.	0.00	0.00	0.00	0.00	-	-	0	0
Acidification, emissions	g SO2 eq.	13.71	31.89	0.02	1,771.66	3,811.20	5,331.54	11,816	23,360
Volatile Organic Compounds (VOC)	g	0.03	0.06	0.09	4.18	5.71	7.96	18	35
Persistent Organic Pollutants (POP)	ng i-Teq	0.75	1.26	0.01	129.18	105.26	144.78	358	679
Heavy Metals	mg Ni eq.	3.33	4.79	0.04	3,280.65	280.77	385.13	815	1,597
PAHs	mg Ni eq.	0.36	0.53	0.05	32.06	29.69	41.41	94	184
Particulate Matter (PM, dust)	g	2.49	2.96	0.00	318.50	97.63	133.01	318	596
Heavy Metals	mg Hg/20	1.92	2.54	2.06	317.35	104.90	144.42	303	595
Eutrophication	g PO4	0.07	0.08	1.98	21.02	1.34	1.62	2	3
Persistent Organic Pollutants (POP)	ng i-Teq	0.00	0.00	0.19	0.00	-	-	0	0

4.12. ECO-DESIGN INDICATORS

The following table proposes some potential eco-design indicators that might be used by designers to understand and manage the environmental impacts of the products they design.

Table 4-68: Potential eco-design indicators for designers

Environmental impact	Cause of impact	Potential eco-design indicator
Consumption of energy	Significant electricity consumption in all the products	• TEC, AEC, consumption per cycle, consumption per functional unit
Consumption of material	Use of metals in production phase (mainly ferrous metals) and plastics (mainly PUR) Use of cardboard for the packaging	• % of recycled content in metal parts • Optimisation of the weight with substitute materials • Ration of the volume of the packaged product with the volume of the product • % of the recycled content in the packaging (cardboard and paper) • Extension of the lifetime and/or the warranty • Strong repair practices • Collecting equipment at the EoL to ensure proper treatment and recycling
Consumption of other resources such as fresh water	Water or other resources used in production processes (relevant share of the life cycle only for service cabinets and WICR) and for electricity production	• The consumption of water (or other resources) in the production phase is mainly due to the extraction and production of ferrous metals (mostly the stainless steel). • Producers of ferrous metals can developed a EMAS scheme (or equivalent) to monitor and manage their water consumption
Emission to air, water and soil	Manufacture and use Refrigerant leakage	• Reduction of amount of material used during manufacture (see consumption of material) • % recovered refrigerant at EoL • Strong repair practices to avoid leakages
Physical effects such as noise	Compressor and/or fans	• For machines under the machinery directive (2006/42/EC) noise is related to potential damage of the user; acoustic pressure [dBA]
Generation of waste materials	Disposal	• % of product and/or refrigerant reused or recycled • Full compliance with WEEE and RoHS Directives, when relevant, and targets set for the appropriate categories
Possibilities for reuse, recycling and recovery of material and/or energy	Significant environmental impact (waste, resource use) if no reuse, recycling and recovery	• Possibility to use the heat removed from the equipment to heat up the building • % of product and/or refrigerant reused or recycled • energy recovery (MJ)

4.13. CONCLUSIONS

There is a great diversity in the type of refrigeration products covered in ENTR Lot 1, with different functionalities but often similar components used in the products. This report draws together information collected to this point, and its purpose is to provide an understanding of the assessment methodology (through a full analysis of the walk-in cold room Base Case), to provide a description of the data gathered to date for comment and feedback, and, importantly, to highlight data gaps.

The technical analysis has described how there are significant potential savings achievable through the use of new technologies, but also highlights many other factors that can affect product performance.

The EcoReport analysis shows that for all product groups, the use phase is the highest contributor to the total environmental impacts over the whole life span of the products due to energy consumption. The production phase is the second highest contributor due to manufacture of the products' housing, which is responsible of most of the environmental impact through eutrophication and heavy metals released to air and water. The comparison between direct GWP emissions due to the refrigerant and indirect emissions due to electricity consumption shows that the contribution of the refrigerant to these is high in all the products under the scope. The use of low-GWP refrigerants, the reduction of the refrigerant charge and leakage rates would drive a reduction of the direct environmental impacts.

The Base Cases will serve as a point of reference when evaluating the improvement potential (in Task 6) of various improvement options explored in Task 5. As most of the environmental impacts are expected to be caused by energy consumption during the use phase (as is the case for the plug-in walk-in cold room Base Case), the analysis of the improvement potential in Task 6 will primarily focus on technologies that reduce power consumption and improve energy efficiency, but will also consider refrigerant options due to the potential to decrease GWP.

ANNEXES

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4.14. SERVICE CABINETS

Table 4-69: Characteristics of the service cabinet Sub Base Cases

Product characteristics	Sub Base Case HT	Sub Base Case LT
Product type/model/design:	Vertical, 1-door	Vertical, 1-door
Location of condensing unit:	Integral (plug-in)	Integral (plug-in)
Climate class:	4	4
M-package temperature class:	M1	L1
Test standard:	EN 441	EN 441
Internal cold storage temperature [°C]:	+5°C	-18°C
Internal cold storage temperature range(s) (°C):	+2 to +12°C	-5 to -25°C
Air-on temperature (ambient temperature) [°C]:	+30°C	+30°C
Net internal volume [litres][110]:	450	450
Product use pattern [hours/year]:	8760	8760
Functional unit:	Litre of net volume at +5°C	Litre of net volume at -18°C
Power input [kW]:	0.315	N.A.
Cooling capacity [kW]:	0.35	N.A.
COP:	1.11	N.A.
AEC [kWh/year]:	2,000	5,000
TEC [kWh/48hrs]:	10.96	27.40
EEI [kWh/48hrs/ m3]:	24.35	60.88
Performance [kWh/litre net volume at storage temperature/year]:	4.44	11.11
Price (ex VAT) [€]:	1,000	1,100
Lifetime [years]:	8.5	8.5
Refrigerant:	R134a	R404A
Refrigerant charge [g]:	300	400
Refrigerant leakage [% per annum]:	1%	1%
Defrost type [natural/electric/hot gas/cool gas]:	Natural	Electric
Defrost control (if applicable) [timed/off-cycle/on-demand]:	Off-cycle	Off-cycle
Anti-condensation (if applicable):	None	None
Expansion valve type:	Capillary tube	Capillary tube
Other features not covered above:	-	-
Weight of product [kg]:	114	114

[110] Calculated according to EN 441 method.

Product characteristics	Sub Base Case HT	Sub Base Case LT
External height [m] :	2.06	2.06
External width [m] :	0.7	0.7
External depth [m] :	0.84	0.84
Gross total (shipping) volume [m3] :	1,211	1,211
Number of compressors:	1	1
Type of compressor:	Hermetic reciprocating	Hermetic reciprocating
Power of compressor [W]:	195	N.A.
Capacity of compressor [W]:	320	N.A.
Weight of compressor [kg]:	10	N.A.
Compressor motor control [none/two-speed/VSD]:	None	None
Evaporator heat exchanger type and material:	Fin and tube	Fin and tube
Evaporator face area [cm²]:	240	N.A.
Evaporator fan motor type:	Shaded pole axial	Shaded pole axial
Evaporator fan motor power [W]:	5	5
Evaporator fan motor control [none/two-speed/VSD]:	None	None
Weight of evaporator module [kg]:	1	1
Condenser cooling:	Air-cooled	Air-cooled
Condenser heat exchanger type and material:	Fin and tube	Fin and tube
Condenser face area [cm²]:	N.A.	N.A.
Condenser fan motor type:	Shaded pole axial	Shaded pole axial
Condenser fan motor power [W]:	10	N.A.
Condenser fan motor control [none/two-speed/VSD]:	None	None
Weight of condenser module [kg]:	1.5	N.A.
Number of doors:	1	1
Insulation type:	Polyurethane	Polyurethane
Insulation thickness [mm]:	60	60
Foaming agent:	Cyclo-Pentan / Isopentane	Cyclo-Pentan / Isopentane
Lighting type [incandescent/fluorescent/LED]:	Incendescent	Incendescent
Lighting power [W]:	20	20

4.15. BLAST CABINETS

Table 4-70: Characteristic of the blast cabinet Sub Base Case

Product characteristic	Sub-Base Case
Product type/model/design:	Vertical
Location of condensing unit:	Integrated
Capacity [kg]:	20
Maximum number of trays (GN 1/1):	5
Cooling cycle*:	chilling from +70°C to +3°C in 90 minutes
Electricity consumption [kWh/cycle]:	2
Product use pattern [cycles/year]:	2 cycles per day, 220 days per year
Condensing unit function [hours/day]:	3
Product use pattern [hours/year]:	660
Functional unit:	1 kg of foodstuff (referred to material proposed by NF AC D 40-003) chilling from +70°C to +3°C in 90 minutes
Power input [kW]:	1.2
Cooling capacity [kW]:	0.83
AEC [kWh/year]:	880
Performance [kWh/kg of foodstuff (referred to material proposed by NF AC D 40-003) chilling from +70°C to +3°C in 90 minutes/year]:	88
Performance [kWh/kg of foodstuff (referred to material proposed by NF AC D 40-003) freezing from +70°C to +3°C in 90 minutes/cycle]:	0.100
Price (ex VAT) [€]:	3,400
Lifetime [years]:	8.5
Refrigerant:	R404A
Refrigerant charge [kg]:	0.8
Refrigerant leakage [% per annum]:	5
Defrost type [natural/electric/hot gas/cool gas]:	not included
Defrost control (if applicable) [timed/off-cycle/on-demand]:	not included
Door frame heater wire:	not included
Defrost load [amps]:	-
Anti-condensation (if applicable):	not included
Expansion valve type:	Thermostatic expansion valve
Weight of product [kg]:	120
External height [cm]:	850
External width [cm]:	800
External depth [cm]:	700
Net volume [m³]:	52
Gross total (shipping) volume [m3] :	0.81
Shipping weight [kg]:	150
Number of compressors:	1
Type of compressor:	Hermetic reciprocating
Power of compressor [W]:	969
Capacity of compressor [W]:	813

Product characteristic	**Sub-Base Case**
Weight of compressor [kg]:	12.5
Compressor motor control [none/two-speed/VSD]:	*N.A.*
Evaporator heat exchanger type and material:	*Fined tube / aluminum copper*
Evaporator face area [cm²]:	*N.A.*
Evaporator fan motor type:	Axial
Evaporator fan motor power [W]:	160
Evaporator fan motor control [none/two-speed/VSD]:	*N.A.*
Weight of evaporator module [kg]:	*N.A.*
Condenser cooling:	Air-cooled
Condenser heat exchanger type and material:	*Fined tube / aluminum copper*
Condenser face area [cm²]:	*N.A.*
Condenser fan motor type:	Axial
Condenser fan motor power [W]:	60
Condenser fan motor control [none/two-speed/VSD]:	*N.A.*
Weight of condenser module [kg]:	2.5
Number of doors:	1
Door material :	Stainless steel
Insulation type:	Polyurethane
Insulation thickness [mm]:	55
Foaming agent:	Water
Other features:	Self closing door, evaporation temperature control with thermostat valve, inner door stop, temp. detector probe

**As commonly referred to in brochures. Only for comparison purposes*

4.16. WALK-IN COLD ROOMS

Table 4-71: Estimated characteristics of the walk-in cold room Base Case

Product characteristics	Weighted Base Case
Product type/model/design:	Factory-built
Location of condensing unit:	Packaged refrigeration unit
Test standard:	-
Internal cold storage temperature [°C]:	+2°C
Internal cold storage temperature range(s) (°C):	+1°C to +4°C
Air-on temperature (ambient temperature) [°C]:	+32°C
Net internal volume [m³]:	25
Condensing unit function [hours/day]:	16hrs to 18hrs condensing unit (on/off)
Product use pattern [hours/year]:	8,760
Functional unit:	m³ of net internal volume at +2°C
Power input [kW]:	2
Cooling capacity [kW]:	2.1
COP:	1.5
AEC* [kWh/year]:	10,570
TEC [kW/48hrs]:	58
Performance [kWh/m³ at +2°C/year]:	423
Price (ex VAT) [€]:	8,800
Lifetime [years]:	10
Refrigerant:	R404A
Refrigerant charge [g]:	2,400
Refrigerant leakage [% per annum]:	5
Defrost type [natural/electric/hot gas/cool gas]:	*N.A.*
Defrost control (if applicable) [timed/off-cycle/on-demand]:	*N.A.*
Anti-condensation (if applicable):	*N.A.*
Expansion valve type:	*N.A.*
Other features not covered above:	-
Weight of product [kg]:	1000
External height [cm] :	232
External width [cm] :	362
External depth [cm] :	342
Gross total (shipping) volume [m3] :	29
Number of compressors:	1
Type of compressor:	Hermetic reciprocating
Power of compressor [W]:	*N.A.*
Capacity of compressor [W]:	*N.A.*
Weight of compressor [kg]:	*N.A.*
Compressor motor control [none/two-speed/VSD]:	Not applicable
Evaporator heat exchanger type and material:	Fin and tube

Product characteristics	Weighted Base Case
Evaporator face area [cm²]:	*N.A.*
Evaporator fan motor type:	Shaded pole axial
Evaporator fan motor power [W]:	*N.A.*
Evaporator fan motor control [none/two-speed/VSD]:	None
Weight of evaporator module [kg]:	*N.A.*
Condenser cooling:	Air-cooled
Condenser heat exchanger type and material:	Fin and tube
Condenser face area [cm²]:	*N.A.*
Condenser fan motor type:	Shaded pole axial
Condenser fan motor power [W]:	*N.A.*
Condenser fan motor control [none/two-speed/VSD]:	None
Weight of condenser module [kg]:	*N.A.*
Number of doors:	1
Door type	Hinged; 800x1900mm
Strip door curtains	Included
Insulation type:	Polyurethane; cam-locked
Insulation thickness [mm]:	80
Foaming agent:	Cyclo-Pentan/Isopentane
Lighting type [incandescent/fluorescent/LED]:	Incendescent
Lighting power [W]:	80

**Due to no current measurement standard for walk-in cold rooms and no information provided on real electricity consumption, AEC for this 25m^3 chiller walk-in cold room is calculated from the weighted Base Case, assuming that the market proportion of chiller to freezer if 70% to 30%, and that a freezer of 25m^3 AEC would be 2 times that of a chiller room.*

4.17. PROCESS CHILLERS

Table 4-72: Characteristic of the packaged process chiller[111] Sub Base Cases

Product characteristics	Sub Base Case MT	Sub Base Case LT
Product type/model/design:	Packaged	Packaged
Location of condensing unit:	Integral (packaged)	Integral (packaged)
Evaporator output temperature [°C]:	-8	-18
Water on [°C]:	+25	+25
Air-on temperature (ambient temperature) [°C]:	30	30
Water solution [%]:	Ethylene glycol 35%	Ethylene glycol 35%
Condensing unit function [hours/day]:	12	12
Product use pattern [hours/year]:	4,380	4,380
Functional unit:	1 kW cooling capacity to reach -10°C at 30°C ambient temperature	1 kW cooling capacity to reach -25°C at 30°C ambient temperature
Power input [kW]:	98.8	128
Cooling capacity [kW]:	276.458	251.95
Performance [COP]*:	2.80	1.96
AEC [kWh/year]:	346,206	450,068
Price (ex VAT) [€]:	55,000	70,000
Lifetime [years]:	15	15
Refrigerant:	R134a	R404A
Refrigerant charge [g]:	100	250
Refrigerant leakage [% per annum]:	1	1
Weight of product [kg]:	2,757	3,171
External height [cm] :	188	188
External width [cm] :	86	86
External depth [cm] :	430.5	430.5
Gross total (shipping) volume [m3] :	11.6	13.34
Number of compressors:	2	2
Type of compressor:	Semi-hermetic screw	Semi-hermetic screw
Power of compressor [W]:	*N.A.*	*N.A.*
Capacity of compressor [W]:	*N.A.*	*N.A.*
Weight of compressor [kg]:	*N.A.*	*N.A.*
Compressor motor control [none/two-speed/VSD]:	Included	Included
VSD compressor motor control (if applicable):	Not included	Not included
Evaporator heat exchanger type and material:	Stainless steel	Stainless steel
Evaporator face area [cm²]:	*N.A.*	*N.A.*
Evaporator fan motor type:	*N.A.*	*N.A.*
Evaporator fan motor power [W]:	*N.A.*	*N.A.*
Evaporator fan motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*
Weight of evaporator module [kg]:	*N.A.*	*N.A.*
Condenser cooling:	Water-cooled	Water-cooled
Condenser heat exchanger type and material:	Shell-tube / stainless	Shell-tube / stainless

[111] eto.carrier.com/litterature/Prod_Cat/EN_30XA.pdf

Product characteristics	Sub Base Case MT	Sub Base Case LT
	steel	steel
Condenser face area [cm²]:	*N.A.*	*N.A.*
Condenser fan motor type:	*N.A.*	*N.A.*
Condenser fan motor power [W]:	*N.A.*	*N.A.*
Condenser fan motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*
Weight of condenser module [kg]:	*N.A.*	*N.A.*
Expansion valve type:	Thermostatic	Thermostatic

4.18. REMOTE CONDENSING UNITS

Table 4-73: Characteristics of the remote condensing unit Sub Base Cases

Product characteristics	Sub Base Case MT	Sub Base Case LT
Product type/model/design:	Packaged	Packaged
Test standard	EN 13215:2000	EN 13215:2000
Internal cold storage temperature [°C]:	-10	-35
Internal cold storage temperature range(s) (°C):	0	-25
Air-on temperature (ambient temperature) [°C]:	+32	+32
Product use pattern [hours/year]:	5,840	5,840
Functional unit:	1 kW of cooling capacity at evaporation temperature -10°C and ambient temperature +32°C	1 kW of cooling capacity at evaporation temperature -35°C and ambient temperature +32°C
Power input [kW]:	3.8	5.8
Cooling capacity [kW]:	7.2	5.8
Performance [COP]*:	1.9	1.0
AEC [kWh/year]:	19,068	30,418
Price [€]:	3,095	6,104
Product lifetime [years]	8	8
Refrigerant:	R404A	R404A
Refrigerant charge [kg]:	7	6
Refrigerant leakage [% per annum]:	15	15
Other features not covered above:	-	-
Weight of product [kg]:	117	203
External height [cm]:	90.5	143.1
External width [cm]:	140	124.4
External depth [cm]:	55	51
Gross total (shipping) volume [m^3]:	0.7	0.84
Number of compressors:	1	1
Type of compressor:	Reciprocating hermetic	Reciprocating hermetic
Compressor motor control [none/two-speed/VSD]:	None	None
Condenser cooling:	Air-cooled	Air-cooled
Condenser heat exchanger type and material:	steel	steel
Condenser face area [cm^2]:	*N.A.*	*N.A.*
Condenser fan motor type:	On/Off	On/Off
VSD condenser fan motor control (if applicable):	no	No
Condenser fan motor power [W]:	130	130

** COP: Coefficient of Performance defined as the cooling capacity (kW) divided by the energy power input (kW) to the compressor*

Table 4-74: Weighting factors for annual energy consumption of remote condensing units

Configuration	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor motor drive	Condenser cooling	Total market %	AEC and power input conversion factors	Average energy consumption per year (kWh)	Average COP
Packaged condensing unit with single compressor	Low temperature -35°C)	0.2-20 kW average: 5-7 kW	Hermetic reciprocating	On/off	Air	15.9%	Base Case LT	30,418	1.00
					Water	0.0%	5% energy savings over Base Case LT	30,418	1.00
				2 speeds	Air	0.9%	10% Energy savings over Base Case LT	27,376	1.00
					Water	0.0%	5% energy savings over air-cooled	27,376	1.00
				VSD	Air	0.3%	10% energy savings over Base Case LT	27,376	1.00
					Water	0.0%	5% energy savings over air-cooled	27,376	1.00
			Scroll	On/off	Air	0.9%	10% energy savings over Base Case LT	27,376	1.11
					Water	0.0%	5% energy savings over air-cooled	27,376	1.11
				2 speeds	Air	0.0%	10% Energy savings over on/off	26,007	1.11
					Water	0.0%	5% energy savings over air-cooled	26,007	1.11
				VSD	Air	0.0%	10% Energy savings over on/off	23,057	1.11
					Water	0.0%	5% energy savings over air-cooled	23,057	1.11
			Screw	On/off	Air	0.0%	10% savings over Base Case LT	27,376	1.11
					Water	0.0%	5% energy savings over air-cooled	27,376	1.11
				2 speeds	Air	0.0%	10% Energy savings over on/off	26,007	1.11
					Water	0.0%	5% energy savings over air-cooled	26,007	1.11
				VSD	Air	0.0%	10% Energy savings over on/off	24,639	1.11
					Water	0.0%	5% energy savings over air-cooled	24,639	1.11
			Rotary vane	On/off	Air	0.0%	10% energy savings over Base Case LT	27,376	1.11
					Water	0.0%	5% energy savings over air-cooled	27,376	1.11
				2 speeds	Air	0.0%	10% Energy savings over on/off	26,007	1.11
					Water	0.0%	5% energy savings over air-cooled	26,007	1.11
				VSD	Air	0.0%	10% Energy savings over on/off	24,639	1.11
					Water	0.0%	5% energy savings over air-cooled	24,639	1.11
		20-50 kW average: 20 kW	Hermetic reciprocating	On/off	Air	0.7%	Average power input given by stakeholders AEC calculated using same ratio AEC/PI as per Base Case LT	91,936	1.14
					Water	0.0%	5% energy savings over air-cooled	91,936	1.14
				2 speeds	Air	0.0%	10% Energy savings over on/off	87,339	1.14
					Water	0.0%	5% energy savings over air-cooled	87,339	1.14
				VSD	Air	0.0%	10% Energy savings over on/off	82,742	1.14
					Water	0.0%	5% energy savings over air-cooled	82,742	1.14
			Scroll	On/off	Air	0.0%	10% savings over Hermetic reciprocating	82,742	1.27
					Water	0.0%	5% energy savings over air-cooled	82,742	1.27
				2 speeds	Air	0.0%	10% Energy savings over on/off	78,605	1.27
					Water	0.0%	5% energy savings over air-cooled	78,605	1.27
				VSD	Air	0.0%	10% Energy savings over on/off	74,468	1.27
					Water	0.0%	5% energy savings over air-cooled	74,468	1.27
			Screw	On/off	Air	0.0%	10% savings over Hermetic reciprocating	82,742	1.27
					Water	0.0%	5% energy savings over air-cooled	82,742	1.27
				2 speeds	Air	0.0%	10% Energy savings over on/off	78,605	1.27
					Water	0.0%	5% energy savings over air-cooled	78,605	1.27

Configuration	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor motor drive	Condenser cooling	Total market %	AEC and power input conversion factors	Average energy consumption per year (kWh)	Average COP
				VSD	Air	0.0%	10% Energy savings over on/off	74,468	1.27
					Water	0.0%	5% energy savings over air-cooled	74,468	1.27
			Rotary vane	On/off	Air	0.0%	10% savings over Hermetic reciprocating	82,742	1.27
					Water	0.0%	5% energy savings over air-cooled	82,742	1.27
				2 speeds	Air	0.0%	10% Energy savings over on/off	78,605	1.27
					Water	0.0%	5% energy savings over air-cooled	78,605	1.27
				VSD	Air	0.0%	10% Energy savings over on/off	74,468	1.27
					Water	0.0%	5% energy savings over air-cooled	74,468	1.27
		>50 kW average: 50kW	Hermetic reciprocating	On/off	Air	0.2%	Average power input given by stakeholders. AEC calculated using same ratio AEC/PI as per Base Case LT	241,246	1.09
					Water	0.0%	5% energy savings over air-cooled	229,184	1.14
				2 speeds	Air	0.0%	10% Energy savings over on/off	229,184	1.09
					Water	0.0%	5% energy savings over air-cooled	217,725	1.14
				VSD	Air	0.0%	10% Energy savings over on/off	217,122	1.09
					Water	0.0%	5% energy savings over air-cooled	206,266	1.14
			Scroll	On/off	Air	0.0%	10% savings over Hermetic reciprocating	217,122	1.21
					Water	0.0%	5% energy savings over air-cooled	206,266	1.27
				2 speeds	Air	0.0%	10% Energy savings over on/off	206,266	1.21
					Water	0.0%	5% energy savings over air-cooled	195,952	1.27
				VSD	Air	0.0%	10% Energy savings over on/off	195,409	1.21
					Water	0.0%	5% energy savings over air-cooled	185,639	1.27
			Screw	On/off	Air	0.0%	10% savings over Hermetic reciprocating	217,122	1.21
					Water	0.0%	5% energy savings over air-cooled	206,266	1.27
				2 speeds	Air	0.0%	10% Energy savings over on/off	206,266	1.21
					Water	0.0%	5% energy savings over air-cooled	195,952	1.27
				VSD	Air	0.0%	10% Energy savings over on/off	195,409	1.21
					Water	0.0%	5% energy savings over air-cooled	185,639	1.27
			Rotary vane	On/off	Air	0.0%	10% savings over Hermetic reciprocating	217,122	1.21
					Water	0.0%	5% energy savings over air-cooled	206,266	1.27
				2 speeds	Air	0.0%	10% Energy savings over on/off	206,266	1.21
					Water	0.0%	5% energy savings over air-cooled	195,952	1.27
				VSD	Air	0.0%	10% Energy savings over on/off	195,409	1.21
					Water	0.0%	5% energy savings over air-cooled	185,639	1.27
	Medium temperature (-10°C)	0.2-20 kW average: 5-7 kW	Hermetic reciprocating	On/off	Air	50.9%	Base Case MT	19,068	1.89
					Water	0.0%	5% energy savings over air-cooled	18,115	1.89
				2 speeds	Air	2.7%	10% Energy savings over on/off	18,115	1.89
					Water	0.0%	5% energy savings over air-cooled	17,209	1.89
				VSD	Air	1.1%	10% Energy savings over on/off	17,161	1.89
					Water	0.0%	5% energy savings over air-cooled	16,303	1.89
			Scroll	On/off	Air	6.0%	10% savings over Hermetic reciprocating	17,161	2.11
					Water	0.0%	5% energy savings over air-cooled	16,303	2.11
				2 speeds	Air	0.0%	10% Energy savings over on/off	16,303	2.11
					Water	0.0%	5% energy savings over air-cooled	15,488	2.11
				VSD	Air	0.1%	10% Energy savings over on/off	14,526	2.12
					Water	0.0%	5% energy savings over air-	13,800	2.12

Configuration	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor motor drive	Condenser cooling	Total market %	AEC and power input conversion factors	Average energy consumption per year (kWh)	Average COP
							cooled		
			Screw	On/off	Air	0.0%	10% savings over Hermetic reciprocating	17,161	2.11
					Water	0.0%	5% energy savings over air-cooled	16,303	2.11
				2 speeds	Air	0.0%	10% Energy savings over on/off	16,303	2.11
					Water	0.0%	5% energy savings over air-cooled	15,488	2.11
				VSD	Air	0.0%	10% Energy savings over on/off	15,445	2.11
					Water	0.0%	5% energy savings over air-cooled	14,673	2.11
			Rotary vane	On/off	Air	0.0%	10% savings over Hermetic reciprocating	17,161	2.11
					Water	0.0%	5% energy savings over air-cooled	16,303	2.11
				2 speeds	Air	0.0%	10% Energy savings over on/off	16,303	2.11
					Water	0.0%	5% energy savings over air-cooled	15,488	2.11
				VSD	Air	0.0%	10% Energy savings over on/off	15,445	2.11
					Water	0.0%	5% energy savings over air-cooled	14,673	2.11
		20-50 kW average: 20 kW	Hermetic reciprocating	On/off	Air	9.5%	Average power input given by stakeholders AEC calculated using same ratio AEC/PI as per Base Case MT	60,215	1.67
					Water	0.0%	5% energy savings over air-cooled	57,204	1.67
				2 speeds	Air	0.5%	10% Energy savings over on/off	57,204	1.67
					Water	0.0%	5% energy savings over air-cooled	54,344	1.67
				VSD	Air	0.2%	10% Energy savings over on/off	54,193	1.67
					Water	0.0%	5% energy savings over air-cooled	51,484	1.67
			Scroll	On/off	Air	1.1%	10% savings over Hermetic reciprocating	54,193	1.85
					Water	0.0%	5% energy savings over air-cooled	51,484	1.85
				2 speeds	Air	0.0%	10% Energy savings over on/off	51,484	1.85
					Water	0.0%	5% energy savings over air-cooled	48,909	1.85
				VSD	Air	0.0%	10% Energy savings over on/off	48,774	1.85
					Water	0.0%	5% energy savings over air-cooled	46,335	1.85
			Screw	On/off	Air	0.0%	10% savings over Hermetic reciprocating	54,193	1.85
					Water	0.0%	5% energy savings over air-cooled	51,484	1.85
				2 speeds	Air	0.0%	10% Energy savings over on/off	51,484	1.85
					Water	0.0%	5% energy savings over air-cooled	48,909	1.85
				VSD	Air	0.0%	10% Energy savings over on/off	48,774	1.85
					Water	0.0%	5% energy savings over air-cooled	46,335	1.85
			Rotary vane	On/off	Air	0.0%	10% savings over Hermetic reciprocating	54,193	1.85
					Water	0.0%	5% energy savings over air-cooled	51,484	1.85
				2 speeds	Air	0.0%	10% Energy savings over on/off	51,484	1.85
					Water	0.0%	5% energy savings over air-cooled	48,909	1.85
				VSD	Air	0.0%	10% Energy savings over on/off	48,774	1.85
					Water	0.0%	5% energy savings over air-cooled	46,335	1.85
		>50 kW average: 50kW	Hermetic reciprocating	On/off	Air	3.0%	Average power input given by stakeholders AEC calculated using same ratio AEC/PI as per Base Case MT	136,587	1.84
					Water	0.2%	5% energy savings over air-cooled	129,758	1.93
				2 speeds	Air	0.2%	10% Energy savings over on/off	129,758	1.84
					Water	0.0%	5% energy savings over air-cooled	123,270	1.93
				VSD	Air	0.1%	10% Energy savings over on/off	122,928	1.84

Configuration	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor or motor drive	Condenser cooling	Total market %	AEC and power input conversion factors	Average energy consumption per year (kWh)	Average COP
					Water	0.0%	5% energy savings over air-cooled	116,782	1.93
			Scroll	On/off	Air	0.3%	10% savings over Hermetic reciprocating	122,928	2.04
					Water	0.0%	5% energy savings over air-cooled	116,782	2.15
				2 speeds	Air	0.0%	10% Energy savings over on/off	116,782	2.04
					Water	0.0%	5% energy savings over air-cooled	110,943	2.15
				VSD	Air	0.0%	10% Energy savings over on/off	110,636	2.04
					Water	0.0%	5% energy savings over air-cooled	105,104	2.15
			Screw	On/off	Air	0.0%	10% savings over Hermetic reciprocating	122,928	2.04
					Water	0.0%	5% energy savings over air-cooled	116,782	2.15
				2 speeds	Air	0.0%	10% Energy savings over on/off	116,782	2.04
					Water	0.0%	5% energy savings over air-cooled	110,943	2.15
				VSD	Air	0.0%	10% Energy savings over on/off	110,636	2.04
					Water	0.0%	5% energy savings over air-cooled	105,104	2.15
			Rotary vane	On/off	Air	0.0%	10% savings over Hermetic reciprocating	122,928	2.04
					Water	0.0%	5% energy savings over air-cooled	116,782	2.15
				2 speeds	Air	0.0%	10% Energy savings over on/off	116,782	2.04
					Water	0.0%	5% energy savings over air-cooled	110,943	2.15
				VSD	Air	0.0%	10% Energy savings over on/off	110,636	2.04
					Water	0.0%	5% energy savings over air-cooled	105,104	2.15
Packaged condensing unit with twin compressors or more	Low temperature (-35°C)	0.2-20 kW		-	-	0.0%	-		
		20-50 kW average: 20 kW	scroll	-	Air	0.8%	10% savings over single compressor	74,468	1.27
					Water	0.0%	5% energy savings over air-cooled	70,745	1.27
			screw	-	Air	0.0%	10% savings over Hermetic reciprocating	74,468	1.27
					Water	0.0%	5% energy savings over air-cooled	70,745	1.27
		>50 kW average: 50kW	scroll	-	Air	0.2%	10% savings over single compressor	195,409	1.21
					Water	0.0%	5% energy savings over air-cooled	185,639	1.27
			screw	-	Air	0.0%	10% savings over Hermetic reciprocating	195,409	1.21
					Water	0.0%	5% energy savings over air-cooled	185,639	1.27
	Medium temperature (-10°C)	0.2-20 kW		-	-	0.0%	-		
		20-50 kW average: 20 kW	scroll	-	Air	3.0%	10% savings over single compressor	48,774	1.85
					Water	0.0%	5% energy savings over air-cooled	46,335	1.85
			screw	-	Air	0.0%	10% savings over Hermetic reciprocating	48,774	1.85
					Water	0.0%	5% energy savings over air-cooled	46,335	1.85
		>50 kW average: 50kW	scroll	-	Air	0.9%	10% savings over single compressor	110,636	2.04
					Water	0.0%	5% energy savings over air-cooled	105,104	2.15
			screw	-	Air	0.1%	10% savings over Hermetic reciprocating	110,636	2.04
					Water	0.0%	5% energy savings over air-cooled	105,104	2.15

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ANNEX 4-2: Component material proportions

Compressor

Typical compressors used in the majority of refrigeration and freezing equipment are reciprocating hermetic compressors and present the following characteristics: a 0.3 – 0.7 kW cooling capacity (at an evaporating temperature of -10 °C, measured with EN 12900, condensing temperature of +55 °C) and a weight between 10-14 kg.

The approximated material composition of this type of compressors was estimated together with compressor manufacturers during the Lot 12 study. The data collected was then averaged and showed the following distribution of materials for a 10 kg compressor (Table 4-75).

Table 4-75: Material composition of a typical hermetic piston compressor

Materials	Weight in g	Category	Material
Compression Module			
cast iron of the compressor casing	2100	3-Ferro	**23-Cast iron**
steel of the compressor	2850	3-Ferro	**21-St sheet galv.**
steel for motor lamination	3850	3-Ferro	**24-Ferrite**
aluminium	190	4-Non-ferro	**26-Al sheet/extrusion**
rubber	10	1-BlkPlastics	**4-PP**
epoxy	10	2-TecPlastics	**14-Epoxy**
ester oil	250	7-Misc.	
polypropylene	10	1-BlkPlastics	**4-PP**
copper	700	4-Non-ferro	**28-Cu winding wire**
PET	30	1-BlkPlastics	**2-HDPE**
TOTAL	**10000**		

Heat exchangers

The following material composition for evaporator and the condenser was identified during the Lot 12 study. The same assumptions were used here if data was not given by the manufacturer.

Table 4-76: Material composition of the heat exchangers

Materials	Weight in %	Category	Material
Evaporator			
Aluminium fins	2/3 mass	4-Non-ferro	**26-Al sheet/extrusion**
Suction line	1/3 mass	4-Non-ferro	**30-Cu tube/sheet**
Condenser			
Suction line	1/2 mass	4-Non-ferro	**30-Cu tube/sheet**
Aluminium fins	1/4 mass	4-Non-ferro	**26-Al sheet/extrusion**
Steel	1/4 mass	3-Ferro	**22-St tube/profile**

- **Fans and fan motors**

For the evaporator and condenser fans' motors, the identified components show the following characteristics: the overall weight of the fan module is 621.1 g (around 500 g for the motor with power input of 18 W). The fan is made with an aluminium blade and is connected to a shaded pole motor. The material composition is presented in Table 4-77. It mostly comprises steel, plastics and copper. In some cabinets, the blade of the evaporator fans can also be made of plastic. However the typical fan was identified as fitted with aluminium blades.

Table 4-77: Material composition of a typical fan and fan motor

Materials	Weight in g	Category	Material
Fan blade			
Aluminium	100.0	4-Non-ferro	26-Al sheet/extrusion
Fan motor			
Steel	235.3	3-Ferro	21-St sheet galv.
Iron	36.0	3-Ferro	24-Ferrite
Copper	117.3	4-Non-ferro	28-Cu winding wire
PA	125.5	2-TecPlastics	11-PA 6
Electronics	7.0	6-Electronics	98-controller board
TOTAL	**621.1**		

ANNEX 4-3: Service cabinets – EcoReport results and detailed BOM

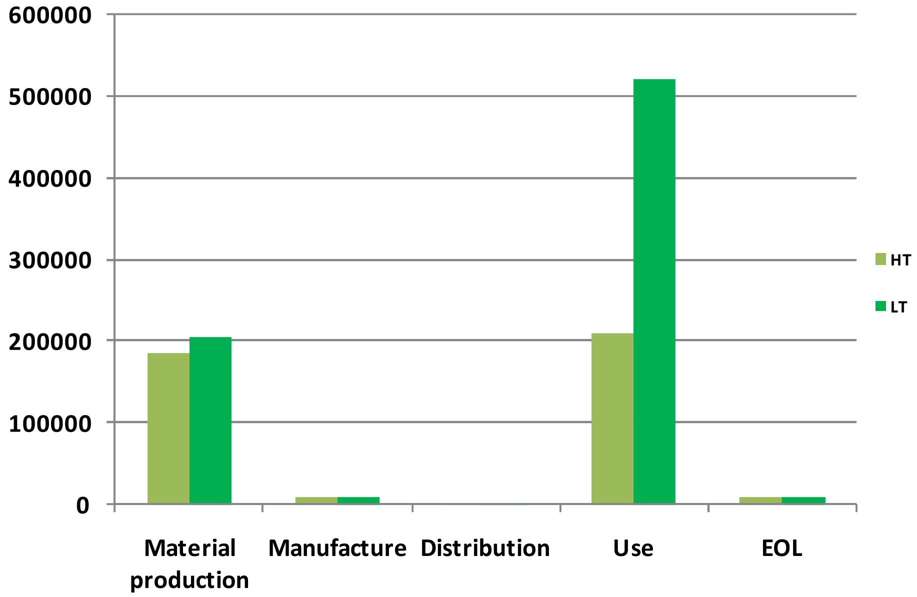

Figure 4-56: Waste (non-hazardous) related to each phase of the life cycle of service cabinet (g)

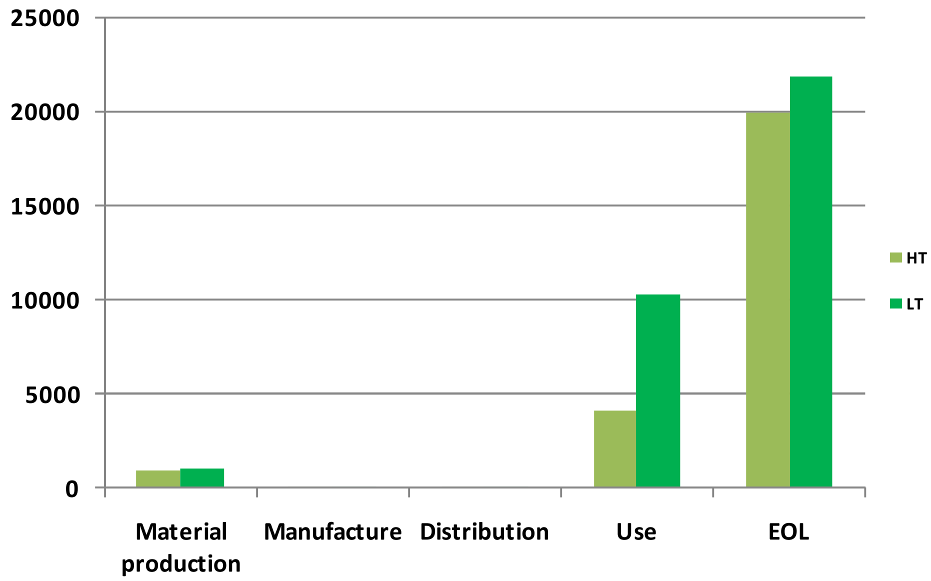

Figure 4-57: Waste (hazardous) related to each phase of the life cycle of service cabinet (g)

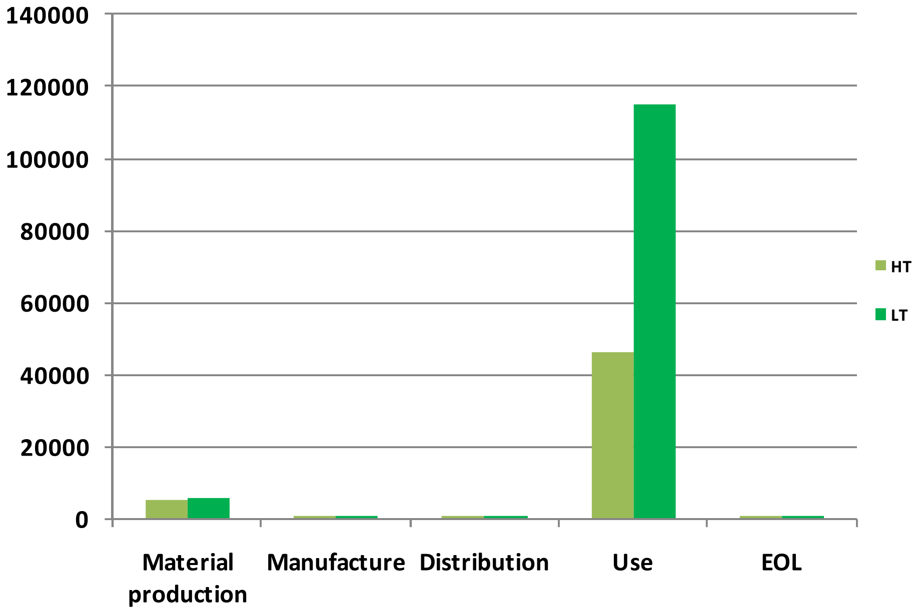

Figure 4-58: Acidification related to each phase of the life cycle of service cabinet (gSO2 eq.)

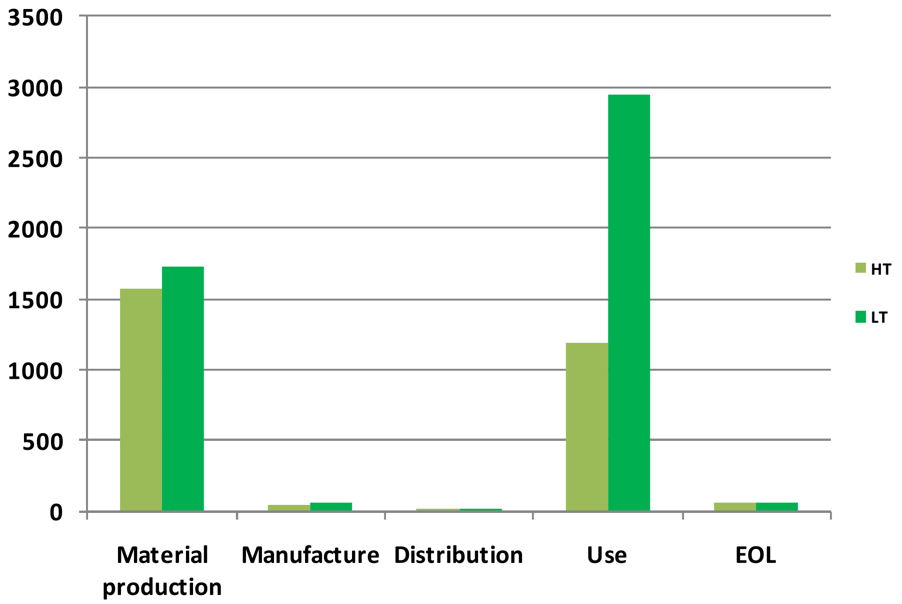

Figure 4-59: POPs related to each phase of the life cycle of service cabinet (ng i-Teq)

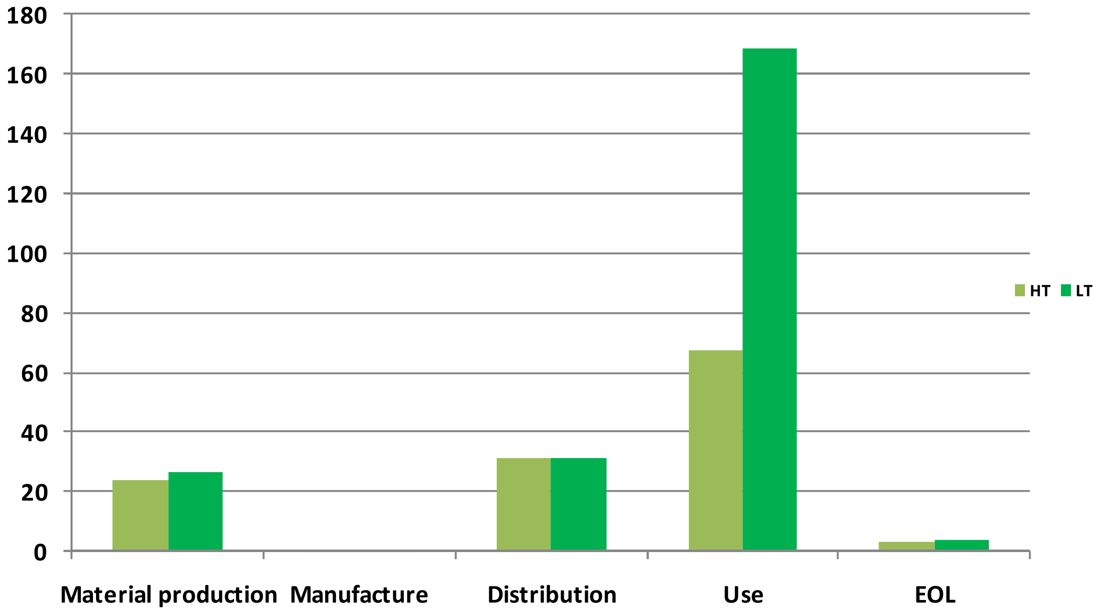

Figure 4-60: VOCs related to each phase of the life cycle of service cabinet (g)

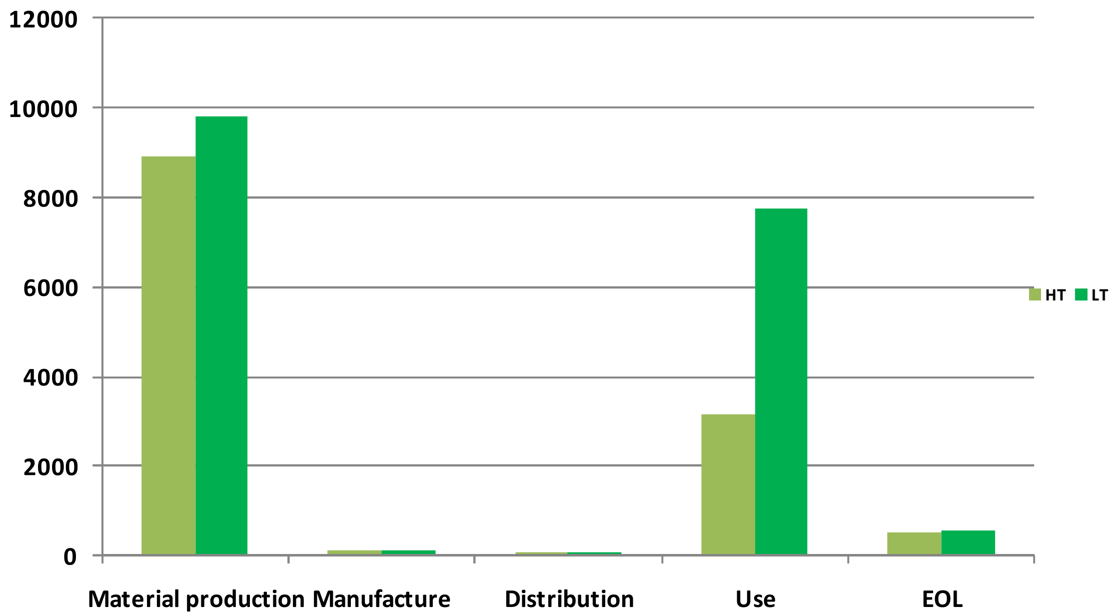

Figure 4-61: Heavy metals related to each phase of the life cycle of service cabinet (mgNi eq.)

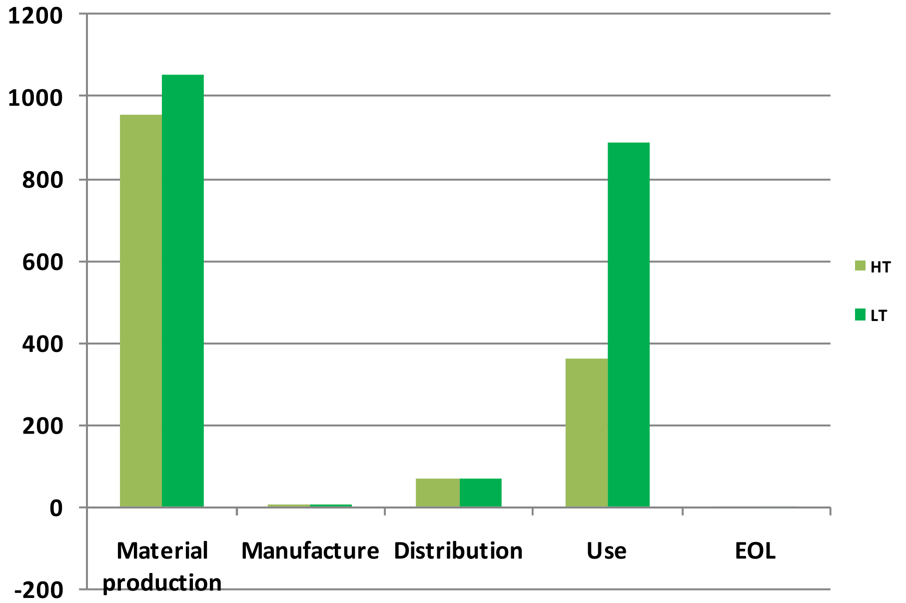

Figure 4-62: PAHs related to each phase of the life cycle of service cabinet (mgNi eq.)

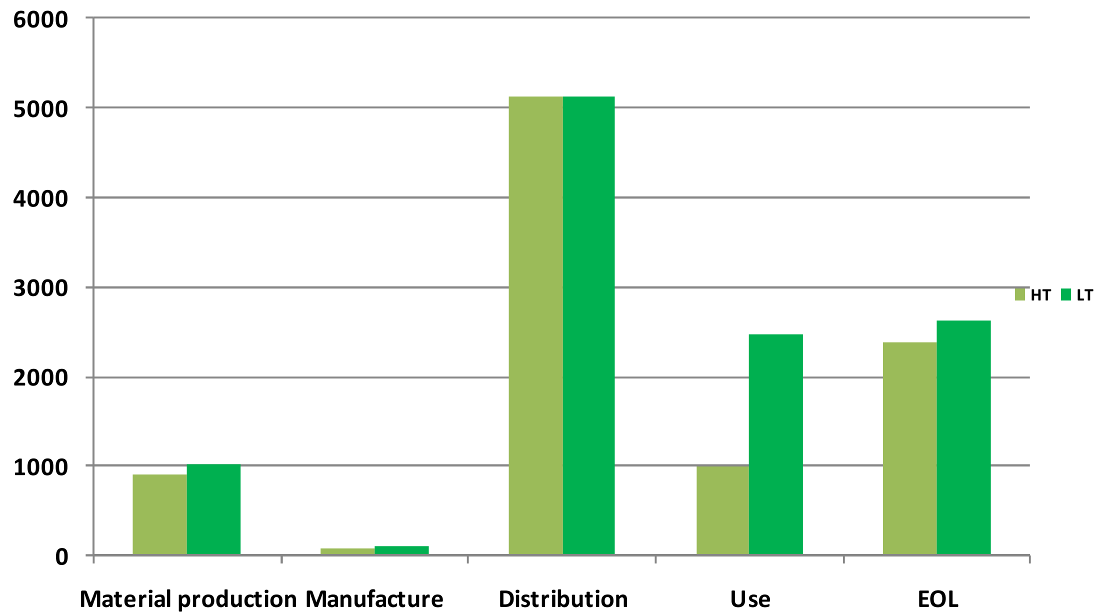

Figure 4-63: PMs related to each phase of the life cycle of service cabinet (g)

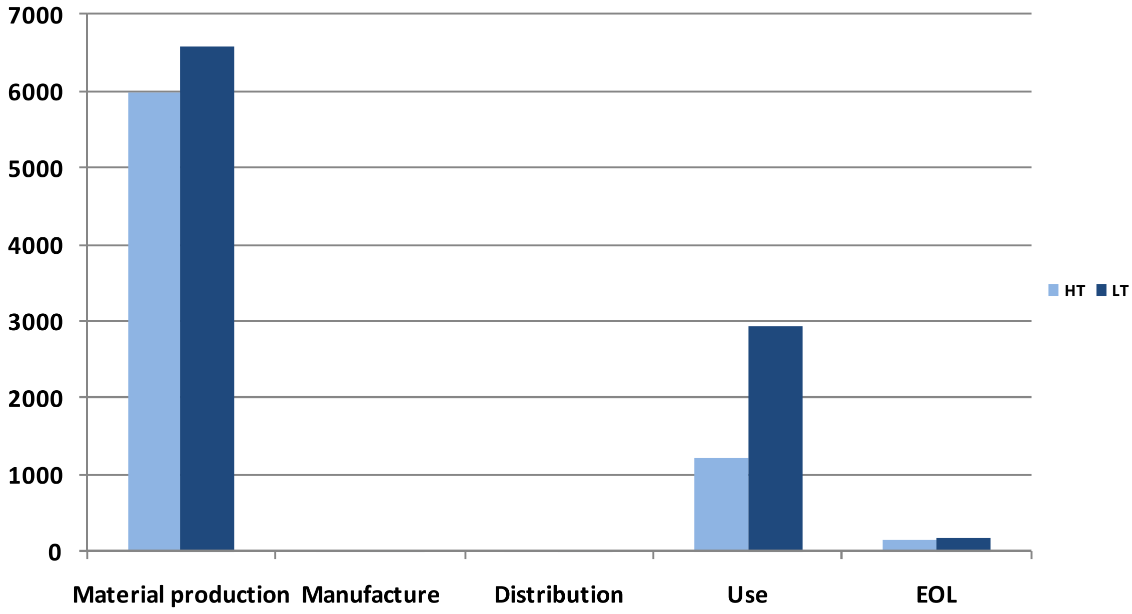

Figure 4-64: Heavy metals (water) related to each phase of the life cycle of service cabinet (mg Hg/20)

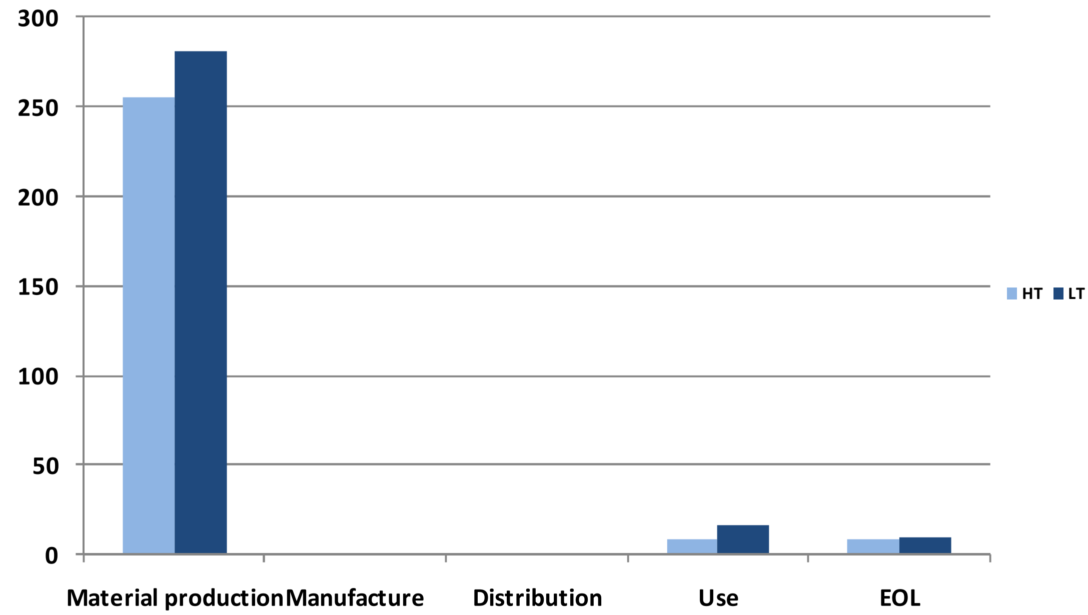

Figure 4-65: Eutrophication related to each phase of the life cycle of service cabinet (g PO_4)

Table 4-78: Materials inputs in the EcoReport tool for service cabinets

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
1	Housing			
2	**Insulated casing**			
3	**External housing**			
4	panels pre coating (external panels)	15883	5-Coating	**38-pre-coating coil**
5	chassis (cabinet structure)	6507	3-Ferro	**21-St sheet galv.**
6	mounting internal components	4352	3-Ferro	**21-St sheet galv.**
7	inner cabinet lining	8820	1-BlkPlastics	**7-HI-PS**
8	lateral motor space	1116	1-BlkPlastics	**4-PP**
9	adhesive expanded	437	2-TecPlastics	**16-Flex PUR**
10	EPS parts	447	1-BlkPlastics	**6-EPS**
11	PVC parts	231	1-BlkPlastics	**8-PVC**
12	fan housing	182	1-BlkPlastics	**7-HI-PS**
13	back grid (condenser)	1192	3-Ferro	**22-St tube/profile**
14	front grid	230	1-BlkPlastics	**7-HI-PS**
15	top panel cover	361	1-BlkPlastics	**10-ABS**
16	PC parts (insert)	48	2-TecPlastics	**12-PC**
17	plastic ring	2	1-BlkPlastics	**1-LDPE**
18	nylon parts	22	2-TecPlastics	**11-PA 6**
19	**Foam insulation**			
20	polyurethane	9920	2-TecPlastics	**15-Rigid PUR**
21	**Shelves & Grids**			
22	shelves	8500	3-Ferro	**22-St tube/profile**
23	**Door**			
24	steel sheet	7345	5-Coating	**38-pre-coating coil**
25	support frame	4140	3-Ferro	**22-St tube/profile**
26	handle and plastic cover	505	1-BlkPlastics	**10-ABS**
27	plastics (frame)	165	1-BlkPlastics	**8-PVC**
28	polyurethane	2790	2-TecPlastics	**15-Rigid PUR**
29	gasket	690	1-BlkPlastics	**8-PVC**
30	spring	120	4-Non-ferro	**32-ZnAl4 cast**
31	plastic sheet	2975	7-Misc.	
32	plastics parts	12	2-TecPlastics	**11-PA 6**
33	**Components for assembling**			
34	screws, etc.	255	3-Ferro	**23-Cast iron**
35	sealing mastic	570	7-Misc.	
Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
42	Evaporation module			
43	**Evaporator**			
44	roll bond	1685	4-Non-ferro	**26-Al sheet/extrusion**

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !
45	brackets	25	1-BlkPlastics	**10-ABS**
46	copper high pressure line	80	4-Non-ferro	**30-Cu tube/sheet**
47	**Evaporator fans**			
48	**Frame**			
49	iron	244	3-Ferro	**25-Stainless 18/8 coil**
50	**Blades**			
51	fan blades	80	4-Non-ferro	**26-Al sheet/extrusion**
52	**Evaporator fans motors**			
53	aluminium	75	4-Non-ferro	**27-Al diecast**
54	iron	488	3-Ferro	**24-Ferrite**
55	copper	150	4-Non-ferro	**28-Cu winding wire**
56	PVC parts	38	1-BlkPlastics	**8-PVC**
57	**Evaporation tray**			
58	drip tray	109	1-BlkPlastics	**4-PP**
59	PVC pipe	20	1-BlkPlastics	**8-PVC**
60	Compression module			
61	**Compressor**			
62	cast iron of the compressor casing	3880	3-Ferro	**23-Cast iron**
63	steel	8110	3-Ferro	**24-Ferrite**
64	aluminium	270	4-Non-ferro	**27-Al diecast**
65	rubber	15	1-BlkPlastics	**4-PP**
66	ester oil	410	7-Misc.	
67	copper	960	4-Non-ferro	**28-Cu winding wire**
68	polyptropylen	15	1-BlkPlastics	**4-PP**
69	PET	40	1-BlkPlastics	**2-HDPE**
70	Condensation module			
71	**Condenser**			
72	steel	1905	3-Ferro	**22-St tube/profile**
73	brackets	18	2-TecPlastics	**11-PA 6**
74	**Condenser fans**			
75	**Frame**			
76	iron	194	3-Ferro	**24-Ferrite**
77	**Blades**			
78	fan blades	80	4-Non-ferro	**26-Al sheet/extrusion**
79	**Condenser fans motors**			
80	aluminium	75	4-Non-ferro	**27-Al diecast**
81	iron	488	3-Ferro	**24-Ferrite**
82	copper	150	4-Non-ferro	**28-Cu winding wire**
83	PVC parts	38	1-BlkPlastics	**8-PVC**
84	Expansion valve module			
85	capillary tube	22	4-Non-ferro	**30-Cu tube/sheet**
Pos	MATERIALS Extraction & Production	Weight	Category	Material or Process

Pos	MATERIALS Extraction & Production	Weight	Category	Material or Process
nr	Description of component	in g	Click &select	select Category first !
nr	Description of component	in g	Click &select	select Category first !
89	Electric assembly (not included in other modules)			
90	**Electric panel**			
91	electrical box	40	1-BlkPlastics	**10-ABS**
92	**Cables**			
93	cables plastic parts	360	1-BlkPlastics	**8-PVC**
94	cables metal parts	330	4-Non-ferro	**29-Cu wire**
95	terminal (plug)	30	6-Electronics	**45-slots / ext. ports**
96	Packaging			
97	**Manuals**			
98	general instructions	67	7-Misc.	**57-Office paper**
99	plastics (LDPE)	7	1-BlkPlastics	**1-LDPE**
100	**Protection**			
101	pallet (wood)	6000	7-Misc.	
102	plastics (film)	400	1-BlkPlastics	**1-LDPE**
103	EPS parts	1435	1-BlkPlastics	**6-EPS**
104	PVC parts	25	1-BlkPlastics	**8-PVC**
105	Miscellaneous			
106	**Temperature control and display system**			
107	set thermostat	55	3-Ferro	**24-Ferrite**
108	set thermostat	15	2-TecPlastics	**12-PC**
109	LCD screen	30	6-Electronics	**42-LCD per m2 scrn**
110	**Pipes in the refrigeration system**			
111	copper tubes	57	4-Non-ferro	**30-Cu tube/sheet**
112	**Others**			
113	drain pipes	6	1-BlkPlastics	**7-HI-PS**
114	knitting alloy	9	4-Non-ferro	**29-Cu wire**
115	lock	65	3-Ferro	**24-Ferrite**

ANNEX 4-4: Blast cabinets – EcoReport results

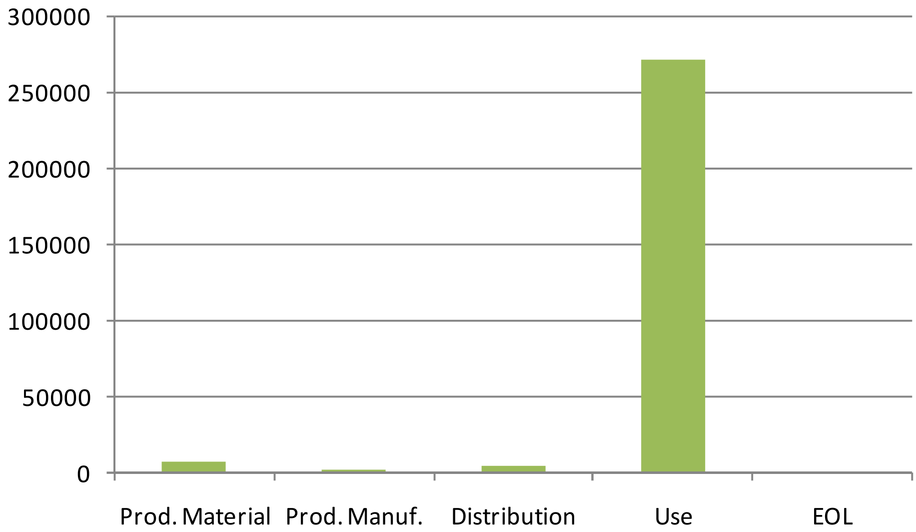

Figure 4-66: GER related to each phase of the life cycle of blast cabinet (MJ)

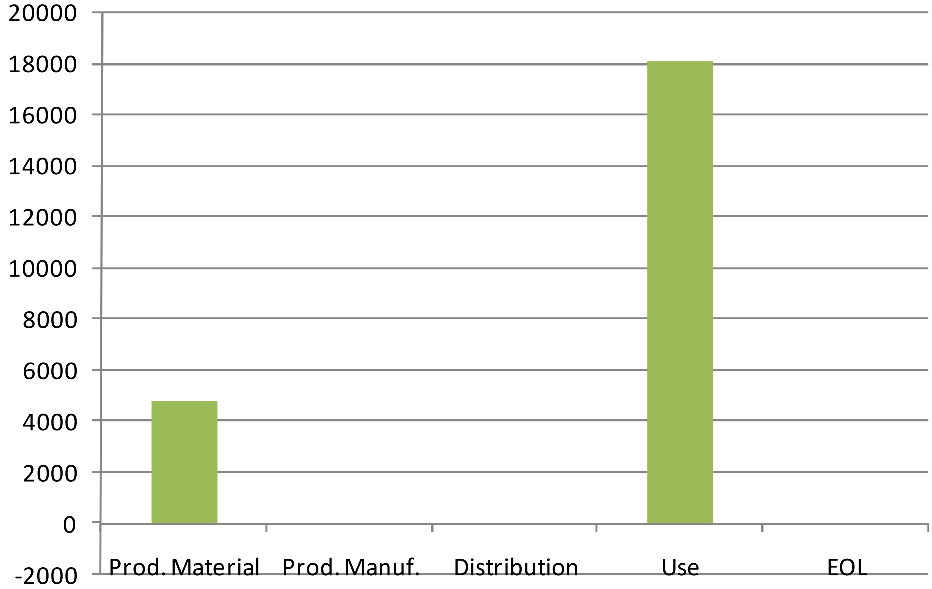

Figure 4-67: Process water related to each phase of the life cycle of blast cabinet (ltr)

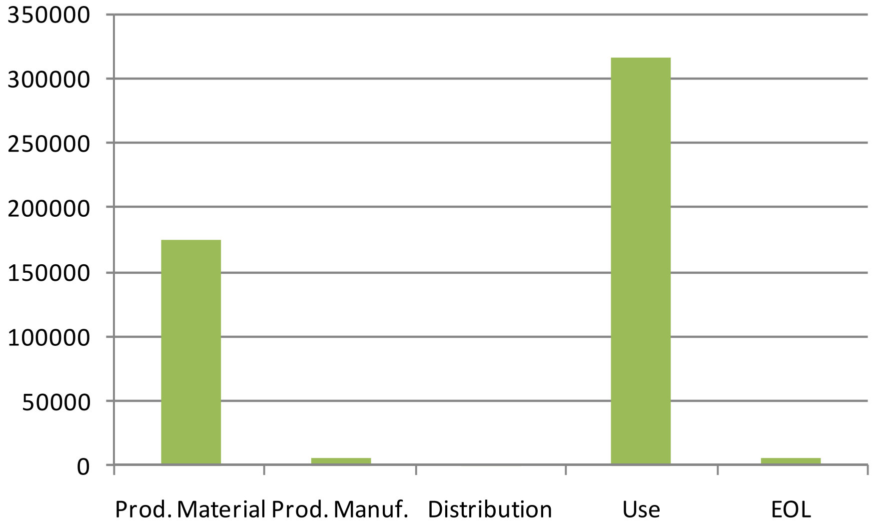

Figure 4-68: Waste (non-hazardous) related to each phase of the life cycle of blast cabinet (g)

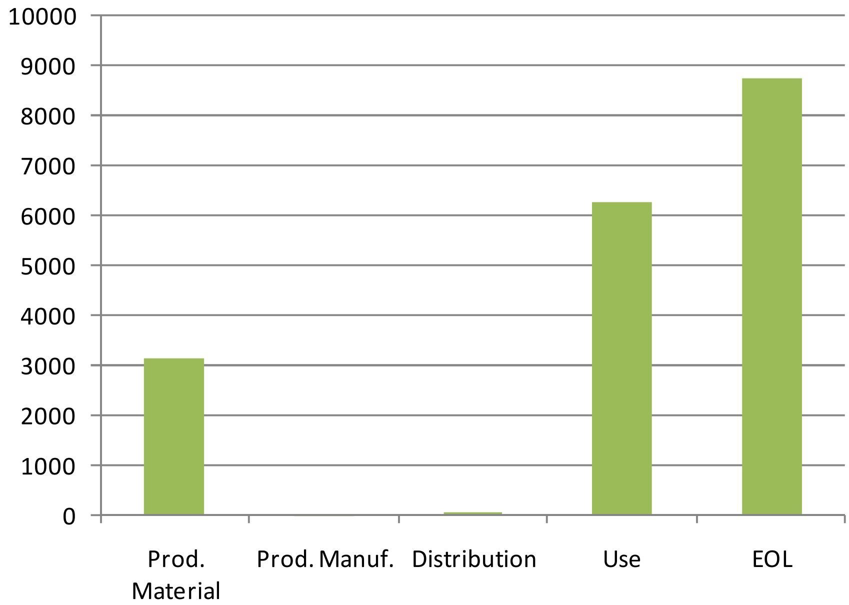

Figure 4-69: Waste (hazardous) related to each phase of the life cycle of blast cabinet (g)

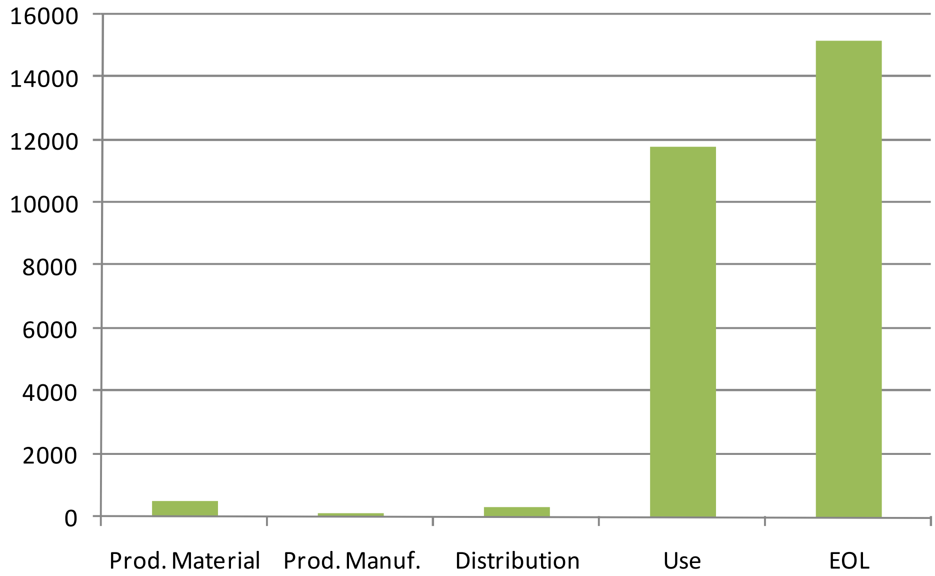

Figure 4-70: GWP related to each phase of the life cycle of blast cabinet (kg CO2 eq.)

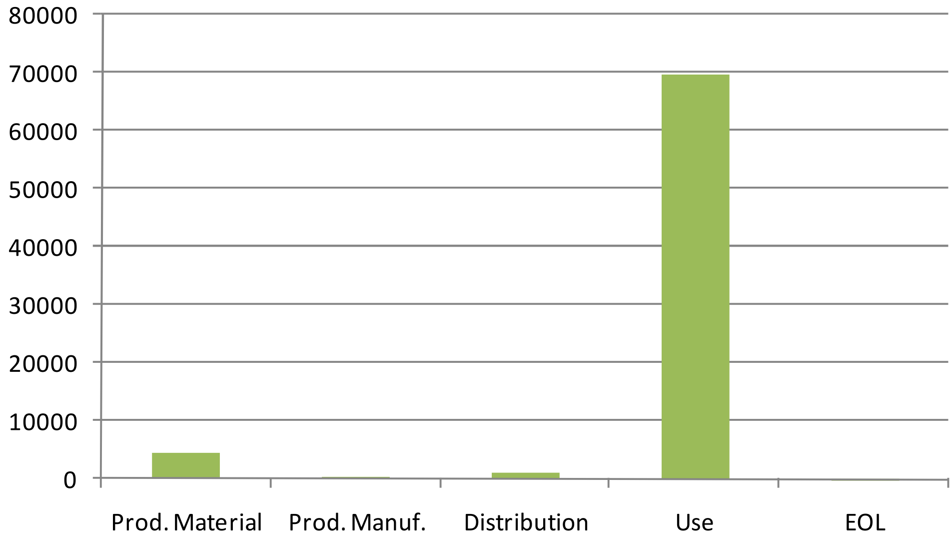

Figure 4-71: Acidification related to each phase of the life cycle of blast cabinet (gSO2 eq.)

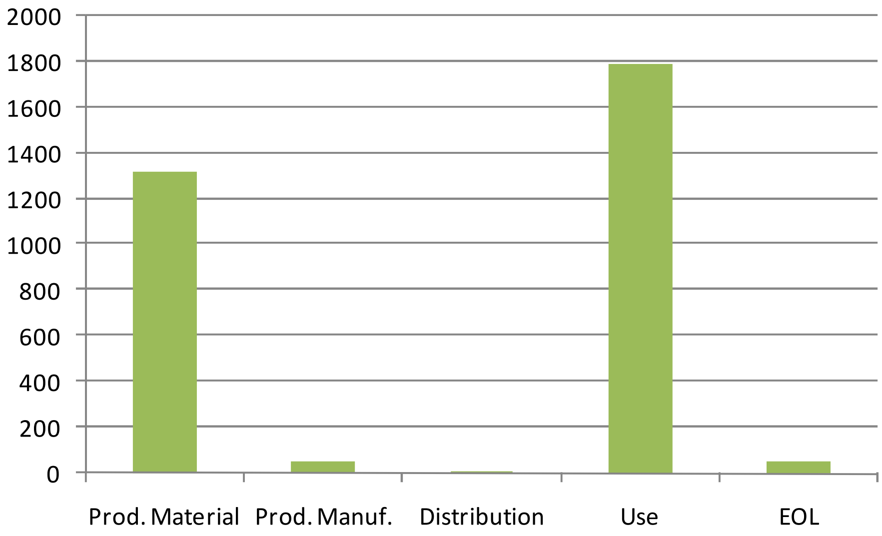

Figure 4-72: POPs related to each phase of the life cycle of blast cabinet (ng i-Teq)

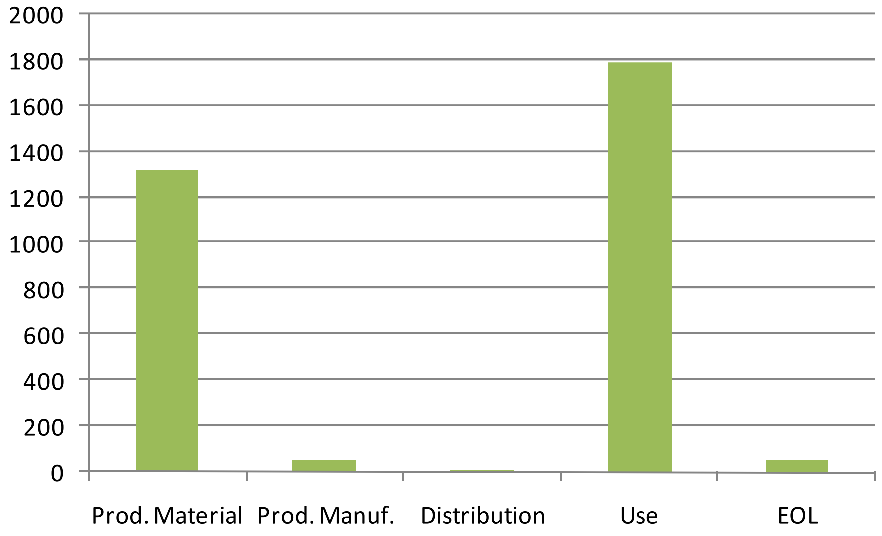

Figure 4-73: VOCs related to each phase of the life cycle of blast cabinet (g)

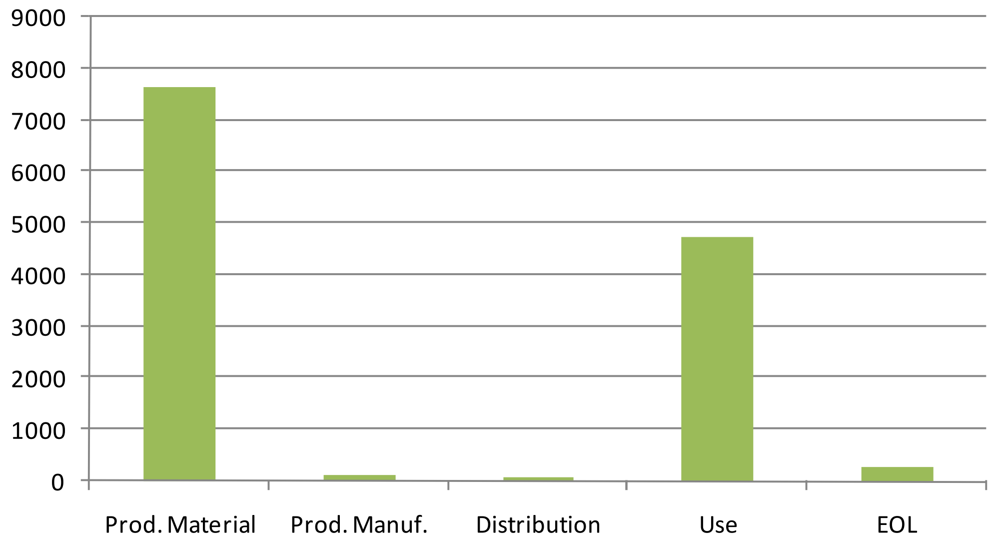

Figure 4-74: Heavy metals to air related to each phase of the life cycle of blast cabinet (mgNi eq.)

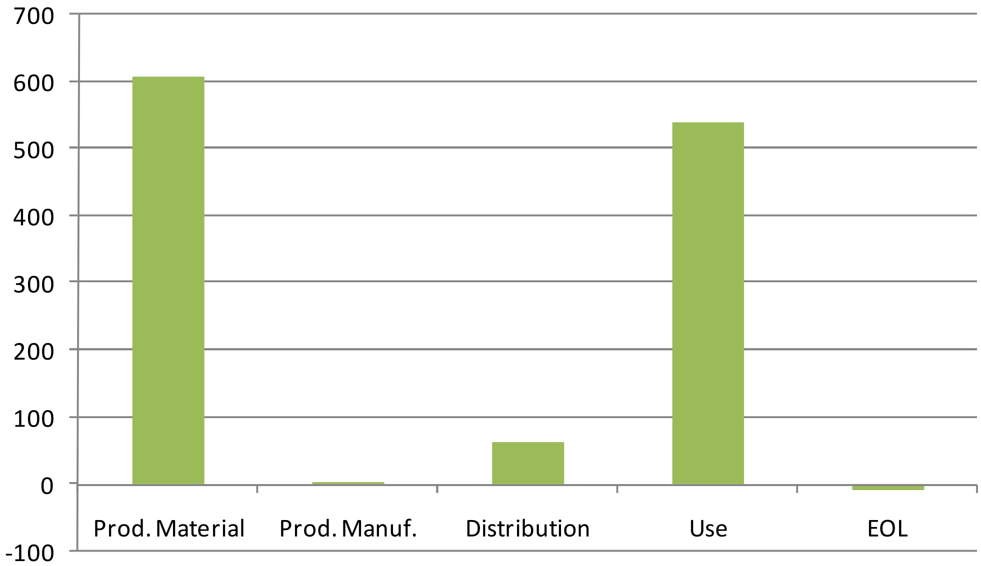

Figure 4-75: PAHs related to each phase of the life cycle of blast cabinet (mgNi eq.)

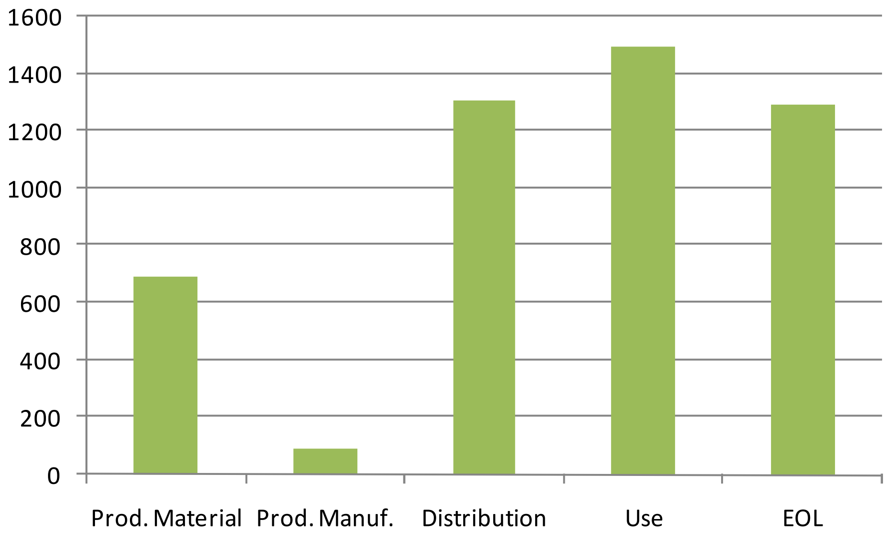

Figure 4-76: PMs related to each phase of the life cycle of blast cabinet (g)

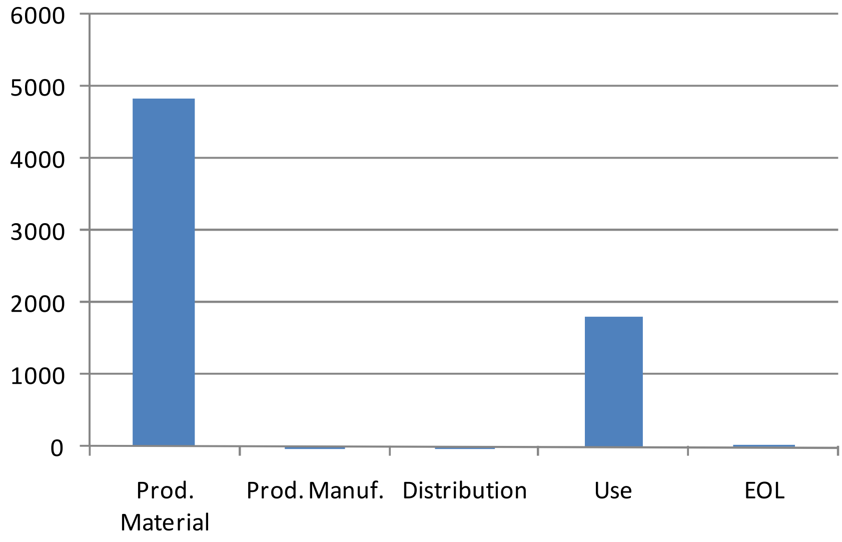

Figure 4-77: Heavy metals (water) related to each phase of the life cycle of blast cabinet (mg Hg/20)

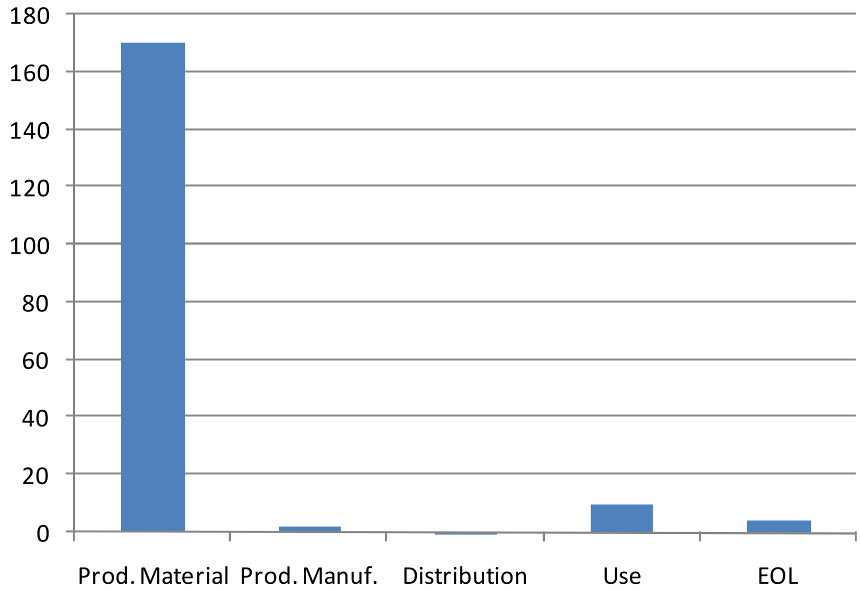

Figure 4-78: Eutrophication related to each phase of the life cycle of blast cabinet (g PO4)

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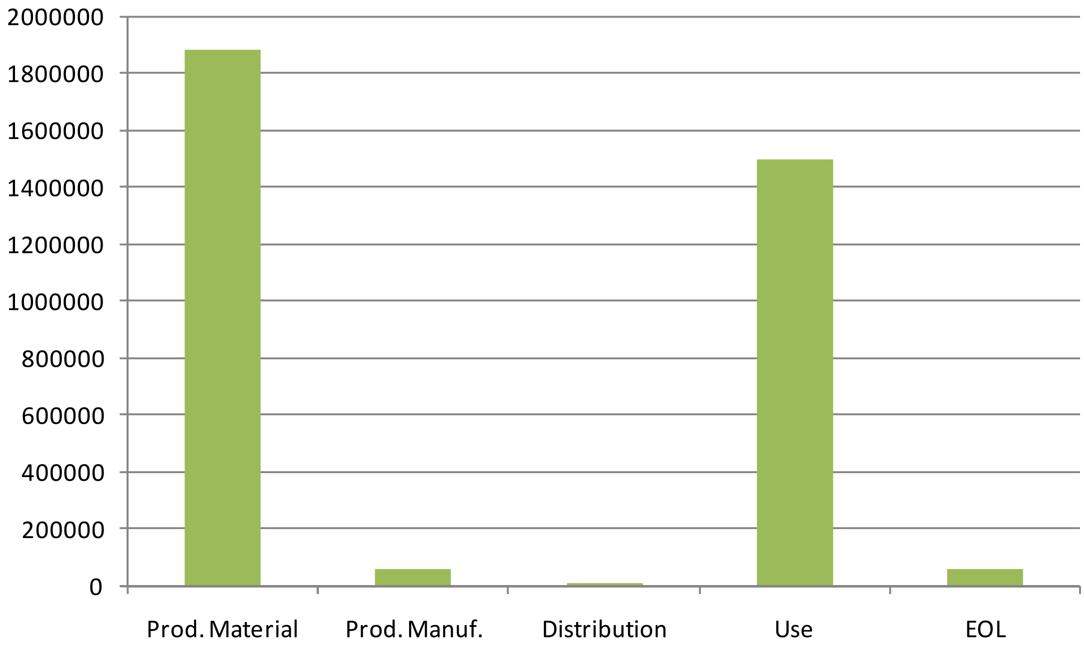

Figure 4-79: Waste (non-hazardous) related to each phase of the life cycle of walk-in cold room (g)

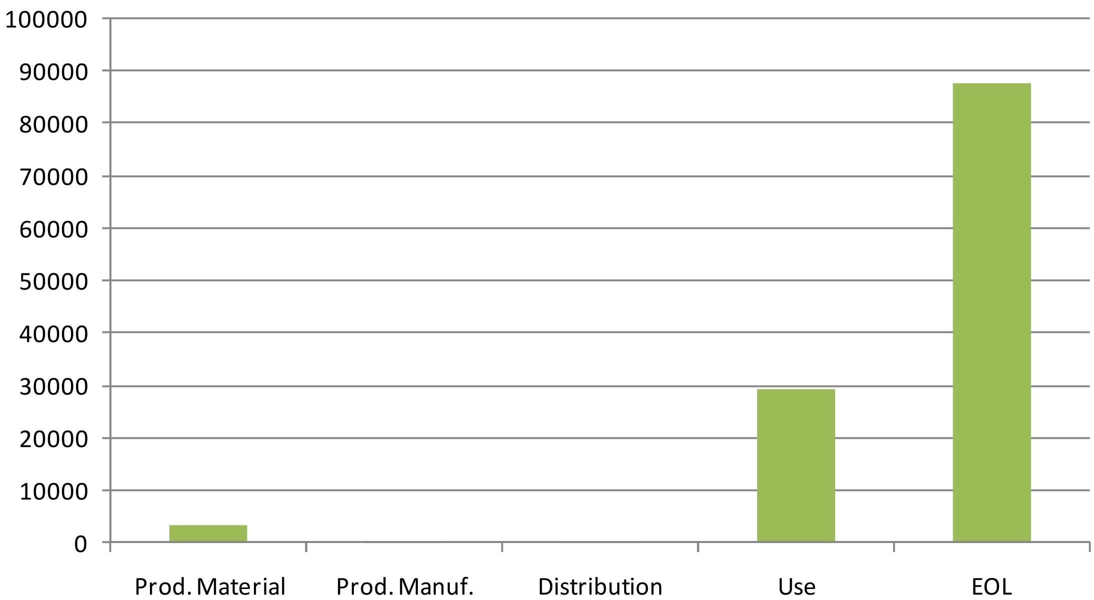

Figure 4-80: Waste (hazardous) related to each phase of the life cycle of walk-in cold room (g)

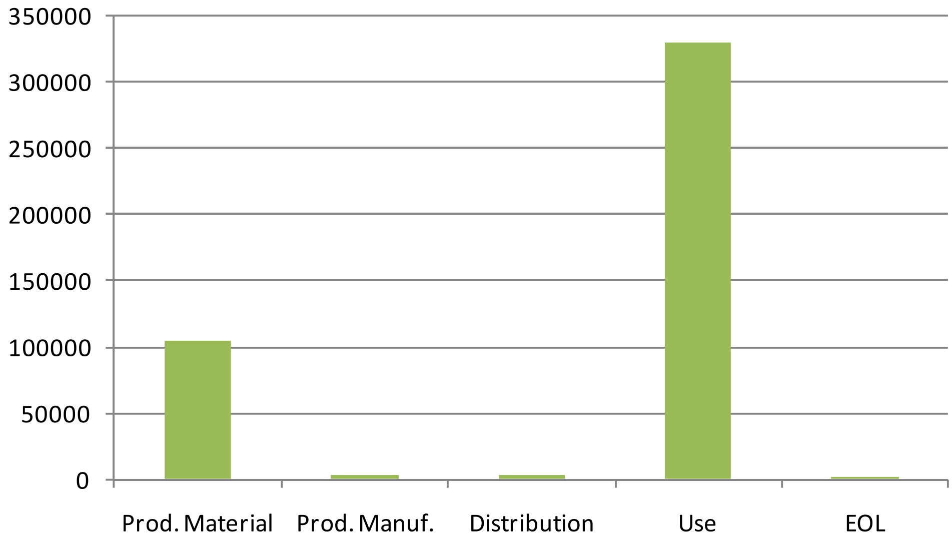

Figure 4-81: Acidification related to each phase of the life cycle of walk-in cold room (gSO2 eq.)

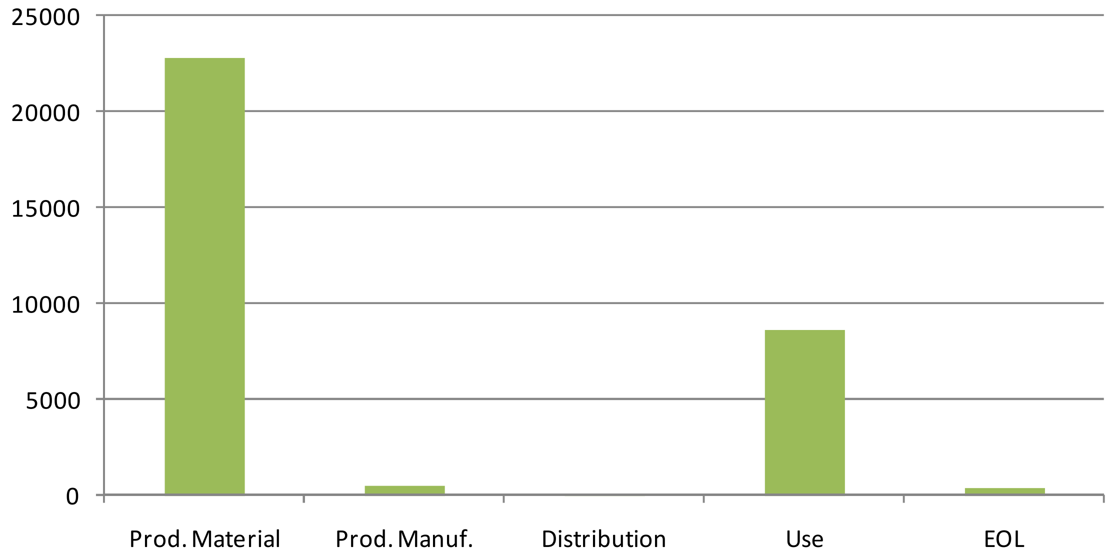

Figure 4-82: POPs related to each phase of the life cycle of walk-in cold room (ng i-Teq)

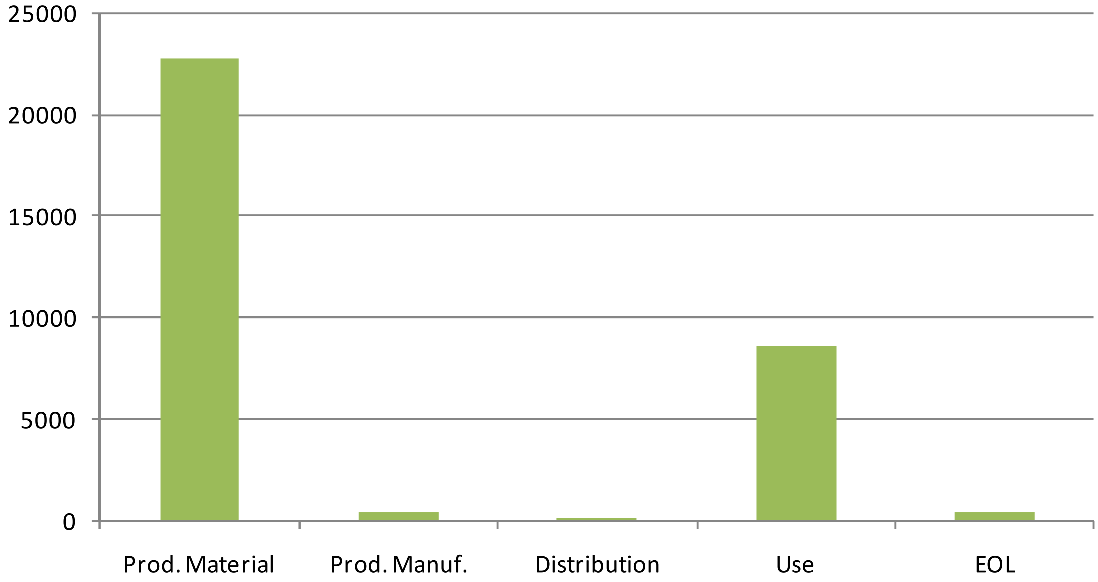

Figure 4-83: VOCs related to each phase of the life cycle of walk-in cold room (g)

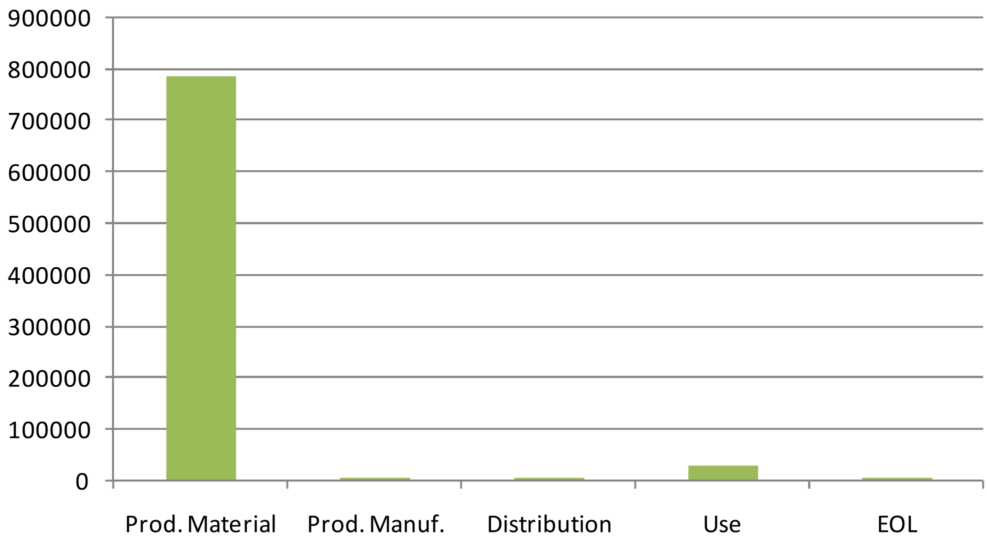

Figure 4-84: Heavy metals related to each phase of the life cycle of walk-in cold room (mgNi eq.)

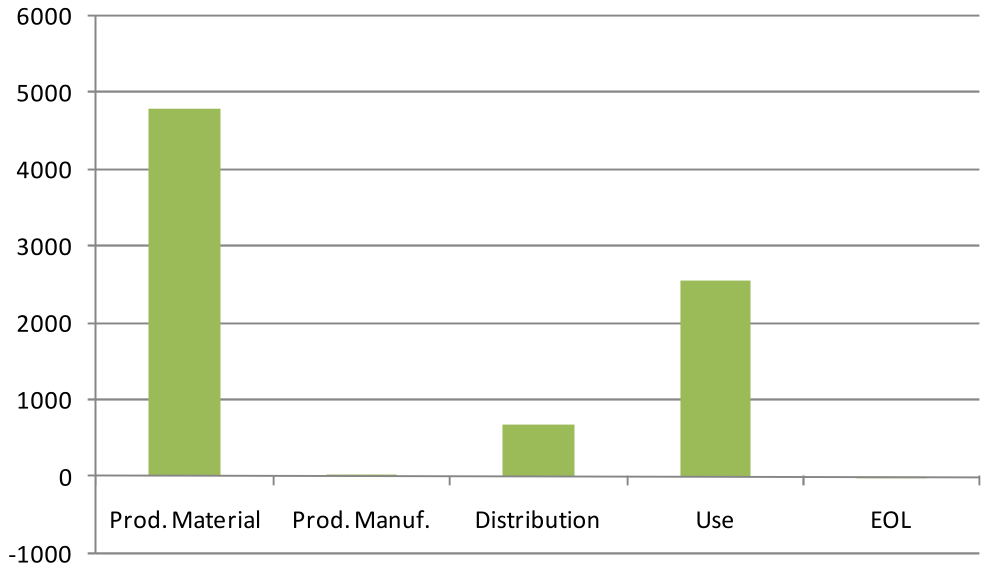

Figure 4-85: PAHs related to each phase of the life cycle of walk-in cold room (mgNi eq.)

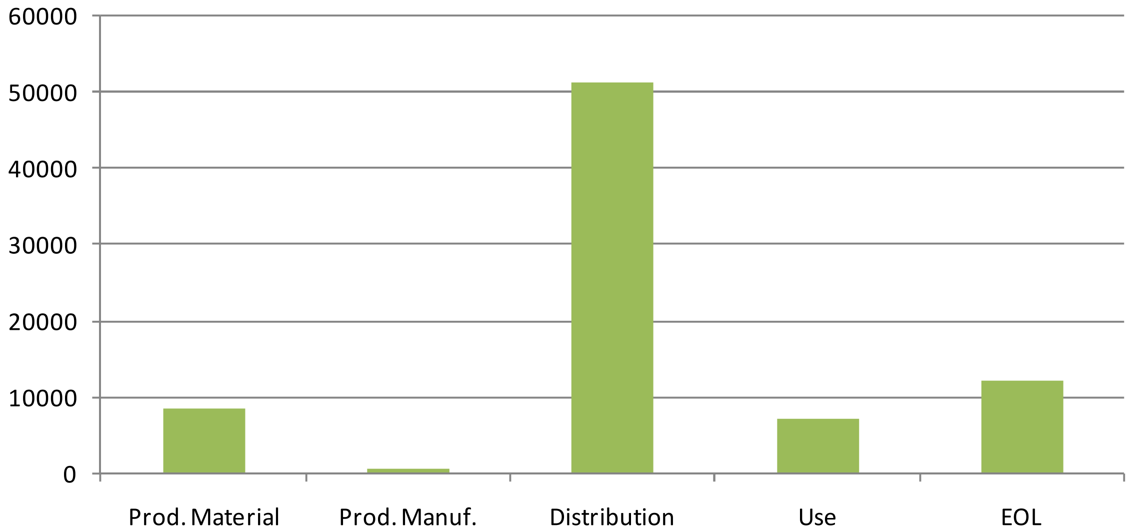

Figure 4-86: PMs related to each phase of the life cycle of walk-in cold room (g)

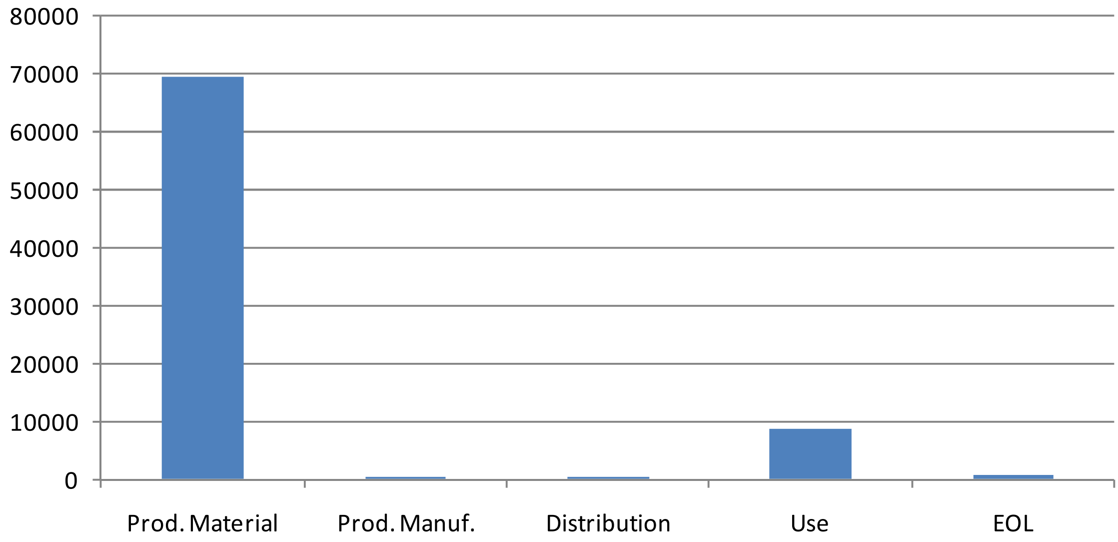

Figure 4-87: Heavy metals (water) related to each phase of the life cycle of walk-in cold room (mg Hg/20)

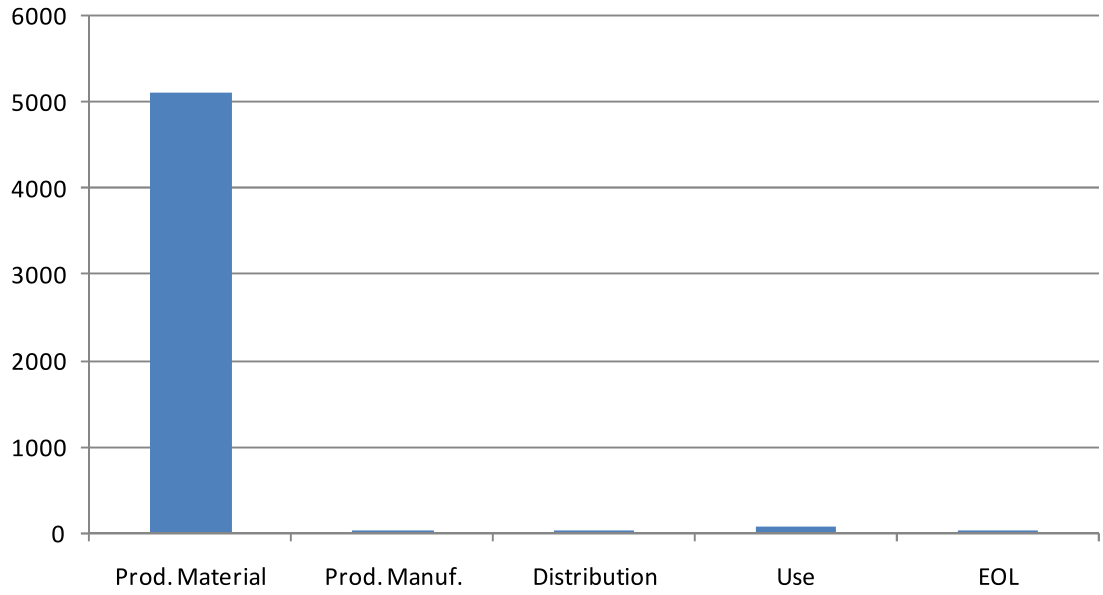

Figure 4-88: Eutrophication related to each phase of the life cycle of walk-in cold room (g PO_4)

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ANNEX 4-6: Process chillers – EcoReport results

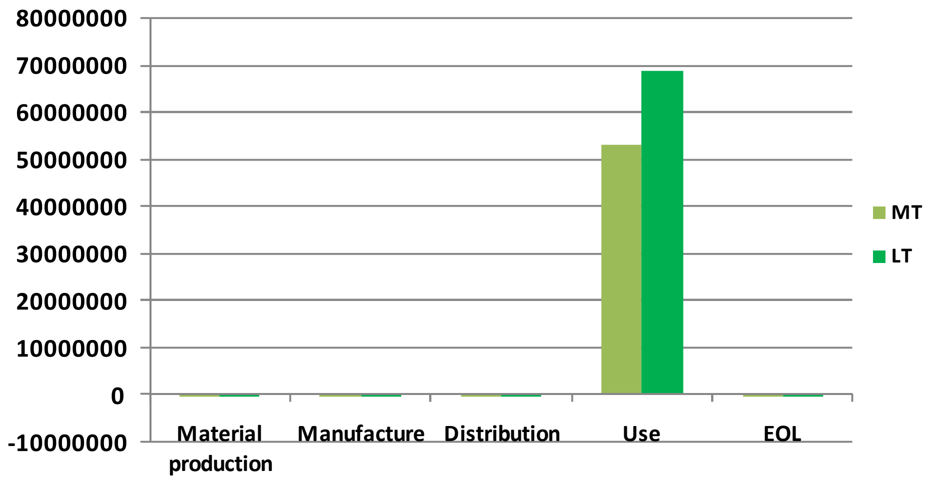

Figure 4-89: GER related to each phase of the life cycle of process chiller (MJ)

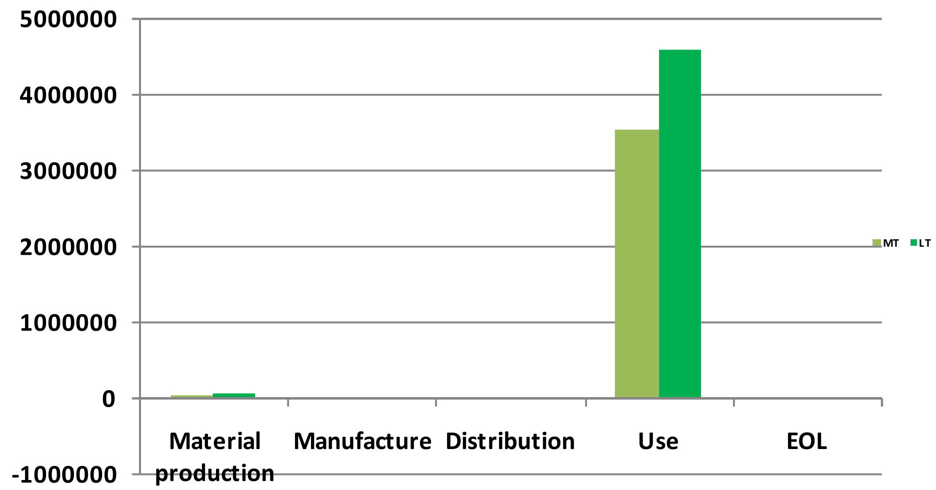

Figure 4-90: Process water related to each phase of the life cycle of process chiller (ltr)

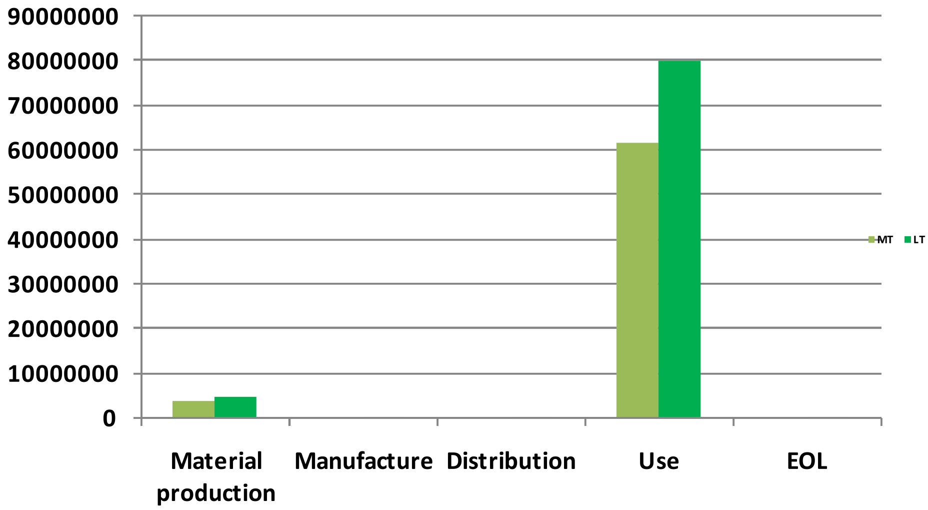

Figure 4-91: Waste (non-hazardous) related to each phase of the life cycle of process chiller (g)

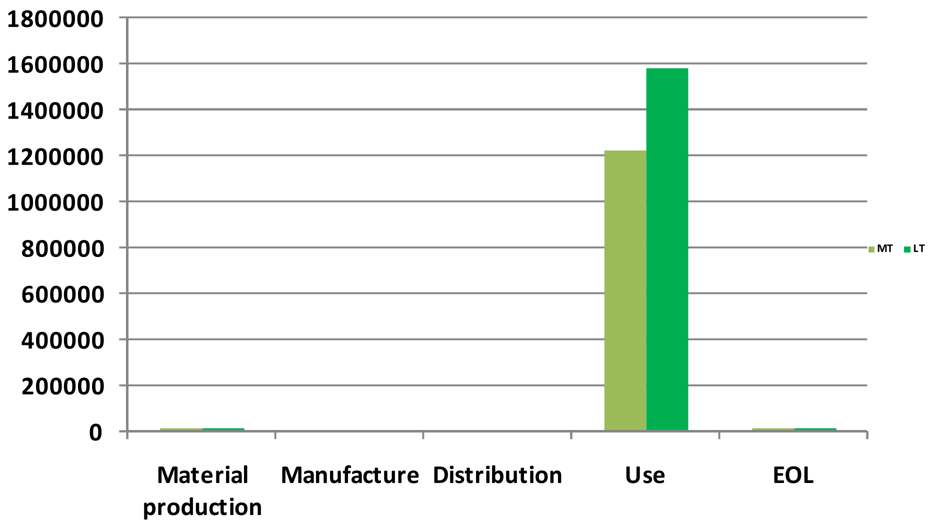

Figure 4-92: Waste (hazardous) related to each phase of the life cycle of process chiller (g)

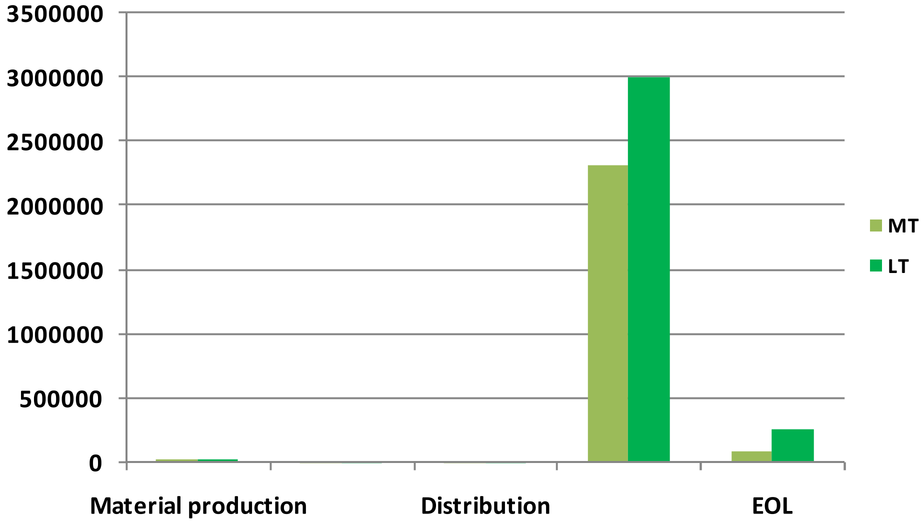

Figure 4-93: GWP related to each phase of the life cycle of process chiller (kg CO2 eq.)

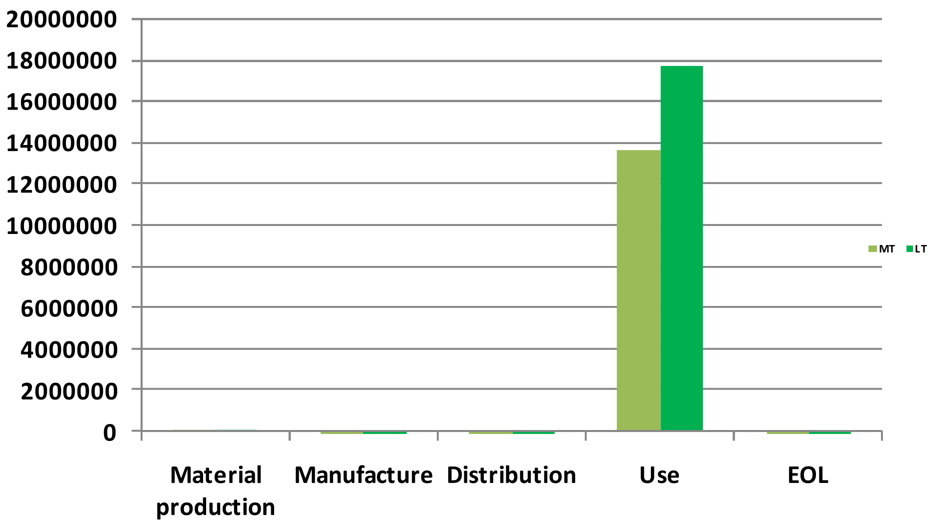

Figure 4-94: Acidification related to each phase of the life cycle of process chiller (gSO2 eq.)

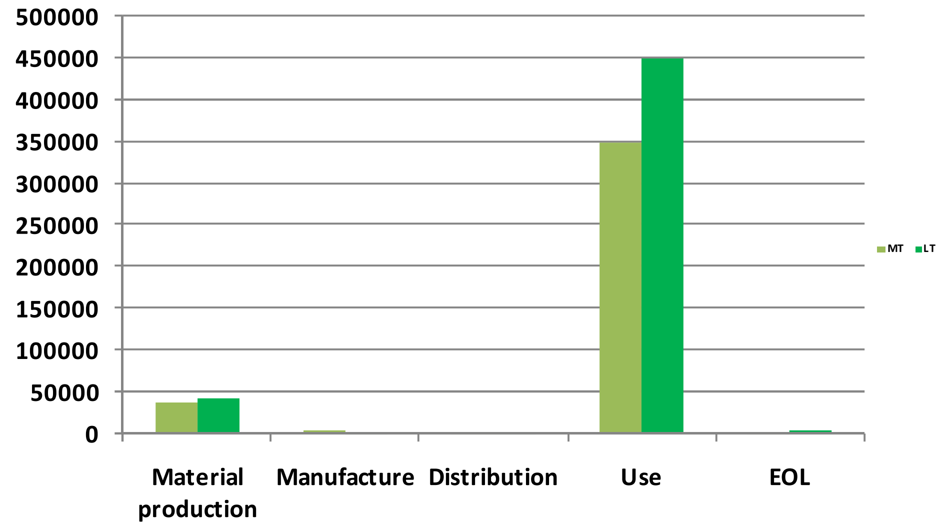

Figure 4-95: POPs related to each phase of the life cycle of process chiller (ng i-Teq)

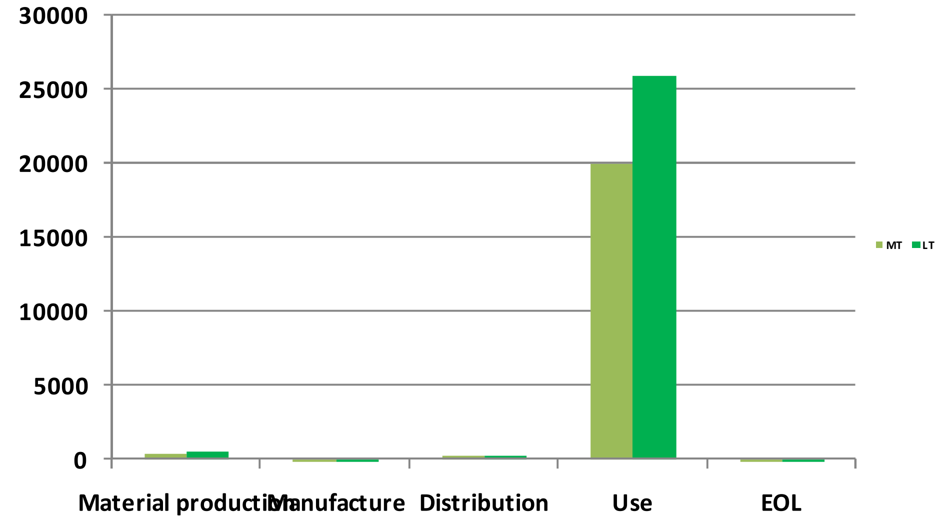

Figure 4-96: VOCs related to each phase of the life cycle of process chiller (g)

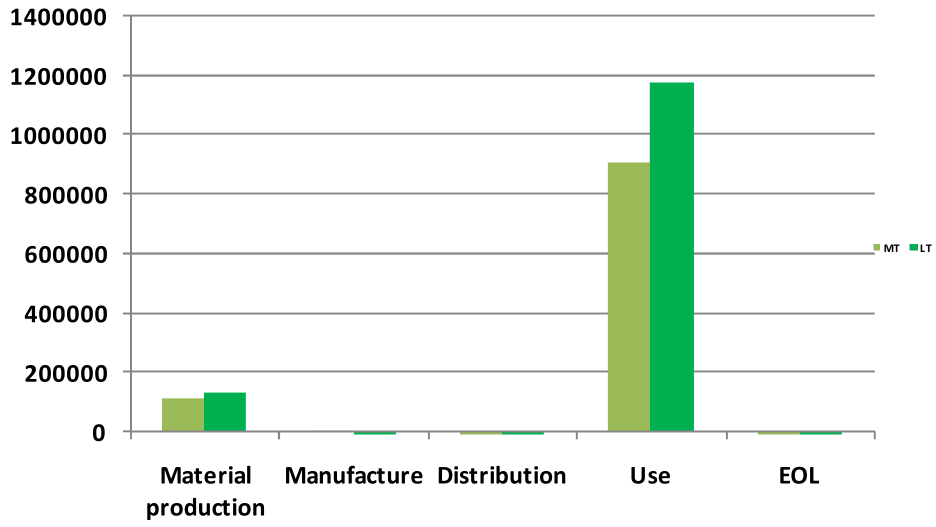

Figure 4-97: Heavy metals related to each phase of the life cycle of process chiller (mgNi eq.)

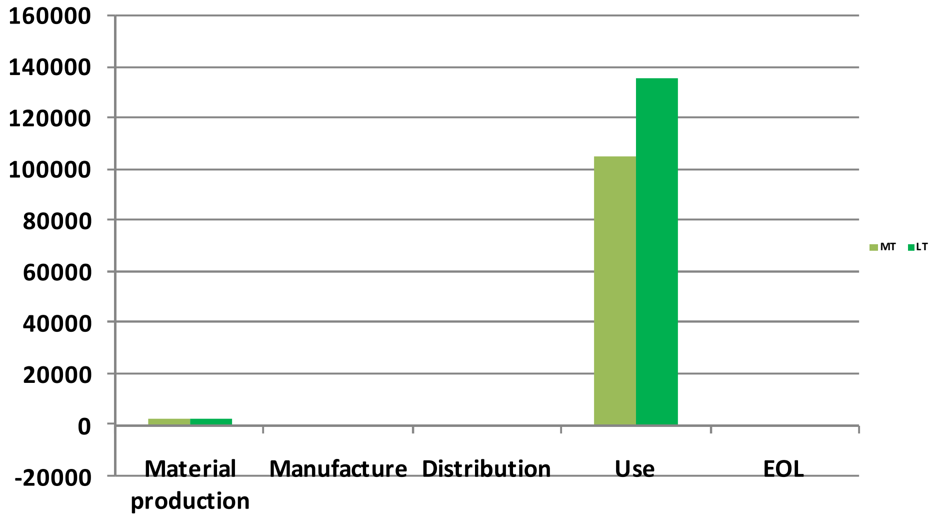

Figure 4-98: PAHs related to each phase of the life cycle of process chiller (mgNi eq.)

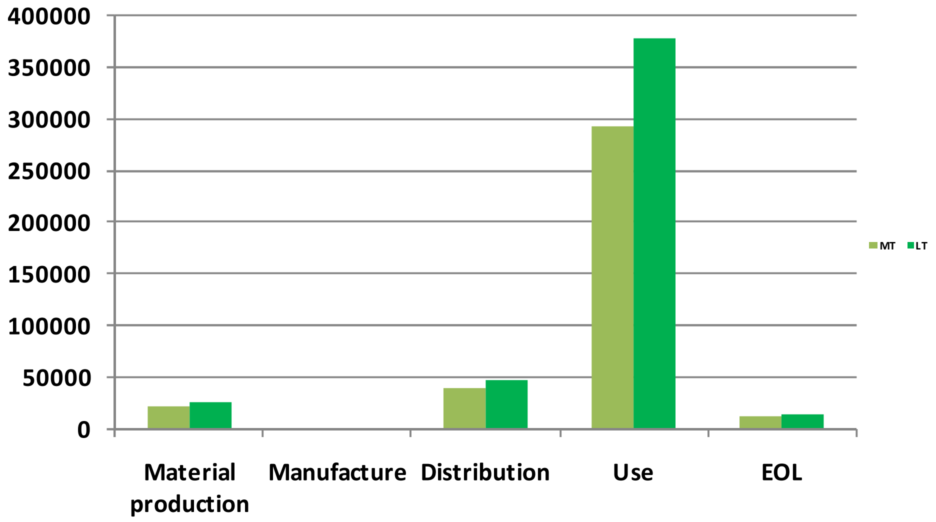

Figure 4-99: PMs related to each phase of the life cycle of process chiller (g)

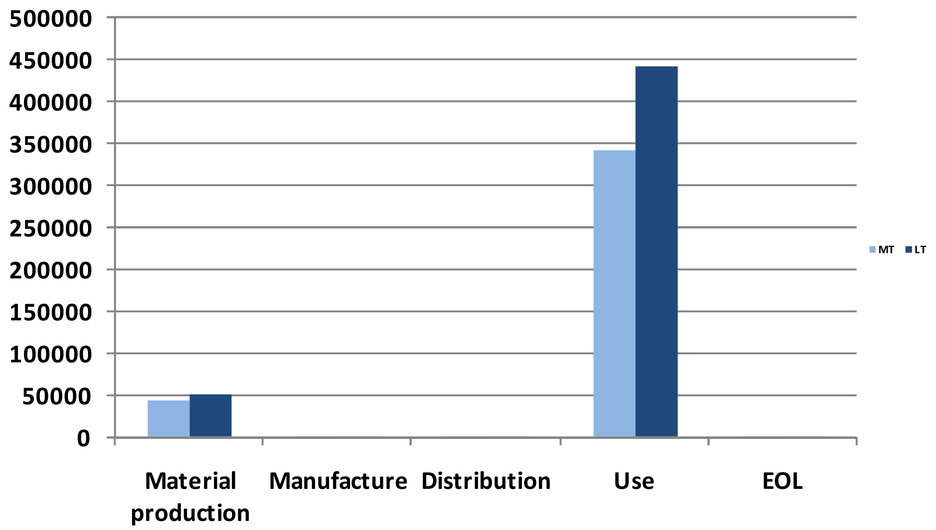

Figure 4-100: Heavy metals (water) related to each phase of the life cycle of process chiller (mg Hg/20)

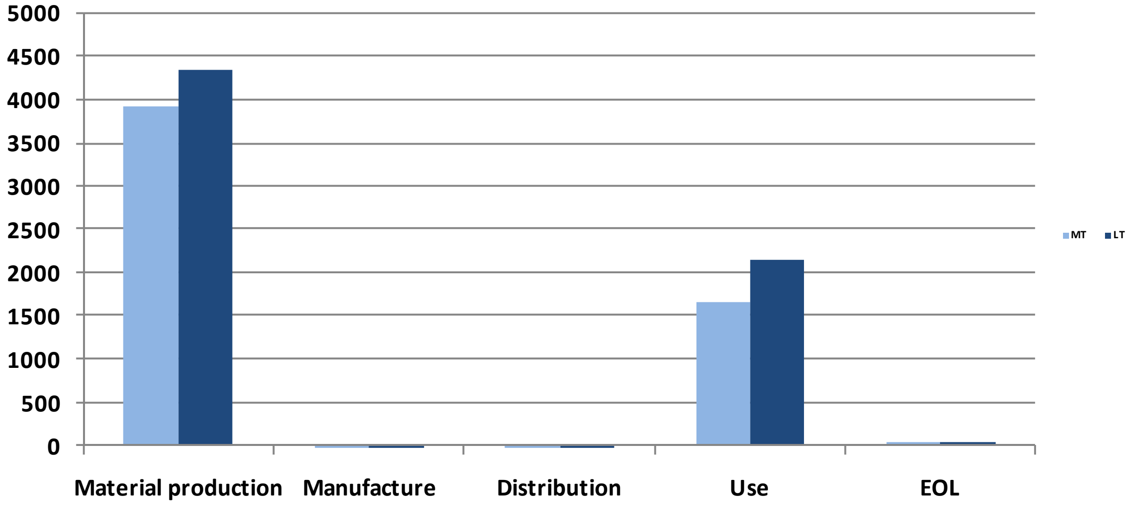

Figure 4-101: Eutrophication related to each phase of the life cycle of process chiller (g PO_4)

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ANNEX 4-7: Remote condensing units EcoReport results

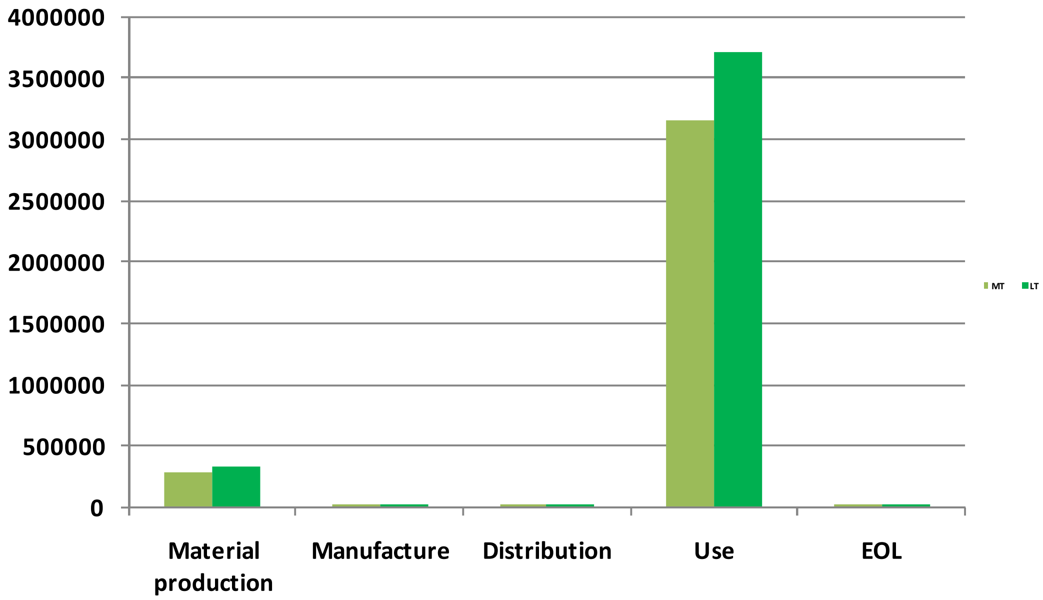


Figure 4-102: Waste (non-hazardous) related to each phase of the life cycle of condensing unit (g)

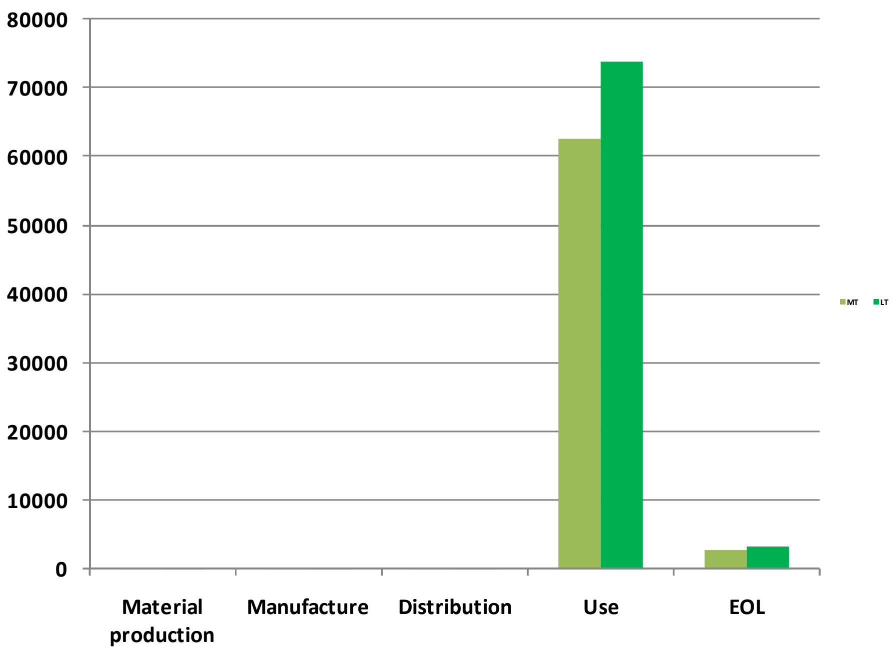


Figure 4-103: Waste (hazardous) related to each phase of the life cycle of condensing unit (g)

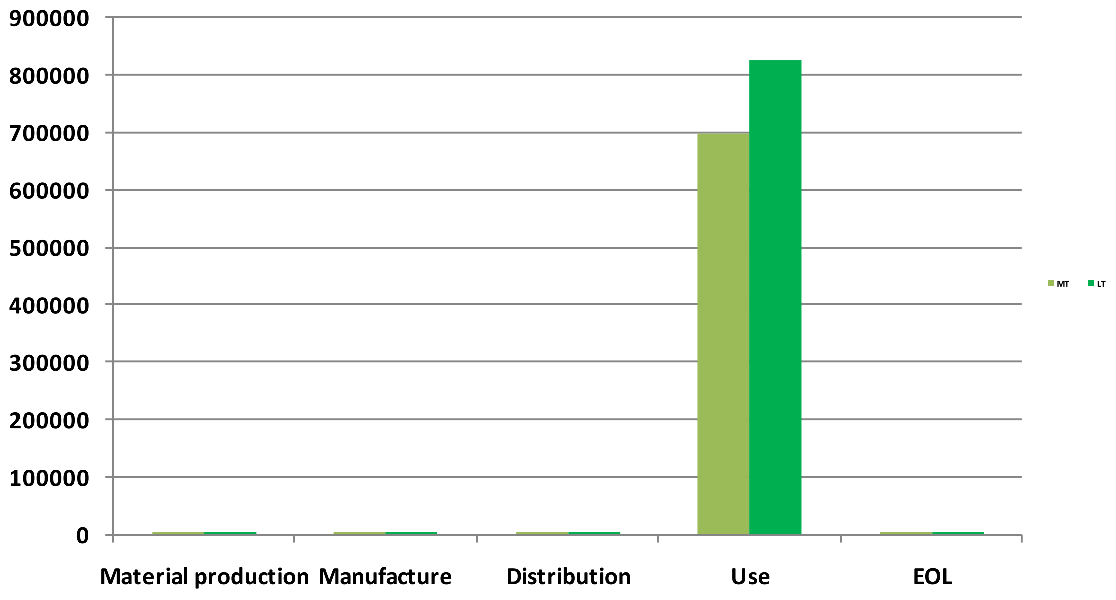


Figure 4-104: Acidification related to each phase of the life cycle of condensing unit (gSO2 eq.)

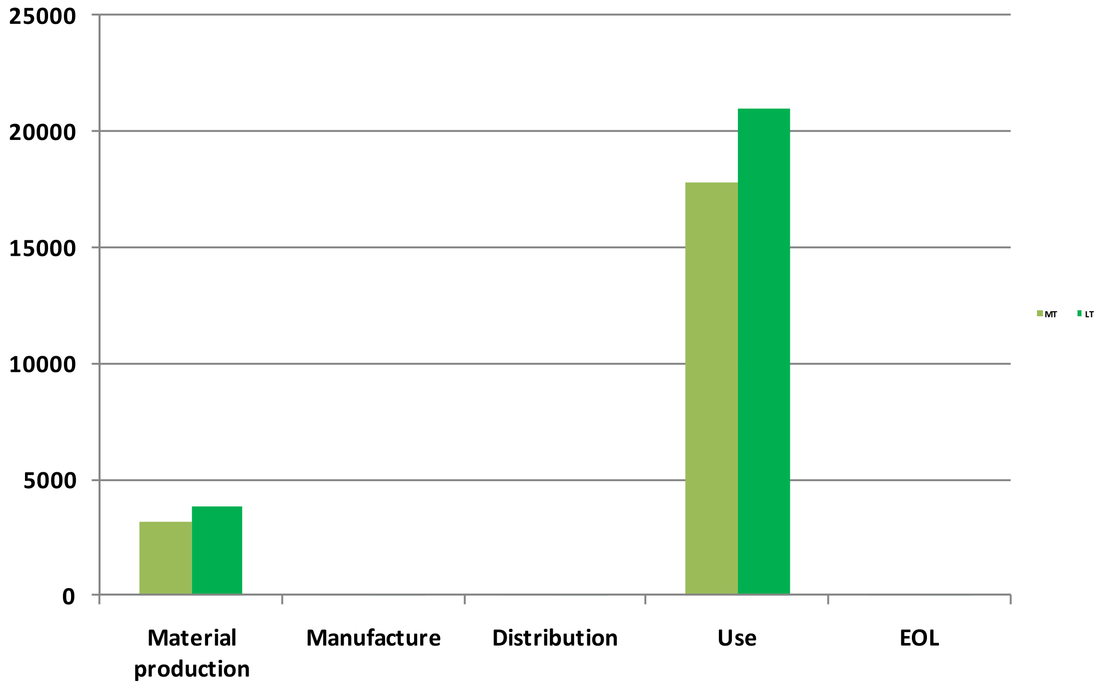


Figure 4-105: POPs related to each phase of the life cycle of condensing unit (ng i-Teq)

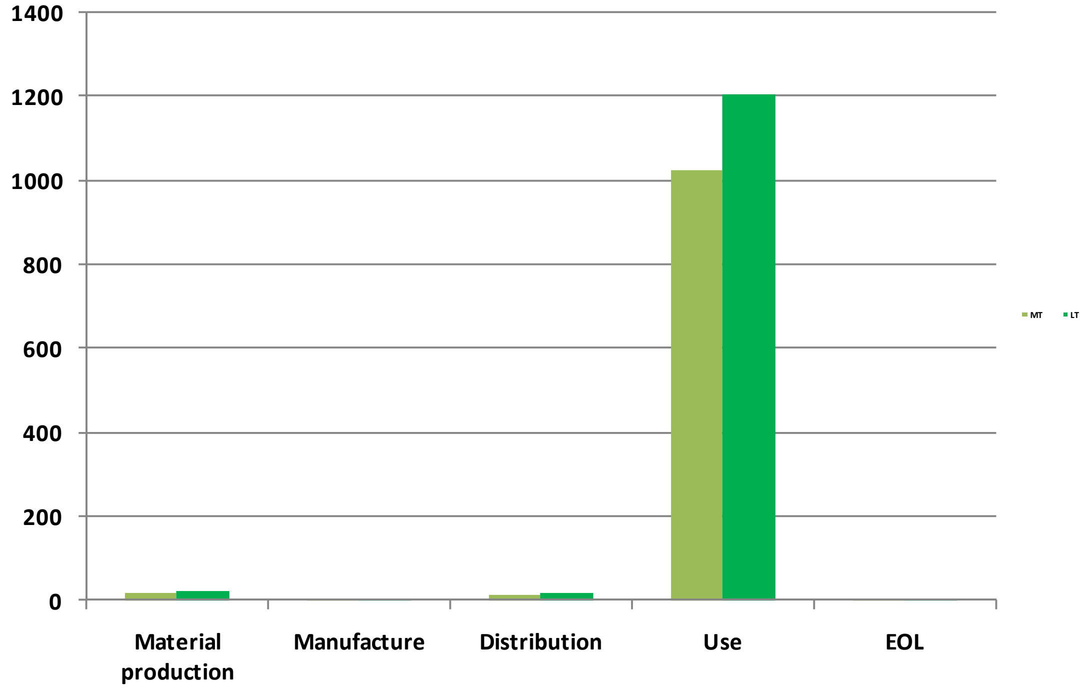


Figure 4-106: VOCs related to each phase of the life cycle of condensing unit (g)

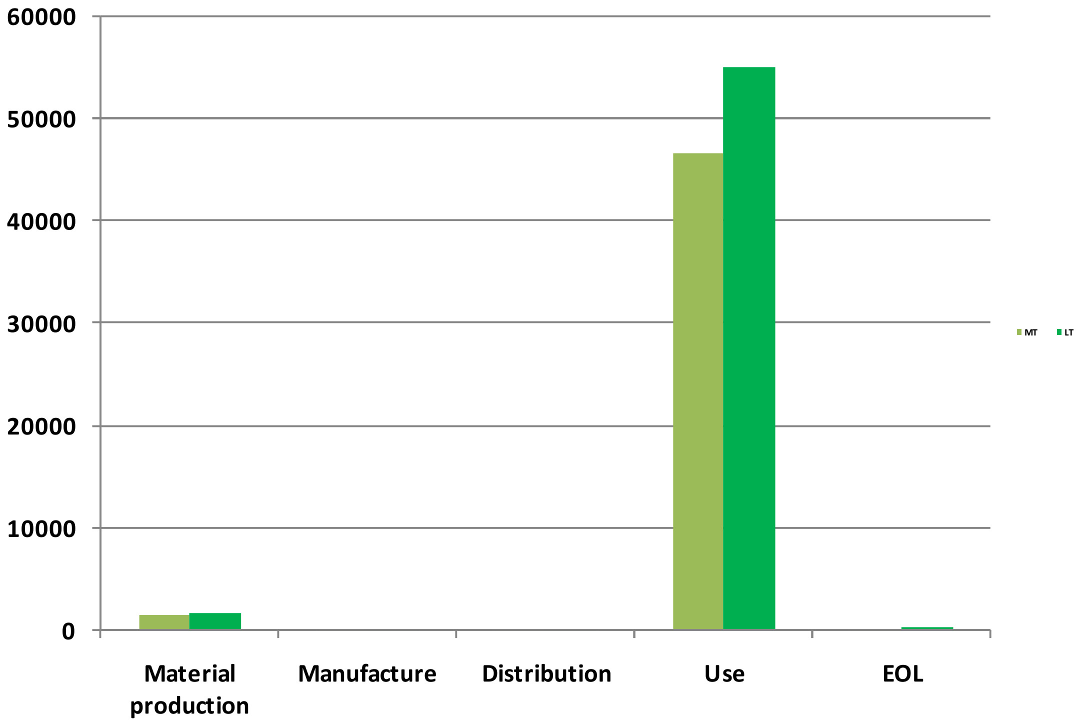


Figure 4-107: Heavy metals related to each phase of the life cycle of condensing unit (mgNi eq.)

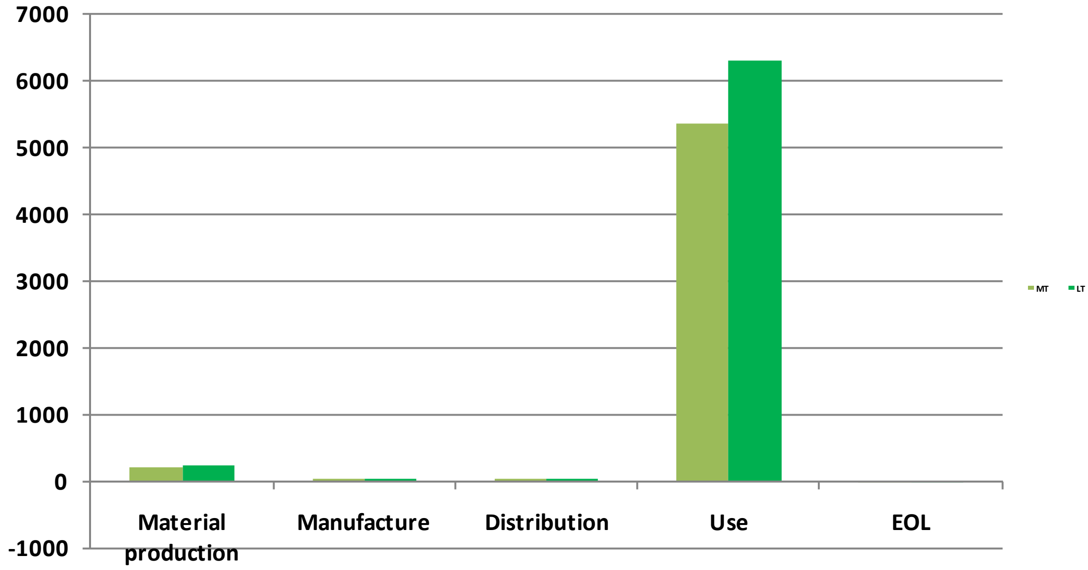


Figure 4-108: PAHs related to each phase of the life cycle of condensing unit (mgNi eq.)

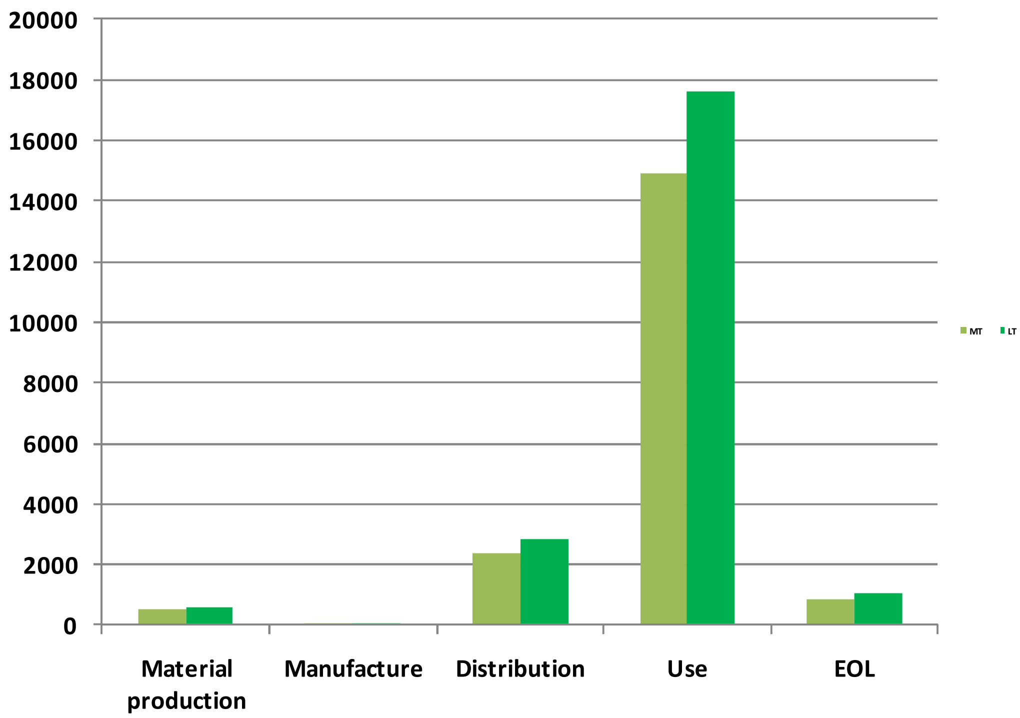


Figure 4-109: PMs related to each phase of the life cycle of condensing unit (g)

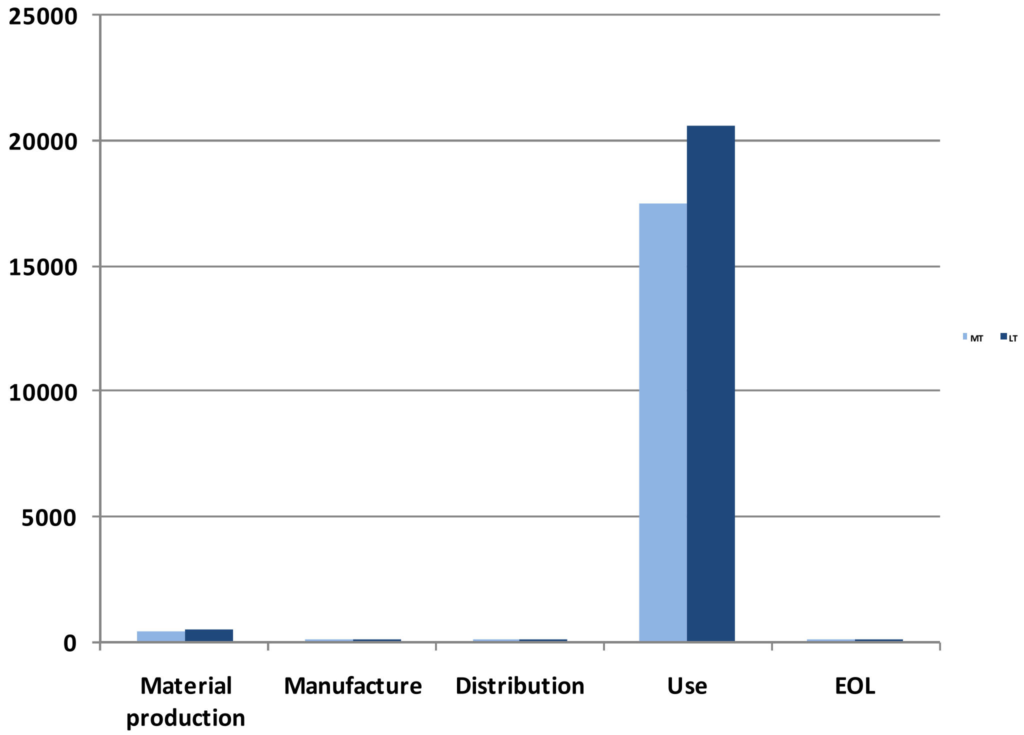


Figure 4-110: Heavy metals (water) related to each phase of the life cycle of condensing unit (mg Hg/20)

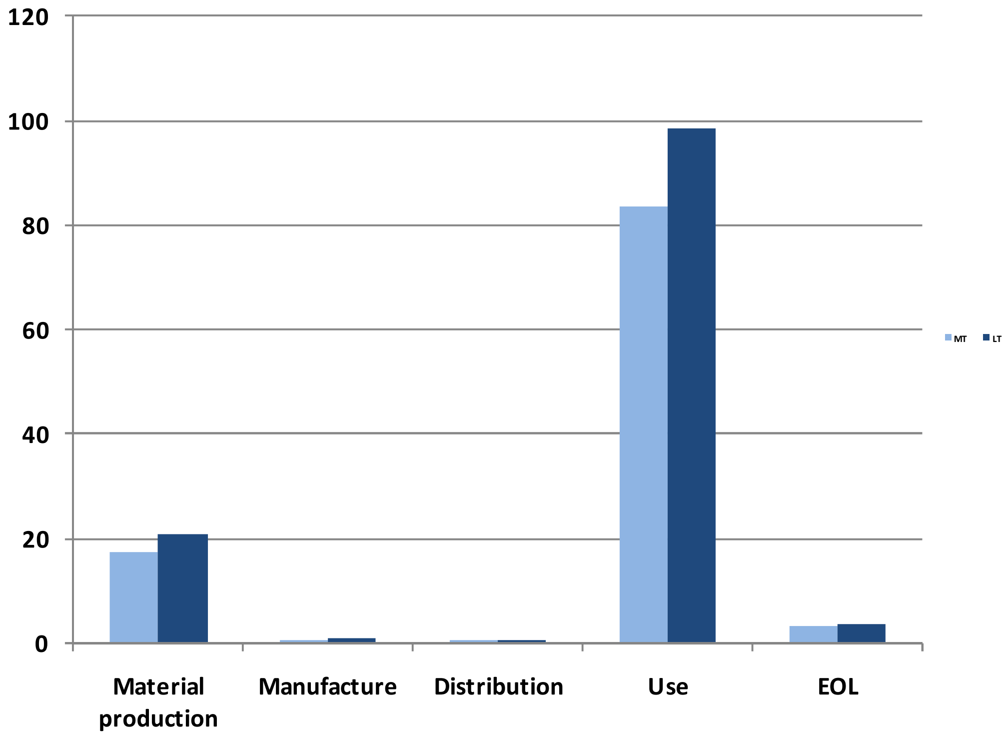


Figure 4-111: Eutrophication related to each phase of the life cycle of condensing unit (g PO_4)

Annex 4-8: Dessert and beverage machines, water dispensers and ice-makers

4.19. DESSERT AND BEVERAGE MACHINES

Product description at component level

Concerning energy consumption of individual components, not much data is available. Technical drawings (Figure 4-112) are provided only for plug-in slush machines and ice-cream machines as the principle of the general design is similar for all beverage and dessert machines. In case of remote dessert and beverage machines, the equipment does not comprise the compressor and the condenser.

- evaporator: it is in direct contact with the product to cool. In typical ice cream machines, the evaporator is mounted right behind the dispensing head (Figure 4-112, 4). Here there are no uses of fan motors at the evaporator. However, motors are used for the stirrer.
- Stirrer: it is driven typically by electric motors, therefore, this component has a direct impact in the overall electricity consumption of dessert and beverage machines. Nevertheless, the most important role of the stirrer is to give the final product the desired texture. Stirrers are designed to break up crystals in the freezing mixture while allowing a good freezing process of the final product (i.e. ice cream, slush).
- compressor: The function of compressor(Figure 4-112, 1)in dessert and beverage machines is already described in § 4.6.1. .
- expansion device (Figure 4-112, 3): both thermostatic valves and capillary tubes are used in dessert and beverage machines.
- condenser and condenser fan (Figure 4-112, 2). The function of condenser in dessert and beverage machines is already described in §4.6.5. .
- tank: the tank (Figure 4-112, 5) is where the beverage or dessert is stored. In some cases, the tank can be transparent

Some equipment is available that includes a heat treatment option for sterilising dairy products. This is a relatively new advancement where the machine provides a daily heating and cooling cycle to safely maintain dairy products for longer, before a complete disassembly and cleaning is required. Moreover, some beverage machines also include an ice making function.

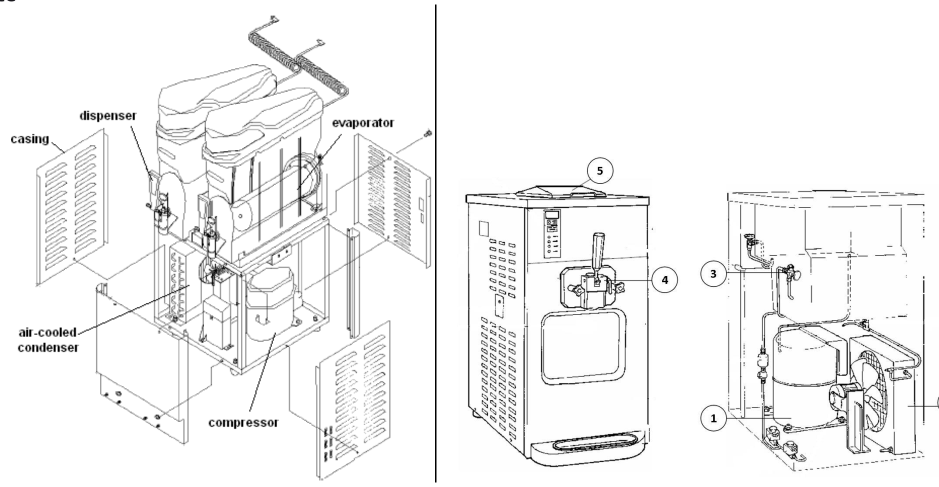


Figure 4-112 Typical plug-in slush machine[112] (left) and ice cream machine (right) [113]

Dessert and beverage machines' features affecting energy consumption levels

Based on the description of the components of dessert and beverage machines, this section introduces product features that can affect the overall energy consumption of this kind of products.

- **Location of the condensing unit: remote vs. plug-in**

Based on the findings of the preparatory study to TREN Lot 12 on commercial refrigeration, and on qualitative analysis, it is assumed that plug-in beverage and dessert machines usually present higher energy consumption than remote ones.

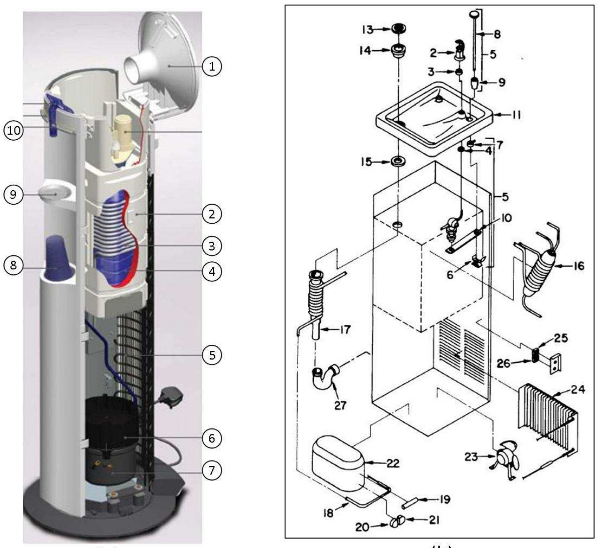
- **Type of beverage or dessert produced**

The type of dessert or beverage produced will determine the operating temperature of the machine and might imply the use of a stirring device driven by a motor.

[112] Source: http://www.bakemax.com
[113] Source: COLDELITE; UC711 G/P; Soft Serve Freezer Spare Parts Manual; COLDELITE CORPORATION OF AMERICA.

4.20. WATER DISPENSERS

Product description at component level



(a) (b)

Figure 4-113 (a) Typical water cooler, (b) Typical Water fountain

- bottle support (only for water coolers): Item 1 in Figure 4-113(a)
- water reservoir: Item 4 in Figure 4-113(a). The function of this water reservoir is to store chilled water so that the user does not have to wait until water gets the desired low temperature.
- water reservoir insulation jacket (only for water coolers): item 2 in Figure 4-113(a). The main function of this insulation jacket is to avoid heat transfer from the surroundings towards the water reservoir. Without this component the cooling load demand in the compressor would be higher.
- condenser: Item 5 in Figure 4-113(a) and Item 24 in Figure 4-113(b). The function of condenser in water dispensers as well as its role in energy consumption is already described in §4.6.5. Due to space restrictions, water dispensers generally use water-cooled condenser.
- evaporator: Item 3 in Figure 4-113(a) and Item 16 in Figure 4-113(b). The function of the evaporator in water dispensers as well as its role in energy consumption is already described in §4.6.4. .
- compressor: Item 7 in Figure 4-113(a) and Item 22 in Figure 4-113(b). The function of the compressor in water dispensers as well as its role in energy consumption is already described in §4.6.1. .
- dispenser valves: Item 10 in Figure 4-113(a) and Item 2 in Figure 4-113(b).
- pre-cooler: (water fountains only) Item 17 in Figure 4-113(b). As unused water has low temperature, a heat exchanger might be connected to the drain pipe in order to transfer heat before it is wasted. This component reduces the cooling load demand in the compressor.

Water dispensers features affecting energy and water consumption levels

Based on the description of the role of each component on the overall product consumption, some criteria have been identified for the product features which might play a significant role in determining the overall environmental performance of a water dispenser.

Based on this preliminary analysis, key variables affecting energy use have been identified and are presented below:

- **Water dispensers with/without hot water**

Presence of water heaters increase the overall electricity consumption of water dispensers since the heating element is usually an electric resistance. Additionally, water heater represent a source of heat that will increase the cooling load demand of the compressor, thus increasing its electricity consumption.

- **Bottled or water mains connected water dispensers**

According to a previous study, water mains connected type models showed better energy performance than equivalent bottle type water dispensers[114].

4.21. ICE-MAKERS

Product description at component level

An ice-maker consists of two major parts: the refrigeration system and water system. It also includes the housing (typically stainless steel panels) and a control (e.g. temperature settings, etc.) box.

The water system consists of the following main components:

- potable water inlet connection and water inlet valve (see Figure 4-114 - 1).
- water pump (Figure 4-114, 4). This component is responsible for 1.5% of the total electricity consumption of a typical air cooled ice-maker
- water sump (Figure 4-114, 5)
- water circuit - plastic tubing and evaporator water distributor
- freezing chamber (Figure 4-114, 6), which is an insulated casing where the ice making surface is located and where the ice making process takes place. Typical insulation is around 1.3 cm thick. Doubling the insulation typically provides up to 3% energy savings.[115]
- purge drain (Figure 4-114, 2), which is often controlled through the setting of a water purge time, and which can influence the water consumption by adjusting the amount of purge water. The water purge is colder than the

[114] Source: Mark Ellis and Associates, Analysis of Potential for Minimum Energy Performance Standards for Boiling and Chilled Water Dispensers, Australian Greenhouse office, 2004.

[115] Source: Arthur D. Little Inc, *Energy Savings Potential for Commercial Refrigeration Equipment*, US DOE, 1996 and MARK ELLIS & Associates, *Self-Contained Commercial Refrigeration*, Australian Greenhouse Office, 2000 and MARK ELLIS & Associates, *Remote Commercial Refrigeration*, Australian Greenhouse Office, 2000

inlet water and can be used to pre-cool the inlet water through a heat exchanger allowing 3 to 4% energy savings.[116]

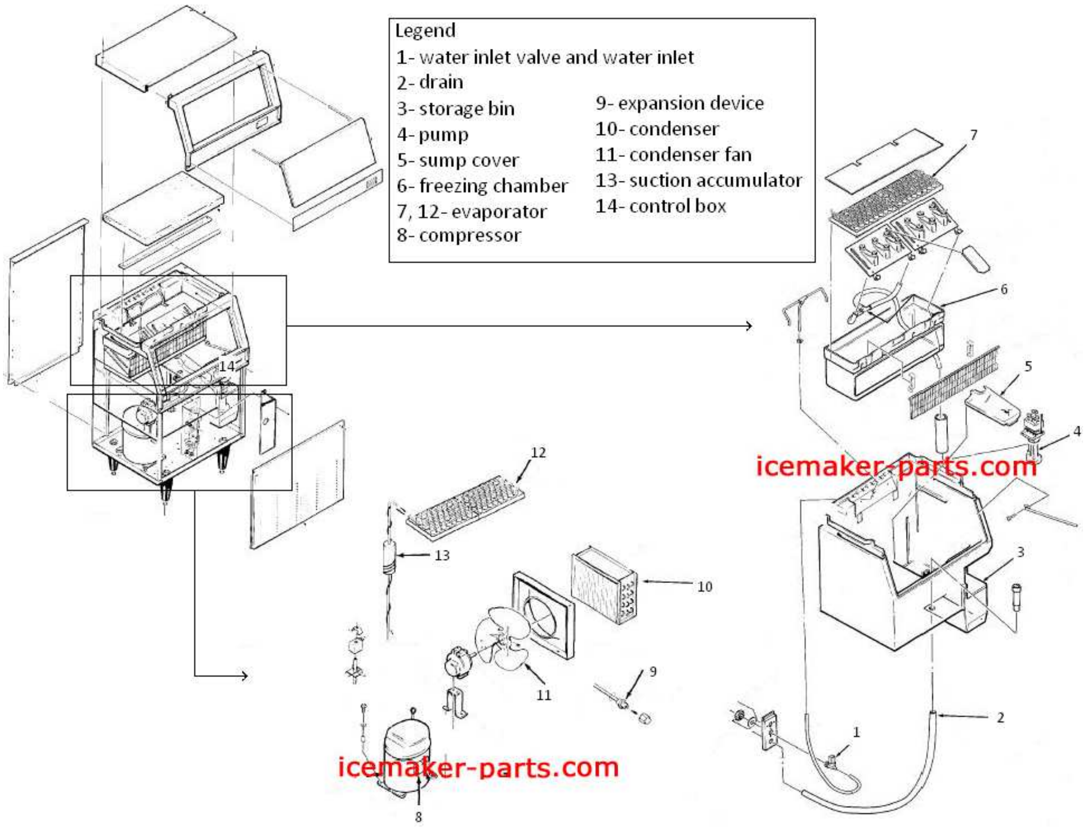


Figure 4-114: Simplified exploded diagram of a typical ice-maker[117]

The refrigeration system of a typical ice-maker comprises the main components of the vapour compression cycle:

- evaporator: (Figure 4-114, 7 and 12) it is typically connected to an ice making surface. Typical method is to fill a divided tray with water, freeze it and dump it. In some variations the tray is vertical and carousel shaped. Sheet freezing also exists, where the water is frozen in a flat tray, then cut into cubes by a grid of heated wires. Depending on the type of ice produced, other methods include freezing water into cylinders, flakes, etc.
- compressor (for plug-in ice-makers only) (Figure 4-114, 8): This component is responsible for over 90 % of the total electricity consumption of a typical air cooled ice-maker.
- expansion device (Figure 4-114, 9): both thermostatic and capillary tubes are used in ice-makers.

[116] Source: Arthur D. Little Inc, *Energy Savings Potential for Commercial Refrigeration Equipment*, US DOE, 1996 and MARK ELLIS & Associates, *Self-Contained Commercial Refrigeration*, Australian Greenhouse Office, 2000 and MARK ELLIS & Associates, *Remote Commercial Refrigeration*, Australian Greenhouse Office, 2000

[117] Source: Icemaker-parts www.icemaker-parts.cpm (Scotsman AC125)

- condenser and condenser fan (Figure 4-114, 10 and 11): This component is responsible for 8 % of the total electricity consumption of a typical air cooled ice-maker

Additional components include a:

- hot gas bypass line which is used to deviate a certain amount of refrigerant vapour for harvesting the ice and detaching the ice from the ice making surfaces
- hot gas valve which controls the flow of vapour refrigerant directed to the evaporator. This component is responsible for less than 0.5 % of the total electricity consumption of a typical air cooled ice-maker
- suction accumulator which protects the compressor by stopping liquid refrigerant entering the compressor (Figure 4-114, 13)
- storage bin (Figure 4-114, 3). Ice storage bins are non-refrigerated and the great majority consume no power, however their effectiveness does influence the quantity of ice available.

Reductions in total electricity consumption are possible through the use of typical options to improve vapour-compression based equipment: with the use of high-efficiency motors in condenser fans and compressors, and thicker insulation. A study estimated that energy savings of 10% can be realised through the use of high-efficiency compressors, and other measures.

Ice-maker's features affecting energy and water consumption levels

The description of the role of each component on the overall product energy efficiency provides a basis to identify the product features which might play a significant role in determining the overall environmental performance of an ice-maker.

◆ **Water use**

Based on this preliminary analysis, key variables affecting water use have been identified and are presented below:

➢ **Water controls: inlet valve and purge timing**

System water pressure which may/may not be regulated through the inlet valve and water purge time setting can also be adjust to optimise the water usage.

Preliminary literature analysis shows that a controlled valve and adjusting the purge time allows regulating the water supply and can lead to 20 - 40% potable water savings[118]

➢ **Condenser type: air cooled vs. water cooled**

Ice-makers using water-cooled condensers imply higher water consumption (around 15 litres per kg of ice produced). However, they allow achieving lower condensing temperatures increasing the energy efficiency of the ice-maker (see below key variables affecting electricity consumption).

[118] Source: Mark Ellis, *National Appliance and Equipment Energy Efficiency Program, Analysis of Potential for Minimum Energy Performance Standards for Self-Contained Commercial Refrigeration,* Prepared for the Australian Greenhouse Office, by Mark Ellis & Associates, Final Draft Report, March 8th, 2000

◆ **Energy use**

Based on this preliminary analysis, key variables affecting the electricity consumption have been identified and are presented below:

➢ **Size/ capacity of the ice-maker**

Energy consumption decreases with capacity (kg of ice produced per day) ranging typically from 10kWh/100lb of ice (45kg) per day for smaller capacity machines (200lb or 90 kg of ice per day) down to 6kWh/100lb for larger capacity machines (1400lb or 630kg of ice per day)

Such decrease can be attributed to several elements[119]:

- Large ice-makers usually operate with larger compressors with higher compressor efficiencies
- Larger storage bins tend to have less surface area exposed to ambient surroundings per kg of ice stored, which reduces melting
- Reduced water consumption because sumps are typically oversized in smaller ice makers

➢ **Type of condenser: air cooled vs. water-cooled**

Three main types of condenser technologies are found in ice-makers:

- smaller air-cooled ice makers use the most energy, but are less expensive than water-cooled models. They also use less water. Their energy use ranges from 5kWh/100lb (45kg) of ice for machines making 1 500lbs (680kg) of ice per day to 20kWh/100lb for self-contained machines making 50 lbs (23kg) of ice per day.
- remote water-cooled models are more efficient than air-cooled units. Their energy use ranges from 3.5kWh/100lb of ice for machines making 1 800lbs (817kg) of ice per day to 10.5kWh/100lb of ice for machines making 150lbs (68kg) of ice per day.
- remote air-cooled condensers transfer the heat generated by the ice-making process outside of the building. Their energy use ranges from 4kWh/100lb of ice for machines making 1,650lbs (750kg) of ice per day to 9kWh/100lb of ice for machines making 400lbs (180kg) of ice per day. They also reduce noise levels inside by up to 75%, but there are extra installation costs for running lines to a remote location.

This leads to the preliminary conclusions that smaller plug-in air cooled ice-makers have higher electricity consumptions compared to other types of ice-maker, however they use less water. Water-cooled models use less electricity per kg of ice produced but imply higher water consumption (around an extra 15 litres per kg of ice produced).

[119] Source: Arthur D. Little Inc, *Energy Savings Potential for Commercial Refrigeration Equipment*, US DOE, 1996 and MARK ELLIS & Associates, *Self-Contained Commercial Refrigeration*, Australian Greenhouse Office, 2000 and MARK ELLIS & Associates, *Remote Commercial Refrigeration*, Australian Greenhouse Office, 2000

- **Location of the condenser or condensing unit: plug-in vs. remote**

ARI standard[120] rating of remote ice-makers electricity consumption compared to plug-in ice makers shows that typically, remote models use less electricity per kg of ice produced. This can be explained by the fact that remote ice-makers often come in larger capacity ranges and large size plug in ice-makers and remote air cooled ice-makers have electricity consumption in the same range. Moreover, in case of remote equipment, the condensing unit can be more easily located in well ventilated areas to increase the performance of the condenser.

- **Ice-making process: Continuous vs. batch**

Preliminary literature review shows that the ice-making process (i.e. continuous or batch) has an influence on the ice-maker's performance, with continuous process being more efficient as it allows an optimised operation of the compressor.

[120] Based on ARI 810 standard see measurements in Fisher Nickel, Inc. A field study to characterize water and energy use of commercial ice cube machines and quantifying saving potential, Food Service Tehnology Center, USA, 2007