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 remote condensing units

Task 5: Technical analysis of improvement options

Final report

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5 Technical analysis of improvement options

5.1 INTRODUCTION

Task 5 describes and analyses Best Available Technology (BAT) as well as Best Not yet Available Technology (BNAT) for all types and sizes of refrigerating equipment in the scope of ENTR Lot 1, both at the component and product levels.

BAT is defined as a technology which is presently available on the market (existing products inside and outside the EU market will be reviewed), and the use of which leads to minimised environmental impacts. BNAT refers to a technology which has the potential to enable environmental performance improvements, but that is still subject to research and development and is a longer-term future option.

While Task 4 has shown that energy efficiency is a major aspect of product performance to consider — due to the environmental impacts which result from energy consumption — refrigerating and freezing equipment are responsible for other environmental impacts as well, such as direct emissions due to refrigerant leakage. Task 5 therefore seeks to describe the potential trade-offs between the total environmental impacts of the various improvement options.

The assessment of BAT and BNAT provides input for the assessment of improvement potential in Task 5 and Task 6.

The description of technologies presented here is based on ongoing research and assesses the most relevant technologies according to stakeholders and the available literature. However, details of new, cutting-edge technologies are likely to be closely guarded for competitive reasons and detailed public information may be limited.

Please note: The efficiency or other performance levels claimed by stakeholders have not been verified independently in all cases.

5.2 BEST AVAILABE TECHNOLOGY COMPONENTS

The objective of this section is to identify a list of BAT options that can be applied to the equipment within the scope of ENTR Lot 1 and to assess the improvement potential associated to each BAT option at the product and component levels. Possible barriers for the uptake of BAT are also assessed. Unless stated otherwise, the figures provided in this section are stakeholder estimates, or figures which were provided in Task 4, which have been then been completed with additional figures from the literature.

5.2.1 COMPRESSORS

Compressors are used in all vapour-compression cycle equipment included within the scope of ENTR Lot 1 and are responsible for the majority of a product's total energy consumption (TEC). More efficient compressors reduce overall energy consumption, thereby increasing the coefficient of performance (COP) of the refrigeration system. Increasing efficiency can be achieved by reducing losses from suction and discharge gas pressure, mechanical friction, and the electric motor, or other improvements. The possible improvements that are analysed in this section are summarised below:

- Compressor construction improvements: high efficiency compressors and high efficient motors for compressors
- Compressor type: reciprocating, scroll, screw and rotary vane compressors
- Compressor controls: variable speed drive and digital modulation
- Parallel compressors: multiple compressors

According to stakeholders' information, the maximum improvement potential in the compressor side (improving construction, heat losses, and electric motor) would be up to 20%, comparing the worst compressor to the best compressor in the market. Future developments for compressors would only achieve up to 3% improvement in the compressor efficiency.

Ensuring proper compressor sizing for the system load is also crucial to improving refrigeration equipment efficiency. Most components used in refrigerating and freezing equipment, and especially the compressor, are over-sized, to ensure good operation of the refrigeration system even in the worst conditions (e.g. very hot summers) while maintaining low noise levels[1].

Major improvements are change of compressor type, implementation of speed controls and seasonal performance. However, the speed control improvements and seasonal performance are not translated into higher COP values, since COP is tested at full load conditions.

However, part-load operation typically reduces the efficiency of any compressor system, and oversized refrigeration compressors must therefore operate at less than peak efficiency throughout most operating conditions. Controls enabling

[1] If the capacity is too low, the motor is working and making noise non-stop. If capacity is bigger, it will work part-time and therefore provide breaks in the noise.

compressors to function at part load may therefore provide benefits in certain circumstances.

The change of type of compressor can give higher COP values. Semi-hermetic reciprocating compressors, hermetic scroll compressors, screw compressors and rotary vane compressors can be more efficient than hermetic reciprocating compressors, but for low cooling capacities (below 20kW) these compressors are rarely used in the market because of the high price of the technology. This leads to a small improvement potential for smaller compressors, which are the biggest share of the market

In the following sections these different improvement options for compressors are analysed.

5.2.1.1 Compressor type

Relevance:

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

As discussed in Task 4, the most common type of compressor in refrigeration machines is the reciprocating hermetic compressor. The same applies to semi-hermetic reciprocating compressors in medium to large refrigeration systems.

The semi-hermetic reciprocating technology is dominating the medium to large commercial refrigeration systems in condensing units and supermarket applications. They are recently gaining significant improvements in terms of efficiency, due to new developments designed for integrated refrigerant cooled frequency inverter among other improvements[2]. According to information provided by stakeholders, semi-hermetic reciprocating compressors can be from 45% to 60% more expensive than scroll compressors for the same cooling capacity. In remote condensing units, the compressor means from 30% to 50% of the price of the unit, depending on the size and the manufacturer[3]. For other commercial refrigeration products, this percentage is usually lower, as they include other components.

Open reciprocating compressors are normally used for NH_3 applications. In this case the compressor motor and the compressor are in separate casings, and the access to the components is easier for maintenance. This type of configuration is only used in remote refrigeration systems, and often results in refrigerant leaks. This kind of compressors offers a better performance than hermetic compressors, and higher cooling capacities. However, these compressors are not usual in commercial refrigeration, and are typically used in larger refrigeration and air conditioning systems.

Scroll, rotary vane and screw compressors belong to the rotating type technology. Rotary vane compressors are dedicated for the smaller capacity range in air conditioning systems, not being applied in commercial refrigeration machines. Scrolls are applied for medium capacity equipment and screws for the larger

[2] Source : Bitzer

[3] Source : Tecumseh

capacity range (see also Table 4-3, Task 4 Document). In their particular capacity segment rotating compressors can achieve higher efficiencies than equivalent hermetic reciprocating compressors in ranges of small pressure ratios, whereas with medium to larger pressure ratios modern semi-hermetic reciprocating compressors can achieve higher COP values.

Scroll compressors are being introduced in refrigeration machines in recent years, whereas screw and rotary vane compressors are mostly utilised in large capacity air conditioning machines.

- **Scroll**

The increase in cost of scroll and rotary vane technology was quoted in T4 to be around 25% of the Base Case[4], and can provide energy savings up to 10%. Previous feedback on energy savings of scroll compressors pointed out a maximum energy savings of 20% to 30%[4]. According to Asercom, the issues regarding prices of compressor technologies are discounts and I+D investment. Manufacturers do not usually sell components to the final user, and prices for retailers, wholesalers and installers can have different discounts depending on the client, number of products, technical services contracted, etc. On the other hand, manufacturing costs can be similar for different types of compressors depending on the materials, size and configuration, but companies need short payback times of I+D investments on newer compressors and technologies. Thus, on average, a scroll compressor costs from 30% to 50% more than a hermetic reciprocating compressor[5]. However, comparing scroll compressors with semi-hermetic reciprocating compressors, the price is higher for the latter[6].

In medium-temperature applications (i.e. between i.e. between 0°C and +4°C)[7], the COP of a scroll compressor is assumed to be higher than for a hermetic reciprocating compressor in similar 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 COP values[8]. Therefore, the choice of the compressor depends mostly on average annual evaporator and condenser temperatures.

- Walk-in cold rooms (WICR): Scroll compressors can be used for medium capacity walk-in cold rooms.
- Blast cabinets (BC): The current use of scroll compressors for blast equipment has not been observed to date, but is expected to be applicable in the future.
- Remote condensing units (RCU): Scroll compressors are increasingly used in refrigeration systems (mainly in medium temperature applications) and are often arranged in parallel. Industrial continuous blast equipment can be benefit from scroll compressors. However, these machines are not

[4] Source : Tecumseh

[5] TEV Ltd

[6] Source: Daikin

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

[8] Bitzer

within the scope of ENTR Lot 1. The compressor means from 30% to 50% of the price of the remote condensing unit, depending on the size and the manufacturer. Therefore, a condensing unit using a scroll compressor is calculated to be around 16% more expensive than an equivalent condensing unit using a reciprocating compressor. The energy savings of scroll compressors within remote condensing units can be up to 10%, as explained above, depending on the operating temperature.

Table 5-1: Scroll compressor – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
Service cabinet - High Temperature (SC HT)	N.A.	N.A.	N.A.	N.A.	N.A.
Service cabinet - Low Temperature (SC LT)	N.A.	N.A.	N.A.	N.A.	N.A.
Blast cabinet (BC)	Now	N.A.	N.A.	N.A.	N.A.
Walk-in cold room (WICR)	Now	N.A.	N.A.	N.A.	N.A.
Process chiller – Medium Temperature (CH MT)	N.A.	N.A.	N.A.	N.A.	N.A.
Process chiller – Low Temperature (CH LT)	N.A.	N.A.	N.A.	N.A.	N.A.
Remote condensing unit – Medium Temperature (RCU MT)	Now	10	10	800*	16
Remote condensing unit – Low Temperature (RCU LT)	Now	5	10	1200*	16

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

- **Screw**

The cost of screw compressors is higher than hermetic reciprocating and scroll compressors. Semi-hermetic screw compressors are used for high cooling capacities and the price can be around 30% higher than scroll compressors. This type of compressor can achieve energy savings of up to 20% compared to hermetic reciprocating compressors. Screw compressors are used mostly in air conditioning machines and process chillers with high cooling capacity. Previous figures showed a price increase of screw compressors for commercial refrigeration around 50%, but stakeholder feedback suggested that those prices were overstated[9].

- Screw compressors can work with higher efficiencies at partial load, as opposed to the average centrifugal chillers[10]. However, different opinions have been received from stakeholders regarding this aspect, and screw

[9] Source : Bitzer

[10] Iowa State University (2005). *Energy-related best practice: A source for the chemical industry.* CIRAS

compressors may need implementation of VSD in order to achieve energy savings at part load, as in other kind of compressors.

- RCU: screw compressors are currently only applied to high cooling capacities around 300 kW for economical reasons. The compressor means from 30% to 50% of the price of the remote condensing unit, depending on the size and the manufacturer. Therefore, a condensing unit with a screw compressor would be 30% more expensive than the base case.

Table 5-2: Screw compressor – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Now	N.A.	40	N.A.	N.A.
CH LT	N.A.	N.A.	40	N.A.	N.A.
RCU MT	Now	0.5	10	1,600*	30
RCU LT	Now	0	10	2,400*	30

** Increase in price calculated from the weighted base case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

- **Rotary vane**

The use of rotary vane compressors in refrigeration machines is negligible, as shown in Task 2, According to information provided by stakeholders[11], rotary vane compressors are used in air conditioning systems below 50 kW.

5.2.1.2 High efficiency compressor motor

Relevance:

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

Replacing the compressor motor with a more efficient option has been shown to provide potential energy savings.

- **Permanent split capacitor motor**

No evidence has been identified of the use of permanent split capacitor motor (PSCM) technology in compressors.

- **Electronically commutated motor**

As described in Task 4, ECM is a high efficiency motor. However, 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. For a remote

[11] Bitzer, 2011

condensing unit for commercial refrigeration below 10 kW, the use of an ECM in the compressor can increase the price of the product in 9%, and combined with the inverter technology can reduce the energy consumption of the motor up to 10%, due to part load management. The use of this kind of motors in the compressors is increasing in the commercial refrigeration industry and it is supposed to continue in this trend, since this eases the application of capacity controls and thus reductions in the annual energy consumption of the machines[12].

As discussed in Task 4, AC/DC inverters, also known as variable-frequency drives, allow the application of electronically commutated motors (ECM). The conversion losses from AC to DC and back can be up to 3 to 5% per step, even though these have been reduced significantly in recent designs. DC motors are much easier to control than single phase shaded-pole AC motors. Inverter systems control the rotational speed of the DC electric motor by controlling the frequency of the AC electrical power supplied to the motor.

- Service cabinet (SC): Normally service cabinets use capacitor start compressors to overcome the high head pressure on start up; ECM motors are not able to handle high start loads (hence suitable for fans). It may be possible to use them in small systems (e.g. domestic style systems used for light commercial applications)[13]. Literature from the US estimates a 12% energy savings at a cost of €108 for a 2-door, high-temperature cabinet and 12% energy savings at a cost of €122 for a 1-door, low-temperature cabinet[14].

- Process chillers (CH): chiller experts have mentioned that the savings for ECM might occur for low capacities chillers. For larger capacities the potential savings are smaller. Industry stakeholders have mentioned that this option by itself does not provide significant improvement. It should be combined with controls.

- RCU: electronically commutated motors can reduce the energy consumption of the electronic motor up to 10%. Within compressors, it is usually used together with digital controls, which have the main advantage of allowing variable capacity management. This option can additionally reduce the energy consumption in around 10%.

Table 5-3: ECM compressor – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	2 to 3	N.A.	12	108	N.A.
SC LT	2 to 3	N.A.	12	122	N.A.
BC	2 to 3	N.A.	10	100	N.A.
WICR	now	N.A.	4	N.A.	N.A.
CH MT	Now	N.A.	35 to 46	8,520*	15
CH LT	Now	N.A.	12 to 35	10,500*	15
RCU MT	Now	less than 10	10	500*	10
RCU LT	Now	less than 10	10	700*	10

[12] Source: Daikin

[13] Source: Foster

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

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

5.2.1.3 High efficiency compressor

Relevance:

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

High efficiency compressors (achieved by reducing suction and discharge gas pressure losses, mechanical losses through friction, and electrical losses in the motor) directly reduce energy consumption. Moreover, the improved gas management as well as optimised matching of the motor to the specific compressor displacement and its application might improve the COP within existing technologies. Average compressor efficiency depends on the type and price of the product. For example, small plug-in products use small compressors that can have a high improvement potential, whereas bigger products, systems or compressor racks use more efficient compressors and the improvement potential is lower. According to stakeholders[15] and experts consulted, the improvement potential in the actual compressors in the market is very low, and future energy savings will be more related to ambient, temperature differences and capacity controls than to the construction of the compressor.

- SC: Stakeholders quoted a figure of 10% energy savings potential at a cost of €10 to €40[16]. However, other stakeholder comments have indicated that, on average, only a 5% improvement in efficiency of compressors might be attainable by 2020. The figure 12% is quoted in the literature, as described in Task 4. Other estimates in the literature from the US are 7% energy savings at a cost of €17 for a 2-door, high-temperature cabinet and 14% energy savings at a cost of €19 for a 1-door, low-temperature cabinet[17]. A figure of 7% energy saving has been used for high-temperature and 10% energy savings for low-temperature.
- WICR: In addition to stakeholder figures, estimates in the literature from the US are 9% energy savings at a cost of €431 for a 48.31m^3, high-temperature and 10% energy savings at a cost of €517 for a 13.4m^3, low-temperature, walk-in cold room[17]. As this improvement is applicable only to larger (remote) products[18], with higher cooling capacity, which represent approximately half the market, a weighted estimate of 5% energy saving and cost of €200 has been used.

[15] Daikin, Bitzer

[16] Source : Friginox, Gram, Electrolux

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

[18] Source: GR Scott

- CH: The newest high-efficiency development in the high-capacity compressor market would be a digitally-modulated compressor and variable speed centrifugal compression. This technology can be used for very large remote condensing units and chillers with estimated energy savings of up to 15% compared to conventional systems (according to the manufacturers). Due to the high production costs, this kind of compressors is not yet available for low cooling capacity requirements. With the spread of the technology and increased production, however, it is thought that this efficiency will be achieved for all compressor ranges in the future. According to stakeholders[19], the future medium-term average compressor in a chiller will save around 5% of the energy compared to the average current compressor (not including VSD). If comparing extremes, the current worst performer against the best future performer, this gap can increase up to 30%.
- RCU: The improvement potential within the compressor construction is very low and improvements would be more related to refrigerant selection, part load and seasonal performance. The efficiency of the compressor itself depends on the size of the compressor, the refrigerant used, the operating temperatures and the technology used (hermetic or semihermetic reciprocating, scroll, etc.). As these improvement options are being analysed separately, high efficiency compressor will not be further investigated as independent improvement option for remote condensing units.

[19] Source: Daikin; McQuay

Table 5-4: High efficiency compressors – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	40	7	20	N.A.
SC LT	Now	40	10	40	N.A.
BC	Now	40	10	40*	0.5
WICR	Now	N.A.	5	200	N.A.
CH MT	Now	N.A.	5**	6,000*	10
CH LT	Now	N.A.	5**	7,000*	10
RCU MT	Now	N.A.	N.A.	N.A.	N.A.
RCU LT	Now	N.A.	N.A.	N.A.	N.A.

** Increase in price calculated from the weighted base case product price using % price increase figure*
***Over analysis of other individual technologies related to compressors, these values are more likely to be achieved*
-: Not applicable to this product group
N.A.: No data available

5.2.1.4 Compressor control

Relevance:

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

As discussed in Task 4, there are several control methods available for altering the workload performed by the compressor. The most common load-control technology in the compressor market is on/off, while technologies such as variable speed controls and digital controls could potentially lead to energy savings.

- **Variable speed drive**

VSD compressors only allow energy savings when working under part load conditions. Generally, if a constant-speed compressor is expected to operate at or above 80% of its capacity, it is the more efficient choice. On the other hand, if a constant-speed compressor operates below 80% of its capacity, then replacing it with a VSD compressor will provide additional savings. However, the energy saving varies depending on the ambient conditions and workload. Inverter technology for VSD also allows the compressor to operate above nominal speed.

That said, VSD technology has higher installation costs and thus is typically not the first choice for installers and purchasers. With the development of the technology and economies of scale, this technology could become affordable in lower capacity ranges in the future.

- SC: One stakeholder quoted a 20% saving potential for service cabinets using VSD compressor, compared to the range of 10% to 15% described in Task 4, but this figure seems high, particularly in consideration of the relative steady state load in these products and the rarity of remote products. Other estimates in the literature from the US are 13% energy savings at a cost of €157 for a 2-door, high-temperature cabinet and 14%

energy savings at a cost of €168 for a 1-door, low-temperature cabinet[20]. Stakeholders state that these types of compressors are not yet available, but are currently undergoing laboratory tests.

- BC: After revision of the figures by stakeholders, the potential energy savings of 20% was reduced to 10% by using this technology. The price is assumed to be similar to the one found for SC, while the market penetration is estimated to be between 1 to 2% according the stakeholders (Friginox, 2010). This technology can be applied to all capacities. However, for small equipment is currently too expensive.
- WICR: As this improvement is applicable only to larger products[21], its development for walk-in cold rooms is expected to develop over the coming years.
- CH: Stakeholder feedback has suggested that chillers run at 80% full load on average and that inefficient offloading may be an issue. Equipping the process chiller with a motor convertor, to reduce loads in an efficient way and to deal with periods of lower load, may provide energy savings. There are several chiller manufacturers already using this technology in their products who claim that the highest efficiencies are observed when energy consumption is measured to take into account seasonality (ESEER)[22].
- RCU: VSD compressors can save up to 80% of TEC, depending on the workload. According to experts consulted, with an average load of 70% to 80%, energy savings are approximately 10%. According to stakeholders[23], VSD inverter technology can increase the price of the unit around 25% to 50%, depending on the maximum capacity reached by the compressor with the inverter.

Table 5-5: VSD compressor – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)**	Increase in price of product (€)	Increase in price of product (%)
SC HT	2 to 3	0	10	80	N.A.
SC LT	2 to 3	0	10	168	N.A.
BC	Now	1 to 2	10	200	N.A.
WICR	Now	0	15	N.A.	N.A.
CH MT	Now	N.A.	15	10,800	18
CH LT	Now	N.A.	15	12,600	N.A.
RCU MT	Now	2	10	1,300*	25
RCU LT	Now	2	10	1,900*	25

** Increase in price calculated from the weighted base case product price using % price increase figure*
*** Depends on the use conditions - may require more energy*
-: Not applicable to this product group

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

[21] Source: GR Scott

[22] European Seasonal Energy Efficiency Ratio. Weighted value of Energy Efficiency Ratio (EER) considering the variation of this parameter with the load requirement and the change of ambient temperature. $ESEER = 0.03*EER_{100\%} + 0.33*EER_{75\%} + 0.41*EER_{50\%} + 0.23*EER_{25\%}$

[23] Tecumseh, 2010, Danfoss, 2010, Bitzer, 2011

	Applicability (years)	Market penetration (%)	Savings (% TEC)**	Increase in price of product (€)	Increase in price of product (%)

N.A.: No data available

◆ **Digital modulation control**

As discussed in Task 4, digital controls for compressors are a type of variable speed control.

According to information provided by stakeholders, Digital modulation controls can achieve up to 10% energy savings in refrigeration machines and the increase in price is around 25%, depending on the product and the size of the compressor. For remote condensing units, a 25% of price increase in the compressor means an increase on the total product price of 10%.

Table 5-6: Digital modulation controls for compressor – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	Now	less than 10	10	1,700*	10
RCU LT	Now	less than 10	10	2,000*	10

** Increase in price calculated from the weighted base case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.1.5 Parallel compressors

Relevance:

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

As discussed in Task 4, using one compressor on several fixtures results in greater efficiency, because larger compressor motors are inherently more efficient. The disadvantages of using a single large compressor are as follows:

- the refrigeration load cannot be closely matched;
- starting and stopping larger compressors is more difficult;
- short cycling larger compressors may increase both electrical demand and energy consumption; and
- larger compressors are less efficient if refrigeration load decreases.

Therefore, when the pressure head requirement is high enough, several compressors might be used in place of a single large compressor. Parallel compressors using step control in refrigeration and freezing products can operate as variable speed drive controls and achieve higher efficiency in seasonal peaks by switching on one or several compressors, when needed, and turning them off again when the load decreases. This technology can be used with all the types of compressors, even though for more expensive compressors, the investment price might be too high. The energy savings can be around 10%, similar to the VSD and other part load technologies.

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 group[24]. Parallel compressors are technically applicable to all capacity ranges and operating temperatures, but the over cost of this technology makes it inaccessible to products of low and medium capacity ranges, being applied mostly over 100 kW of cooling capacity, and in some cases over 50 kW.

- The increase in cost of the additional compressor is assumed to be around 10% of the total price per compressor added. This is probably because the additional compressor will not require of such big capacities.

Table 5-7: Parallel compressors – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	Now	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Now	NA	10	6,000*	10
CH LT	Now	NA	10	7,000*	10
RCU MT	Now	5	10	2,300*	35
RCU LT	Now	5	10	2,700*	35

** Increase in price calculated from the weighted base case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

5.2.2 Fans

Fans are also used in all vapour-compression cycle equipment included within the scope of the preparatory study. High efficiency motors, blades and control mechanisms can be used to achieve energy savings.

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

5.2.2.1 High efficiency fan motors

Relevance:

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

Fans within a 125W to 500kW power range, including those integrated in other products, are being currently considered for regulation under Directive 2009/125/EC. Please see Task 1 for more details. However, as described in Task 4, many products include fans of power under 125W, hence investigation of technologies to improve efficiencies of these fans is needed.

- **Permanent split capacitor motor**

As described in Task 4, PSCM are more efficient than traditional shaded-pole motors. They are commonly applied to direct drive fans and blowers with low starting torque.

- WICR: In addition to stakeholder figures, estimates in the literature from the US are 9% energy savings at a cost of €172 for a 48.31m^3, high-temperature walk-in cold room and 11% energy savings at a cost of €65 for a 13.4m^3, low-temperature walk-in cold room when installed at the evaporators and 5% energy savings at a cost of €23 for low-temperature walk-in cold rooms when installed at the condenser[25]. Other sakeholder feedback suggests that these savings may in fact be approximately 2%[26].

Table 5-8: PSC motor for fans – market data and improvement potential

Evaporator	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	2 to 5	N.A.	N.A.
SC LT	Now	N.A.	N.A.	N.A.	N.A.
BC	Now	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	10	100	N.A.
CH MT	Now	N.A.	N.A.	N.A.	N.A.
CH LT	Now	N.A.	N.A.	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-
Condenser	**Applicability (years)**	**Market penetration (%)**	**Savings (% TEC)**	**Increase in price of product (€)**	**Increase in price of product (%)**
SC HT	Now	N.A.	N.A.	N.A.	N.A.
SC LT	Now	N.A.	N.A.	N.A.	N.A.
BC	Now	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	N.A.	N.A.	N.A.
CH MT	Now	N.A.	N.A.	N.A.	N.A.
CH LT	Now	N.A.	N.A.	N.A.	N.A.
RCU MT	Now	N.A.	N.A.	N.A.	N.A.

[25] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)
[26] Source: Viessmann

Evaporator	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
RCU LT	Now	N.A.	N.A.	N.A.	N.A.

** Increase in price calculated from the weighted base case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

- **Electronically commutated motor**

As described in Task 4 and in §5.2.1.2 above, ECM is a high efficiency DC motor. An ECM motor is up to 10% more efficient than a PSC motor, and with electronic control of the rotating speed, the energy savings would be slightly higher. ECM motors can be up to 50% more expensive than PSC motors depending on the size and the electronic speed controls that can include.

- SC: In Task 4, potential savings of 2 to 5 % for the evaporator fan and 3% for the condenser fan were quoted. Other estimates in the literature from the US are 18% energy savings at a cost of €37 for a 2-door, high-temperature cabinet and 7% energy savings at a cost of €18 for a 1-door, low-temperature cabinet at the evaporator and 14% energy savings at a cost of €23 for a 2-door, high-temperature cabinet and 3% energy savings at a cost of €26 for a 1-door, low-temperature cabinet at the condenser[27]. Averaged figures have been used. Stakeholders have mentioned that ECM fans sometimes include high efficiency fan blades.
- BC: According to stakeholder comments, the market penetration for this improvement option is considerably lower than service cabinets, around 5%. The impact on the energy savings will be related mainly to the hold-in mode. Therefore the energy savings in blast cabinets is expected to be lower than for service cabinets, up to 7%.
- WICR: In addition to stakeholder figures, estimates in the literature from the US are 13% energy savings at a cost of €380 for a 48.31m^3, high-temperature and 14% energy savings at a cost of €108 for a 13.4m^3, low-temperature walk-in cold room when installed at the evaporators and 2% energy savings at a cost of €65 the high temperature walk-in and 7% energy savings at a cost of €52 the low-temperature walk-in when installed at the condensers[27]. Other stakeholder feedback suggests that the savings at the evaporator may in fact be only 4 to 5%[28].
- CH: according to the feedback from stakeholders[29], the ECM fans for the condenser can reach up to 2% of the total energy consumption.
- RCU: according to information provided by stakeholders and experts, ECM for fans in a remote condensing unit can be up to 100% more expensive than a standard fan[30], meaning an increase in price of the product of 5%,

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

[28] Source: Viessmann

[29] Source: Eurovent, Ziehl-abegg

[30] Ziehl-Abeg

and can reduce the energy consumption in 0.5% for medium temperature and 1% for low temperature.

Table 5-9: ECM fan – market data and improvement potential

Evaporator	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	20	12	18	N.A.
SC LT	Now	20	7	18	N.A.
BC	Now	5	14 to 21	84*	0.7
WICR	Now	0	13	150	N.A.
CH MT	Now	N.A.	N.A.	N.A.	N.A.
CH LT	Now	N.A.	N.A.	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-
Condenser	**Applicability (years)**	**Market penetration (%)**	**Savings (% TEC)**	**Increase in price of product (€)**	**Increase in price of product (%)**
SC HT	Now	20	8	20	N.A.
SC LT	Now	20	3	20	N.A.
BC	Now	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	3	60	N.A.
CH MT	Now	N.A.	2	2200*	0.5
CH LT	Now	N.A.	2	2800*	0.5
RCU MT	Now	20	0.5	260	5
RCU LT	Now	20	1	370	5

** Increase in price calculated from the weighted base case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.2.2 Fan motor controls

Relevance:

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

Fan motor controls are devices that monitor and regulate the speed of a fan motor. Energy savings can be achieved by reducing the speed of the fan motor, or switching it off entirely, when the refrigeration load has decreased. Fan motor controls are usually made out of several blocks, and the sensor (thermistor) is situated on key blocks. The thermistor measures the temperature and modulates the voltage applied to the motor, thereby controlling its speed. The other blocks consist of electronic circuits which physically modulate the power to modify speed. Control of the fan could be achieved by electronically commutated motors (ECM), variable speed drives, or by installing several fans on the same evaporator/condenser

For on/off systems, some of the condenser fans might be switched off at lower load, meaning that some of the condenser coil will not be ventilated, thereby reducing efficiency. 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.

Variable speed drivers and similar technologies in fans are not however always beneficial. When airflow over an evaporator falls, the surface film heat transfer coefficient is reduced, thereby reducing the heat transfer capacity of the evaporator (the system is effectively equipped with a smaller capacity evaporator). The compressor suction pressure falls as a consequence, leading to an increase in the pressure ratio, fall in COP, and potentially reduced service life of the compressor. As the energy consumed by the evaporator fan is small in comparison to the energy consumed by the compressor, reducing evaporator fan speed is likely to lead to an overall loss of system efficiency. Only modelling can determine the trade-off point for any given case.

- SC: As discussed in Task 4, VSD or two-speed fan motors could provide energy savings of around 3%[31] . However, if these variable speed fan motors prevent the condensing temperature from falling, this could reduce the system efficiency and increase the energy consumption.
- WICR: In addition to stakeholder figures, estimates in the literature from the US are 5% energy saving at a cost of €108 for a 48.31m^3, high-temperature and 4% energy saving at a cost of €108 for a 13.4m^3, low-temperature walk-in cold room for VSD control[32].
- RCU: According to information provided by stakeholders and experts, variable speed fans in remote condensing units can be up to 100% more expensive than a standard fan[33], meaning an increase in price of the product of 5%. Savings are the result of VSD control; however, as explained above, these savings in the fan motor consumption can have a drawback in the compressor motor consumption, due to the compressor suction pressure falling, and the overall efficiency of the product might be lower. Therefore, this option would only be beneficial in case of part load and seasonal performance.

[31] 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

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

[33] Ziehl-Abeg

Table 5-10: Fan motor control – market data and improvement potential

Evaporator	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	3	N.A.	N.A.
SC LT	N.A.	N.A.	3	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	2 to 3	0	3	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-
Condenser	**Applicability (years)**	**Market penetration (%)**	**Savings (% TEC)**	**Increase in price of product (€)**	**Increase in price of product (%)**
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	N.A.	20	N.A.	260	5
RCU LT	N.A.	20	N.A.	370	5

** Increase in price calculated from the weighted base case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.2.3 High efficiency fan blades

Relevance:

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

The fans typically used in refrigeration equipment have sheet metal blades, with an energy efficiency of around 40 %[34]. This could be improved by a better design.

One manufacturer[35] uses leading-edge air management technology to help light commercial Heating, Ventilation, and Air Conditioning (HVAC) manufacturers design higher efficiency products and significantly reduce the amount of power required to run their condenser and evaporator fans. Studies indicate that this blade technology can increase efficiency by 30 to 35% or increase airflow volume by 12 to 15% without having to increase the power supply to the fan motor. Additionally, some manufacturers replace metal blades by plastic ones for a more efficient design.

[34] Source: Mark Ellis & Associates, *Analysis of Potential for MEPS for Remote commercial Refrigeration*. (March 2000)
[35] Delphi Corporation

The 2008 ASERCOM competition winner was a manufacture[36] of new energy efficient fan range. These fans are characterized by low noise, long life time, no required maintenance, high controllability and safety. The combination of an aluminium support structure with a glass fibre-reinforced plastic cover employing aerodynamic design features delivers better noise characteristics as well as higher efficiency than traditional blades. These fans are used in refrigeration technology applications such as evaporators and condensers[37].

Stakeholders have stated that usually ECM fans include high efficiency fan blades.

- SC: Other than stakeholder figures provided, estimates in the literature from the US are 7% energy saving at a cost of €6 for a 2-door, high-temperature cabinet and 3% energy saving at a cost of €4 for a 1-door, low-temperature cabinet[38].
- BC: Service cabinet evaporator fans use about 3 times less energy than the blast cabinet evaporator fans. Therefore, the improvement potential for high efficiency blades in blast cabinets is assumed to be about 3 times greater than for service cabinets. In the same way, because blast cabinet fans are usually bigger, the price increase is considered to be at least 3 times higher. These assumptions apply to each fan installed in the appliance.
- WICR: In addition to stakeholder figures, estimates in the literature from the US are 6% energy saving at a cost of €130 for a 48.31m^3, high-temperature and 5% energy saving at a cost of €36 for a 13.4m^3, low-temperature walk-in cold room. An estimate of cost of €50 has been used. Other sakeholder feedback suggests that the savings may in fact be only 1%, and that the main benefit of these is a reduction of noise[39].
- RCU: according to experts and stakeholders consulted[40], efficient blades design in fans would reduce the energy consumption of the fan motor from 1% to 5%, which means up to 0.5% savings in the overall consumption of the condensing unit.

[36] ebm-papst

[37] ASERCOM Energy Efficiency Award 2008, www.asercom.org/

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

[39] Source: Viessmann

[40] Ziehl-Abegg

Table 5-11: High efficiency fan blades – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	20	3	5	N.A.
SC LT	Now	20	3	5	N.A.
BC	Now	N.A.	9	10	N.A.
WICR	Now	0	3	50	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	Now**	20	0.5	100*	0.5
RCU LT	Now**	20	0.5	150*	0.5

** Increase in price calculated from the weighted base case product price using % price increase figure*
***Only applicable at the condenser*
-: Not applicable to this product group
N.A.: No data available

5.2.3 Heat exchangers

Heat exchangers are used in both condensers and evaporators.

Relevance:

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

5.2.3.1 Increase of the heat exchanger surfaces

One way to achieve higher efficiency is to increase the heat exchangers' surface area at the evaporator and at the condenser. This can be done through one, or a combination of the following approaches:

- increased size;
- increased fin density (although this option can lead to higher risks of fouling for the condenser and potential for frost at the evaporator); and
- use of rifled tubing (copper tubing with small ridges formed on the inside) rather than smooth tubing.

Figure 5-1: Example of rifled tube

As a means to improve capacity performance in refrigeration appliances, using rifled tubing in an evaporator is more effective than using it in a condenser. Depending on the temperature differences between the air-on and the evaporator and condenser saturated temperatures, a percentage increase in the capacities of condenser and evaporator will change the compressor pressure ratio and alter the system performance. Use of rifled tubing to increase heat exchanger capacities by

10% could result in around 3% increase in system performance.[41] In general, efficiency is improved more by increasing condenser capacity than evaporator capacity by a given amount[42].

However, increasing evaporator and/or condenser surface requires increasing the fan power by the same ratio. Hence, an optimal surface area has to be defined in order to maximise energy savings. The optimal surface is mainly determined by the ambient conditions and refrigeration load profile.

On the evaporator side, the surface area influences the humidity level in the product, whereas on the condenser side, increased surface area in low ambient temperature (such as winter time) might cause a large drop in condensing pressure. This can lead to the pressure difference across the expansion valve to be too low for it to function correctly. In most cases, however, pressure is maintained at a high level throughout the year (it also possible to decrease the air flow rate to maintain pressure at acceptable levels, as required by the compressor manufacturer). However, this would be a move away from floating head pressure, as described in §5.2.10.1), although this is not advisable as it leads to higher energy consumption than necessary.

Another disadvantage of bigger condensing surface mentioned by stakeholders is that the refrigerant tends to accumulate in the condenser in winter period and, with larger condensers, this could lead to refrigerant shortage in the rest of the circuit[43].

- SC: Stakeholders have stated that this improvement option requires further analysis to determine percentage increase in heat exchanger surface area required to achieve the quoted 4% energy savings, which might result from fine-tuning of the surface area to optimise system efficiency. Due to the uncertainty of the figures, this improvement will not be investigated in the analysis until further stakeholder feedback is received.
- WICR: Due to the uncertainty of the figures, this improvement will not be investigated in the analysis until further stakeholder feedback is received.

Table 5-12: Increase of the heat exchanger surfaces – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	5	4	2	N.A.
SC LT	Now	5	4	2	N.A.
BC	Now	5	5	9*	0.1
WICR	Now	N.A.	3	10	N.A.
CH MT	Now	5	4	1,100*	2
CH LT	Now	5	4	1,400*	2
RCU MT	Now	5	4	120*	2
RCU LT	Now	5	4	140*	2

** Increase in price calculated from the weighted base case product price using % price increase figure*

[41] Rifled tube: An effective answer in many applications, September 2000 www.achrnews.com/Articles/Feature_Article/c2cad180ec75a010VgnVCM100000f932a8c0____

[42] Source: Defra

[43] Source: Equipment manufacturer

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)

-: Not applicable to this product group
N.A.: No data available

5.2.3.2 Heat transfer semi-welded plates

API Heat Transfer, an American company specialised in heat exchangers, features plates that are welded using advanced laser welding techniques. The resulting plate pack is fully serviceable, while maintaining the integrity of the welded plate pair. This is especially suitable for critical fluids and gases, such as ammonia or caustic process chemicals where fluid loss is not acceptable. In the case of ammonia refrigeration, the reduced volume results in significant savings. This type of heat exchanger is thus highly appropriate for plug in or remote refrigeration equipment using ammonia.

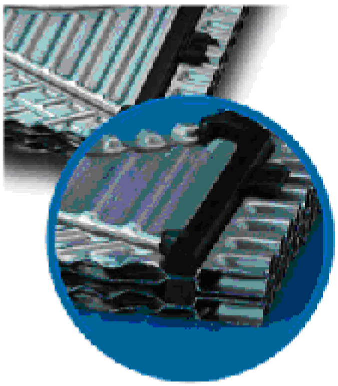


Figure 5-2: Cut away of semi-welded plates for heat exchangers

5.2.3.3 Brazed plate heat exchangers

Brazed plate heat exchangers are increasingly used by the heat transfer industry as a result of their compact size and high-efficiency design. Brazed plate units are up to six times smaller than alternative methods of heat exchange with the same capacity. Up to 150 corrugated stainless steel plates are brazed together with every second plate rotated 180 degrees. This design creates two highly turbulent fluid channels that flow in opposite directions over a massive surface area. This results in a significantly higher heat transfer coefficient, with less surface area required.

Figure 5-3: Flow channel diagram in a Brazed Plate Heat Exchanger[44]

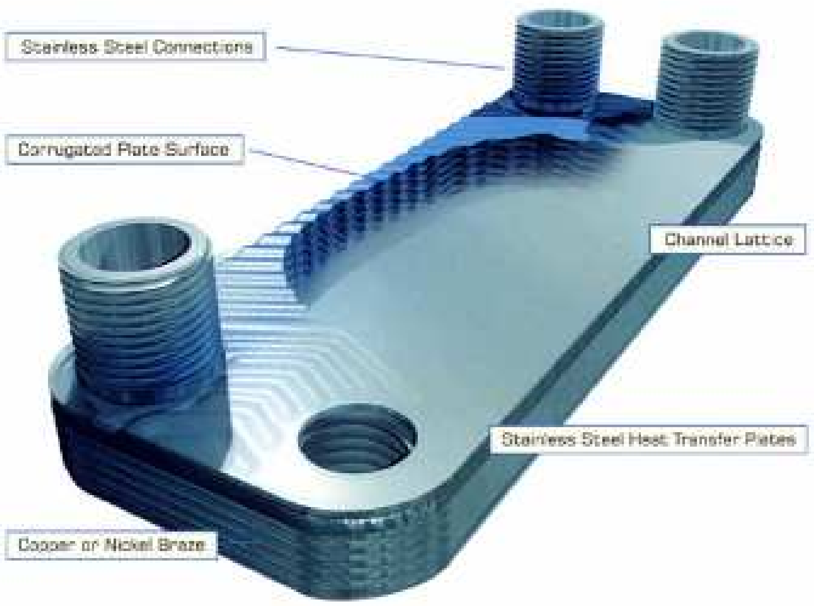


Figure 5-4: Cutaway of a Brazed Plate Heat Exchanger[44]

Brazed plate heat exchangers are used in various applications of the refrigeration sector, such as liquid coolers, supermarket systems or water chillers.

5.2.3.4 Mini-channel heat exchangers

Mini-channel heat exchangers[45] are being developed for advanced cooling and climate control applications. Bulk and surface micromachining techniques are used to fabricate the test devices. Each heat exchanger section consists of over 150 mini-channels etched in silicon substrates by either chemical etching or ion milling processes. The channels are 100 micrometers deep, 100 micrometers wide, and spaced 50 to 100 micrometers apart and connected with headers. Other heat exchangers have also been fabricated in copper and aluminium using machining

[44] Source: Diversified Heat Transfer Inc.

[45] Kandlikar, S G, A Roadmap for Implementing Minichannels in Refrigeration and Air-Conditioning Systems—Current Status and Future Directions; Heat Transfer Engineering, 28(12):973–985, 2007

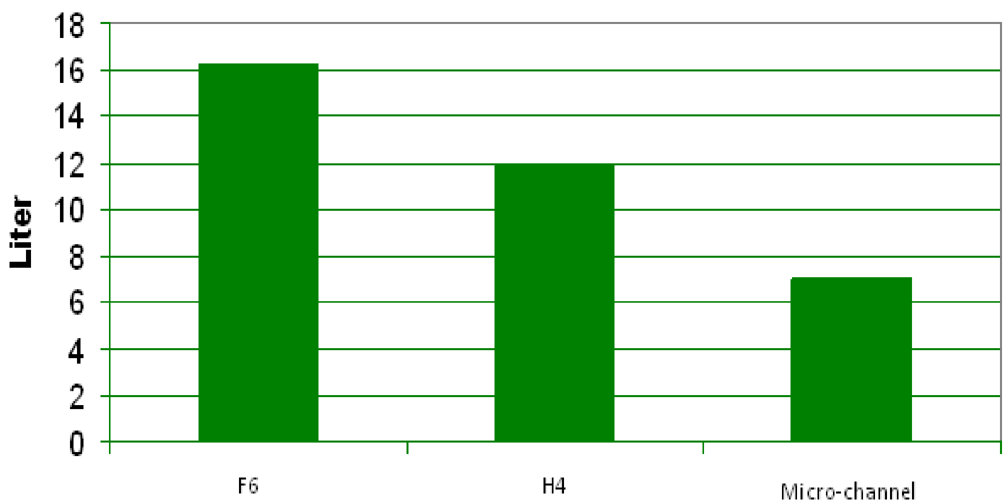
and ion milling processes. Recent heat exchangers have the silicon laminated to copper substrates.

Table 5-13: Performance comparison of various heat exchangers[46]

Parameter	Shell and Tube Heat Exchanger	Compact Heat Exchanger	Micro-channel Heat Exchanger
Surface Area Per Unit Volume (m^2/m^3)	50 – 100	850 – 1500	> 1500
Heat Transfer coefficient ($W/m^2/K$) (liquid)	~ 5000 (tube side)	3000 – 7000	> 7000
Heat Transfer coefficient ($W/m^2/K$) (Gas)	20 – 100	50 – 300	400 – 2000
Approach Temperature (°C)	~ 20°C	~ 10°C	< 10°C
Flow Regime	Turbulent $\frac{\Delta P}{L} \propto V^{1.75}$	Turbulent $\frac{\Delta P}{L} \propto V^{1.75}$	Laminar $\frac{\Delta P}{L} \propto V$

Mini-channel heat exchangers can have a reduced refrigerant volume of up to 70% in comparison to finned heat exchangers. Below, a comparison between 2 conventional coils (F6 and H4) and 1 mini-channel coil, all of the same dimensions (1m x 1m) is presented.

Table 5-14: Comparison of refrigerant volume of different heat exchanger coils with the same effective surface areas



This is an enabling technology especially for refrigerants that have not been widely used due to safety considerations and charge limitations, such as ammonia or hydrocarbons, which can achieve high efficiencies and have very low GWP values. A study by the University of Padova[47] has revealed that a charge reduction of 20% with the adoption of a mini/micro-channel condenser. Prototype ammonia chillers

[46] Source: A. Lee Tonkovich, Velocys Inc., *Micro-channel Heat Exchanger: Applications and Limitations*.

[47] L. Cecchinato. "Experimental Analysis of a Water Chiller Using Ammonia as Refrigerant"

using this technology have been already showed by the industry[48] and are expected to be developed for hydrocarbons in the future[49].

The costs of a heat exchanger are mainly determined by its material costs and the production costs. Due to the lower material expenditure and the lower price of aluminium in comparison to copper, the material costs of a mini-channel heat exchanger are much lower than those of a finned heat exchanger. When considering the production costs, production times are reduced, due to a highly automated production process. The individual unit price, however, may increase slightly, as high investment costs must be allocated to the respective production quantities, whilst also considering the life span of the production machinery. In the long run though, a mini-channel heat exchanger will represent a much more economic alternative than a finned heat exchanger with copper tubes, and even be more cost-efficient than a finned heat exchanger with aluminium tubes.[50]

The mini-channel technology has been well-established in the automotive industry for many years but, until now, this technology was never adapted to be used in the stationary refrigeration industry. The reason is that conventional mini-channel production processes are designed to produce high numbers of identical mini-channels, whereas a manufacturer of stationary refrigeration units would require a great variety of mini-channels, but in small quantities each. Reliability in operation due to fouling or corrosion over time is also a challenge to these technologies.

Table 5-15: Mini-channel heat exchangers – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Next five years	N.A.	N.A.	N.A.	N.A.
CH LT	Next five years	N.A.	N.A.	N.A.	N.A.
RCU MT	Next five years	0	10	1,300*	20
RCU LT	Next five years	0	10	1,600*	20

**Increase in price calculated from the weighted Base Case product price using % price increase figure.*
-: Not applicable to this product group
N.A.: No data available

5.2.3.5 Non-circular and flattened heat exchangers

Several projects have addressed the potential enhancement in the performance of heat exchangers through the use of small tube, oval, and flattened-tube designs. In addition to taking advantage of reduced air-side pressure losses over the coil and the associated reduction in fan power consumption, these tube designs have the potential of providing the same cooling capacity with a much smaller refrigerant charge. Manufacturing cost, tube integrity, and durability play a key role in enhanced coil tube design and marketability.

[48] Bitzer Australia. Source: Shecco
[49] microox micro-channel technology, H Guntner UK Limited. Source: Shecco
[50] Source: Dr. Franz Summerer *A new Heat Exchanger Technology for air-cooled condensers*

According to experimental studies on display cabinets[51], flat-tubing can decrease the energy consumption by 15%[52]. However, this result has not tested directly for blast cabinets. The availability of blast cabinets using this technology has not been found. Due to the structural similarities of blast, display and service cabinets, it is assumed as applicable. Although the energy improvement could be bigger for blast, since the heat transfer requirements are bigger and faster, the value proposed is up to 15%.

Figure 5-5: Flattened-tube heat exchangers[53]

Table 5-16: Non-circular and flattened heat exchangers – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	15	N.A.	N.A.
SC LT	Now	N.A.	15	N.A.	N.A.
BC	Now	N.A.	15	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Now	N.A.	15	N.A.	N.A.
CH LT	Now	N.A.	15	N.A.	N.A.
RCU MT	Now	N.A.	N.A.	N.A.	N.A.
RCU LT	Now	N.A.	N.A.	N.A.	N.A.

-: Not applicable to this product group
N.A.: No data available

5.2.4 EVAPORATOR

For improvement options which apply to heat exchangers in general (i.e. evaporators and condensers) please see in §5.2.3.

5.2.4.1 Pool boiling (flooded-evaporator)

Relevance:

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

[51] Source: STIGNOR, C., SUNDEN, B., FAHLEN P. *Energy-efficient flat-tube heat exchangers for indirectly cooled display cabinets*. 2009

[52] Source: ee.emsd.gov.hk/english/air/air_technology/air_tech_air.html

[53] Source: ARTI (Air-Conditioning & Refrigeration Technology Institute), *Basic Research Driving the Future of America's Heating, Ventilation, Air Conditioning and Refrigeration Technologies.* (2004)

- CH: Pool boiling is a recent technology where the refrigerant is placed in the shell side of the heat exchanger, instead of the typical location in the tube-side. This technology can increase the system efficiency by 10% to 15%. The application of this technology is limited by its high cost. The extra cost is estimated to be around 2 or 2.5 times more expensive than typical heat-exchangers, as it uses almost 6 times more refrigerant.

Table 5-17: Pool boiling – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	-	-	-	-	-
SC LT	-	-	-	-	-
BC	-	-	-	-	-
WICR	-	-	-	-	-
CH MT	Now	less than 5	15	82,500*	150
CH LT	Now	less than 5	10	105,000*	150
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.5 CONDENSER

For improvement options which apply to heat exchangers in general (i.e. evaporators and condensers) please see in §5.2.3.

5.2.5.1 Water cooling

Relevance:

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

Water has better heat transfer properties than air; therefore, water-cooled and evaporative-cooled condensers are typically more efficient than air-cooled models. In the case of water-cooled and evaporative condensers, pumps can be used to improve the heat transfer.

Water-cooled systems transfer heat to water in a shell-and-tube heat exchanger. The circulated water is rarely discarded as waste after a single pass through the condenser. Generally, in a closed loop, the thermal energy is transferred to the ambient air through a humidification process in a cooling tower.

The performance of a water-cooled condenser depends on the heat transfer between the refrigerant tubes and water flow. Water-cooled condensers not only have a higher heat transfer coefficient than air-cooled condensers but also have a simpler configuration than evaporative-cooled condensers.

The cost of the water-cooled condensers with cooling towers and the evaporative cooling condensers for remote condensing units are higher than the base case. Nevertheless, the conventional water-cooled condensers involve a cooling tower, which also imply a larger installation space and extra power for fan and pump[56].

Water cooling is used in industrial process chillers, but its application in commercial refrigeration or air conditioning is limited due to safety problems related to *legionella* contamination and other bacteria. Furthermore, performance test methods for chillers do not take into account the power consumption of the water pumps, leading to unrealistic efficiencies. According to stakeholder information, if the power consumption of all the cooling tower system is accounted, water cooling would not provide any efficiency improvement.

- RCU: The energy consumption of water-cooled systems in remote condensing units can be up to 32%-45% lower than air-cooled systems, according to literature[54], but feedback provided by stakeholders suggested that these gains could be nullified due to the extra energy consumption of the water pumps[55]. Water cooling is not applicable to all the cooling capacity ranges in remote condensing units for commercial refrigeration, but mostly over 100 kW.

Table 5-18: Water cooling – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	Now	5	up to 5	700*	10
RCU LT	Now	5	up to 5	800*	10

** Increase in price calculated from the weighted base case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.5.2 Evaporative cooling

Evaporative cooled condensers include a spray of water falling onto the condenser tubes as air is simultaneously blown over the tubes. All of the heat rejection is by evaporation.

A fan system forces air through the falling water and over the coil surface. Part of the water is evaporated, removing heat from the refrigerant, and condensing it inside the coil. The water that is not evaporated then drains to the bottom of the condenser unit and is pumped back up to the sprayers. Cooling is accomplished by the evaporation of the water in the air-stream. The flow-rate of water need only be enough to thoroughly wet the condensing coil to provide uniform water distribution and prevent accumulation of scale.

Evaporative-cooled condensers are complicated since the surface of the condenser tubes needs to be covered with a layer of fibre to maintain a perfect contact between air and water[56].

[54] G.P. Maheshwari, A.A. Mulla Ali, Comparative study between air-cooled and water-cooled condenser of the air conditioning systems.
[55] Source: Daikin Europe
[56] S.S. Hu, B.J. Huang, Study of a high efficiency residential split water-cooled air conditioner. Applied Thermal Enginering 25 (2005) 1599-1613

Evaporative condensers have even better efficiency than water-cooled ones, since they reduce the need for water pumping. 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[57]. 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[58]), 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[59]. They are therefore rarely used in certain countries (e.g. the UK).

Evaporative condensers offer important cost-saving benefits for refrigeration systems, although they have been used mostly on air-conditioning machines to date. They eliminate problems of pumping and treating large quantities of water as is the case in water-cooled systems. Furthermore, they require substantially less fan capacity than air-cooled condensers. These systems can be designed for a lower condensing temperature and subsequently lower compressor energy input than systems operating conventional air-cooled condensers[60].

Evaporative condensers are normally appropriate to large cooling systems, and are not currently applicable to small cooling machines covered in ENTR Lot 1 preparatory study. Therefore, they will be presented as a BNAT option that could be available in the future depending on the technical developments within the next years.

- WICR: As described in Task 4, evaporative cooling could lead to 8.2% reduction in electricity consumption. However, stakeholders have raised concerns over the issue of growth of legionella. This option is therefore not currently analysed further.
- RCU: The primary benefit of an evaporative water cooled condenser unit is 11% to 40% of energy savings in overall power consumption[61],[62] (depending on the source), and a 40% to 50% reduction in peak power consumption, according to the manufacturer. These systems have a better performance in hot, arid climates.

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

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

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

[60] Baltimore Aircoil

[61] K.A. Manske et al, Evaporative condenser control in industrial refrigeration systems, International journal of refrigeration, Vol. 24, No. 7, pp. 676-691, (2001).

[62] Nahb Research Centre

Table 5-19: Evaporative cooling – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	8.2	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	Next 5 years	Less than 5	10	1,300 *	20
RCU LT	Next 5 years	Less than 5	10	1,600*	20

** Increase in price calculated from the weighted base case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

5.2.6 Expansion valves

Relevance:

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

5.2.6.1 Electronic expansion valve

Electronic expansion valves (EEV) can be used in refrigeration equipment instead of capillary tubes or thermostatic expansion valves (TEV). EEVs make it possible to avoid the minimum pressure drop required to allow proper operation of a standard thermostatic valve. Therefore, it is possible to optimise the condensing pressure at a minimum level permitted by the ambient conditions. Using an EEV, it is possible to better regulate the superheating of the evaporator and thus improve the product's performance. Moreover, this allows better temperature control, which ensures a better preservation of products, regardless of the external conditions, and an increase of the compressor's lifespan, through the reduction of the duty cycle and internal pressure.

The reduction of electricity consumption with the use of an electronic expansion valve mainly depends on seasonal variations, and thus it is difficult to measure in standard conditions. EEV in combination with floating head pressure is discussed in §5.2.10.2. This configuration is expected to provide higher energy savings, but it does not limit the use EEV alone. The integration with floating head pressure is only applicable for remote condensing equipment.

Large energy savings using EEVs can be achieved only when the complete installation has a close control system as well as variable evaporating and condensing temperature. By installing electronic expansion valves and not changing the remaining parts, reduced energy savings might be achieved.

- SC: Due to the rarity of remote service cabinets, it is thought that few products will be able to achieve the energy savings described in the table below. This option is therefore not currently analysed further.

- BC: According to information presented by stakeholders and manufacturers, the electronic expansion valve would represent an energy saving similar to 2% of the compressor consumption per Celsius degree in the condenser. According to the feedback from stakeholders the energy savings for EEV can reach around 12%. This option is not commonly used in small size machines because of the extra cost.
- CH: According to one of the manufacturers, this can represent savings from 5% to 10% by it self. The combination of this option floating head pressure is considered in section § 5.2.10.2. However, the improvement in this case would be only relevant for part-load conditions. Installing EEV instead of TEV increases cost by about 400% of the component. It has been found in brochures that the price of EEV by itself can be 100% higher than the price of a TEV. An estimate of 200% of component increase is therefore used.

Table 5-20: EEV – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	35	100-200	N.A.
SC LT	Now	N.A.	35	100-200	N.A.
BC	Now	5	12	100	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Now	N.A.	5	1,000	N.A.
CH LT	Now	N.A.	5	1,000	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.6.2 Bubble expansion valve

In 2006, ASERCOM (Association of European Refrigeration Compressor and Controls Manufacturers) designated the bubble expansion valve an innovative expansion device[63], as it provides better overall refrigerant heat transfer in the evaporator, and thus better system efficiency.

In small and medium sized refrigeration units, a dry expansion system controlled by a thermostatic valve is a common practice. This system requires that the vapour leaves the evaporator in a superheated state. Thus, part of the evaporator is used to attain a dry and superheated condition, and this deteriorates the overall heat transfer of the heat exchanger. This drawback is not found with flooded evaporators used in large industrial applications. In these types of systems, more liquid refrigerant is supplied to the evaporator than is evaporated in one pass. The surplus of liquid not evaporated at the outlet is re-circulated. This so-called liquid overfeed of flooded systems show excellent refrigerant side behaviour of the evaporator because the entire surface is used for boiling heat transfer.

This invention aims to extend the liquid overfeed system to small equipment as well. The expansion (throttling) is controlled by a valve, whose position is defined

[63] Swedish Bubble Expansion Valve BXV(R)AB (www.bxv.se)

at the state where there is no liquid in the condenser, similar to the float valve system described above. The new device allows that liquid, together with a small amount of gas, to leave the condenser. This small volume of non-condensed gas 'slip stream' is measured, and this acts as a signal for the expansion valve. The new device incorporates an ejector to obtain a good fluid recirculation in the evaporator loop, a tiny drum to separate flash gas, and a unit to return oil to the compressor, heated by sub cooling of the liquid from the condenser. All these functions are integrated into a compact unit. No electronics are used in the control. In addition to the advantage concerning evaporation, the new device allows for a good performance of the condenser (i.e. avoids liquid build-up), the pressure of which can fluctuate with the seasonal and daily air temperature (floating pressure).

The energy savings depend on the type of equipment, which can lead to a reduction in total electricity consumption between 10% and 20%. It is expected that the equipment using this bubble expansion valve can, in several applications, compete successfully with the traditional dry expansion equipment with superheating controls in terms of electricity consumption. Nevertheless, further verifications are required to prove its reliability and technical performance.

- SC: Stakeholders have commented that further verifications are required to prove reliability and technical performance, and stated that incorporating this might lead to complications in manufacture.

Table 5-21: Bubble expansion valve – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	2 to 3	N.A.	10 to 20	N.A.	N.A.
SC LT	2 to 3	N.A.	10 to 20	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted base case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.7 Defrosting

Relevance:

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

5.2.7.1 Defrost control

Defrosting involves the introduction of heat inside the appliance and this penalises the refrigeration system performance due to the fact that process energy is used while producing no useful cooling. Furthermore, during defrosting, the temperature inside the cabinet rises above the set limit for normal operation.

Typical defrost types include off-cycle, where the defrost initiates when the compressor has shut down (and in case of freezers when the evaporator fan have shut down); natural air defrost is often used for high temperature applications, where the evaporator fan is used to blow the warmer storage temperature air onto the evaporator coil to allow defrosting. Energy efficiency and better temperature control can be helped by either reducing the consumption of the defrost components through an alternative management control or initiating defrost operations only when required (and not through a timer) through control systems detecting lack of performance and by stopping the defrost cycle as soon as the evaporator is clear of ice.

A number of defrost control strategies have been applied over the years such as: reducing the time of the defrost run to make use of the residual heat in the electric defrost coil, measuring the air pressure drop across the evaporator, sensing the temperature difference between the air and the evaporator surface, fan power sensing, variable time defrost based on relative humidity, and air differential across the coil. Most recent methods include measuring the ice thickness by monitoring the resonant frequency of an acoustic oscillator installed on the evaporator, measuring the thermal conductivity of the ice, using photo optical systems and fibre optic sensors to measure the presence of frost.

The energy savings made by using “on demand” defrost control rather than timed defrost are quite difficult to estimate, as they depend on the type of appliance and the defrost time. However, according to information obtained from stakeholders, a recent UK development modelled one on-demand defrost system during one year using an analysis of TEV superheat signals at a UK supermarket, showing a 9.5% energy saving compared to a conventional timed defrost[64].

- SC: Stakeholders have stated that some form of defrost control is a standard feature. In addition to stakeholder figures, estimates in the literature from the US are 4% saving at a cost of €49 for a 1-door, low-temperature cabinet[65]. An estimate of 3% energy saving and cost of €50 has been used.
- BC: According to a study made on the energy related to the conservation of fruits and vegetables, defrosting of the evaporator in blast freezer can lead to a 3% savings of energy consumption[66]. For blast cabinets, it has been found that this is rarely automatically controlled, but is a manually activated process. Although in most of the machines there exist “defrost systems”, for the smaller ones it can consist on leaving the door open with optionally the fan running after the blast cycle. The increase in price for this improvement is assumed to be similar to the increase in price for service cabinets. This option is considered relevant for the bigger machines when used in freezing cycles, representing a small part of the market.

[64] Using the PREDICT algorithm

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

[66] The energy and resources institute. *Energy conservation measures in the fruit and vegetable processing sector. 2008*

- WICR: In addition to stakeholder figures, estimates in the literature from the US are 2% energy savings at a cost of €108 for a 13.4m^3, low temperature walk-in cold room[65]. An estimate of 3% energy saving has been used.

Table 5-22: Defrost control – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	-	-	-	-	-
SC LT	Now	30	3	50	N.A.
BC	Now	5	3	50	N.A.
WICR	Now	0	3	108	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.7.2 Hot and cool gas defrosting

As described in Task 4, hot gas defrost uses the hot discharge (high pressure) gas directly from the compressor piped to the evaporator, and the 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.

No information has been identified on the benefits or costs of cool gas defrost.

- SC: Estimates in the literature from the US are 8% energy saving at a cost of €129 for a 1-door, low-temperature cabinet for hot gas defrosting[65]. It is however considered that this technology is not current applied to service cabinets in the EU, but might be available in the near future.
- WICR: Estimates in the literature from the US are 4% energy saving at a cost of €81 for a 13.4m^3, low-temperature walk-in cold room[67]. Again, it is assumed that this technology is not currently applied to walk-in cold rooms in the EU, but might be available in the near future.

Table 5-23: Hot gas defrost – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	2 to 3	N.A.	8	129	N.A.
BC	-	-	-	-	-
WICR	2 to 3	N.A.	4	81	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-

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

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
***LT only*
-: Not applicable to this product group
N.A.: No data available

5.2.8 ANTI-CONDENSATION HEATER

Relevance:

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

5.2.8.1 Anti-condensation control

Anti-condensation heaters are used to reduce condensation. Anti-condensation heater controls ensure that the heater is used only when needed. It requires measurement of the local dew point or humidity level. The heaters can be turned on when a given dew point temperature is exceeded, or the heaters can be cycled, with on-time increasing with dew point. Dew point sensors can be factory-installed in individual cases. Good design can prevent the need for this feature[68].

Anti-condensation heater controls save money in two ways. First, they reduce the amount of time the anti-condensation heater needs to run. Second, because the anti-condensation heater runs less often, the refrigeration system does not have to compensate for the extra heat generated. Thus there are two areas of energy savings: in the anti-condensation heater and in the operation of the refrigeration system.

- SC: One source quotes that 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). However, stakeholders have quoted a range of 2 to 5% energy saving potential.
- WICR: Estimates in the literature from the US are 2% energy saving at a cost of €489 for a 48.31m^3, high-temperature and 6% energy saving at a cost of €489 for a 13.4m^3, low-temperature walk-in cold room[70]. An estimate of 3% energy saving has been used, at a cost of €370.

[68] Source : GR Scott
[69] Source: APS Utility service www.aps.com/main/services/business/WaysToSave/BusWaysToSave_59.html
[70] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)

Table 5-24: Anti-condensation control – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	2 to 20	N.A.	N.A.
SC LT	N.A.	N.A.	2 to 20	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	3	370	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

5.2.8.2 Hot and cool gas anti-condensation

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. Hot gas anti-condensation consists of pipe circuit that replaces the electrical anti-condensation heaters, which allows circulation of hot refrigerant gas from the compressor.

No information has been identified on the benefits or costs of cool gas defrost.

- SC: Estimates in the literature from the US are 18% energy saving at a cost of €94 for a 2-door, high-temperature cabinet and 9% energy saving at a cost of €94 for a 1-door, low-temperature cabinet[70]. It is, however, assumed that this technology is not currently applied to service cabinets in the EU, but might be available in the near future. Stakeholders have also stated that this improvement may be difficult to implement, due to the complex combinations of doors and drawers used for some service cabinets.
- WICR: Estimates in the literature from the US are 13% energy saving at a cost of €323 for a 13.4m^3, low-temperature walk-in cold room. Again, it is considered that this technology is not current applied to walk-in cold rooms in the EU, but might be available in the near future[70].

Table 5-25: Hot gas anti-condensation – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	2 to 3	N.A.	18	94	N.A.
SC LT	2 to 3	N.A.	9	94	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	2 to 3	N.A.	13	323	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)

N.A.: No data available

5.2.9 Housing and insulation

5.2.9.1 Insulation

Relevance:

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

Reduction in heat loads transmitted through the insulation into the refrigerated interior of a product, hence reducing energy consumption, can be achieved by increasing the insulation's thermal resistance or increasing the thickness of the insulating material.

Insulation material

Figure 5-6 presents the thermal conductivity (expressed in mW/m.K) of various insulating materials with minimum (in blue) and maximum (in purple) values.

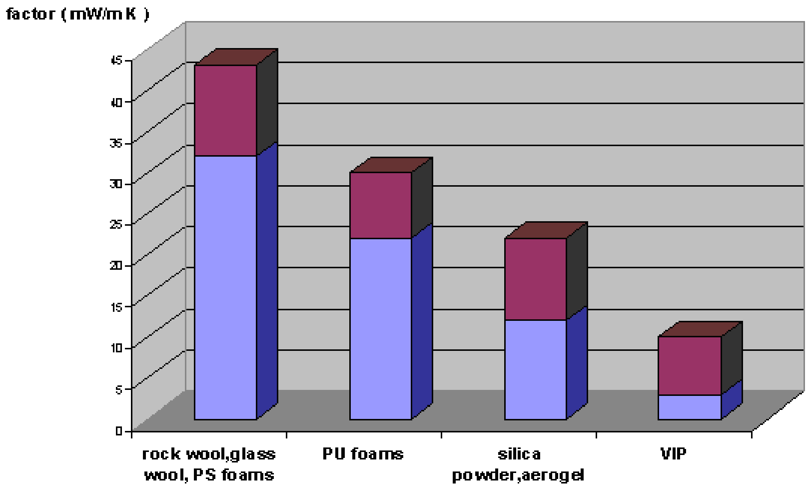


Figure 5-6: Thermal conductivity of various insulating materials[71]

Reduction in thermal conductivity is mainly due to the formation of smaller cells within the foam insulation structure and better cell-size consistency. Nevertheless, the implementation of the improved foaming technology requires the purchase of new foaming equipment, which can significantly increase the cost of the insulation.

Vacuum insulation panels are highly efficient insulating materials made by placing a micro-porous filler inside a high barrier containment system and evacuating the air from inside the panel (see Figure 5-7).

[71] Source: M. Paolo, G. Pastore and P. Di Gregorio, *Vacuum Insulated Panels Technology: A Viable Route to Reduce Energy Consumption in Domestic, Industrial and Civil Applications*

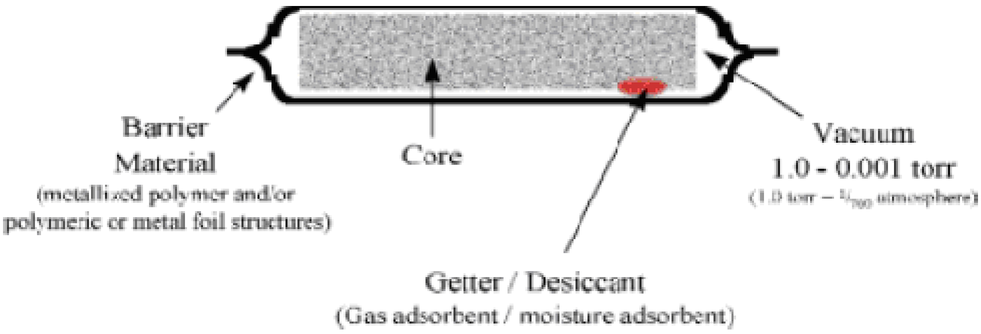


Figure 5-7: Vacuum Panel Construction[72]

The benefit of using vacuum insulated panels is that they have a lower thermal conductivity than conventional insulators such as polyurethane and polystyrene foams, thus achieving superior insulation performances. This implies energy savings without increasing insulation thickness. The use of a getter allows internal pressure to be kept as low as possible to limit the thermal conductivity of the panels. Several core materials can be used in vacuum insulated panels: open-cell polyurethane[73], open-cell polystyrene, precipitated (also called fumed) silica powder, nanogel, glass fibre, etc. To exploit insulation performances fully, panels must be evacuated and kept at suitable vacuum levels during operation. Table 5-26 presents characteristics of various core materials.

Table 5-26: Comparison of various vacuum insulated panels core materials[74]

	Polystyrene	Open-cell PU	Silica powder	Glass fibre
Conductivity at 10 Pa abs. (mW/m.K)	4,8–5,8	9,7	5,8	2,4
Manufacturing time	Fast	Medium	Medium	Long
Density (kg/m^3)	80–144	64	192	128
Drying need	No	Yes	Yes	No
Thermal stability	Low	Medium	Good	Very good
Recyclability	Yes	Difficult	Yes	n.a.
Cost	Low	Medium	High	Very high

Abbreviation: NA = not applicable.

This technology is not used in the average products currently being analysed in this study, but research is ongoing and some manufacturers estimate that the potential energy savings could be between 5% and 10% of the total electricity consumption with polyurethane as core material. However, their reliability in the long term has yet to be proven.

- SC: Estimates in the literature from the US are 2% energy saving at a cost of €330 for a 2-door, high-temperature cabinet and 2% energy savings at a cost of €1115 for a 1-door, low-temperature cabinet[75].

[72] Source: B. Malone and K. Weir, *State of the Art for Vacuum Insulated Panel Usage in Refrigeration Applications* (2001)

[73] The conventional polyurethane (or polystyrene) foam is also called closed-cell polyurethane (or polystyrene).

[74] Source: Preparatory Study for Eco-design Requirements of EuP, Lot 13, ISIS

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

- WICR: Stakeholders have stated that vacuum panels are effective, but not practical, due to the amount of holes that are drilled into cold room panels and potential for damage caused by constructors (if a vacuum panel is punctures, its effectiveness is severely reduced). High expense could also prove a barrier. As described in Task 2, polyurethane insulation (PUR) and polyisocyanurate (PIR) foams are the most commonly used. Expanded polystyrene (EPS), and phenolic (PF) foam are also used. PIR has a higher thermal rating than EPS and its price is about 30% higher. Table 5-27 below indicates potential reduction of energy consumption according to usage of different insulation materials. All results are presented for a standard walk-in cold room with dimensions of 1.8 x 1.8 x 2.4m.

Table 5-27: Possible energy savings, 100mm PIR versus 75mm EPS for walk-in rooms application[76]

Door type	Room load (W)		Reduction of energy consumption (%)
	75mm EPS	100mm PIR	
Solid	862	656	24
Glass	1 621	1 455	10
Double glazed	1 142	976	15

The payback for switching from 75mm EPS to 100mm PIR can be reached within 3.5 to 5 years.

Table 5-28: Insulation material – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	2	330	N.A.
SC LT	N.A.	N.A.	2	1,115	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

Insulation thickness

Thicker insulation might serve as an option to increase energy efficiency, especially in walk-in cold room applications. Below, potential energy savings as well as costs associated with thicker panels are presented for both freezing and refrigerating walk-in cold rooms with the dimensions 2.5m x 8m x 4m. Regarding cost calculation, only the cost of additional foam was taken into consideration. This data has been obtained from a foam insulation manufacturer, providing some indicative values, but it should be noted that the specific values are only applicable to this particular case.

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

The energy efficiency has been calculated based on heat flow losses between the temperature outside and inside of the appliance. Reduced head load therefore requires a refrigeration system with smaller cooling capacity, and leads to reduced energy consumption. Thicker insulation will however have a finite improvement potential, and would increase the size of the product.

Table 5-29: Energy saving and cost associated due to varying thickness of panels application

	Panel thickness (m)	Electricity consumption (kWh/year)	% energy saving compared to minimum thickness	Additional foam cost (€) – 1.7 €/kg of foam
Refrigerator (+5°C)	0.06	15 142	-	0
	0.08	11 356	25	169
	0.1	9 085	40	337
Freezer (-40°C)	0.14	21 090	-	0
	0.16	18 454	12.5	169
	0.18	16 403	22.22	337

Table 5-30: Loss of volume due to varying thickness of insulation panels[77]

Insulation thickness (mm)	60	80	100	125	150
Internal depth (m)	3.5	3.46	3.42	3.37	3.32
Internal width (m)	3.3	3.26	3.22	3.17	3.12
Internal height (m)	2.2	2.16	2.12	2.07	2.02
Volume (m^3)	25.41	24.36	23.35	22.11	20.92
Loss of volume (m^3)	-	1.05	2.06	3.30	4.49

The insulation thickness increase is supposed to have influence only in the external volume of blast cabinets. This has been mentioned by stakeholders as a consequence of the common use of GastroNorm sized trays inside these machines.

In the increase of external volume due to application of extra thickness insulation for blast cabinets is presented. The information refers to 3 different models with insulation panels of 60mm[78]. The insulation panels have standard sizes. The increase of thickness considered to make the analysis will be 5mm in addition to the 60mm. The increase in volume is expected to be around less than 4% for this equipment sizes.

Table 5-31: External volume change for 3 blast cabinet models due to increase of insulation thickness

Model	Width	Depth	Height	Volume	Volume with additional insulation*	Volume increase
Model 1	820	700	950	545	566	3.75%
Model 2	820	800	1800	1181	1217	3.05%
Model 3	820	800	2000	1312	1351	3.00%

*(W+2x5)x(D+2x5)x(H+2x5)

[77] Source: GR Scott. External surface area of model – $53m^2$.

[78] Source: www.pabatech.com/asp/scheda_prod.asp?menu=2&lingua=e&ID=10

- SC: In addition to stakeholder figures, estimates in the literature from the US are 4% energy saving at a cost of €102 for a 2-door, high-temperature service cabinet and 5% energy savings at a cost of €112 for a 1-door, low-temperature service cabinet (going from 57 to 82.5mm)[79].
- BC: According to some studies the inclusion of insulation in refrigeration equipment can provide up to 40% of energy savings if compared to the scenario where no insulation is present[80]. In the case of blast cabinets, it is assumed that current market models include insulation by default. In that case, any change in the thickness of the insulation thickness can lead only up to 4% of additional energy savings. The increase of insulation thickness will be reflected in the exterior size, since the interior is normally designed to fit the Gastronorm standard trays. The insulation of this type of equipment also has the function of providing structure to the wall of the machines, and according the stakeholder due to the rapid nature of the cycle, the insulating feature is considered less important.
- WICR: In addition to the figures of 25 to 40% saving presented in Table 5-29, estimates in other literature from the US are no energy savings at a cost of €462 for a 48.31m^3, high-temperature and 4% energy savings at a cost of €251 for a 13.4m^3, low-temperature walk-in cold room (going from 100 to 127mm)[81]. An estimate of 15% energy saving has been used, at a cost of €250. Other stakeholder feedback suggests that these savings may in fact be approximately 2% for a move from 100 to 120mm PUR and 4% saving from 100 to 150mm[82].
- CH: According to stakeholders, chillers are only benefit of better insulation in the piping.

Table 5-32: Insulation thickness – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	35	4	100	N.A.
SC LT	Now	35	5	110	N.A.
BC	Now	5	4	100	N.A.
WICR	Now	N.A.	15	250	N.A.
CH MT	Now	N.A.	1	N.A.	N.A.
CH LT	Now	N.A.	1	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

[79] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)
[80] D. Fisher. *Better building design conference 2008. Designing of sustainable commercial kitchen.* 2008
[81] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)
[82] Source: Viessmann

5.2.9.2 Insulated enclosure airtightness

Relevance:

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

Another key element of insulation for walk-in cold rooms is the very low level of air leakage that can be achieved - factory engineered joints can ensure that an air tightness of $5m^3/hr/m^2$ or better is commonplace, whilst figures lower than $2m^3/hr/m^2$ have also been achieved[83].

5.2.9.3 Reducing air infiltration of the insulated enclosure entrance

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

<u>Strip door curtains</u>

Strip door curtains are rows of overlapping clear flexible strips, often fabricated from PVC, which are hung over the opening of a walk-in refrigerator or freezer. Air curtains are devices that blow a stream of air across the face of the door opening. Their purpose is to allow passage into and out of the refrigerated space, while reducing ambient air infiltration when the door is open, slowing down heat transfer from adjacent warm and humid spaces when main door is opened. In that way, the cooling load is reduced and due to decreased infiltration of outside air into the refrigerated space. Energy savings of 5-10 % have been observed for strip-door curtains.[84] No saving potential figures were found for air curtains.

- WICR: In addition to stakeholder figures, estimates in the literature from the US are 9% energy saving at a cost of €57 for a $48.31m^3$, high-temperature walk-in and 24% energy saving at a cost of €57 for a $13.4m^3$, low-temperature walk-in cold room[85]. A weighted energy saving of 13% is used, assuming the market share of chillers to freezers is 70% to 30%. Other figures received were up to 40% energy saving, but depend on the user behaviour and temperature[86].

Table 5-33: Strip door curtains – market data and improvement potential

	Applicability (years)	**Market penetration (%)**	**Savings (% TEC)**	**Increase in price of product (€)**	**Increase in price of product (%)**
SC HT	-	-	-	-	-
SC LT	-	-	-	-	-
BC	-	-	-	-	-
WICR	Now	60	13	70	N.A.

[83] source: www.epic.uk.com/breeam.jsp
[84] www.sce.com/b-sb/design-services/RTTC/ResearchProjects/supermarket/strip_curtains.htm
[85] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)
[86] Source: Viessmann, GR Scott

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

Automatic door closers

Automatic door closers close the door when it is left open, reducing ambient air infiltration and decreasing refrigeration load. It is possible for these to function only when the door is ajar, to prevent closing when purposefully left open.

Automatic tracks for sliding doors are available and are programmable to close after a given period of time. The open time can be regulated to suit the site requirements. Auto systems can contribute significantly towards efficient energy usage, as open times are strictly controlled. It could be also argued that they would negate the requirements of both PVC curtains. Stakeholders have stated that many of these technologies are not very effective, although some do work well[87]. A partial opening function may also be available for larger doors, to let one person walk through, if a full opening is not necessary (normally required to let fork lift enter)[88].

- Estimates in the literature from the US are 8% energy saving at a cost of €111 for a 48.31m^3, high-temperature and 23% energy saving at a cost of €111 for a 13.4m^3, low-temperature walk-in cold room[85]. A weighted figure of 12% energy saving has been used.

Table 5-34: Automatic door closer – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	12	111	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

Additional elements of design of walk-in cold rooms could lead to reduction of energy consumption, such as use of a pre-cooling room. This feature is a second compartment fitted around the door that accesses the refrigerated space, in itself accessed via a door, to prevent spillage of cold air from the storage space and to

[87] Source: GR Scott, Fermod

[88] Source: INCOLD

reduce heat infiltration. Automatic shutdown of evaporator ventilation, in order to avoid unnecessary flow of cold air out of the cold room, can also help to reduce heat load and hence energy consumption.

5.2.9.1 Alarms

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

For walk-in cold rooms, some manufacturers offer a system that incorporates a micro switch within the fastener. This enables the lights and evaporators to be operated by the actual door action. Audio/visual alarms could also be fitted on a timer to alert operatives that the door has been left open for an extended period. Such systems could also be adapted into an energy management system to, for example, record door openings.

These types of technologies may be adaptable for use with service and blast cabinets.

5.2.9.2 Gaskets and sealing the face frame from the interior

Relevance:

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

The design of the refrigerating and freezing appliance's housing is a key aspect for improving insulation and reducing heat infiltrations. Gaskets play an extremely important role by creating an insulated seal around the door.

For example, for service cabinets, the face frame design is a key aspect. The face frame metal wraps around the front of the face and penetrates into the refrigerator interior, creating a path for heat leak (see Figure 5-8 in red frame). It is one of the key differences in construction between residential refrigerators and conventional professional refrigerators: in residential refrigerators, the face frame metal is sealed from the interior by the gasket.

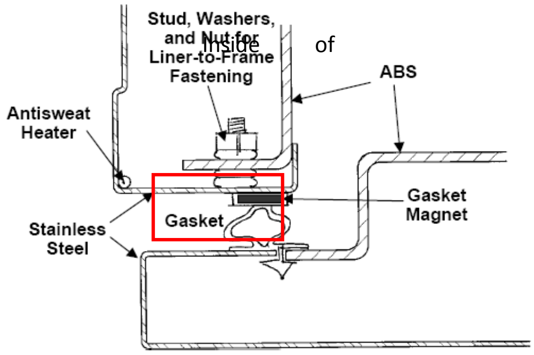


Figure 5-8: Typical service cabinet face frame cross section[89]

Different design concepts for the face frame exist and could be analysed for energy savings and cost impact:

- sealing the metal face frame from the interior by the gasket to prevent the creating of a heat path which could lead to heat infiltration; and
- repositioning the gasket closer to the external corner, allowing the stainless steel face frame to be cut back further, thus moving this key path for heat leak further from the interior of the refrigerator.

Face Frame Design Concept	Cabinet Load Reduction (%)	Antisweat Heater Wattage Reduction (%)	Total Energy Use Reduction (%)	Total Cost Premium ($)
1	15%	46%	19%	$0
2	16%	78%	26%	$0

Figure 5-9: Improvement potential of face frame design (refrigerated plug-in service cabinets) [90]**design**[91]

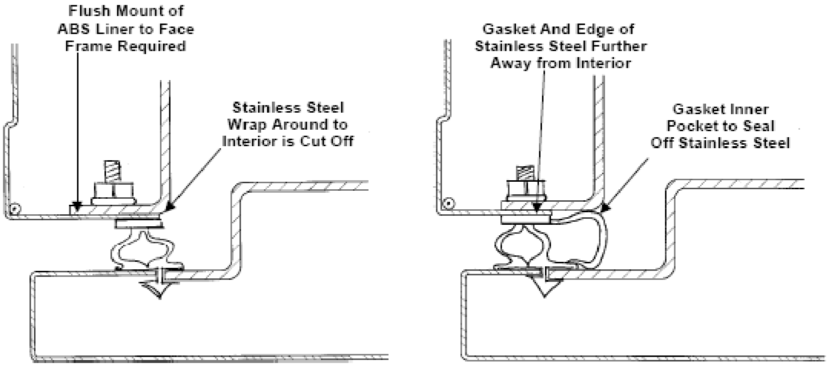


Figure 5-10: BAT options for service cabinet face frame

[89] TIAX, Application of best industry practices to the design of commercial refrigerators, Development of a high efficiency reach in refrigerator, US Department of Energy, 2002

[90] TIAX, Application of best industry practices to the design of commercial refrigerators, Development of a high efficiency reach in refrigerator, US Department of Energy, 2002

[91] ibid

- SC: As discussed in Task 4, this option could provide 19 to 26% saving at no additional cost.

Table 5-35: Sealing the face frame – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	19	0	N.A.
SC LT	Now	N.A.	26	0	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	N.A.	N.A.	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

Walk-in cold room freezer doors should be fitted with heater tape and a double profile gasket for greater energy efficiency. A double gasket on refrigerated rooms could also be of benefit[92].

5.2.9.3 Transparent sections in doors and walls

Relevance:

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

When taking under consideration the products groups covered in ENTR Lot 1, only service cabinets and walk-in cold rooms can have doors partially made of transparent (glass) sections (e.g. windows for walk-in cold rooms), even though these have reportedly small market shares (1 to 2% for service cabinets[93] and 1 to 5% for walk-ins[94]) and is not a general trend in the market. Transparent doors can more than double the energy consumption of a product, depending on their size[95]. However, the increase in refrigeration load can be reduced as much as 30% by simply using double-glazing[96].

[92] Source: GR Scott, Fermod
[93] Source: Foster, Gram, Infrico
[94] Source: GR Scott, Smeva
[95] Source: Expert feedback
[96] Mark Ellis, In from the cold – Strategies to increase the energy efficiency of non-domestic refrigeration in Australia & New Zealand

Figure 5-11: Walk-in cold room door with glass window

There are opportunities to increase the insulation value of a glass door (or window), as described in Table 5-36.

Table 5-36: Glass door K values (U values)[97]

4 = thickness glass; T = Tempered glass; LE = Low energy glass;
20 = Distance between the glass; Ar = Gas Argon

Vetrocamera/Insulated Glass	mm	K (W/mq°K)
4T/20/4	28	2.8
4T/20Ar/4	28	2.6
4TLE/20/4	28	1.4
4TLE/20Ar/4	28	1.1
4T/9/3/9/3	28	2.0
4TLE/9/3/9/3	28	1.4
Triple Blues	28	<1.0

- SC: Transparent sections with poor insulation are estimated to double AEC, while the best available options are estimated to increase AEC by 20%.
- WICR: Further evidence is required in order to evaluate the impacts of glass used in walk-in cold rooms, and potential improvements. Stakeholders have stated that glass is used in few products.

Table 5-37: Glass windows – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	-	-	-	-	-
SC LT	-	-	-	-	-
BC	-	-	-	-	-
WICR	N.A.	N.A.	30	N.A.	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-

97

RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.9.4 Zeolite filter cassettes[98]

Relevance:

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

Zeolite filter cassettes are made of natural mineral filters (molecular sieves), containing a blend of different kind of zeolites, depending on the environment where they are to be used, i.e. in refrigerators/freezers with packed/sealed products (canned food, lemonades, etc.) or in refrigerators with unpacked products (meat, fruit, vegetables, etc.). The cost of 2.5m^3 moisture filters is €90 and of 20 m^3 filters €650. The technology is not patented.

However, a stakeholder has stated that reducing the amount of moisture inside the appliance might lead to a quality reduction of products which require high level of humidity (meat, fruits, vegetables etc.).

The manufacturer claims that the filters are made not to reduce the amount of moisture but just to avoid condensation, thereby increasing the COP by reducing dew/frost points with a claimed average reduction in energy usage of 25% in freezers and refrigerators, and that in 8 years they have never experienced damage to the interior of equipment due to drying action and that the filters have no negative effect on unpacked products. The technology affects surface chemistry, where the single gaseous water molecules are prevented from building up into long chains to form water; hence it is the ability for the air to condensate that is drastically changed, not the relative humidity. A transcript of a Coca Cola test report was provided claiming that the relative humidity in a refrigerated beverage machine decreased from 91% to 81.3% and a measured 35.3% reduction in compressor runtime. However, no data resulting from evaluation under a testing standard is available.

In addition, this blend is said to be capable of reducing the content of ethylene gas. The manufacturers also claim that testimonials from users indicate reduced servicing bills.

However, it has been claimed that good design and product management would prevent the issues that lead to this technology seeks to solve[99].

- SC: No benefit was shown from one stakeholder testing. An estimate of 25% reduction of the defrost cycle has been used, resulting in estimated energy saving of 0.5% (25% of 2% AEC), and at low temperature 2% (25% of 10% AEC).

[98] www.digitech.se
[99] Source: GR Scott

* WICR: Energy savings claimed by manufacturer of product. One stakeholder tested these and found no quantifiable benefits[100].

Table 5-38: Zeolite filter cassettes – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	0.5	90	N.A.
SC LT	Now	N.A.	2	90	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	25	650	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.9.5 eCube

Relevance:

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

eCube is a small wax cube containing a thermostat, which reduces energy consumption by more accurately simulating the temperature of food stored in refrigerated space, allowing the refrigeration system react to this rather than respond to air temperature. It can be connected to the thermostat sensor and thus can reduce energy consumption by as much as 33%. Other benefits of the eCube are reduction in CO_2 emissions, longer life for refrigeration equipment as well as potential noise reduction.[101] However, some stakeholders have found that they provide little benefit when used in product testing.

The price of an eCube for the end user is about €120 including VAT regardless of size of cube. It has a guarantee for 5 years and can be re-installed into new equipment. This equipment cannot be used in blast chillers due to water build-up in these products. eCubes are patented.

Due to its patented status and uncertainty over benefits, this technology is not included in the prioritised improvement options. It is recommended that the technology be assessed under standard testing methodologies to evaluate its performance.

Table 5-39: eCube – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	30	120	N.A.

[100] Source: Foster
[101] www.ecubedistribution.com/aboutecube.html; www.guardian.co.uk/environment/2007/mar/17/climatechange.climatechangeenvironment

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC LT	Now	N.A.	30	120	N.A.
BC	-	-	-	-	-
WICR	Now	N.A.	30	120	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.9.6 High efficiency lighting

Relevance:

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

Although fluorescent lamps provide good energy efficiency in many lighting applications, their use in refrigeration is not ideal. Indeed, for this application, they have several drawbacks:

- poor performance (with conventional ballast), due to heat losses (Joule effect);
- wasted light;
- non uniform lighting; and
- sensitivity to temperature (Figure 5-12), due to the decrease in mercury vapour pressure (T5 does not respond well to low ambient temperature when turning on).

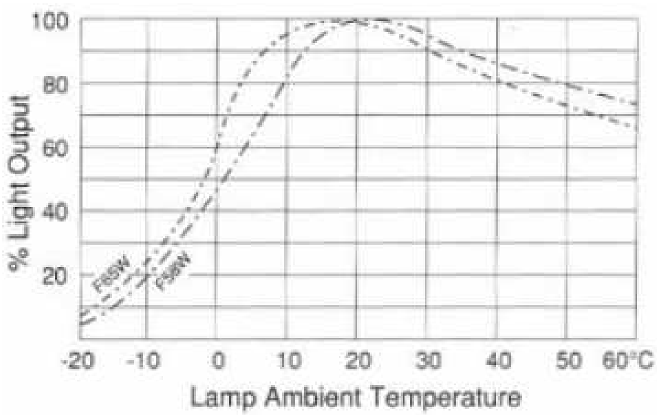


Figure 5-12: Percentage of light output versus temperature for two typical T8[102]

Alternative lighting technologies may provide better solutions to improve these drawbacks. One such technology is the Light-Emitting Diode (LED).

[102] Source: Sylvania Fluorescent Lamps Technical Manual

The main benefits of LED are:

- LED light output and efficacy are not affected by cold temperature;
- white LEDs provide luminous efficiency near levels produced fluorescent lamps under cold temperatures; and
- significant improvement in lamp efficacy (+470%) and lifetime (+1500%) compared to fluorescent lamps.

However, an LED can cost 40€, which is almost 1300% more expensive than a fluorescent lamp with equivalent light output[103].

- SC: Very little energy is consumed by the lighting in service cabinets, therefore stakeholders have stated that there is minimal benefit from efficient lighting.
- WICR: In addition to stakeholder figures, estimates in the literature from the US are 4% energy saving at a cost of €560 for a 48.31m^3, walk-in cold room for LED lighting and 0% energy savings at a cost of €24 for high-lumen bulbs[104]. Stakeholder estimates were 2 to 5% energy saving and cost of €30. An estimate of 4% energy savings and cost of €200 has been used.

Table 5-40: High efficiency LED light bulbs – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	Minimal	30	N.A.
SC LT	Now	N.A.	Minimal	30	N.A.
BC	-	-	-	-	-
WICR	Now	N.A.	4	200	N.A.
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.9.7 Full baffling (air-flow circulation)

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

- BC: This adaptation of the housing leads to better distribution of the air within the cabinets, by locating baffles to deflect the airflow. This modification has been reported to achieve energy savings of up to 6% for

[103] Preparatory Studies for Eco-design Requirements of EuPs, Lot 19: Domestic lighting- Part 2 Directional lamps and household luminaires Task 7: IMPROVEMENT POTENTIAL

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

blast equipment. However, larger equipment benefits more from this improvement, in contrast to smaller equipment where the smaller size assure the proper circulation. The price related to this modification is assumed to be negligible as it is included in the designing phase.

Table 5-41: Full baffling – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	-	-	-	-	-
SC LT	-	-	-	-	-
BC	Now	99	6	Negligible	N.A.
WICR	-	-	-	-	-
CH MT	-	-	-	-	-
CH LT	-	-	-	-	-
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.9.8 Insulated drawers

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

Products are available on the market that feature insulated drawers. The manufacturer claims that this design can provide up to 40% energy saving (savings measured in use) compared to similar products.

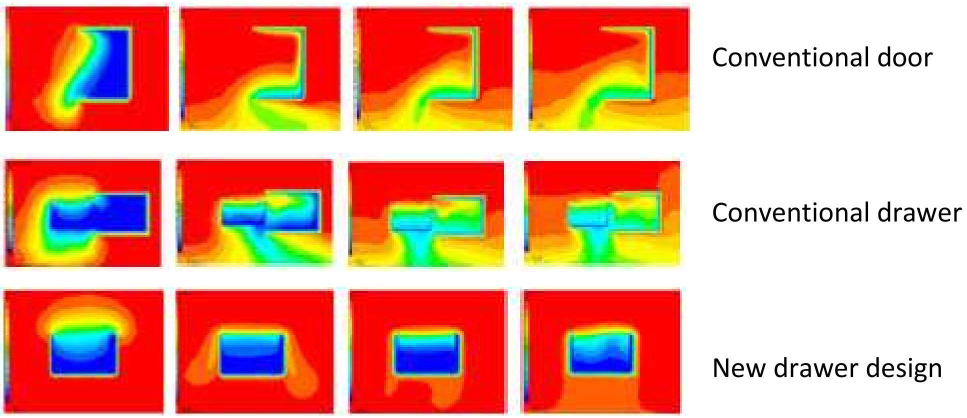


Figure 5-13: Insulated drawer – reduced air infiltration

Savings are provided due to reduced infiltration of hot air, leading to a reduced workload on the refrigeration system and reducing frosting and condensation.

These savings are not however realised during testing under testing standards, as the savings are partially due to the use of insulated drawers. Current test methodologies do not permit the assessment of products with drawers.

5.2.10 Refrigeration system adaptations

5.2.10.1 Remote condensation

As discussed in Task 4, remotely located condensing units are estimated to have an energy consumption which is around 90% of the total energy consumption of plug-in cabinets[105].

Stakeholders have mentioned that remote condensing units improve the energy efficiency of equipment. In the case of blast cabinets, it has been observed that 15% of the market share is represented by remote equipment. These remote appliances have, in general, larger capacities. Smaller equipment can benefit from the energy savings of remote condensing, but it depends on the availability of space.

However, this improvement options is not considered further as an improvement option, as it would require a significant alteration of product design.

5.2.10.2 Floating head pressure

Relevance*:

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

*All refrigeration systems in general; common feature for AC chillers and refrigeration chillers

In general, compressor pressure is kept at a fixed, high level to assure safe, reliable operation over a range of outdoor temperatures. Fixed high head pressure maintains adequate refrigerant flow, freeze protection for the evaporative condenser, and an adequate pressure difference across the expansion valve. However, it consumes a lot of energy because it always overestimates the pressure needed. A changeable (floating) pressure that adapts to external conditions has therefore been proposed instead (if there is a fixed head, it is unlikely that part load performance would be improved by the use of VSD for compressors).

Condenser capacities are based, in part, on the temperature difference between the ambient air and the refrigerant condensing temperature. As the ambient temperature falls, and the temperature difference increases, the condenser capacity will increase. Increased condenser capacity leads to lower head pressure and reduced energy consumption.

A reduction of head pressure could also provide large energy savings for chillers, as they are often set up to function at “worst case scenario” parameters. When the ambient temperature is below that which the chiller was design for, and the condenser capacity is therefore increased, the head pressure can be allowed to fall and energy consumption to be lowered.

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

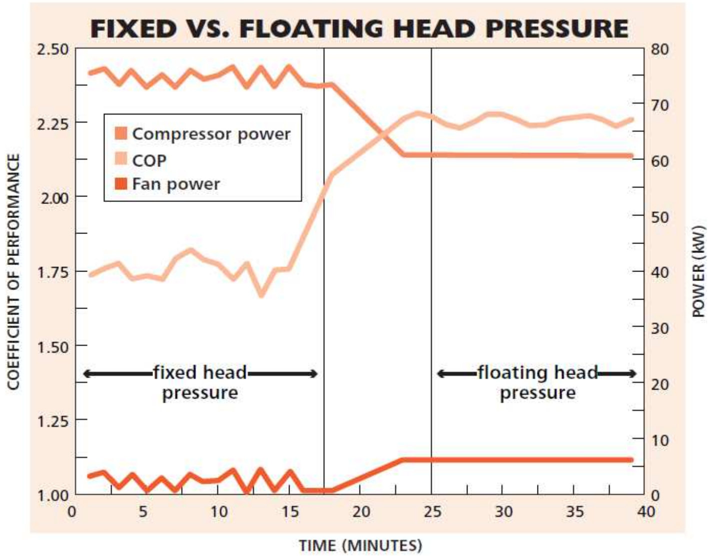


Figure 5-14: Comparison between fixed and floating head pressure performance[106]

A simple change in control of head pressure can reduce the overall operating costs by as much as 21%[107]. When using floating head pressure, the fan is constantly operating (in the case of a fixed fan, it cycles on and off). This constant operation results in increased energy consumption for the fan, but lower overall consumption of the system. This option is available to retrofit existing refrigeration systems though results of this adaptation will depend largely on initial design and local climates and loads.

One risk of this approach is that head pressure can fall below certain minimums. Should this happen, system performance can be adversely affected through[108]:

- underfeeding the thermostatic expansion valves (used only for small capacity equipment) and starving evaporators;
- oil logging; and
- reduced compressor efficiency and higher discharge temperatures.

The integrated use of electronic expansion valves and floating head pressure can lead to energy savings of up to 30% of, but it is only applicable to remote equipment.

- SC: Capillary system already floats head pressure as part of operation.
- WICR: In addition to stakeholder figures, estimates in the literature from the US are 16% energy saving at a cost of €271 for a 48.31m^3, high-temperature walk-in cold room[109]. Stakeholders estimated an energy saving of 5 to 16%, and cost of €130. As this improvement is applicable

[106] Energy Centre of Wisconsin, Cutting Energy Waste in Large Refrigeration Systems, 1999
[107] 21 % is an estimate but results largely depend on initial design and local climates and loads.
[108] Source: www.legacychillers.com/kb/default~action~detail~intID~30.asp
[109] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)

only to larger (remote) products[110], with cooling capacity over 3kW, a weighted estimate of 8% energy saving and cost of €150 has been used.

Table 5-42: EEV when integrated with floating head pressure – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	-	-	-	-	-
SC LT	-	-	-	-	-
BC	Now	5	30	100*	N.A.
WICR	Now	1	8	150	N.A.
CH MT	Now	N.A.	15	N.A.	N.A.
CH LT	Now	N.A.	20	N.A.	N.A.
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

**For reasons of lack of information the increase in price assumed to be the same as per EEV*
-: Not applicable to this product group
N.A.: No data available

5.2.10.3 Raising liquid line pressure

The expansion valve cannot tolerate wide variations in pressure. Refrigerant entering this component is in pressurized liquid form. A liquid pump may be used to raise the pressure of this liquid to the level required for the expansion valve whilst allowing the condensing temperature to fall as far as the prevailing ambient temperature will allow. A pump will achieve this with a very small expenditure of energy, far less than that saved by allowing the compressor condensing pressure to fall. That said, the technique is harder to apply than this simple description indicates. It is currently commercialised with the name “Liquid Pressure Amplification” (LPA). According to information provided by stakeholders, this technology could save up to 15% of energy consumption, but this depends on the characteristics of the systems and its performance.

5.2.10.4 Liquid suction heat exchangers

As discussed in Task 4, liquid suction heat exchangers are used in refrigeration systems to ensure the correct operation of the system and increase its performance, allowing exchange of energy between the cool gaseous refrigerant leaving the evaporator and warm liquid refrigerant exiting the condenser.

No data has been found on the benefits and costs of this improvement option, but it is thought that it may no longer provide significant benefits.

5.2.10.5 Economiser cooling

The economiser technology allows a portion of the high-pressure liquid from the condenser to be expanded in the economiser, reaching an intermediate pressure. This portion of liquid sub-cools the main liquid line, increasing the capacity in the evaporator without increasing the compressor size. Then, the superheated vapour is injected into the economizer port of the compressor at an intermediate stage pressure rather than low compressor suction pressure. This technology also

[110] Source: GR Scott

decreases the discharge temperature, which further lessens compressor load and results in even greater energy savings[111].

Typical application is a supermarket LT pack where an economiser allegedly makes a scroll compressor competitive with reciprocating machines. It is only applicable to rotary compressors such as scrolls or screws when employed with a single compressor.

- WICR: Estimates in the literature from the US are 4% energy saving at a cost of €3,668 for a 48.31m^3, high-temperature walk-in cold room[112]. However, it has been stated that gains from economisers are mainly found in low temperature applications, contradicting this data[113].
- CH: According to some manufacturers, the economiser can provide between 10 to 15% of energy reduction for chillers[114].

Table 5-43: Economiser cooling – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	4	N.A.	N.A.
CH MT	N.A.	N.A.	10 to 15	N.A.	N.A.
CH LT	N.A.	N.A.	10 to 15	N.A.	N.A.
RCU MT	Now	less than 10	N.A.	N.A.	N.A.
RCU LT	Now	less than 10	N.A.	N.A.	N.A.

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.10.6 Energy integration

This technology uses the pinch approach to recover the wasted heat from chillers. It requires an extra pumping system including valves, pipes and compressor, which can reach about 10% extra of the total cost of the chiller. The savings coming from this approach depend on the system adaptation considered in the equipment.

Table 5-44: Energy integration – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Now	less than 5	15	6,000	10
CH LT	Now	less than 5	10	7,000	10
RCU MT	N.A.	N.A.	N.A.	N.A.	N.A.

[111] Daikin Europe N.V.
[112] Navigant Consulting, Energy Savings Potential and R&D Opportunities for Commercial Refrigeration (2009)
[113] Source: Defra
[114] Source: www.legacychillers.com/2010/Chiller_Economizers_Introduction.asp

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
RCU LT	N.A.	N.A.	N.A.	N.A.	N.A.

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.10.7 Ambient sub-cooling

Relevance:

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

Ambient subcooling is accomplished using a heat exchanger (subcooler) to further cool the refrigerant leaving the condenser, thereby boosting refrigeration capacity with no increase in compressor power draw.

- WICR: In addition to stakeholder figures, estimates in the literature from the US are 8% energy saving at a cost of €342 for a 48.31m^3, high-temperature walk-in cold room[115]. As this improvement is applicable only to remote products, which represent approximately half the market, a weighted estimate of 4% energy saving and cost of €170 has been used.
- CH: this option is based on using water from the chilled water circuit to sub-cool. This option should be considered from the product or the installation. However, it has been mentioned by chiller experts that manufacturers should open the possibility of having this feature in the equipment.

Table 5-45: Ambient subcooling – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	4	170	N.A.
CH MT	Now	less than 5	5	3,000*	5
CH LT	Now	less than 5	5	3,500*	5
RCU MT	-	-	-	-	-
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

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

5.2.10.8 Improved system design

Relevance*:

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

*All refrigeration systems in general

Good design practices can have a significant impact on refrigeration systems; the proper matching of components can lead to higher efficiency and reduced energy consumption.

For example, one manufacturer of packaged rerigeration units[116] for walk-in cold rooms has increased the COP of their products through re-design, reducing energy consumption by approximately 20%, and attaining COP values in the region of 2 to 2.2.

5.2.10.9 Equipment oversizing

Relevance*:

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

*All refrigeration systems in general with AC motors

The appropriate matching of the components in the machines is important. However, in some case oversizing machines have positive influence in the energy efficiency. The gains in efficiency due to oversizing are bigger in the case of equipment working within a narrow speed range close to base speed (design speed)[117]. Oversizing can minimize the heat losses for AC motors. The internal heat transfer is then avoided in plug-in equipment, and the efficiency increases. The improvement results due to this option are more significant for bigger equipment. For applications with variable load this option does not provide great benefits (due to system inefficiency).

As a drawback, this option can lead to extra production costs as different components will not necessarily be shared by different models, and the costs or replacing larger components and costs of maintenance could increase. The energy savings are not generally measured or quoted, since the comparability of equipment suffers under this improvement option.

[116] Source: Viessmann

[117] Kari, R. *Oversizing and efficiency*. ABB Drives (2010). Available at: www05.abb.com/global/scot/scot201.nsf/veritydisplay/ba71df6b9df8e8fbc12576d9003dd364/$File/Oversizing_and_efficiency.pdf

5.2.11 Alternative refrigeration technology

5.2.11.1 Absorption

Most equipment within the scope of the study is designed to work by using vapour-compression process. However, as was explained in Task 1, absorption is an alternative process. This technology has been proved in minibars, but stakeholders have mentioned that it is not suitable for more power-demanding processes.

5.2.11.2 Water use for refrigeration system adaptations[118]: vacuum process

The vacuum-process technology is able to produce binary ice-water slurry, by using water as refrigerant. The water is injected into the evaporation vessel (vacuum vessel) and is cooled by direct contact flash evaporation. It is possible to work under triple point conditions[119] in this system, generating binary ice[120]. The cold water vapour produced during this process is removed from the evaporator vessel. This process requires a large volume of water flow to perform correctly.

This system requires high pressure ratios, especially for "heavy duty" applications (fluid temperature 0°C). This requirement is only achievable with several compressors.

It is possible to increase the COP of the system by 2 or more, but having a cost increase of 100% with respect to a conventional water chiller.

This process is generally conducted under vacuum conditions, but this will depend on the temperature requirements of the fluid to be cooled.

Sublimation or compression and condensation can be used to remove the cold water vapour generated in the evaporator vessel. An identified drawback for this process is the volume of flows that must be handled; despite superior evaporating enthalpy, larger specific volume is expected for water at these temperatures. The swept volume of a water vapour compressor has to be around 500 times higher than for a conventional refrigerant.

The pressure lift for vacuum process technology is very little (20/50 mbar). Using multiple compression stages for the water vapour compressor will result in an increase of the COP.

This technology is currently in use for water chillers, ice makers and heat pumps[121], but it has not been widely accepted. One of the advantages of these systems is being able to cool any kind of water, generate binary ice and work fully with water as refrigerant, avoiding the use of high ODP and GWP refrigerants. Please note

[118] J. Kühnl-Kinel. European Organization for Nuclear Research (1998). *New age water chillers with water as refrigerant.*

[119] State where co-existence of liquid-, vapour- and solid-phase is possible. This phenomenon depends on the pressure and temperature.

[120] Binary ice is the mixture of a substance in solid state in micron size and the same substance in liquid state. In some cases, it requires of a depressant to avoid coagulation of the solid part. Normally the employed substance is water.

[121] Water has been classified in group A1 in the ANSI/ASHRAE 34 standard.

that the overall temperature that can be reached by the cooled media is around 0 to -2°C, so it is not suitable for all applications.

Table 5-46: Vacuum-process technology – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	N.A.	N.A.	N.A.	N.A.	N.A.
CH MT	Now	less than 1	50	55,000*	100
CH LT	-	-	-	-	-
RCU MT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU LT	N.A.	N.A.	N.A.	N.A.	N.A.

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

5.2.12 Refrigerants[122]

R-134a and R-404a are two of the most commonly used and accepted refrigerants. These two substances were considered as the refrigerants for the 5 Base Cases, as shown in table below.

Table 5-47: Base Case refrigerants

Type of equipment	Refrigerant
SC HT	R134a
SC LT	R404A
BC	R404A
WICR	R404A
CH MT	R134a
CH LT	R404A
RCU MT	R404A
RCU LT	R404A

Although R404A is a good initial alternative for CFC and HCFC, this refrigerant presents some problems regarding its high GWP. For this reason alternatives are being analyzed. Alternative refrigerants can be other HFC with lower GWP (e.g. R134a for MT, R407A, R407C, R410A), hydrocarbons (e.g. R290, R600a), carbon dioxide (R744), ammonia (R717), other blends using ammonia, or other synthetic refrigerants (e.g. HFC1234yf, HFC1234zeCC(E)).

Natural refrigerants are seen by many as technology options that may provide environmental benefits. Natural refrigerants are gases, which occur naturally in the environment and include ammonia, carbon dioxide, hydrocarbons, water and air. Although environmentally superior, natural refrigerants are not free of other concerns, such as corrosion, toxicity, high pressures, and flammability or, in some cases, lower operating efficiencies.

[122] "The refrigerants and the environmental challenge" ASHARE – materials from XII European Conference on Latest Technologies in Refrigeration and Air Conditioning

While selecting the correct refrigerant for an application, the following criteria have to be taken into account: capital and operating costs, equipment size and location, operating temperature/pressures, staff capability etc. Table 5-49 below, the characteristics of the natural refrigerants are presented. Table 5-48 shows the applicability of some refrigerants in the Base Cases under the scope of this study. The safety information of refrigerants should follow the standards ANSI/ASHRAE 34[123], EN 378-1:2009 or ISO 817. The ANSI/ASHRAE standard has been suggested by the manufacturers to classify the refrigerants in terms of safety, although it is not totally harmonised to the EU Directives and some stakeholders suggested that it is too restrictive for most of the “natural” refrigerants.

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

Table 5-48: Alternative refrigerants currently used or being developed to be used in the Base Cases

Refrigerant	Service cabinets	Blast cabinets	Walk-in cold rooms	Chillers	Remote condensing units	Comments
CO_2 R744	✓	✓	✓	✓	✓	Not appropriate for small cold rooms. Used in large cascade systems, not in high ambient temperatures. Only applicable for remote blast equipment
Ammonia R717	✗	✗	✗	✓	✓	Toxicity and corrosion issues
Propane R290	✓	✓	✓	✓	✓	May be used in small applications with small refrigerant charge
Isobutane R600a	✓	✗	✗	✗	✗	If hydrocarbons are to be used propane is more efficient option to choose
HFC 1234yf	✓	✓	✓	✓	✓	Expected to be used in the automotive industry, blends being developed for commercial refrigeration
R1270	✗	✓	✗	✓	✗	Possible alternative for R404A.

In general, some alternatives (based on their thermodynamic properties) for R134a are: R290, R600a, R744, R152a and R1234yf As for R404A, the possible alternatives identified are: R744, R407A and R507.

Table 5-49: Main characteristics for R134a and R404A and some alternative refrigerants[124]

Refrigerant	Boiling point (°C)	Critical point (°C)[125]	Ozone depletion potential (ODP)	GWP, 100y	Safety classification (ANSI/ASHRAE 34)
R134a (hydrofluorocarbon)	-26	101	0.0	1410	A1
R404A (hydrofluorocarbon)	-46	72	0.0	3300	A1
R410A (hydrofluorocarbon)	-49	73	0.0	1890	A1
R407A (hydrofluorocarbon)	-43	82	0.0	1900	A1
R290 (propane)	-42	97	0.0	3	A3
R600a (isobutane)	-12	135	0.0	3	A3
R1270 (propylene)	-48	92	0.0	3	A3
ECP717 (ethane + ammonia)	-55	41.9	0.0	2	A2
R717 (ammonia)	-33	132	0.0	0	B2
R718 (water)	100	373	0.0	0	A1

[124] Source: M. Fatouh, M. El Kafafy. Assessment of propane/commercial butane mixtures as possible alternatives to R134a in domestic refrigerators. Elsevier. 2006

[125] The temperature and pressure at which the liquid and gaseous phases of a pure stable substance become identical. Also called critical state.

Refrigerant	Boiling point (°C)	Critical point (°C)[125]	Ozone depletion potential (ODP)	GWP, 100y	Safety classification (ANSI/ASHRAE 34)
R744 (carbon dioxide)	-78	31	0.0	1.0	A1
R152a (difluoroethane)	-24	113	0.0	122	A2
HFC-1234yf (unsaturated HFC)	-30	94	0.0	4	A2
HFC-1234ze(E) (unsaturated HFC)	-19	110	0.0	6	A2

5.2.12.1 HFCs

Other HFC refrigerants, such as R134a (MT), R410A or R407A, are being used as direct substitutes of R404A, achieving similar efficiencies with lower GWP (see Table 5-49).

The use of these refrigerants does not require major changes in the equipment, and the increase in prices is, thus, minimal. However, the reduction in direct greenhouse emissions is not as high as using other alternative refrigerants and there is no variation in the refrigerant charge. The refrigerant R407F is increasingly recognised as suitable to replace R404A in low and high temperature operation, especially in the retail sector, it is classified as A1 in the ASHRAE safety classification and its GWP is 1,825. Manufacturer's claim is based on 20% of energy savings reported by supermarkets[160], but no evidence has been found to support this statement.

- RCUs: for a 7kW capacity semi-hermetic compressor working at -10°C evaporating temperature and +25°C ambient temperature with zero subcooling and 20k useful superheat, improvement of 6% has been reported using R410A instead of R404A[126].
- WICR: A stakeholder mentioned the potential increase in cost due to the use of these refrigerants. No data on refrigerant prices was found or provided.

Table 5-50: Refrigerant R134a – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	N.A.	13	N.A.	0
SC LT	Now	N.A.	13	N.A.	0
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	0	N.A.	0
CH MT	Now	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	Now	33	0	0	0
RCU LT	-	-	-	-	-

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

[126] Source : Defra

Table 5-51: Refrigerant R410A – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	N.A.	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	0	N.A.	0
CH MT	Now	N.A.	N.A.	N.A.	N.A.
CH LT	Now	N.A.	N.A.	N.A.	N.A.
RCU MT	Now	10	6	0	0
RCU LT	Now	10	6	0	0

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.12.2 Hydrocarbons

Hydrocarbons are one of the current trends for this change, despite their classification as highly flammable refrigerants (A3) by the ASHRAE Standard 34. Under EN 378 Part 1 they are classified as L3, with a limit of 1.5 kg for class C environments (which includes “cold stores” and “non-public areas of supermarkets”).

Naturally occurring hydrocarbons include oil and natural gas. Hydrocarbons have attractive properties for refrigeration applications, however they are flammable.

Hydrocarbons are increasingly present because of the phase out of CFCs. They are mainly used in small systems with a low refrigerant charge. The use of hydrocarbons as the primary refrigerant in centralized indirect systems in supermarkets, as well as chillers in the range of 1kW-150kW (even capacities above 600kW are available[127]) is increasing but still not generalized.

Propane (R290) and isobutane (R600a) are the two most commonly used hydrocarbons. R600a is used in household fridges and very small commercial equipment, but its volumetric cooling capacity is about one third as compared to R404A. Thus, its use in commercial refrigeration is very limited. R290 is increasingly used in service cabinets and remote condensing units using this refrigerant are also available on the market. The main characteristics for these two hydrocarbons are shown in table below.

[127] Source: ECOS

Table 5-52. Main characteristics for Propane and Isobutane[128]

Characteristic	Propane	Isobutane
Boiling point (°C)	-42	-11.7
Critical temperature (°C)	97	135
Compatibility	Non corrosive	Non corrosive
Safety group as per as ANSI/ASHRAE 34	A3	A3

The principal drawback of R600a and R290 is that they are flammable. They are also considered to be complex to handle when they are applied to secondary circuits. However, the mixture of them in different proportions can produce very attractive benefits. It has been shown[129] that a 68/32 mixture of R290/R600a has higher COP than R12 and R134a (3.9% - 25.1%) for evaporating temperatures from -18°C to 3°C with condensing temperature of 35°C. They can directly replace the refrigerant in systems designed to work with R134a.

Refrigerant R290 can achieve up to 5% energy savings of the total consumption of the product over systems running R404A, at a similar initial cost[127], and is applicable to all the evaporating temperature ranges. Due to the flammability of this refrigerant, the charge per application is limited depending on the situation type of the system occupation of the space, etc., which can limit the capacity of the machine. This limitation of capacity can be solved throughout improving the efficiency of other parts of the system so that the cooling capacity needed from the compressor is lower. One of the options is the implementation of mini-channel heat exchangers, among others (see §5.2.3.4). additionally, some design guidelines in terms of security and leakage alarms or sensors are recommendable in machines running high quantities of hydrocarbons.

Refrigerant charge size limits are prescribed in a number or different standards[130]:

- EN 378
- EN/IEC 60335-2-24
- EN/IEC 60335-2-40
- EN/IEC 60335-2-89

In general, HC refrigerants should be used only in sealed systems with restricted charge, or in occupancy categories where only competent members of staff are present.

Stakeholders have mentioned that R290 could be used in small blast cabinets. However, no further information or currently available equipment has been found. For chillers, R290 using equipment has been identified. Nonetheless, no particular information about the energy improvement or price increase has been found for the use of R290 in chillers.

[128] Source: BIO Intelligence Service. Preparatory studies for Eco-design requirements of EuP's. Lot12: Commercial Refrigerators and Freezers. Dec. 2007

[129] Source: K. Mani, V. Selladurai. Experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a. Elsevier. 2008

[130] Proklima. Guidelines for the safe use of hydrocarbon refrigerants.

R600a working by itself has been proved to reduce the energy demand by up to 13% with respect to R134a (in the case of commercial bottle coolers) and to reduce the energy consumption of freezers operating on R290 by 9% with respect to systems running on R404A; improving COP in both cases. R600a refrigerant reduces the charge requirement by 50% in ice-cream freezers[131]. However, the lower pressure of R600a requires a compressor with a higher displacement, which can increase the cost of the machine. However, this cost increase is marginal[132].

When considering R152a, there are two big drawbacks. It is very flammable and it produces a lethal by-product (HF).

- SC: Products using R290 are available on the market. There is disagreement between stakeholders as at the proportion of market penetration, but it is thought to be between 10 to 20%[133]. Cost per unit associated with implementing a manufacturing line adapted to use of R290 is €40[134]. R290 implementation in large freezers may require a double refrigeration system (due to charge limits)[135].
- BC: as a replacement for R404A, it has been found that the R1270 (propylene) can be employed as perfect match[136]. This refrigerant is supposed to have a similar energy performance as R22[137] and R404A[138]. However, this refrigerant is said to be a very unusual refrigerant in commercial refrigeration[139].
- CH: several chiller manufacturers from all over the world have been identified as using natural refrigerants within their equipment. However, this number is very low (less than 5). According to stakeholders (ECOS, 2010) the energy improvement is about 15%, while the cost can be increased by 5%

Some benefits and drawbacks are summarised below**[140]**:

- Benefits:
    - No major adjustments in systems already working with R22 or R404A;
    - good thermal properties, leading to good efficiency;
    - no ODP – low GWP;
    - low cost; and

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[131] Source: M. Mohanraj, S. Jayaraj, C. Muraleedharan. Environment friendly alternatives to halogenated refrigerants—A review. Elsevier. 2008

[132] Source : ECOS

[133] Source: Friginox, Gram

[134] Source: ECOS, Electrolux

[135] Source: Electrolux

[136] N. Cox. *Developments and opportunities using hydrocarbon refrigerant blends*. 2010

[137] K. Park, D. Jung. Performance of R290 and R1270 for R22 applications with evaporator and condenser temperature variation. 2008

[138] J. Calm, P. Domanski. *R22 replacement status.* 2004

[139] Source : Defra

[140] Source: BIO Intelligence Service. Preparatory studies for Eco-design requirements of EuP's. Lot12: Commercial Refrigerators and Freezers. Dec. 2007

- reduction of pressure in the compressor translates into lower levels of noise.

- Drawbacks:
  - flammability (only indirect use in supermarkets due to safety constrains);
  - limited charge permitted;
  - cost related to safety requirements for the production process; and
  - higher average installation and maintenance costs.

Hydrocarbons are already being used by manufacturers for indirect remote systems and plug-ins as discussed in Task 4. A comprehensive enquiry into the use of hydrocarbons in residential air-conditioning has shown an energy efficiency increase of up to 5.7% over R22[141]. This is accompanied with a decrease in refrigerant charge of up to 55%[142] due to the smaller density of hydrocarbons[143].

Additional hydrocarbon refrigerant blends offer great opportunities as HFC replacements in wide range applications. For example, R432A, an R1270/E170 hydrocarbon blend can serve as R407C replacement[144].

Table 5-53: Refrigerant R290 – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	Now	10 to 20**	5	40	0
SC LT	Now	10 to 20**	5	40	0
BC	Now	N.A.	N.A.	N.A.	N.A.
WICR	Now	N.A.	N.A.	N.A.	N.A.
CH MT	Now	N.A.	15	2,750	N.A.
CH LT	Now	N.A.	15	3,500	N.A.
RCU MT	Now	less than 10	5	30	0.5
RCU LT	Now	less than 10	5	40	0.5

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
***Also includes R600a*
-: Not applicable to this product group
N.A.: No data available

5.2.12.3 Ammonia (R717)

Ammonia-based refrigerating systems are often subject to legal regulations and standards because of safety issues. However, according to ASHRAE, while suitable training for maintenance personnel is provided, danger from ammonia use is no different from that of most refrigerants. It is important to point out, however, that ammonia is classified as "high toxicity" in the ANSI/ASHRAE 34 standard and has to be handled with care to minimize risks. When ammonia is used as refrigerant, the predominant technology is open reciprocating compressors in which copper or

[141] Park K.J., Jung D "Thermodynamic performance of HCFC22 alternative refrigerants for residential air-conditioning applications", Energy and Buildings (2007), 675-680
[142] Maclaine-cross I.M, Leonardi E, "Why do hydrocarbons save energy?" Australian AIRAH Journal 51 (1997) 33–37.
[143] Cool technologies : working without HFCs-2010. Examples of HFC-free cooling technologies in various industrial sectors. Greenpeace, 2010
[144] Source: Shecco

copper allow is not used, because of the corrosion that ammonia causes in this metal.

In order to reduce the potential of ammonia leakage, compact and fully sealed refrigeration units have been recently designed and tested, mostly for factories and large industrial systems with a charge of less than 50 kg of ammonia for 1,000 kW cooling capacity. The results are not definite, but work is being done on this field.

Ammonia has been used in several applications over the last 150 years and has ozone depletion potential (ODP) and GWP equal to zero. Moreover, it has high refrigeration system energy performance, good thermodynamic properties and high heat transfer. Ammonia is available at a relatively low price, since it is mainly produced in large quantities for use as a fertilizer.

Ammonia is easily detected by smell even at low concentrations (5 ppm), therefore the risk associated with toxicity at higher concentrations (i.e. above 300 ppm) reduced. It is not compatible with copper and copper alloys.

- CH: in large industrial systems where there is a need for low temperatures (-30 to -50°C), ammonia is used in cascade refrigerating systems with CO_2[145]. Absorption chillers with an ammonia/water mixture are both suitable and cost effective for several specific applications; in particular those that use waste heat. Being a natural refrigerant, does not have major issues regarding GWP and ODP. The amount of refrigerant required is significantly reduced compared to R134a or R404A.In the same way, the energy efficiency of the product is the same compared to R134a and slightly worse when compared to R410A[146]. Chillers using ammonia are currently more expensive than fluorocarbon-based chillers, but the price difference is expected to decrease as production volumes increase. A semi-hermetic ammonia compressor is already on the market. In addition to water chillers, ammonia could be used in service cabinets and supermarket and convenience store refrigeration[147]. Ammonia chillers are expected to reduce the energy consumption up to 30% when compared to traditional refrigerants[148].
- BC: For freezing cycles, ECP717 seems to be an alternative. It is an azeotrope blend of R170 (ethane) and R717 (ammonia). This refrigerant seems to have higher refrigerant capacity, lower compression ratio, and lower compression discharge temperature[149]. No comparison regarding the level of energy performance has been identified to compare this refrigerant to R404A or R134. However, it features a high temperature glide and would end up in the worst safety group B3 in the ANSI/ASHRAE 34 standard.

[145] Source : ASHRAE Position Document on Natural Refrigerants. January 28, 2009
[146] J. Calm, P. Domanski. *R22 replacement status.* 2004
[147] Source: www.ashrae.org/docLib/200622793710_347.pdf. 2010
[148] Source: www.ammonia21.com/content/articles/2010-07-27-ammonia-chiller-enables-australia-s-first-carbon-neutral-wine.php
[149] Source: UNEP. *Report of the Refirgeration, Air Conditioning and Heat Pumps Techinical Options Committee*. Montreal Protocol On Substances that Deplete the Ozone Layer, January 2007

- BC: New developments are emerging using ammonia in combination with carbon dioxide in cascade systems, even for small condensing units, but these are still in development[150].

Ammonia has been classified in safety group B2 in the ANSI/ASHRAE 34 standard, which means that it has a high toxicity (B = evidence of toxicity at concentrations below 400 ppm) and moderate flammability (2 = lower flammability limit of more than 0.10 kg/m3 at 21°C and 101 kPa and a heat of combustion of less than 19 kJ/kg).

5.2.12.4 Carbon dioxide (R744)

Carbon dioxide is neither flammable nor toxic. Therefore, it can be an interesting alternative for all applications where the safety of the public is important (e.g. supermarkets), and when the average ambient temperature does not exceed 15°C. For higher temperatures, the efficiency of systems running CO_2 decreases, even though some new systems are being developed and tested to solve this issue (e.g. split cycles with two stage rotator compressors.)

Carbon dioxide has zero ozone depletion potential and low global warming potential. Carbon dioxide is used in vapour compression systems, from low temperature freezers to high temperature heat pumps. It is also frequently used as a secondary refrigerant, bringing an increase in efficiency compared with water, glycol or brine systems. Today, many carbon dioxide systems are sold in supermarkets, mostly in Scandinavian countries and for low-temperature, subcritical installations. The COP can be equal for systems using carbon dioxide than HFCs, depending on the configuration of the system, the target temperature, etc, but its main benefit is the low GWP of the refrigerant. According to information provided by stakeholders, this refrigerant can be used in any type of unit, but the efficiency is usually lower than with conventional refrigerants[151].

One major difference between carbon dioxide and other refrigerants is due to the pressure and temperature characteristics. The pressures are up to ten times higher than those in ammonia or R-404A systems, depending on operating conditions and operating mode (subcritical or transcritical). This high pressure results in high gas density, which allows a greater refrigerating effect to be achieved from a given compressor. It also produces very small reductions in saturation temperature[152] allowing higher mass flux in evaporators and suction pipes without efficiency penalties. This effect is particularly noticeable at low temperatures (-30 to -50°C). Very good performance of this refrigerant has been noticed in low temperature blast cabinets (improvements in efficiency and reduction in freezing time).

The carbon dioxide that is used as a refrigerant is typically recovered from the waste streams of industrial processes. The energy required to reclaim, clean, liquefy and transport carbon dioxide is estimated to have a carbon equivalent of 1 kg CO_2eq per kg. In contrast, ammonia production process has a carbon equivalent of 2 kg CO_2eq per kg and for fluorocarbons it is typically about 9 kg CO_2eq per kg.

[150] Source: Shecco

[151] Source: Defra

[152] The saturation temperature is the temperature for a corresponding saturation pressure at which a liquid boils into its vapour phase.

Benefits of using CO_2[153] include the following:

- Similar efficiency in low and moderate ambient temperatures due to the sensitivity of the components to this condition;
- CO_2 is an abundant resource;
- very low global warming potential (GWP);
- very low refrigerant cost respect traditional HFC;
- high refrigerant capacity;
- low toxicity;
- non flammable;
- small compressor displacement; and
- small sized piping.

However, there are some drawbacks in the use of CO_2 as listed below:

- lower COP than conventional refrigerants at high ambient temperature;
- higher working pressures in comparison to other refrigerants. Furthermore, it requires high pressures for optimal operation due to transcritical operation of the process. This increases the cost of equipment as it must be more robust.

In order to use CO_2 as a refrigerant, some modifications of the equipments must be made to fit with the thermodynamic properties of this gas[154].

- Heat exchangers: the good heat transfer properties presented by CO_2 allow using smaller heat exchangers (less transfer area) to reach the same conditions, as well as meet the PED.
- Valves: some valves have been developed especially for these systems: electronic modulating coil valve with different purposes; mechanical thermostatic valve; and, mechanical automatic valve, and all must meet the PED as well.

The piping in CO_2 systems must handle increased pressures as well, requiring that pipes be thicker (in some cases, more than twice as thick). However, the less heat transfer area required results in smaller, lighter piping overall.

R744 has been mentioned by stakeholders as a refrigerant alternative for remote equipment in cascade with ammonia. In complex supermarket systems, the improvement in the performance due to cascade R744 has been proved to reach up to 26%[155]. There is no information regarding the improvement potential of this for remote blast cabinets solely.

Due to its higher density and performance, it is possible to reduce the size of the equipments. However, the main drawback for R744 is its reduced efficiency under

[153] Source: BIO Intelligence Service. Preparatory studies for Eco-design requirements of EuP's. Lot12: Commercial Refrigerators and Freezers. Dec. 2007

[154] Source: BIO Intelligence Service. Preparatory studies for Eco-design requirements of EuP's. Lot12: Commercial Refrigerators and Freezers. Dec. 2007

[155] www.r744.com/articles/2010-07-02-first-south-american-r744-store-to-save-20-energy.php

high ambient temperatures, which translates into need for technology developments to overcome this issue and extra expenses.

Carbon dioxide has been classified in group A1 in the ANSI/ASHRAE 34 standard, which means that toxicity has not been identified at concentrations less than or equal to 400 ppm and do not show flame propagation when tested in air at 21°C and 101 kPa.

- SC: It is feasible that R744 could be used for service cabinets, but no information or evidence of research into these was found. Potential barriers to this are that most of these products are plug-in, hence the refrigeration system is small in size, and that there is high ambient temperature in their typical environment (e.g. kitchens).
- BC: The market share of blast cabinets that potentially could use carbon dioxide as a refrigerant is assumed to be 15% (remote configuration).It is estimated that this portion of the market consumes between 35% and 40% of the overall energy. It has been found that using R744 increases the cost of the equipment. Also, as this refrigerant is only useful in cold temperature weather, it is not applicable in all European countries.
- WICR: There are products on the market that enable use of R744 with small cold stores[156]. No data is available on their use for smaller walk-in cold rooms.
- CH: R744 can be an alternative refrigerant for chillers. Does not have major issues regarding GWP and ODP, but requires cascade systems to work properly.

Table 5-54: Refrigerant R744 – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	N.A.	N.A.	N.A.	N.A.	N.A.
SC LT	N.A.	N.A.	N.A.	N.A.	N.A.
BC	Now	less than 1	15	N.A.	N.A.
WICR	Now	N.A.	N.A.	N.A.	N.A.
CH MT	N.A.	N.A.	N.A.	N.A.	N.A.
CH LT	N.A.	N.A.	N.A.	N.A.	N.A.
RCU MT	Now	less than 10	0	3,000*	50[158]
RCU LT	Now	less than 10	0	4,000*	50

** Increase in price calculated from the weighted Base Case product price using % price increase figure*

-: Not applicable to this product group

N.A.: No data available

5.2.12.5 Unsaturated HFCs (HFO's)

Newly developed synthetic refrigerant blends of unsaturated HFCs (also known as HFOs), HFC1234yf and HFC1234ze(E), among others, have passed some tests proving efficiencies similar to R404A and very low GWP values[157]. The price of the technology needed to run on these new refrigerants is estimated to be between

[156] Advansor compSUPER XS: www.r744.com/articles/2010-03-19-advansor-adds-integrated-co2-refrigeration-units.php

[157] N. Achaichia, G. Matteo "Application and characteristics of the new refrigerant HFO-1234yf"

5%[160] and 20% higher[158] than the base price of machines running R404A. However, these refrigerants are classified as A2L in the safety classification because of their flammability.

Their atmospheric lifetime is estimated to be 11-18 days with a GWP of around 4-6 kg eq CO_2 , and being non-ozone-depleting substances. The common composition of these substances is fluorine and carbons and they shall have at least a double bond[159] linking these molecules.

The main scope for HFC1234yf is automotive refrigeration as a substitute to R-134a. These refrigerants are expected to be wildly available within the time frame of BNAT, as within the next 5 years the majority of Mobile Air Conditioning is expected to operate with unsaturated HFCs[160]. However, this product is still under research and testing, but a blend of HFC1234yf is supposed to be suitable in the future for service cabinets and remote condensing units.

Among the benefits presented by HFC1234yf are[161]:

- lower lifetime greenhouse emissions;
- shorter lifetime in atmosphere;
- compatibility with intended equipments (automotive);
- similar efficiency; and
- minimal changes to equipments design.

A study on unsaturated HFCs in commercial freezer models (ice cream vending) showed HFC-1234fy to be comparable to R-134a in these equipments, having at least 96% of the capacity and COP under the same conditions[162].

The safety class of HFC-1234ze(E) and HFC-1234yf is A2L as per as standard ANSI/ASHRAE 34, even though the energy required for ignition is lower than in hydrocarbons.

According to revised information by stakeholders (Friginox, Daikin, 2010) the applicability of HFCs for blast cabinets and chillers has changed from “1 to 2 years” to “2 to 4 years” and “5 years” respectively.

According to stakeholders feedback (ECOS, 2010), the increase in price of the application of unsaturated HFCs has changed fom 5% to 20%

[158] Source: ECOS
[159] Source :www2.dupont.com/Refrigerants/en_US/uses_apps/automotive_ac/SmartAutoAC/Glossary.htm
[160] Source : Honeywell
[161] Source: www51.honeywell.com/sm/genetron/prod-apps/low_global_warming_refrigerants.html
[162] Source: www2.dupont.com/Refrigerants/en_US/assets/downloads/SmartAutoAC/HFO-1234yf_IIR_Leck.pdf

Table 5-55: Refrigerant unsaturated HFC blends – market data and improvement potential

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Increase in price of product (%)
SC HT	1 to 2 years	0	N.A.	N.A.	20
SC LT	1 to 2 years	0	N.A.	N.A.	20
BC	2 to 4 years**	0	N.A.	N.A.	20
WICR	1 to 2 years	0	N.A.	N.A.	20
CH MT	5 years	0	N.A.	N.A.	20
CH LT	5 years	0	N.A.	N.A.	20
RCU MT	5 years	0	5	1,400	20
RCU LT	5 years	0	5	1,600	20

** Increase in price calculated from the weighted Base Case product price using % price increase figure*
-: Not applicable to this product group
N.A.: No data available

5.2.12.6 Refrigerant charge

Another important issue connected with the use of the refrigerant is the need to decrease its dose. This is important for ammonia and hydrocarbons for safety reasons, and for the high-GWP refrigerants for the high direct emissions shown in the TEWI analysis carried out in Task 4. Through design techniques such as plate heat exchangers, dry expansion evaporators or mini-channel technology, it is possible to reduce the quantity of refrigerants required. Another way to decrease the refrigerant charge is to use the indirect refrigeration system with secondary coolants. In these systems, the refrigerant is limited to the machine room, and the secondary coolants circulate in the occupied spaces. Apart from traditional secondary coolants like glycols and salt brines, CO_2 has gained considerable interest for this application.

5.2.12.7 Refrigerant leakage

Refrigerant leakage must be controlled in refrigerating and freezing applications. The F-Gas Regulation specifies a legislative requirement for a fixed leakage detection system to be installed on all refrigeration systems containing ≥300kg of fluorinated greenhouse gases.

A number of systems are commercially available on the market, both for fixed refrigerant detection systems and for portable electronic refrigerant detectors. Moreover, refrigerant detection can be performed while using a fluorescent or coloured dye which is added into the system and is distributed throughout the system with the lubricant. It indicates leaks by its emission with the leaking refrigerant. The refrigerant evaporates and the additive remains at the site of the leak. This becomes visible under an ultraviolet lamp.[163]

[163] British Refrigeration Association "Code of practice for refrigerant leak tightness in compliance with the F-gas Regulation" www.ior.org.uk/ior_/images/pdf/Code%20of%20Practice%20for%20Tightness%20Testing%20for%20Leakage%20on%20Fluorocarbon%20Commercial%20Refrigeration%20Systems%2018.12.pdf

5.2.12.8 Alternative refrigerants for the Base Cases

Finally, according to UNEP[164], alternatives for refrigerants in relation to appliances are shown in Table 5-56.

Table 5-56: UNEP recommendation for refrigerants according to the working systems

Systems type	Refrigerant alternative
Large supermarket systems	R717, R744, R290, R1270
Cold storage	R717, R744
Ice cream freezers	R744, R600a, R290
Water fountains	R600a
Ice making machines	R600a
Vending machines	R744, R290, R600a
Plug-in display cabinets	R600a
Condensing unit systems	R600a, R290, R744
Spiral, tunnel and blast freezers	R717, R744
Industrial chillers	R718, R717, R744

5.2.12.9 Summary

Table 5-49 shows some characteristics of all refrigerants presented, including environmental impacts. In general, alternative HFCs can achieve similar efficiencies in all the product types with slightly lower GWP values and a low increase in price due to changes in the equipment. Hydrocarbons have higher inherent efficiency and very low GWP, but the cooling capacity is limited by the maximum charge permitted due to their high flammability. Ammonia has high efficiency but the main drawback is its toxicity and while carbon dioxide is beneficial for remote machines in low ambient temperatures, it has high installation costs and is not efficient in warm climates. For ammonia and hydrocarbons the development of new technologies for heat exchangers can allow the charge reduction in the next years.

In choosing the best refrigerant for each application, performance, environmental impacts, safety classification and overall system performance and requirements should be taken into account. Regarding the costs, installation costs and running costs have to be considered: alternative refrigerants usually require higher initial investments to implement technologies not really spread in the market. Running costs are related to cost of the refrigerant liquid, maintenance needed, and energy efficiency.

[164] Source: www.unep.fr/ozonaction/topics/hcfc_alternatives.htm; 2007

Table 5-57: Comparative table for different refrigerants performance

Refrigerant	Benefits	Drawbacks
CO_2	• Very low direct cost respect to traditional refrigerants • High efficiency • Small displacement for the compressor • Small pipe dimensions	• Less efficient than HFCs at high ambient temperatures • High pressures in the system • High capital cost due to low mass production of CO_2 compressors • Compatibility: risks of corrosion to ferrous steel with humidity
Ammonia	• Good efficiency • Low cost • Refrigeration systems cost 10 - 20 % less • Low charge of refrigerant	• Toxicity ⇨ Leakages not permitted • Limited charge permitted • Compatibility: Corrosive to copper alloys
HCs (e.g. propane, isobutane)	• Can use evaporators designed for R22 or R404A • Good thermal properties ⇨ Good efficiency • Low cost • Less noise due to the reduction of pressure in the compressor	• Limited charge permitted • High installation cost in supermarkets due to safety fittings
Unsaturated HFCs (HFOs)	• Used with minimal modifications	• Still in development
HFCs	• High energy efficiency • Used with minimal modifications	• Increasing regulation

5.3 APPLICABILITY OF THE BEST AVAILABLE TECHNOLOGIES

Summaries of the BAT per product, their potential energy savings, and increased cost are presented in this section. The impact of each of the BAT on energy consumption as well as on price is based on the responses to the second online questionnaire for refrigerating equipment manufacturers, literature review, and information provided by stakeholders.

The technologies applicable to the different products are shown in the section below. The last column indicates their implementation priority based on the current potential energy savings and the increase in price. This prioritisation has been made dividing the energy savings (% of TEC) by the increase in price of the product. In some cases, market penetration or applicability to the whole product range in the market commented by stakeholders has also been taken into account. In such cases, an explicative note has been added. The long term options are also prioritised based on the potential of energy savings and the additional price.

Options classified as BNAT are, in some cases, currently available technologies. However, for these options either their applicability to the product has not yet been well tested, their applicability is limited by the increase of price or they are relevant only for a small proportion of the market and analysis are being made for other categories.

5.3.1 SERVICE CABINETS

The table below presents the improvement options, estimates of their current market penetration, their energy saving potential and cost. However, for some of these options, either their applicability to the product has not yet been well tested, their applicability is limited by the increase of price, they are relevant only for a small proportion of the market, or they are not yet on the market.

Table 5-58: Summary of the prioritised applicability of BAT for service cabinets together with their impact on energy savings and price

	Applicability (years)	Market penetration (%)	Savings for HT (% TEC)	Savings for LT (% TEC)	Increase in price of HT product (€)	Increase in price of product LT (€)	Priority HT	Priority LT
High efficiency compressor*	Now	40	7	10	20	40	5	4
ECM evaporator fan	Now	20	12	7	18	18	2	3
ECM condenser fan	Now	20	8	3	20	20	4	5
High efficiency fan blades	Now	20	3	3	5	5	3	2
Sealing door face frame	Now	N.A.	19	26	0	0	1	1
Insulation thickness	Now	35	4	5	100	110	7	8
R290	Now	10 to 20	5**	5**	40	40	6	6
Zeolite filter cassettes	Now	N.A.	0.5	2	90	90	9	10
Bubble expansion valve	Now	NA	10 to 20	10 to 20	N.A.	N.A.	9	11
Defrost control	Now	30	-	3	-	50	-	7
Anti-condensation control	Now	N.A.	2 to 20	-	N.A.	-	10	-

	Applicability (years)	Market penetration (%)	Savings for HT (% TEC)	Savings for LT (% TEC)	Increase in price of HT product (€)	Increase in price of product LT (€)	Priority HT	Priority LT
Insulation material	Now	N.A.	2	2	330	1115	8	9
				BNAT				
VSD compressor	2 to 3	N.A.	10	10	80	168	2	4
Hot gas anti-condensation	2 to 3	N.A.	18	9	94	94	1	2
ECM compressor	2 to 3	N.A.	12	12	108	122	3	1
Hot gas defrost	2 to 3	N.A.	N.A.	8	N.A.	129	4	3
R744	2 to 3	N.A.	N.A.**	N.A.**	N.A.	N.A.	5	5

**Selected from technologies related to the component*
***The benefit of this improvement is also the lower GWP of the refrigerant and reduced refrigerant charge – although it could provide high energy savings at no extra cost, it has not been selected as top priority due to its flammability.*
N.A.: Data not available
Note: Savings are not additive.

5.3.2 BLAST CABINETS

The technologies applicable to blast cabinets are shown in the table below. The last column indicates their applicability priority based on the energy savings and increase of price. Option 4 is only applicable for a part of the market (remote or freezers).

The long-term options are also prioritised based on the increase in price and potential energy savings. Some of these options are classified as currently applicable, but they only have been tested for small proportion of the market in the case of full baffling, or as in the case of improved heat exchangers, there is only evidence of their use in prototypes.

Table 5-59: Summary of the prioritised applicability of BAT for Blast Cabinet together with their impact on energy savings and price

	Applicability	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Priority
High Efficiency Fan Blades	Now	0%	9%	10	1
Electronic expansion valve	Now	5%	15%	100	5
Variable speed drive (VSD) compressor	Now	2%	10%	400	7
Insulation thickness	Now	5%	4%	100	6
ECM Fan for evaporator	Now	<5%	7%	40	4
Defrost Control	Now	5%	3%	10	2
Electronic Expansion Valve (EEV) when integrated with floating head pressure	Now	2%	20%	100	3
Remote condensing	Now	<1%	15%	1200	9
Full baffling	Now	99%	6%	Negligible	10
R290	N.A.	N.A.	5%	200	8
CO2	Now*	N.A.	N.A.	N.A.	11
			BNAT		
ECM compressor	2 to 3 years	0%	10%	100	1

	Applicability	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Priority
Improved heat exchanger**	Now***	5%	5%	60	2
Unsaturated HFC blends	3 to 4 years	0%	0****	300	3

**Applicable only for remote condensing units*
***Selected from technologies related to the component*
****Tested in prototypes, but there is no evidence of current application in the market*
*****The benefit of this improvement is also the lower GWP of the refrigerant and reduced refrigerant charge – although it could provide high energy savings at no extra cost, it has not been selected as top priority due to its flammability. No evidence of currently available equipment has been found*
N.A.: Data not available
Note: Savings are not additive.

5.3.3 Walk-in cold rooms

The technologies applicable to walk-in cold rooms are shown in the table below. The last column indicates their applicability priority based on the market penetration, current potential energy savings and the increase in price. The long term options are also prioritised based on the potential of energy savings and the additional price.

Table 5-60: Summary of the prioritised applicability of BAT for walk-in cold room together with their impact on energy savings and price

	Applicability (years)	Market penetration (%)	Savings (% TEC)	Increase in price of product (€)	Priority
Strip door curtains	Now	60	13	70	1
Auto door closer	Now	N.A.	12	111	2
PSC evaporator fan	Now	N.A.	10	100	3
ECM evaporator fan	Now	N.A.	13	150	4
High efficiency fan blades	Now	N.A.	3	50	5=
Insulation thickness	Now	N.A.	15	250	5=
ECM condenser fan	Now	N.A.	3	60	8
High efficiency LED light bulbs	Now	N.A.	4	200	12
R134a to replace R404A at HT, and R410A to replace R404A at LT	Now	N.A.	0**	0	9
Floating head pressure (plus electronic expansion valve) HighCap	Now	1	8	150	7
Ambient subcooling	Now	N.A.	4	170	11
High efficiency compressor* HighCap	Now	N.A.	5	200	10
Anti-condensation control	Now	N.A.	3	370	13
Defrost control	Now	0	3***	108	14
VSD compressor HighCap	Now	N.A.	15	N.A.	15
ECM compressor HighCap	Now	N.A.	4	N.A.	16
Zeolite filter cassettes	Now	N.A.	25	650	17
R290	Now	N.A.	N.A.**	N.A.	18
BNAT					
Hot gas defrost	2 to 3	N.A.	4***	81	1
Hot gas anti-condensation	2 to 3	N.A.	13***	323	2
Fan motor control	2 to 3	0	3	N.A.	3
R744	Now	N.A.	N.A.**	N.A.	6

**Selected from technologies related to the component*

**The benefit of this improvement is also the lower GWP of the refrigerant
***Applicable to low temperature only
HighCap: Applicable only to larger capacity products
N.A.: Data not available
Note: Savings are not additive.

5.3.4 PROCESS CHILLERS

Table 5-61 below presents the improvement options, estimates of their current market penetration, their energy saving potential and cost. In the last column the priority related to the improvement is expressed. This selection was done based on the current market penetration and their relevance to be used for the rest of the market, increase in price, and energy savings potential.

The BNAT options are also prioritised based on the increase in price and potential energy savings. These options are classified as currently applicable, but they only have been tested for small proportion of the market and their price is quite limitative.

Table 5-61: Summary of the applicability of BAT for process chillers together with their impact on energy savings and price

	Applicability	Market penetration (%)	Savings MT (% TEC)	Savings LT (% TEC)	Increase in price of MT product (€)	Increase in price of LT product (€)	Priority
Electronic expansion valve	Now	N.A.	5%	5%	1,000	1,000	1
High efficiency compressor*	Now	N.A.	5%	5%	6,000	7,000	6
Improved heat exchangers*	Now	N.A.	15%	15%	11,000	14,000	4
ECM fan condenser**	Now	N.A.	2%	2%	2,200	2,800	5
R290	Now	less than 1	5%	5%	2,750	3,500	3
Ambient subcooling	Now	less than 5	5%	5%	3,000	3,000	2
Economiser	Now	less than 2	10%	15%	N.A.	N.A.	7
R744/R717***	Now	N.A.	30%	30%	N.A.	N.A.	8
BNAT							
HFC 1234yf	2 to 4 years	0	3%	5%	11,000	14,000	1
Energy integration	Now	less than 5	5%	10%	6,000	6,000	2
Vacuum-process technology	Now	less than 1	20%	0%	60,000	-	3

*Including several features within the options for increasing the component efficiency
** Only applicable to air-cooled chillers
***Changes in the system are required. Integrated with a secondary fluid
N.A.: Data not available
Note: Savings are not additive.

BNAT improvement option applicabilities are approximate and indicative. Although these technologies may be available in 2 to 4 years, due to cost or other reasons like actual application, they might not be applicable in products within the same timeframe.

5.3.5 Remote condensing units

The table below presents the improvement options for remote condensing units, estimates of their current market penetration, as well as their energy saving potential and cost.

Table 5-62: Summary of the applicability of BAT for remote condensing unit together with their impact on energy savings and price

	Applicability (Years)	Market penetration (%)	Energy savings MT (% of TEC)	Energy savings LT (% of TEC)	Increase in price of MT product (€)	Increase in price of LT product (€)	Priority
Increase heat exchanger surfaces	Now	5%	5%	5%	157	223	1
ECM compressor	Now	less than 10	9%	9%	525	742	2
Digital modulation control for compressor*	Now	less than 10	10%	10%	525	742	3
Scroll compressor	Now	5%	10%	10%	840	1,187	4
Variable speed drive*	Now	2%	10%	10%	1312	1,855	5
High efficiency fan blades	Now	20%	0.5%	0.5%	105	148	6
ECM for fans	Now	20%	0.5%	1%	262	371	7
R290**	Now	less than 10	5%	5%	262	371	8
BNAT							
Water cooling	Next five years	5%	5%	5%	663	793	1
Mini-channel heat exchangers	Next five years	0%	10%	10%	1,325	1,587	2
Unsaturated HFCs**	Next five years	0%	5%	5%	1,325	1,587	3
CO2**	Next five years	less than 10	0%	2%	3,313	3,966	4

**Improvement not reflected on COP tested in EN13215 standard conditions*
***The benefit of this improvement is also the lower GWP of the refrigerant*
N.A.: Data not available
Notes: Savings are not additive.

BNAT improvement option applicability and prices are approximate and indicative. Although these technologies may be available in the next five years, due to cost or other reasons, they might not be practicably applicable in products within the same timeframe.

5.3.6 Technical constraints

There are several barriers for to implementing the BAT listed above. The first is the cost increase for the most energy-saving technologies. In general, purchase decisions are not based on life-cycle cost or payback considerations. The cheapest product which fulfils the given technical specification is chosen in most of the cases.

The second barrier is the complexity of technological issues related to refrigeration products. Always, there is a lack of resources among end-users[165] for assessing the available technology options together with their energy costs. The number of the technologies discussed adds more complexity for the service technicians and it might cause some difficulties in maintenance. Therefore, training should be considered in order to maintain product reliability. Moreover, it must be noted that the improvement of technologies are not cumulative, and tradeoffs exist.

The following table describes some of the technical limitations identified that should be noted in reference to improvement options.

Table 5-63: Constraints of improvement options

Technology	Constraints and drawbacks
Remote condensing	• Requires piping to, and location for, external condensing unit • Increased potential for refrigerant leakage due to increased piping • Benefits to small capacity systems may not compensate for high installation cost
Thicker insulation	• Will influence the refrigeration volume capacity or product footprint
Electronic expansion valve	• Benefits reached only when the complete installation has a close control system as well as flexible evaporating and condensing temperature • Benefits to small capacity systems may not compensate for current high cost of control system
VSD motors	• Less efficient at full load • Benefits to small capacity systems may not compensate for current high cost of control system
VSD motors for fans	• Stakeholder feedback states that condenser fans should keep condenser pressure down; VSD motors for fans is not advisable as will not benefit from energy savings at partial load • However, other feedback has claimed that in fact it is complementary, that once a VSD on the compressor is installed, it is necessary to maintain the pressure ratio at a minimum value indicated by the compressor manufacturer. Having a variable speed fan enables that to be achieved without having to cycle the fan (which in general is detrimental, mainly to the life time of the fan). In addition, having the two components with VSD enables optimisation of both speeds in order to get the best performance for each point
ECM compressor	• Does not provide a significant improvement for screw chillers
Parallel compressors	• Leaks affect whole compressor rack
Increased heat exchanger surface area	• On the evaporator side, the surface area influences the humidity level in the product • On the condenser side, increased surface area in low ambient temperature might cause a large drop in condensing pressure. This can lead to the pressure difference across the expansion valve to be too low to function correctly. If pressure is maintained at a high level throughout the year, there would be no point in increasing heat exchange.

[165] The efficiency of systems also degrade over time unless maintained; while some poor maintenance may be due to a lack of training, more can be caused by the lack of a maintenance budget. Keeping coils and exchangers clean, for example, is simple and effective, is often overlooked (for example ECM motors can fail early due to dust built-up through lack of cleaning). Source : Expert stakeholder

Technology	Constraints and drawbacks
	• Refrigerant tends to accumulate in the condenser in winter period and, with larger condensers, this could lead to refrigerant shortage in the rest of the circuit
Mini-channel heat exchanger	• Can produce pressure drops
R134a refrigerant	• Does not work at low temperatures
HC refrigerant	• Flammability
R744 (CO_2) refrigerant	• High pressure in refrigeration required • Benefits reliant on ambient conditions • Efficiency of simple systems is likely to be poorer than with conventional refrigerants
Hot gas anti-condensation	• Increased potential for refrigerant leakage due to increased piping
Evaporative cooling	• Potential health risks due to growth of *Legionella* bacteria
Pipeline pressure drops	• These reduce compressor efficiency by raising its pressure ratio above that of condensing and evaporating pressures

5.4 BEST AVAILABLE TECHNOLOGY PRODUCTS

All products presented in this section are for illustration purposes only. They provide examples of what is technically feasible but should not be looked at as "role models". Also, it should be kept in mind that several barriers exist to the production of such efficient products, such as the limitation in the amount of hydrocarbon authorised in plug-in appliances and other end-user related barriers, such as the importance of the purchase cost.

5.4.1 SERVICE CABINETS

The characteristics of models recognised as the best performing (BAT) plug-in service cabinets on the EU market, a 450 litre 1-door vertical model, are presented.

Figure 5-15: Service cabinet, PLUS M 600 CXG 4N and Midi F 625 G, GRAM

Table 5-64: Characteristics of the BAT service cabinet compared to the sub-Base Cases

Product characteristic	Sub-Base Case HT	Sub-Base Case LT	BAT HT	BAT LT
Product type/model/design:	Vertical, 1-door	Vertical, 1-door	Vertical, 1-door	Vertical, 1-door
Location of condensing unit:	Integral (plug-in)	Integral (plug-in)	Integral (plug-in)	Integral (plug-in)
Climate class:	4	4	4	4
M-package temperature class:	M1	L1	M1	L1
Test standard:	EN 441	EN 441	EN 441	EN 441
Internal cold storage temperature [°C]:	+5°C	-18°C	+5°C	-18°C
Internal cold storage temperature range(s) (°C):	+2 to +12°C	-5 to -25°C	+2 to +12°C	-5 to -25°C
Air-on temperature (ambient temperature) [°C]:	+30°C	+30°C	+30°C	+30°C
Net internal volume [litres][166]:	450	450	441	441
Product use pattern [hours/year]:	8760	8760	8760	8760
Functional unit:	Litre of net volume at +5°C	Litre of net volume at -18°C	Litre of net volume at +5°C	Litre of net volume at -18°C
Power input [kW]:	0.315	N.A.	0.291	0.425
Cooling capacity [kW]:	0.35	N.A.	0.389 (to = -10 °C)	0.475 (to = -25 °C)
COP:	1.11	N.A.	1.87	1.38

166 Calculated according to EN 441 method

Product characteristic	Sub-Base Case HT	Sub-Base Case LT	BAT HT	BAT LT
AEC [kWh/year]:	2,000	5,000	508	2,220
TEC [kWh/48hrs]:	10.96	27.40	2.79	12.16
EEI [kWh/48hrs / m3]:	24.35	60.88	6.32	27.58
Performance [kWh/litre net volume at storage temperature/year]:	4.44	11.11	1.15	5.03
Price (ex VAT) [€]:	1,000	1,100	2,300	2,550
Lifetime [years]:	8.5	8.5	10	10
Refrigerant:	R134a	R404A	R290	R290
Refrigerant charge [g]:	300	400	102	92
Refrigerant leakage [% per annum]:	1%	1%	1%	1%
Defrost type [natural/electric/hot gas/cool gas]:	Natural	Electric	Natural (Air)	Electric
Defrost control (if applicable) [timed/off-cycle/on-demand]:	Off-cycle	Off-cycle	Timed	Timed
Anti-condensation (if applicable):	None	None	None	None
Expansion valve type:	Capillary tube	Capillary tube	Capillary tube	Capillary tube
Other features not covered above:	-	-	-	-
Weight of product [kg]:	114	114	145	145
External height [m] :	2.06	2.06	2.01	2.01
External width [m] :	0.7	0.7	0.695	0.695
External depth [m] :	0.84	0.84	0.876	0.876
Gross total (shipping) volume [m3] :	1,211	1,211	1.52	1.52
Number of compressors:	1	1	1	1
Type of compressor:	Hermetic reciprocating	Hermetic reciprocating	Hermetic reciprocating	Hermetic reciprocating
Power of compressor [W]:	195	N.A.	208 (to = -10 °C)	344 (to = -25 °C)
Capacity of compressor [W]:	320	N.A.	389 (to = -10 °C)	475 (to = -25 °C)
Weight of compressor [kg]:	10	N.A.	7.5	13.1
Compressor motor control [none/two-speed/VSD]:	None	None	None	None
Evaporator heat exchanger type and material:	Fin and tube	Fin and tube	Fin evaporator with copper tubes and aluminium fins.	Fin evaporator with copper tubes and aluminium fins.
Evaporator face area [cm²]:	240	N.A.	24,069	24,069
Evaporator fan motor type:	Shaded pole axial	Shaded pole axial	Electric commutated with permanent magnets	Electric commutated with permanent magnets
Evaporator fan motor power [W]:	5	5	10 W	10 W
Evaporator fan motor control [none/two-speed/VSD]:	None	None	None	None
Weight of evaporator module [kg]:	1	1	2,87 (Evaporator, heatexchanger, suspension and shieldings)	3,15 (Evaporator, heatexchanger, defrosting heating element, suspension and shieldings)
Condenser cooling:	Air-cooled	Air-cooled	Air-cooled	Air-cooled
Condenser heat exchanger type and material:	Fin and tube	Fin and tube	Fin condenser with copper tubes and aluminium fins.	Fin condenser with copper tubes and aluminium fins.
Condenser face area [cm²]:	N.A.	N.A.	7,500	15,000
Condenser fan motor type:	Shaded pole axial	Shaded pole axial	Electric commutated with permanent magnets	Electric commutated with permanent magnets
Condenser fan motor power [W]:	10	N.A.	10 W	10 W

Product characteristic	Sub-Base Case HT	Sub-Base Case LT	BAT HT	BAT LT
Condenser fan motor control [none/two-speed/VSD]:	None	None	None	None
Weight of condenser module [kg]:	1.5	N.A.	2,6 (Condenser, fan shroud and motor)	3,13 (Condenser, fan shroud and motor)
Number of doors:	1	1	1	1
Insulation type:	Polyurethane	Polyurethane	Polyurethane	Polyurethane
Insulation thickness [mm]:	60	60	60	60
Foaming agent:	Cyclo-Pentan / Isopentane	Cyclo-Pentan / Isopentane	Cyclopenthane	Cyclopenthane
Lighting type [incandescent/fluorescent/LED]:	Incendescent	Incendescent	Halogen	Halogen
Lighting power [W]:	20	20	2x10	2x10

This comparison of the sub-Base Case and real BAT for high-temperature demonstrates that a saving potential of 75% AEC exists for vertical single-door models, and for low-temperature the saving potential is 56% AEC (for vertical single-door models too).

The energy consumption conversion factors used to calculate the weighted Base Case have been applied to the real BAT and it is assumed that design options and improvement potential are equivalent for the vertical single-door model as for any other type of service cabinet (e.g. double-door, horizontal, or chest).

If the energy consumption conversion factors used to calculate the weighted Base Case and the improvement potentials are applied, the following average AEC figures shown in Table 5-65 for BAT in the sub-categories are estimated.

Table 5-65: Estimated AEC of Base Case and BAT categories

Configration	Operation temperature	Model type: door numbers	Average net volume (litres)[167]	Estimated average AEC of average Base Case product sub-categories (kWh)	Estimated average AEC of BAT product sub-categories* (kWh)
Vertical	Refrigerator	1	450	2,000	500
		2	900	3,200	800
	Freezer	1	450	5,000	2,200
		2	900	9,500	4,180
Horizontal	Refrigerator	1	150	900	225
		2+	200	960	240
	Freezer	1	100	1,167	513
		2+	200	2,217	975
Chest	Freezer	1	400	3,556	1,564
Weighted HT	-	-	-	**2,000**	**500**
Weighted LT	-	-	-	**5,000**	**2,200**

[167] Calculated according to EN 441 method

5.4.2 Blast cabinets

A 21kg model has been identified as a BAT product currently available on the EU market in the blast cabinet category.

Figure 5-16: BC21 blast cabinet BAT model, Foster

Table 5-66: Characteristics of the BAT blast cabinet compared to the sub-Base Case

Product characteristic	Sub-Base Case	BAT	BAT
Product type/model/design:	Vertical	Vertical	Vertical
Location of condensing unit:	Integrated	Integrated	Integrated
Capacity [kg]:	20	21	21
Maximum number of trays (GN 1/1):	5	6	6
Cooling cycle*:	chilling from +70°C to +3°C in 90 minutes	chilling from +70°C to +3°C in 90 minutes	freezing from +70°C to -18°C in 240 minutes
Electricity consumption [kWh/cycle]:	2.0	1.3	3.7
Product use pattern [cycles/year]:	2 cycles per day, 220 days per year	2 cycles per day, 220 days per year	1 cycles per day, 220 days per year
Condensing unit function [hours/day]:	3	3	4
Product use pattern [hours/year]:	660	660	880
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	1 kg of foodstuff (referred to material proposed by NF AC D 40-003) chilling from +70°C to +3°C in 90 minutes	1 kg of foodstuff (referred to material proposed by NF AC D 40-003) freezing from +70°C to -18°C in 240 minutes
Power input [kW]:	1.2	2.3	-
Cooling capacity [kW]:	0.83	0.83	1.012
AEC [kWh/year]:	880	572	814
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]:	44.00	27.23	-
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	0.0619	-

Product characteristic	Sub-Base Case	BAT	BAT
Performance [kWh/kg of foodstuff (referred to material proposed by NF AC D 40-003) freezing from +70°C to -18°C in 240 minutes/year]:	-	-	38.76
Performance [kWh/kg of foodstuff (referred to material proposed by NF AC D 40-003) freezing from +70°C to -18°C in 2490 minutes/cycle]:	-	-	0,176
Price (ex VAT) [€]:	3,400	3,800	*N.A.*
Lifetime [years]:	8.5	8.5	8.5
Refrigerant:	R404A	R404A	R404A
Refrigerant charge [kg]:	0.8	1.5	1.5
Refrigerant leakage [% per annum]:	5	5	5
Defrost type [natural/electric/hot gas/cool gas]:	not included	not included	Automatic
Defrost control (if applicable) [timed/off-cycle/on-demand]:	not included	not included	Timed
Door frame heater wire:	not included	2,200mm	2,200mm
Defrost load [amps]:	-	-	1.0
Anti-condensation (if applicable):	not included	not included	-
Expansion valve type:	Thermostatic expansion valve	Electronic expansion valve	Electronic expansion valve
Weight of product [kg]:	120	130	130
External height [cm]:	850	1291	1291
External width [cm]:	800	700	700
External depth [cm]:	700	800	800
Net volume [m³]:	52	69	69
Gross total (shipping) volume [m3] :	0.81	1.23	1.23
Shipping weight [kg]:	150	*N.A.*	*N.A.*
Number of compressors:	1	1	1
Type of compressor:	Hermetic reciprocating	Hermetic reciprocating	Hermetic reciprocating
Power of compressor [W]:	969	*1089*	*1248*
Capacity of compressor [W]:	1120	*N.A.*	*N.A.*
Weight of compressor [kg]:	12.5	23	23.7
Compressor motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*	*N.A.*
Evaporator heat exchanger type and material:	*Fined tube / aluminum copper*	*Fined tube / aluminum copper*	*Fined tube / aluminum copper*
Evaporator face area [cm²]:	*N.A.*	*N.A.*	*N.A.*
Evaporator fan motor type:	Axial	Axial	Axial
Evaporator fan motor power [W]:	160	*N.A.*	*N.A.*
Evaporator fan motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*	*N.A.*
Weight of evaporator module [kg]:	*N.A.*	*N.A.*	*N.A.*
Condenser cooling:	Air-cooled	Air-cooled	Air-cooled
Condenser heat exchanger type and material:	*Fined tube / aluminum copper*	*Fined tube / aluminum copper*	*Fined tube / aluminum copper*
Condenser face area [cm²]:	*N.A.*	*N.A.*	*N.A.*
Condenser fan motor type:	Axial	Axial	Axial
Condenser fan motor power [W]:	60	*N.A.*	*N.A.*

Product characteristic	Sub-Base Case	BAT	BAT
Condenser fan motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*	*N.A.*
Weight of condenser module [kg]:	2.5	*N.A.*	*N.A.*
Number of doors:	1	1	1
Door material :	Stainless steel	Stainless steel	Stainless steel
Insulation type:	Polyurethane	Polyurethane	Polyurethane
Insulation thickness [mm]:	55	55	55
Foaming agent:	Water	Cyclo-Pentan/Isopentane (CFC free)	Cyclo-Pentan/Isopentane (CFC free)
Other features:	Self closing door, evaporation temperature control with thermostat valve, inner door stop, temp. detector probe	Self closing door, temperature detector probe	Self closing door, temperature detector probe

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

This comparison of the sub-Base Case and real BAT for chilling cycles demonstrates that a saving potential of 35% AEC exists for the typical reach-in model of 20kg capacity (plug-in). Based on the sub-Base Case for chilling and factors provided by stakeholders between chilling and freezing cycles, the expected energy consumption per freezing cycle for equipment of this type and capacity is estimated to be 5.00 kWh per cycle. This would lead to an energy saving of 35% for the freezing cycles.

The characteristics of this real chilling BAT model apparently are very similar to the characteristics of the equivalent sub-Base Case model (reach-in 20kg). The provider of this BAT equipment has mentioned that the reason for improved performance is more accurate matching between the product components, meaning no sub-sizing of components, and perhaps also because there is a little oversizing of the product (i.e. more power than strictly required to process its stated capacity within the defined cycle). This option is discussed in §5.2.10.9.

The proper matching of components for optimal performance is related to the use of elements that are compatible and will avoid leakage for instance. The misuse of valves, or use of incorrect or low-quality materials, can lead to decrease of performance.

The energy consumption conversion factors used to calculate the weighted Base Case have been applied to the real BAT and it is assumed that design options and improvement potential are equivalent for the reach-in 20 kg model (plug-in) as for any other type of blast cabinets (trolley, pass-through, remote, and larger models).

If the energy consumption conversion factors used to calculate the weighted Base Case and the improvement potential are applied, the following average AEC figures for BAT in the sub-categories are estimated.

Table 5-67: Estimated AEC of Base Case and BAT categories

Configuration	Operation temperature	Size	Location condensing unit	Market share (%)	Assumptions of electricity consumption	Average consumption per year (kWh/year)
Reach-in	Chilling	Small R	Plug-in	1.91	0.60 energy cons. as reach-in medium (Base)	343
		Medium R	Plug-in	4.21	(Base)	572
		Large R	Plug-in	0.77	2.40 energy cons. as reach-in medium (Base)	1,373
		Extra-large R	Remote	0.77	3.8 energy cons. as reach-in medium (Base)	2,174
	Freezing	Small	Plug-in	0.26	2.5 energy cons. as reach-in small (Base)	429
		Medium	Plug-in	0.43	2.5 energy cons. as reach-in medium (Base)	715
		Large	Plug-in	0.09	2.5 energy cons. as reach-in large (Base)	1,716
		Extra-large	Remote	0.09	2.5 energy cons. as reach-in extra-large (Base)	2,717
	Chilling / Freezing*	Small	Plug-in	22.95	Aggregate energy cons. from chilling and freezing cycles*	601
		Medium	Plug-in	38.25	Aggregate energy cons. from chilling and freezing cycles*	1,001
		Large	Plug-in	7.65	Aggregate energy cons. from chilling and freezing cycles*	2,402
		Extra-large	Remote	7.65	Aggregate energy cons. from chilling and freezing cycles*	3,804
Roll-in (trolley)	Chilling	Small	Plug-in	0.06	1.15 energy consumption cabinet similar capacity	2,696
		Medium	Remote	0.03	1.15 energy consumption cabinet similar capacity	4,042
		Large	Remote	0.02	1.15 energy consumption cabinet similar capacity	6,567
	Freezing	Small	Plug-in	0.06	2.5*1.15 times energy consumption cabinet similar cap.	3,370
		Medium	Remote	0.03	2.5*1.15 times energy consumption cabinet similar cap.	5,053
		Large	Remote	0.01	2.5*1.15 times energy consumption cabinet similar cap.	8,208
	Chilling/ Freezing*	Small	Plug-in	5.88	Aggregate energy cons. from chilling and freezing cycles*	4,718
		Medium	Remote	2.94	Aggregate energy cons. from chilling and freezing cycles*	7,074

Configuration	Operation temperature	Size	Location condensing unit	Market share (%)	Assumptions of electricity consumption	Average consumption per year (kWh/year)
		Large	Remote	0.98	Aggregate energy cons. from chilling and freezing cycles*	11,491
Pass-through	Chilling	Small	Plug-in	0.03	1.15 energy consumption cabinet similar capacity	2,696
		Medium	Remote	0.01	1.15 energy consumption cabinet similar capacity	4,042
		Large	Remote	0.01	1.15 energy consumption cabinet similar capacity	6,567
	Freezing	Small	Plug-in	0.03	2.5*1.15 times energy consumption cabinet similar cap.	3,370
		Medium	Remote	0.02	2.5*1.15 times energy consumption cabinet similar cap.	5,053
		Large	Remote	0.01	2.5*1.15 times energy consumption cabinet similar cap.	8,208
	Chilling/ Freezing*	Small	Plug-in	2.94	Aggregate energy cons. from chilling and freezing cycles*	4,718
		Medium	Remote	1.47	Aggregate energy cons. from chilling and freezing cycles*	7,074
		Large	Remote	0.49	Aggregate energy cons. from chilling and freezing cycles*	11,491
Weighted Base Case	-	-	-	-	-	**3,031**
Weighted BAT	-	-	-	-	-	**1,970**

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

5.4.3 WALK-IN COLD ROOMS

According to the answers from the second questionnaire addressed to walk-in cold room manufacturers, the following properties characterise the best performing models on the European Market.

Table 5-68: Estimates of characteristic of the best available walk-in cold rooms on the EU market

Characteristic	LT cold room	HT cold room
Storage temperature (°C)	-20°C	+3°C
Net internal refrigerated volume (m^3)	27	27
Estimate of AEC (kWh/y)	11,306	8,109
Type of refrigerant	R404A	R134a
Performance [kWh/m^3/year]:	418.74	300.33

In addition, it is estimated in the literature that walk-in cold rooms have a potential improvement of 20 to 51%[168]. It is therefore assumed that the AEC of the BAT model is 35% less than that of the sub-Base Case.

Assumptions and estimates of the main characteristics of BAT walk-in cold room, similar to Base Case model, are presented in Table 5-69. **As the energy consumption of walk-in cold rooms has no standard testing method, the numbers below are indicative.**

Table 5-69: Characteristics of an estimated BAT walk-in cold room compared to the estimated Base Case

Product characteristics	Estimated Base Case	Estimated BAT
Product type/model/design:	Factory-built	Packaged refrigeration unit
Location of condensing unit:	Packaged	Packaged
Test standard:	-	-
Internal cold storage temperature [°C]:	+2°C	+2°C
Internal cold storage temperature range(s) (°C):	+1°C to +4°C	+1°C to +4°C
Air-on temperature (ambient temperature) [°C]:	+32°C	+32°C
Net internal volume [m^3]:	25	25
Condensing unit function [hours/day]:	16hrs to 18hrs condensing unit (on/off)	16hrs to 18hrs condensing unit (on/off)
Product use pattern [hours/year]:	8,760	8,760
Functional unit:	m^3 of net internal volume at +2°C	m^3 of net internal volume at +2°C
Power input [kW]:	2	0.95
Cooling capacity [kW]:	2.1	2.1
COP:	1.5	2
AEC [kWh/year]:	10,570	6,870
TEC [kW/48hrs]:	58	38
Performance [kWh/m^3 at 2°C/year]:	423	275
Price (ex VAT) [€]:	8,800	10,560
Lifetime [years]:	10	12
Refrigerant:	R404A	R134a for HT/R410A for LT
Refrigerant charge [g]:	2,400	2,040
Refrigerant leakage [% per annum]:	5	5

[168] UK MTP, *BNCR CR04 Walk-in Cool Rooms Government Standards Evidence Base 2009: Best Available Technology Scenario*, 2010. Available at: efficient-products.defra.gov.uk/cms/product-strategies/subsector/commercial-refrigeration

Product characteristics	Estimated Base Case	Estimated BAT
Defrost type [natural/electric/hot gas/cool gas]:	*N.A.*	*N.A.*
Defrost control (if applicable) [timed/off-cycle/on-demand]:	*N.A.*	*N.A.*
Anti-condensation (if applicable):	*N.A.*	*N.A.*
Expansion valve type:	*N.A.*	*N.A.*
Other features not covered above:	-	-
Weight of product [kg]:	1,000	*N.A.*
External height [cm] :	232	*N.A.*
External width [cm] :	362	*N.A.*
External depth [cm] :	342	*N.A.*
Gross total (shipping) volume [m3] :	29	*N.A.*
Number of compressors:	1	1
Type of compressor:	Hermetic reciprocating	Hermetic reciprocating
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]:	Not applicable	*N.A.*
Evaporator heat exchanger type and material:	Fin and tube	Fin and tube
Evaporator face area [cm²]:	*N.A.*	*N.A.*
Evaporator fan motor type:	Shaded pole axial	ECM
Evaporator fan motor power [W]:	*N.A.*	*N.A.*
Evaporator fan motor control [none/two-speed/VSD]:	None	None
Weight of evaporator module [kg]:	*N.A.*	*N.A.*
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	ECM
Condenser fan motor power [W]:	*N.A.*	*N.A.*
Condenser fan motor control [none/two-speed/VSD]:	None	None
Weight of condenser module [kg]:	*N.A.*	*N.A.*
Number of doors:	1	1
Type of door	Hinged; 800x1900mm	Sliding; 800x1900mm
Strip door curtains	None	Yes
Insulation type:	Polyurethane	Polyurethane
Insulation thickness [mm]:	80	180
Foaming agent:	Cyclo-Pentan/Isopentane	Cyclo-Pentan/Isopentane
Lighting type [incandescent/fluorescent/LED]:	Incendescent	LED
Lighting power [W]:	80	*N.A.*

This comparison of the estimated Base Case and the BAT models suggests that a saving potential of 35% AEC exists. If the energy consumption conversion factors used to calculate the weighted Base Case and the improvement potential are applied, the following average AEC figures for BAT in the the sub-categories are estimated.

The energy consumption conversion factors used to calculate the weighted Base Case have been applied to the BAT and it is assumed that design options and improvement potential are equivalent for the 25m^3 monoblock (packaged refrigeration unit) chiller room as for any other type of walk-in cold room (medium and large models, chillers and freezers).

If the energy consumption conversion factors used to calculate the weighted Base Case and the improvement potentials are applied, the following average AEC figures shown in Table 5-70 for BAT in the sub-categories are estimated.

Table 5-70: Estimated AEC of Base Case and BAT categories

Size	Operation temperature	MTP estimated market proportion	MTP estimated average cooling load (kW)	MTP estimated average COP	BIO estimateda verage net internal volume (m^3)	Estimated average AEC of average BAT product sub-categories (kWh)
Small (up to 20m^3)	Chiller	44.49%	1.4	1.84	12	4,332
	Freezer	22.54%	1.3	1.32	12	5,608
Medium (20m^3 to 100m^3)	Chiller	23.36%	4.5	2.41	40	10,632
	Freezer	8.10%	4.58	1.47	40	17,740
Large (100m^3 to 400m^3)	Chiller	1.13%	18	2.66	300	38,531
	Freezer	0.48%	19	1.47	300	73,596
Weighted BAT	-	-	-	-	-	**7,901**
Weighted Base Case	-	-	-	-	-	**12,155**

5.4.4 PROCESS CHILLERS

The table below shows the specifications for the best available chiller according to the answers to the second questionnaire as well as for a similar product on the market five years ago and within the coming five years.

Table 5-71: Main characteristics of the chiller's development

Characteristic	Product five years ago	BAT
Cooling range	water on at 12°C, off at 7°C	water on at 12°C, off at 7°C
AEC (kWh/year)	341,623	169,790
Type of refrigerant	R407c	R134a

The proposed BAT chillers were provided by stakeholders. Their use is not only intended for foodstuff refrigeration, but also for possible general industrial processes. Their applications to foodstuff process would mean the use of brine and propylene glycol as more safe substance. This change will induce to a different efficiencies.

Figure 5-17: JCI Sabroe, Johnson Controls

Table 5-72: Characteristics of the BAT chiller compared to the sub-Base Cases

Product characteristics	Sub-Base Case MT	BAT MT	Sub-Base Case LT	BAT LT
Product type/model/design:	Packaged	Packaged	Packaged	Packaged
Location of condensing unit:	Integral (packaged)	Integral (packaged)	Integral (packaged)	Integral (packaged)
Evaporator output temperature [°C]:	-8	-11	-18	-25
Water on [°C]:	+25	+25	+25	+25
Air-on temperature (ambient temperature) [°C]:	30	30	30	30
Water solution [%]:	Ethylene glycol 40%	Ethylene glycol 40%	Ethylene glycol 40%	Ethylene glycol 40%
Condensing unit function [hours/day]:	12	12	12	12
Product use pattern [hours/year]:	4,380	4,380	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 -10°C at 30°C ambient temperature	1 kW cooling capacity to reach -25°C at 30°C ambient temperature	1 kW cooling capacity to reach -25°C at 30°C ambient temperature
Power input [kW]:	98.8	90	128	94
Cooling capacity [kW]:	276	279	251.95	260.2
Performance [COP]*:	2.80	2.89	1.96	2.1
AEC [kWh/year]:	346,206	315,360	450,068	409,968
Price (ex VAT) [€]:	55,000	82,500	70,000	105,000
Lifetime [years]:	15	15	15	15
Refrigerant:	R134a	R717	R404A	R717
Refrigerant charge [g]:	100	26	250	32
Refrigerant leakage [% per annum]:	1	1	1	1
Expansion valve type:	Thermostatic	Electronic	Thermostatic	Electronic
Weight of product [kg]:	2,757	4,940	3,171	5,681

Product characteristics	Sub-Base Case MT	BAT MT	Sub-Base Case LT	BAT LT
External height [cm]:	188	260	188	260
External width [cm]:	86	240	86	240
External depth [cm]:	430.5	285	430.5	285
Gross total (shipping) volume [m3]:	11.6	29.6	13.34	29.6
Number of compressors:	2	*2*	2	*N.A.*
Type of compressor:	Semi-hermetic screw	Rotary screw	Semi-hermetic screw	*N.A.*
Power of compressor [W]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Capacity of compressor [W]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Weight of compressor [kg]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Compressor motor control [none/two-speed/VSD]:	Included	Included	Included	Included
VSD compressor motor control (if applicable):	Not included	Capacity controller	Not included	*N.A.*
Evaporator heat exchanger type and material:	Stainless steel	Stainless steel	Stainless steel	Stainless steel
Evaporator face area [cm^2]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Evaporator fan motor type:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Evaporator fan motor power [W]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Evaporator fan motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Weight of evaporator module [kg]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Condenser cooling:	Water-cooled	Water-cooled	Water-cooled	Water-cooled
Condenser heat exchanger type and material:	Shell-tube / stainless steel	Semi-welded	Shell-tube / stainless steel	Shell-tube
Condenser face area [cm^2]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Condenser fan motor type:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Condenser fan motor power [W]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Condenser fan motor control [none/two-speed/VSD]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*
Weight of condenser module [kg]:	*N.A.*	*N.A.*	*N.A.*	*N.A.*

*COP: Ratio between cooling capacity and power input. Measured at 30°C inlet temperature at the condenser.

This comparison of the sub-Base Case and real BAT for chilling cycles demonstrates that a saving potential of 9% AEC exists. If the energy consumption conversion factors used to calculate the weighted Base Case are again applied to this improvement potential, the following average AEC for BAT are estimated.

The energy consumption conversion factors used to calculate the weighted Base Case have been applied to the real BAT and it is assumed that design options and

improvement potential are equivalent for the medium size as for any other size of chillers.

Table 5-73: Estimated AEC of Base Cases and BAT categories

Operation temperature	Size	Typical capacity (kW)	Cooling system	Market share (%)	Assumed factor	Annual energy consumption (-8°C/-15°C outlet temp./ 30°C)
Medium	Small	50	Air cooled	80	1.15*X	82,350
			Water cooled	20	X	71,608
	Medium	250	Air cooled	75	1.15*4.6*X	368,854
			Water cooled	25	4.6*X	320,743
	Large	500	Air cooled	70	1.15*8.3*X	708,898
			Water cooled	30	8.3*X	616,433
	Extra-large	1000	Air cooled	60	1.15*16*X	1,312,405
			Water cooled	40	16*X	1,141,222
Low	Small	50	Air cooled	80	1.15*Y	115,289
			Water cooled	20	Y	100,252
	Medium	250	Air cooled	70	1.15*4.6*Y	516,396
			Water cooled	30	4.6*Y	449,040
	Large	500	Air cooled	70	1.15*8.3*Y	992,457
			Water cooled	30	8.3*Y	863,006
	Extra-large	1000	Air cooled	60	1.15*16*Y	1,837,368
			Water cooled	40	16*Y	1,597,711
Weighted MT Base Case	-	-	-	-	-	**420,946**
Weighted MT BAT	-	-	-	-	-	**383,061**
Weighted LT Base Case	-	-	-	-	-	**545,518**
Weighted LT BAT	-	-	-	-	-	**534,769**

5.4.5 REMOTE CONDENSING UNITS

The models presented below have been identified as best available products regarding remote condensing units for medium and low temperature, respectively.

Figure 5-18: Hubbard HZB

Figure 5-19 : Daikin Zeas

The Base Case and BAT characteristics and performance are compared below. The technical data for BAT products have been taken from public brochures. Data which has been calculated or estimated is marked as such.

Table 5-74: Characteristics of the BAT remote condensing unit compared to the sub-Base Cases

Product characteristics	Sub-Base Case MT	Sub-Base Case LT	BAT MT	BAT LT
Product type/design:	Packaged	Packaged	Packaged	Packaged
Evaporation temperature [°C]:	-10°C	-35°C	-10°C	-35°C
Operation temperature [°C]:	0°C	-25°C	0°C	-25°C
Ambient temperature [°C]:	+32°C	+32°C	+32°C	+32°C
Condensing unit function [hours/day]:	16	16	16	16
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	1 kW cooling capacity at evaporation temperature -10°C and ambient temperature +32°C	1 kW cooling capacity at evaporation temperature -35°C and ambient temperature +32°C
Power input [kW]:	3.7	5.8	3.5	5.7
Cooling capacity [kW]:	7.1	5.8	7.6	6.3
Performance [COP]*:	1.9	1.0	2.1	1.1
Annual electricity consumption [kWh/year]:	19,068	30,418	14,526**	23,057**
Price (ex. VAT) [€]:	3,095***	6,104***	3,430***	11,582***
Product lifetime [years]	8	8	8	8
Refrigerant:	R404A	R404A	R404A	R410A
Refrigerant charge [kg]:	7	6	N.A.	N.A.
Refrigerant leakage [% per annum]:	15%	15%	15%	15%
Height [cm]:	90.5	143.1	78.7	168
Width [cm]:	140	124.4	115	63.5
Depth [cm]:	55	51	43.5	76.5
Volume [m^3]:	0.7	0.8	0.4	0.8
Weight of product [kg]:	117	203	92	170
Number of compressors:	1	1	1	1
Type of compressor:	Reciprocating hermetic	Reciprocating hermetic	Scroll	Scroll

Product characteristics	Sub-Base Case MT	Sub-Base Case LT	BAT MT	BAT LT
VSD compressor motor control (if applicable):	No	No	Yes	Yes
Condenser cooling:	Air cooled	Air-cooled	Air-cooled	Air-cooled
Condenser heat exchanger type and material:	Steel	Steel	Steel	Steel
Condenser fan motor type:	On/Off	On/Off	Variable speed	Variable speed
VSD condenser fan motor control (if applicable):	On/Off	On/Off	Yes	Yes
Condenser fan motor power [W]:	130	130	130	130
Other features not covered above:	-	-	-	-

* COP: cooling capacity (kW) divided by the energy power input (kW).
**AEC estimated based on information provided by stakeholders:
Base Case MT AEC= 19,068kWh;
Base Case LT AEC= 19,068kWh*(35°C+32°C/10°C+32°C);
BAT MT and LT supposed to achieve 20% energy savings over the Base Case
***Public prices

This comparison of the sub-Base Case and real BAT for both low and medium temperature remote condensing units demonstrates that a saving potential exists. However, the cost of these BAT products cannot be directly extrapolated to the improvement potentials, since other issues such as stocks, discounts and marketing strategies, as well as competitiveness can influence on the public prices of finished products. As explained in §5.2.1.1, manufacturers need to compensate the I+D costs of new technologies, and this can vary the final prices.

The energy consumption conversion factors used to calculate the weighted Base Case in Task 4 have been applied to the real BAT to calculate the weighted BAT values. It is assumed that design options applicable in the sub-Base Cases for low and medium temperature (packaged air-cooled condensing units with single reciprocating compressor, 5-7kW of cooling capacity and R404A as refrigerant) are applicable to all the capacity ranges and configurations considered within the scope and the saving potentials are equivalent.

The average AEC and COP for BAT shown in the Table 5-75 are estimated. The complete weighting table is presented in the Annex, §5.9, Table 5-93.

Table 5-75 Estimated AEC of weighted BAT and weighted Base Case

	Estimated average AEC (kWh)	COP
Medium temperature		
Weighted MT Base Case	32,330	1.88
Weighted MT BAT	24,630	2.15
Low temperature		

	Estimated average AEC (kWh)	COP
Weighted LT Base Case	38,083	1.02
Weighted LT BAT	29,013	1.21

5.4.6 SUMMARY

The calculated estimates for saving potentials for the product groups compared to the BAT savings are described in the table below.

Table 5-76: Summary of energy saving potential estimates

Type of equipment	Saving potentials (%)*
Service cabinets HT	75
Service cabinets LT	56
Blast cabinets	35
Walk-in cold rooms	35**
Process chillers MT	9
Process chillers LT	
Remote condensing units MT	20
Remote condensing units LT	

**Being based on the performance of specific BAT models, the savings potentials calculated here should be taken as indicative.*
***Based on assumptions due to unavailability of measured performance data.*

5.5 BEST NOT YET AVAILABE TECHNOLOGY

The objective of this section is to identify a list of BNAT and to assess the improvement potential associated with each BNAT option at the product level. Possible barriers for the take up of these options will be assessed.

The energy saving for the different BNAT options are not additive. The percentage of savings per option is subtracted from the energy consumption level that already accounts for reductions enabled by other improvement options already considered. The example below gives a better idea of the calculation methodology (figures do not correspond to any particular product).

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

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

5.5.1 BEST NOT-YET AVAILABLE PRODUCTS

This section focuses on feasible, future products which might be placed on the EU market in the coming five years. Due to the nature of product development of refrigeration equipment, which relies heavily on innovations in the components, the following theoretical models were developed, using BAT components, in order to estimate an indicative potential improvement in energy consumption in five years time. There BNAT models are used to indicate potential savings in 2020, and are distinct from BNAT technologies, which are covered in §5.7.

The components and energy saving potentials used to generate these models are based on the improvement options presented in §5.2, and use the energy consumption figures from the weighted Base Case as the reference point.

The best product within the coming five years is assumed to incorporate all relevant technologies available in the near future, including both BAT available now and in the near future, and is compared to the current "average" product consumption (hence several product parameters are assumed to be identical). It is proposed in Task 7 that in 2016, before enforcement of revised MEPS in 2020, that these models are re-assessed to include the most cost effective improvement options, and hence potentially adjust the MEPS levels.

All BNAT models are assumed to be based on the vapour-compression technology and are assumed to have similar operational requirements and conditions as the average products.

5.5.1.1 Service cabinet

The best service cabinet in the coming five years might be equipped as follows:

Table 5-77: Characteristics of service cabinet BNAT assumption

Product characteristic	BNAT HT model	BNAT LT model
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
Internal cold storage temperature [°C]:	5°C	5°C
Net internal volume [litres] [169]**:**	450	450
Product use pattern [hours/year]:	8760	8760
Functional unit:	Litre of net volume at 5°C	Litre of net volume at 5°C
AEC [kWh/year]:	480	1,350
TEC [kW/48hrs]:	2.63	7.4
EEI [kWh/48hrs/ m3]:	5.84	16.44
Performance [kWh/litre net volume at 5°C/year]:	1.07	3
Lifetime [years]:	10	10
Refrigerant:	Low GWP*	Low GWP*
Compressor:	VSD ECM	VSD ECM
Expansion device:	Bubble expansion valve	Bubble expansion valve
Evaporator:	ECM with efficient fan blades and improved heat exchanger	ECM with efficient fan blades and improved heat exchanger
Condenser:	ECM with efficient fan blades and improved heat exchanger	ECM with efficient fan blades and improved heat exchanger
Defrost :	Hot gas, controlled	Hot gas, controlled
Anti-condensation heaters :	Hot gas, controlled	Hot gas, controlled
Lighting:	LED	LED
Insulation:	80mm PUR	80mm PUR
Other:	Liquid suction heat exchanger	Liquid suction heat exchanger

**For example: R290, R600a, R744, or an un-saturated HFC – for the purposes of modelling R717 has been used*

It is assumed that the best available service cabinet within the next five years could therefore achieve energy savings of approximately 76% for high-temperature and 73% for low-temperature.

Table 5-78 Estimated AEC of weighted BNAT, BAT and weighted Base Case

	Estimated average AEC (kWh)
High temperature	
Weighted HT Base Case	2,000
Weighted HT BAT	500
Weighted HT BNAT	480
Low temperature	
Weighted LT Base Case	5,000

[169] Calculated according to EN 441 method

	Estimated average AEC (kWh)
Weighted LT BAT	2,200
Weighted LT BNAT	1,350

5.5.1.2 Blast cabinet

As for service cabinets, blast cabinets are assumed to be equipped with:

- high efficiency compressor with the ECM motor and VSD;
- electronic expansion valve integrated with the floating head pressure;
- heat exchanger area increased;
- full baffling,
- R290
- possible adaptation of R744 (already in use for remote equipment, but only two manufactures identified).

Both R290 and R744 can be used in blast cabinets. R744 has been proven to have more energy efficiency and low safety risks make it the best choice.

Calculation of BNAT based on potential improvement of Base Case. Hence, the BNAT use pattern is assumed to be the same as for the Base Case, corresponding to 660 hours per year (two 90-minute cycles, 220 days per year).

Table 5-79: Characteristics of blast cabinet BNAT assumption

Product characteristic	BNAT
Product type/model/design:	Vertical
Location of condensing unit:	Integrated
Functional unit:	1 kg of foodstuff (referred to material proposed by NF AC D 40-003) chilling cycle
Cooling cycle*:	chilling cycle from +70°C to +3°C in 90min
Capacity [kg]:	20
Maximum number of trays (GN 1/1):	5
Net volume [m³]:	52
Electricity consumption [kWh/cycle]:	1.00
Product use pattern [cycles/year]:	2 cycles per day, 220 days per year
AEC (base model) [kWh/year]:	440
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]:	0.050
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/year]:	22
Power input [kW]:	1.2
Cooling capacity [kW]:	0.83
Refrigerant:	Low GWP
Compressor:	VSD ECM
Condenser:	ECM fan with high efficiency blades and improved heat exchanger
Expansion valve type:	Electronic expansion valve
Full baffling:	Included

Product characteristic	BNAT

**For example: R290, R744 or an un-saturated HFC – for the purposes of modelling R290 has been used*

It is assumed that the best available blast cabinet in the coming five years might achieve energy savings of 50%.

Table 5-80 Estimated AEC of weighted BNAT, BAT and weighted Base Case

	Estimated average AEC (kWh)
Weighted Base Case	3,031
Weighted BAT	1,970
Weighted BNAT	1,516

5.5.1.3 Walk-in cold room

The best walk-in cold room in the coming five years might be equipped as follows:

Table 5-81: Characteristics of walk-in cold room BNAT assumption

Product characteristics	BNAT model
Product type/model/design:	Factory-built
Location of condensing unit:	Packaged
Test standard:	-
Internal cold storage temperature [°C]:	+2°C
Net internal volume [m³]:	25
Product use pattern [hours/year]:	8,760
Functional unit:	m³ of net internal volume at +2°C
AEC [kWh/year]:	3,277
Performance [kWh/m³ at 2°C/year]:	131
Lifetime [years]:	18
Refrigerant:	Low GWP*
Compressor:	VSD ECM
Expansion device:	EEV
Evaporator:	ECM with efficient fan blades and improved heat exchanger
Condenser:	ECM with efficient fan blades and improved heat exchanger
Defrost :	Hot gas, controlled
Anti-condensation heaters :	Hot gas, controlled
Lighting:	LED
Insulation:	+25% thickness PUR
Other:	Strip door curtain and auto door closer; floating head pressure and ambient subcooling

**For example: R717, R290, R1270, R600a, R744, or an un-saturated HFC – for the purposes of modelling R717 has been used*

Concerning the best option for the refrigerant, ammonia and CO_2 have been suggested as potentially the best option for walk-in cold rooms[170].

It is assumed that the best available walk-in cold room in the coming five years might achieve energy savings of 69%.

Table 5-82 Estimated AEC of weighted BNAT, BAT and weighted Base Case

	Estimated average AEC (kWh)
Weighted Base Case	12,155
Weighted BAT	7,901
Weighted BNAT	3,768

5.5.1.4 Process chiller

Industrial process chillers would be equipped with:

- ECM fans condenser,
- economiser cooling,
- vacuum-process technology,
- energy integration.

The refrigerant used might be ammonia, since it offers more efficient heat recovery at higher temperatures as a result of its high latent heat and high critical temperature. It also presents opportunities to improve energy efficiency without comprising the safety requirements[171].

Calculation of BNAT is based on potential improvement of the Base Case. Hence, the BNAT use pattern is assumed to be the same as for the Base Case, corresponding to 4,380 hours/year (365 days/year, 12hrs/day).

Table 5-83: Characteristics of industrial process chiller BNAT assumption

Product characteristics	CH BNAT MT	CH BNAT LT
Product type/design:	Packaged	Packaged
Functional unit:	1 kW cooling capacity to reach -10°C at 30°C water temperature	1 kW cooling capacity to reach -15°C at 30°C water temperature
Cooling capacity [kW]:	265.98	265.20
Power input [kW]:	68	116
Performance [COP]*:	3.88	2.29
Annual electricity consumption [kWh/year]:	214,682	346,719
Use pattern [hours/year]:	4,380	4,380
Evaporator output	-8	-8

170 http://oee.nrcan.gc.ca/industrial/equipment/commercial-refrigeration/index.cfm?attr=24

171 http://ec.europa.eu/environment/ozone/pdf/star_refrigeration_ammonia_chillers.pdf

Product characteristics	CH BNAT MT	CH BNAT LT
temperature [°C]:		
Water solution [%]:	Ethylene glycol 40%	Ethylene glycol 40%
Input condenser temperature [°C]:	30	30
Refrigerant:	Low GWP**	Low GWP**
Number of compressors:	2	2
Compressor:	VSD	VSD
Condenser:	ECM fan with more efficient blades and improved heat exchanger	ECM fan with more efficient blades and improved heat exchanger
Evaporator:	Flooded (pool boiling)	Flooded (pool boiling)
Vacuum-process technology:	Included	Included
Other:	Energy integration	Energy integration

**COP: Coefficient of Performance calculated as cooling capacity divided by power input*[172]

***For example: R717, or an un-saturated HFC – for the purposes of modelling R717 has been used*

It is assumed that the best available industrial process medium temperature chiller within next 5 years will achieve energy savings of 43%, while for low temperature 31%. According to stakeholders, improvement options affecting the energy partial load conditions should be considered in the energy consumption reduction but they do not have impact on the COP value (e.g. electronic expansion valve).

Table 5-84 Estimated AEC of weighted BNAT, BAT and weighted Base Case

	Estimated average AEC (kWh)	COP
	Medium temperature	
Weighted MT Base Case	420,946	2.21
Weighted MT BAT	383,061	2.43
Weighted MT BNAT	214,682	3.88
	Low temperature	
Weighted LT Base Case	587,659	1.58
Weighted LT BAT	534,769	1.74
Weighted LT BNAT	346,719	2.29

5.5.1.5 Remote condensing unit

The best remote condensing unit will include:

- VSD scroll compressor with ECM motor, digital controls;
- ECM motor for fans;
- high efficiency fan blades;
- economiser;
- mini-channel heat exchangers; and
- fan motor controllers.

[172] www.engineeringtoolbox.com/cop-eer-d_409.html

Using refrigerants such as R290, R717 or R744 would help minimise the GWP direct emissions and maximise the energy efficiency[173].

It is assumed that the best available RCU within next five years will achieve energy savings of 31%.

Calculation of BNAT is based on potential improvement of Base Case. Hence, the BNAT use pattern is assumed to be the same as for the Base Case, corresponding to 5840 hours/year (365 days/year, 16hrs/day). This equipment is expected to work at 100% load during 40% of the time, but consuming half of the energy considered for the Base Case and having the same output. This figure takes into account the different stages of the refrigeration cycle, including stand-by mode and high peaks of load.

Table 5-85: Characteristics of remote condensing unit BNAT MT and LT assumption

Product characteristics	Condensing unit MT BNAT	Condensing unit LT BNAT
Product type/design:	Packaged	Packaged
Evaporation temperature [°C]:	-10	-35
Operation temperature [°C]:	0°C	-25°C
Ambient temperature [°C]:	+32°C	+32°C
Condensing unit function [hours/day]:	16	16
Product use pattern [hours/year]:	5,840	5,840
Functional unit:	1 kW cooling capacity at -10°C evaporating temperature and +32°C ambient temperature	1 kW cooling capacity at -35°C evaporating temperature and +32°C ambient temperature
Cooling capacity [kW]:	7.2	5.8
Power input [kW]:	2.9	4.4
Annual electricity consumption [kWh/year]**:	13,157	20,988
Performance [COP]*:	2.49**	1.32**
Product lifetime [years]	8	8
Refrigerant:	Low GWP***	Low GWP***
Compressor:	Digital ECM VSD Scroll	Digital ECM VSD Scroll
Condenser:	ECM with efficient fan blades and mini-channel heat exchanger	ECM with efficient fan blades and mini-channel heat exchanger
Other features not covered above:	-	-

** COP: Coefficient of Performance defined as the cooling capacity divided by the power input*
*** calculated as the cooling capacity from the Base Case assumed to be the same and the power input decreased in 35%*
****For example: R290, R600a, R744, or an un-saturated HFC – for the purposes of modelling R717 has been used*

For the calculation of the weighted energy consumption of the BNAT in the market, the conversion factors used to calculate the weighted Base Case in Task 4 and the BAT in Task 5 are again applied using these BNAT options (31% energy

[173] ec.europa.eu/environment/ozone/pdf/earthcare_nat%20refrig_small_ac_heatpumps.pdf

savings over the weighted Base Case), the average AEC for BNAT shown in the Table 5-86 are estimated. The complete weighting table is presented in the Annex, §5.9, Table 5-93.

Table 5-86 Estimated AEC of weighted BNAT, BAT and weighted Base Case

	Estimated average AEC (kWh)	COP
Medium temperature		
Weighted MT Base Case	32,330	1.88
Weighted MT Real BAT	24,630	2.15
Weighted MT BNAT	22,167	2.47
Low temperature		
Weighted LT Base Case	38,083	1.02
Weighted LT Real BAT	29,013	1.21
Weighted LT BNAT	26,111	1.34

5.6 SUMMARY

Table 5-87 below summarises the predicted near-future energy consumption of the products. The results of this analysis have been compared with the energy consumption of the average products available now as well as with the BAT.

However, it has to be note that a straightforward comparison between the best product of the next five years and best available product now is estimated from empirical evidence and may be questioned. However, the values are indicative and are based on tested technological improvements. Through comparison of the best product within coming five years and average product with the similar characteristics, it can be seen that significant improvements can be achieved.

Table 5-87: Summary of the product improvement potentials

		Base Case model	Weighted Base Case	Current available BAT model	Weighted current available BAT	Theoretical BNAT product model (available in approximately 5 years)	Weighted theoretical BNAT (available in approximately 5 years)
Service cabinet HT	AEC [kWh/year]:	2,000	2,000	500	500	480	480
	EEI [kWh/48hrs / m3]:	10.96	10.96	2.74	2.74	2.63	2.63
	Performance [kWh/litre net volume* at +5°C/year]:	4.44	4.44	1.05	1.05	1.07	1.07
	Improvement over Base Case (%):	-	-	75	75	76	76
Service cabinet LT	AEC [kWh/year]:	5,000	5,000	2,200	2,200	1,350	1,350
	EEI [kWh/48hrs / m3]:	27.40	27.40	12.16	12.16	16.44	16.44
	Performance [kWh/litre net volume* at -18°C/year]:	11.11	11.11	4.67	4.67	3	3
	Improvement over Base Case (%):	-	-	56	56	73	73
Blast cabinet	AEC [kWh/year]:	880	3,031	572	1,970	440	1,516
	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 (with the assumption of 880 chilling cycles per year)]:	0.100	0.187	0.061	0.121	0.050	0.094
	Improvement over Base Case (%):	-	-	35	35	50	50
Walk-in cold room	AEC [kWh/year]:	10,570	12,155	6,870	7,901	3,277	3,768
	Performance [kWh/m^3 net internal volume at storage temperature/year]:	423**	486	275	316	131	151
	Improvement over Base Case (%):	-	-	35	35	69	69
Process chiller MT	AEC [kWh/year]:	338,767	420,946	315,360	383,061	203,260	214,682
	Performance [COP] at -10°C water outlet temperature and +30°C ambient temperature:	2.8	2.21	2.89	2.43	2.00	3.88
	Improvement over Base Case (%):	-	-	9*	9*	43	43
Process chiller LT	AEC [kWh/year]:	467,498	587,659	435,197	534,769	322,574	346,719
	Performance [COP] at -25°C water outlet temperature and +30°C ambient temperature:	1.96	1.58	2.1	1.74	1.50	2.29
	Improvement over Base Case (%):	-	-	9**	9**	31	31
Remote condensing unit MT	AEC [kWh/year]:	19,068	31,270	14,526	25,202	13,047	22,167
	Performance [COP] at -10°C evaporating temperature and +32°C ambient temperature:	1.9	1.9	2.12	2.1	2.5	2.5
	Improvement over Base Case (%):	-	-	20	20	31	31
Remote condensing unit LT	AEC [kWh/year]:	30,418	50,106	23,057	40,180	20,586	34,573
	Performance [COP] at -35°C evaporating temperature and +32°C ambient temperature:	1.0	1.0	1.11	1.1	1.3	1.3
	Improvement over Base Case (%):	-	-	20	20	31	31

**Calculated according to the EN 441 method*

*** at +2°C*

****The low improvement is due to the lack of information available on BAT in the market.*

5.7 ALTERNATIVE REFRIGERATION TECHNOLOGIES

5.7.1.1 Refrigeration process based on magnetic refrigeration

Magnetic refrigeration is a cooling technology based on the magneto caloric effect. This technique can be used to attain extremely low temperatures (well below 1K), as well as the ranges used in common refrigerators, depending on the design of the system.

The refrigeration process based on magnetic refrigeration has many advantages. It has a good potential for high efficiency, and uses environmentally friendly solid refrigerants. Moreover, it is noiseless in its operation and has high potential for compactness. To date, more than thirty published prototypes have been designed.

Many research and development activities on magnetic refrigeration technology are industry related and fulfil certain intellectual property rights or are performed under confidentiality. Therefore, most information on newest developments is not yet available to the public. Certain features of near-term (2-3 years) developments can, however, be foreseen by specialists and have been predicted. These include:

- improved manufacturability and performances of magnetocaloric materials;
- improved designs of permanent magnets and a reduction of the magnets' mass;
- reduction of the costs of the machines;
- substantially improved pressure drop and heat transfer characteristics due to new designs of magnetocaloric regenerators;
- possible introduction of new more efficient thermodynamic cycles;
- increased frequency of operation;
- prototypes with a cooling power and temperature ranges comparable to commercial gas refrigerant devices;
- substantially improved efficiencies.[174]

When electrons within the metal are exposed to the magnetic fields, they are obliged to rest in a particular position, but in order to maintain their potential energy level, they start moving by themselves, increasing the temperature of the metal[175]. The resulting process is normally called magneto caloric effect being a reversible magneto-thermodynamic phenomenon for suitable materials. This is also known as adiabatic demagnetisation. Figure 5-20 compares the conventional refrigeration cycle with the magnetic cycle, by detailing the four processes.

Magnetic refrigerators developed by Ames Laboratories (governmental laboratories of Iowa State University, USA) use water as a refrigerant. In this case, there are two water streams in contact with the warming metal, the first one will cool down the warm metal when it is near the magnet. As the result of this action, when the magnet is away the metal, the metal cools down further. The second

[174] Peter W. Egolf, A. Kitanovski *A selection of present magnetic refrigeration prototypes*, June 2009
[175] www.ameslab.gov/final/Images/Factsheets/MagFridge_Student.pdf

stream is then cooled down by the metal, and that is the one going into de refrigerator. As an analogy to traditional refrigerators, the compressor is replaced by one phase of the turning wheel (heating up the metal), while the expansion valve is substituted by the second phase (away from the metal, cooling it down)[176].

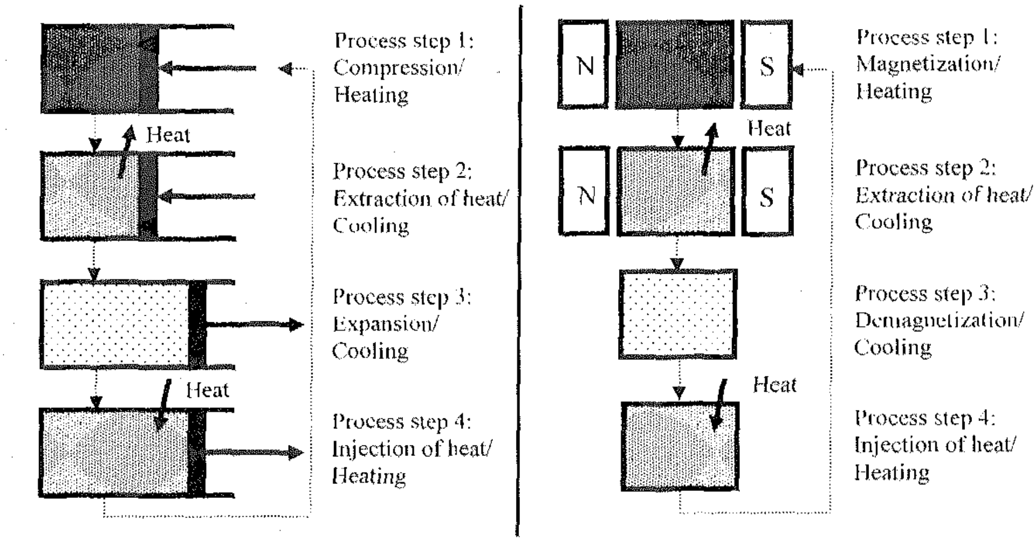

Figure 5-20: Comparison of vapour-compression (on the left) and magnetic (on the right) refrigeration cycles[177]

The Camfridge programme from Cambridge University developed a revolutionary magnetic refrigeration technology. Magnetic refrigeration promises a number of benefits over the vapour compression technology, including a significant reduction in energy consumption, elimination of refrigerant leakage and ease of recycling.

Magnetic refrigeration applications only exist as prototypes. Further research and development will aim at studying the possibility of a commercial application. Magnetic refrigeration is potentially very efficient, harmless to the environment and has low noise levels.

5.7.1.2 Absorption

Refrigeration plants using absorption principles have been around for many years with initial development taking place over 100 years ago. Although the majority of absorption cycles are based on the water/lithium bromide cycle for application above 0°C, other applications exist where ammonia/water can be used, especially where lower temperatures are desirable. The general rule is that evaporating temperature will be around 10°C lower than the desired temperature. The operation of a service cabinet could be at -6°C, meaning that the evaporating temperature should be around -16°C and the heat source at 110°C[178].

With the application of heat at the generator, ammonia vapour is driven from the solution at high pressure. This hot vapour rises into the separator and a portion of

[176] Source: www.ameslab.gov/final/Images/Factsheets/MagFridgeSuccess.pdf

[177] Source: P.W. Wolf, University of applied sciences of Western Switzerland, *An introduction to magnetic refrigeration*. (2007)

[178] Source: K. Rafferty. *Absorption Refrigeration.* Geo-heat Center. Oregon Institute of Technology

the water condenses and flows by gravity into the absorber, passing through a throttling valve to reduce the pressure. The hot ammonia vapour continues to rise into the condenser where it gives up its heat to the surrounding air and condenses into a liquid, it is led to an expansion valve. The liquid ammonia enters by gravity into the evaporator, where it is mixed with hydrogen gas. The circulation of hydrogen gas causes a reduction in the partial pressure within the evaporator. The low pressure causes the ammonia liquid to boil into a gas (evaporating) and absorbing heat in the process (refrigerating effect). The mixture of hydrogen/ammonia vapour that is carrying the absorbed heat is now drawn by gravity into-the absorber. Because the water from the separator has a greater affinity for ammonia, it separates from the hydrogen gas. The hydrogen gas, being very light, rises and returns to the generator to start the cycle again[179].

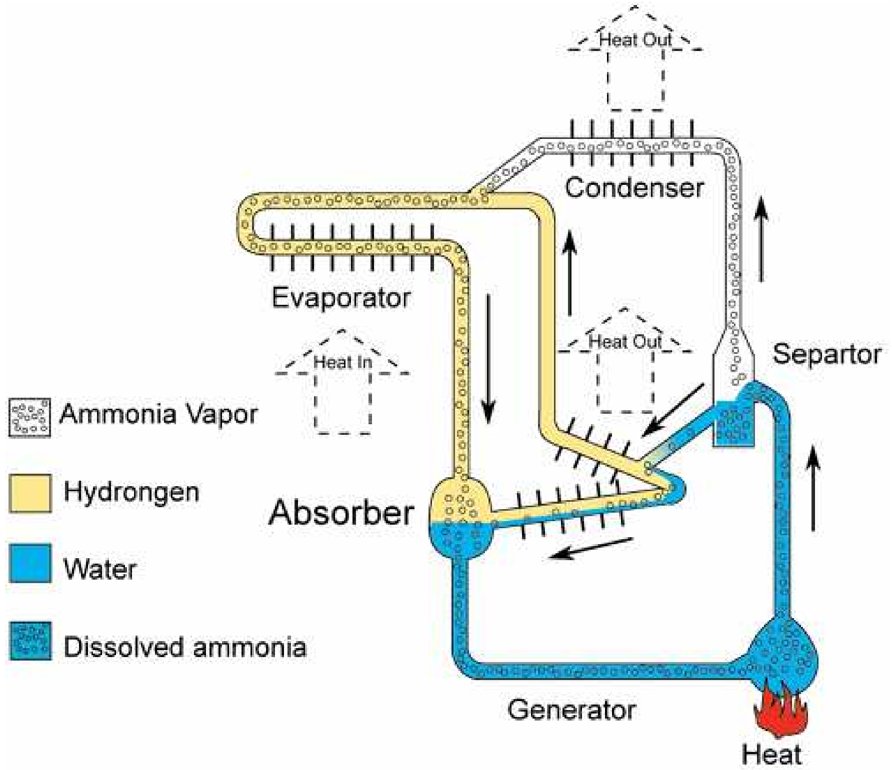

Figure 5-21: Operation of an absorption system for refrigeration

The following table (Table 5-88) summarises the benefits and drawbacks of the absorption technology for refrigeration application.

[179] Source: Engineering Department, San Jose State University (USA). www.engr.sjsu.edu/ndejong/Absorption%20Refrigeration.pdf. 210

Table 5-88: Benefits and drawbacks of the absorption technology

Advantages	Disadvantages
• No moving parts • No vibration or noise on small systems • Small systems can operate without electricity using only heat • Can make use of waste heat • Can make use of solar energy to fulfil the heat requirements	• Potential refrigerant leaks and corrosion • Complicated and difficult to service and repair • Very bulky • High capital cost • More heat exchangers surfaces • Poor efficiency

5.7.1.3 Adsorption

Adsorption is a process where one fluid's molecules are fixed onto a matrix (solid). When they are fixed, they lose energy (exothermic process)[180].

Typical adsorption cycles include two phases:

- Adsorbent cooling with adsorption process. The refrigeration effect is achieved through the refrigerant evaporation inside the evaporator. The sensible heat produced in this phase is consumed by the cooling medium.
- Adsorbent heating with desorption process (generation) resulting in refrigerant condensation (at the condenser) and heat release. The heat required for the generation process can be provided by a low-cost source (solar, waste heat, etc).

Table 5-89: Benefits and drawbacks of the adsorption technology[181]

Advantages	Disadvantages
• Energy saving if they are powered by solar or waste heat • Simpler control than vapour cycle • No vibration • Lower operation cost (no need for pumps) • Large range of heat source temperature	• Low COP • Low specific cooling power

These systems have been tested at prototype level for[182]:

- Ice-makers: results by using activated carbon-methanol and having a solar COP of 0.12. Its production, far from commercial, is about 6kg per m^2 of

[180] Laboratoire d'informatique pour la mécanique et les sciences de l'ingénieur. *Principle of adsorption cycles for refrigeration or heat pumpimp.* www.limsi.fr/Individu/mpons/pricyc.htm. 2010.
[181] R. Wang, G. Oliveira. *Adsorption refrigeration – an efficient way to make good use of waste heat and solar energy.* Shanghai, China. 2005
[182] R. Wang, G. Oliveira. *Adsorption refrigeration – an efficient way to make good use of waste heat and solar energy.* Shanghai, China. 2005

solar collector. Other types of heat source have been tested, for instance exhaust gases.

- Cold room: a design using zeolite-water to refrigerate $12m^3$ with $20m^2$ of panels. At its highest in the experiment, $22MJ/m^2$, the room was able to cool down (20°C difference with the outside) the temperature of 1 000 kg of vegetable with a rotation of 130kg per day. In this case the COP obtained was 0.10.
- Chillers: some experiments have been successful when working with silica gel –water and obtaining a COP of 0.7 for systems with inlet water at 90°C decreased to 3°C.

Some other tested pairs are:

- Ice-making: activated carbon-ammonia, activated carbon-methanol, silica gel-water, activated carbon + blackened steel-methanol, activated carbon + calcium chloride-methanol; with COP range from 0.10 to 0.41.
- Chilled water: activated carbon-methanol. Higher COP are presented in this case, from 0.28 to 0.60

5.7.1.4 Thermo-Acoustic

In 2002, the ice-cream company Ben & Jerry's to support The Pennsylvania State University in developing a thermoacoustic refrigerator. By February 2003, the first prototype was ready and a year later it was interfaced to a standard ice cream storage cabinet (without compressor and condenser).

The prototype is a machine almost 50cm in height and about 25cm in diameter. It has a cooling capacity of 119W at a temperature of -24.6°C Its COP is 0.81, meaning 19% of the Carnot COP. A cut-away of the machinery using a 'Bellows Bounce' resonator is represented in Figure 5-22[183].

[183] Source: www.acs.psu.edu/thermoacoustics/refrigeration/benandjerrys.htm

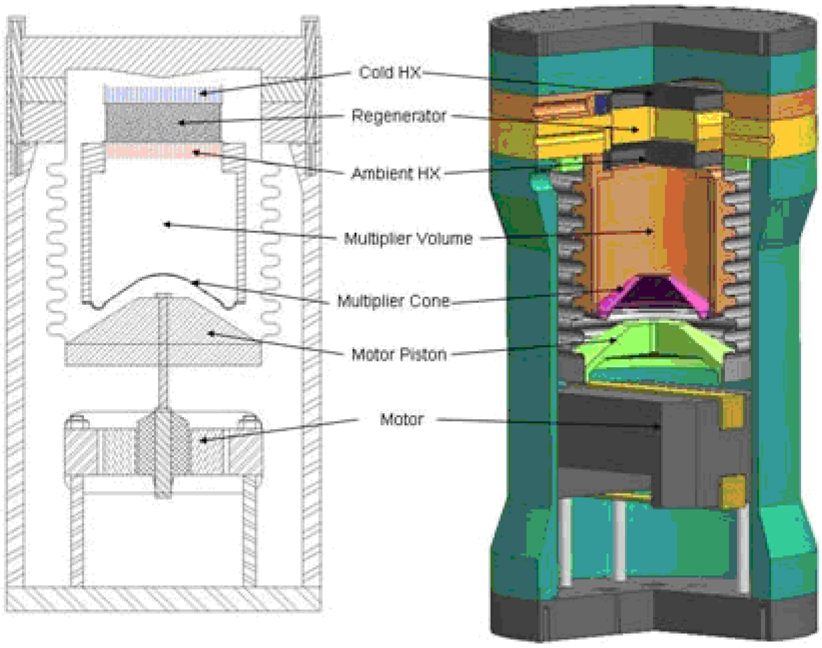

Figure 5-22: Cut-away view of the thermo-acoustic chiller[184]

The freezer uses a stack of small metal screens that can absorb and release more heat than air, and a small amount of helium. The sound waves compress and expand the gas while pushing it back and forth through the screens 100 times a second. Here, the freezer relies on another law of physics, i.e. that heat tends to move from a hot region to a cold one. As its pressure falls, the gas becomes colder than the freezer, sucking warmth away from the ice cream. As the gas moves in the other direction, its pressure increases and it gets hotter than the air outside, so the heat becomes the freezer's exhaust and is blown outside.

This technology has been tested for shipboard electronics chiller (base study for a prototype for home refrigerator/freezer in South Africa), shipboard cooler/air conditioners, and refrigerators[185].

[184] The abbreviation "HX" means "heat exchanger"
[185] Source: www.acs.psu.edu/thermoacoustics/refrigeration/default.htm

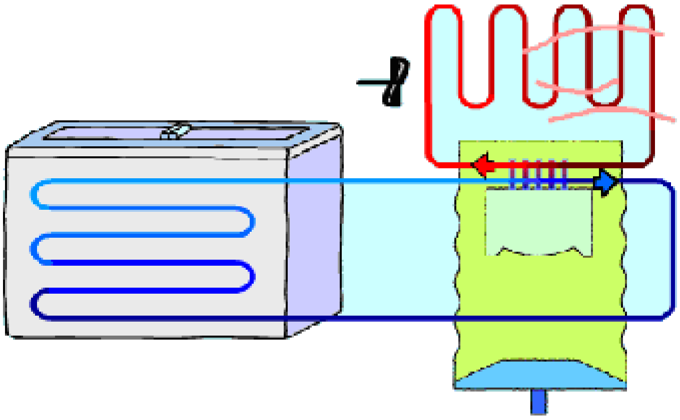

Figure 5-23: Overview of an ice cream freezer using thermo-acoustic refrigeration

The main benefits of the thermo-acoustic refrigeration technology, compared to the conventional vapour-compression technology, are:

- use of eco-friendly refrigerants, such as helium or argon;
- fewer components ⇨ fewer failures and less maintenance;
- no sliding seals, hence no lubrication;
- quiet operation;
- Improved temperature control.

Nevertheless, the main drawback of this system is that, depending on its size, the refrigeration unit may not be integrated in the freezer. Moreover, the refrigeration unit is less efficient than in a vapour-compression system.

5.7.1.5 Thermo-Electric (Peltier Effect)

Thermo-electric cooling, also called "the Peltier Effect," is a solid-state method of heat transfer through dissimilar semiconductor materials. Thermo-electric refrigeration replaces the three main working parts with:

- a cold junction,
- a heat sink,
- a DC power source.

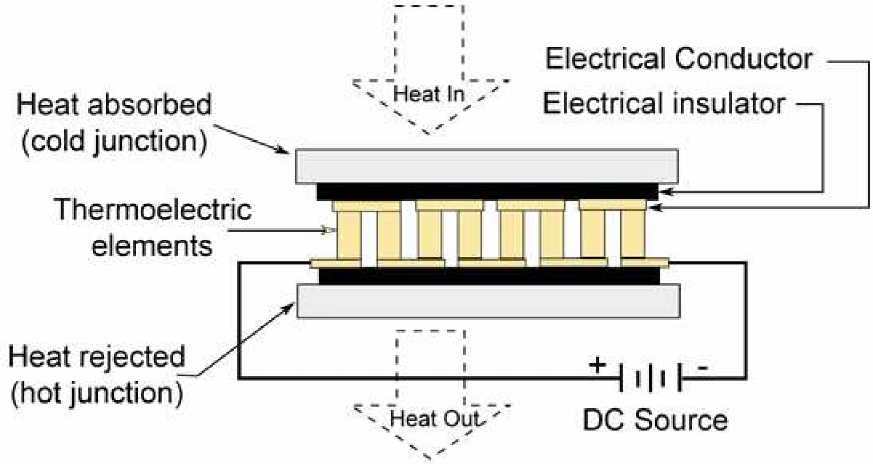

Figure 5-24: Description of heat exchangers in thermo-electric refrigeration

The refrigerant, in both liquid and vapour form, is replaced by two dissimilar conductors. The cold junction (evaporator surface) becomes cold through the absorption of energy by the electrons as they pass from one semiconductor to another, instead of energy absorption by the refrigerant as it changes from liquid to vapour. The compressor is replaced by a DC power source which pumps the electrons from one semiconductor to another. A heat sink replaces the conventional condenser fins, discharging the accumulated heat energy from the system. Thermo-electric modules are installed through mechanical clamping, epoxy bonding, and solder bonding. While the modules are strong in compression, they are weak in shear so excess loading should be avoided.

Advantages of thermo-electric refrigeration:

Compact size with equivalent cooling capacity: Very little space is required by the cooling system. The thermoelectric module is the size of a matchbox.

Light weight

Portable: Carries with one hand and is unaffected by motion or tilting.

Researchers are working on improving the efficiency of thermo-electric devices, reducing the cost of producing them and increasing their applications. Researchers are trying to maximise the electricity output for a given heat source by changing the construction materials. They are also studying materials so they can predict their reliability and long-term performance. Currently, this technology can only be used for very small refrigeration loads.

5.7.1.6 Stirling Cycle

The Stirling cycle cooler is a free piston, linear, motor driven device. The internal running surfaces are supported by a gas bearing, so no contact wear takes place. It is capable of continuous modulation and of maintaining high efficiencies down to very low lifts. This means that it adapts easily to cooling needs and keeps performing with high efficiency even at low demand. The Stirling cycle is fundamentally different to that used in conventional refrigerators (the Rankin cycle). Helium is employed as the working medium and no phase change occurs. The entire unit is hermetically sealed and dynamically balanced for low noise and vibration. Operational characteristics include the fact that the lift (capacity) is easily modulated since the piston amplitude is directly proportional to the drive voltage. In its ideal form, the Stirling cycle has the highest obtainable efficiency of any cooling device. In addition, the use of helium allows for zero ODP and GWP.

The performance of the Stirling cycle cooling motor is, on average, about two to three times more efficient than the Rankin cycle. According to Sunpower, the developers of a product that uses Stirling cycle technology, the Stirling cycle compressor is a "drop-in" replacement for conventional compressors in domestic and commercial refrigerators, air conditioners and heat pumps.

Stirling cycles have been used for particular niche applications (e.g. cryogenics) but recent developments, like the Free Piston Stirling Cooler, have allowed testing as a viable alternative commercial refrigeration technology, especially for smaller sizes.

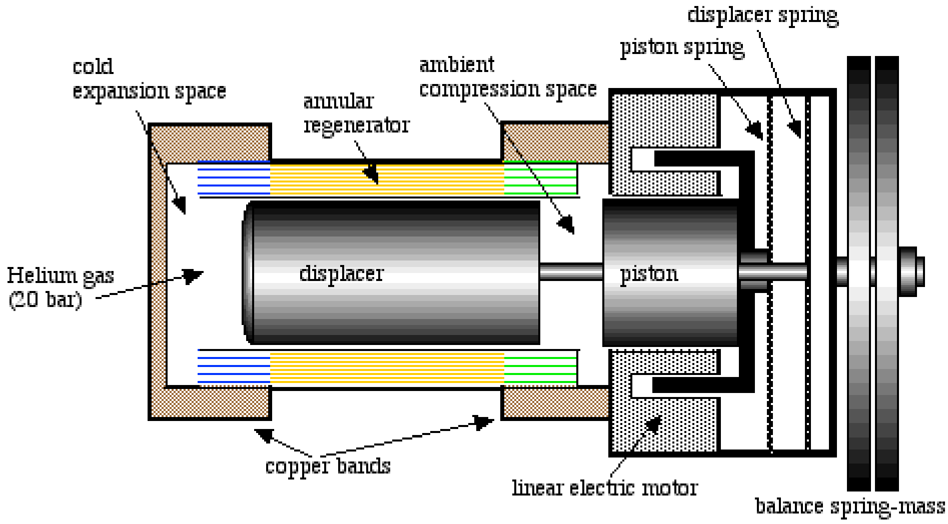

Figure 5-25: Diagram of the inside of a Free Piston Stirling Cooler[186]

5.7.1.7 Summary and comparison of alternative refrigeration technologies

The following table summarises the benefits and drawbacks of the alternative refrigeration technologies presented above. Moreover, their potential use in the five categories of commercial refrigeration equipments is assessed, based on the manufacturers' predictions (Table 5-91).

[186] Source : Global Cooling

Table 5-90: Comparative table for alternative refrigeration technologies

Refrigeration Technology	Benefits	Drawbacks
Magnetic	• High efficiency • Ease of recycling • No refrigerant leakage • Low noise level	• Heavy coils and current to feed magnetic fields are required • Low degree of development • High capital cost
Absorption	• No moving parts • No vibration or noise on small systems • Small systems can operate without electricity, using only heat • Can make use of waste heat	• Potential refrigerant leaks • Complicated and difficult to service and repair • Very bulky • High capital cost • More heat exchangers surfaces • Poor efficiency
Adsorption	• Energy saving if they are powered by solar or waste heat • Simpler control than vapour cycle • No vibration • Lower operation cost (no need for pumps) • Large range of heat source temperature	• Low COP • Low specific cooling power
Thermo-acoustic	• Use of eco-friendly refrigerants, such as helium or argon • Fewer components ⇨ fewer failures and less maintenance • No lubrication • Quiet operation • Better control of the temperature	• Poor efficiency • Bulky: remote refrigeration unit • High capital cost • Complex technology
Thermo-electric	• Compact size • Lightweight • Portable	• Poor efficiency • High capital cost • Currently, only usable for small refrigeration loads
Stirling Cycle	• Safe • High efficiency • Use of eco-friendly refrigerants, such as helium or hydrogen	• Complex technology • High capital cost • Currently, only usable for small refrigeration loads

Table 5-91: Possible application of the alternative refrigeration technologies

Refrigeration Technology	Application				
	Service cabinets	Blast cabinets	Walk-in cold rooms	Packaged industrial process chillers	Remote Condensing Units
Magnetic	Possible, within 3-5 years	-	Possible, within 5-10 years	Possible, within 5-10 years	-
Absorption	Not possible	-	Yes, if source of waste heat available	Only viable if source of waste heat is available	-
Thermo-acoustic	Possible, within 5-10 years	-	-	-	-
Thermo-electric	Not possible	-	Not possible	-	-
Stirling Cycle	-	-	-	-	-

- : No data provided

In addition, for each of refrigeration technology, the impact on the criteria such as life cycle cost, environmental impacts, safety of products, efficiency, degree of development required and practical complexity has been assessed (from --- = highly reduced impact, to 0 = no impact, to +++ = highly increaed impact). The table below indicates that, for example, in noting "+++: for Life Cycle Cost, this refrigeration technology would significantly increase Life Cycle Cost. Table 5-92: is based on the responses to the second questionnaire.

Table 5-92: Assessment of different refrigeration technology options

Criteria	*Absorption*	*Acoustic*	*Magnetic*	*Thermo-electric*
Life Cycle Cost	+++	-	- -	+++
Environmental Impacts	0	- -	- -	+
Safety of product	0	0	0	0
Efficiency	- -	-	++	- -
Degree of development required	+	+++	+++	++
Practical complexity	0	+++	+++	0

5.8 CONCLUSIONS

Data currently available on the performance of products, such as service cabinets and remote condensing units, show that performance varies significantly. The data also indicate that improvements are being made to reduce energy consumption.

As a main trend, stakeholders commented that future technologies would be an improvement of existing technologies in order to obtain higher efficiencies, application to all product ranges, and lower production costs.

Task 5 summarises some of these potential improvement technologies identified (BAT and BNAT), relevant to the Base Cases. Some of the most promising developments are not high in cost, particularly those relating to electric motors. There are also improvements in compressors and system adaptations that provide more efficient management of the vapour-compression cycle, although applicability of these can depend on system capacity. Specifically related to walk-in cold rooms, there are simple and cost-effective options to minimise heat infiltration.

All product groups have been assessed as having at least a 20% improvement potential, considering current BAT options. Many further improvements are available but might not be feasibly applied in the immediate future due to cost, particularly those products which are sold in a more price-competitive market, such as service cabinets.

According to stakeholders' opinion, refrigeration is said to be a conservative sector regarding new technologies, but at the same time research is being carried out on new refrigeration technologies and new, more efficient products with better environmental performance are being introduced in the market. The estimated time-to-market for these new refrigeration technologies varies from 3 to 10 years.

The data presented in Task 5 will be developed in Task 6, for the identification and the impact assessment of improvement options for each of the Base Cases. These will be assessed according to their possible energy consumption improvement, as well as their affordability.

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ANNEXES

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5.9 REMOTE CONDENSING UNITS BAT WEIGHTING FACTORS

Table 5-93: Remote condensing units BAT weighting factors

	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor motor drive	Condenser cooling	Total market %	BAT extrapolated energy consumption per year (kWh)	BAT extrapolated COP	BNAT extrapolated energy consumption per year (kWh)	BNAT extrapolated 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%	23,173	1.18	20,856	1.31
					Water	0.0%	23,173	1.18	20,856	1.31
				2 speeds	Air	0.9%	20,856	1.18	18,770	1.31
					Water	0.0%	20,856	1.18	18,770	1.31
				VSD	Air	0.3%	20,856	1.18	18,770	1.31
					Water	0.0%	20,856	1.18	18,770	1.31
			Scroll	On/off	Air	0.9%	20,856	1.31	18,770	1.46
					Water	0.0%	20,856	1.31	18,770	1.46
				2 speeds	Air	0.0%	19,813	1.31	17,832	1.46
					Water	0.0%	19,813	1.31	17,832	1.46
				VSD	Air	0.0%	17,565	1.31	15,809	1.45
					Water	0.0%	17,565	1.31	15,809	1.45
			Screw	On/off	Air	0.0%	20,856	1.31	18,770	1.46
					Water	0.0%	20,856	1.31	18,770	1.46
				2 speeds	Air	0.0%	19,813	1.31	17,832	1.46
					Water	0.0%	19,813	1.31	17,832	1.46
				VSD	Air	0.0%	18,770	1.31	16,893	1.46
					Water	0.0%	18,770	1.31	16,893	1.46
			Rotary	On/off	Air	0.0%	20,856	1.31	18,770	1.46
					Water	0.0%	20,856	1.31	18,770	1.46
				2 speeds	Air	0.0%	19,813	1.31	17,832	1.46
					Water	0.0%	19,813	1.31	17,832	1.46
				VSD	Air	0.0%	18,770	1.31	16,893	1.46
					Water	0.0%	18,770	1.31	16,893	1.46
		20-50 kW average: 20 kW	Hermetic reciprocating	On/off	Air	0.7%	70,039	1.35	63,035	1.50
					Water	0.0%	70,039	1.35	63,035	1.50
				2 speeds	Air	0.0%	66,537	1.35	59,883	1.50
					Water	0.0%	66,537	1.35	59,883	1.50
				VSD	Air	0.0%	63,035	1.35	56,732	1.50
					Water	0.0%	63,035	1.35	56,732	1.50
			Scroll	On/off	Air	0.0%	63,035	1.50	56,732	1.66
					Water	0.0%	63,035	1.50	56,732	1.66
				2 speeds	Air	0.0%	59,883	1.50	53,895	1.66
					Water	0.0%	59,883	1.50	53,895	1.66
				VSD	Air	0.0%	56,732	1.50	51,058	1.66
					Water	0.0%	56,732	1.50	51,058	1.66
			Screw	On/off	Air	0.0%	63,035	1.50	56,732	1.66
					Water	0.0%	63,035	1.50	56,732	1.66
				2 speeds	Air	0.0%	59,883	1.50	53,895	1.66
					Water	0.0%	59,883	1.50	53,895	1.66
				VSD	Air	0.0%	56,732	1.50	51,058	1.66
					Water	0.0%	56,732	1.50	51,058	1.66
			Rotary	On/off	Air	0.0%	63,035	1.50	56,732	1.66
					Water	0.0%	63,035	1.50	56,732	1.66
				2 speeds	Air	0.0%	59,883	1.50	53,895	1.66
					Water	0.0%	59,883	1.50	53,895	1.66
				VSD	Air	0.0%	56,732	1.50	51,058	1.66
					Water	0.0%	56,732	1.50	51,058	1.66
		>50 kW average: 50kW	Hermetic reciprocating	On/off	Air	0.2%	183,787	1.28	165,408	1.43
					Water	0.0%	174,598	1.35	157,138	1.50
				2 speeds	Air	0.0%	174,598	1.28	157,138	1.43
					Water	0.0%	165,868	1.35	149,281	1.50
				VSD	Air	0.0%	165,408	1.28	148,868	1.43
					Water	0.0%	157,138	1.35	141,424	1.50
			Scroll	On/off	Air	0.0%	165,408	1.43	148,868	1.59
					Water	0.0%	157,138	1.50	141,424	1.67
				2 speeds	Air	0.0%	157,138	1.43	141,424	1.59

	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor motor drive	Condenser cooling	Total market %	BAT extrapolated energy consumption per year (kWh)	BAT extrapolated COP	BNAT extrapolated energy consumption per year (kWh)	BNAT extrapolated COP
					Water	0.0%	149,281	1.50	134,353	1.67
				VSD	Air	0.0%	148,868	1.43	133,981	1.59
					Water	0.0%	141,424	1.50	127,282	1.67
			Screw	On/off	Air	0.0%	165,408	1.43	148,868	1.59
					Water	0.0%	157,138	1.50	141,424	1.67
				2 speeds	Air	0.0%	157,138	1.43	141,424	1.59
					Water	0.0%	149,281	1.50	134,353	1.67
				VSD	Air	0.0%	148,868	1.43	133,981	1.59
					Water	0.0%	141,424	1.50	127,282	1.67
			Rotary	On/off	Air	0.0%	165,408	1.43	148,868	1.59
					Water	0.0%	157,138	1.50	141,424	1.67
				2 speeds	Air	0.0%	157,138	1.43	141,424	1.59
					Water	0.0%	149,281	1.50	134,353	1.67
				VSD	Air	0.0%	148,868	1.43	133,981	1.59
					Water	0.0%	141,424	1.50	127,282	1.67
	Medium temperature (-10°C)	0.2-20 kW average: 5-7 kW	Hermetic reciprocating	On/off	Air	50.9%	14,526	2.12	13,074	2.49
					Water	0.0%	13,800	2.24	12,420	2.49
				2 speeds	Air	2.7%	13,800	2.24	12,420	2.49
					Water	0.0%	13,110	2.24	11,799	2.49
				VSD	Air	1.1%	13,074	2.24	11,766	2.49
					Water	0.0%	12,420	2.24	11,178	2.49
			Scroll	On/off	Air	6.0%	13,074	2.49	11,766	2.76
					Water	0.0%	12,420	2.49	11,178	2.76
				2 speeds	Air	0.0%	12,420	2.49	11,178	2.76
					Water	0.0%	11,799	2.49	10,619	2.76
				VSD	Air	0.1%	11,067	2.50	9,960	2.78
					Water	0.0%	10,513	2.50	9,462	2.78
			Screw	On/off	Air	0.0%	13,074	2.49	11,766	2.76
					Water	0.0%	12,420	2.49	11,178	2.76
				2 speeds	Air	0.0%	12,420	2.49	11,178	2.76
					Water	0.0%	11,799	2.49	10,619	2.76
				VSD	Air	0.0%	11,766	2.49	10,590	2.76
					Water	0.0%	11,178	2.49	10,060	2.76
			Rotary	On/off	Air	0.0%	13,074	2.49	11,766	2.76
					Water	0.0%	12,420	2.49	11,178	2.76
				2 speeds	Air	0.0%	12,420	2.49	11,178	2.76
					Water	0.0%	11,799	2.49	10,619	2.76
				VSD	Air	0.0%	11,766	2.49	10,590	2.76
					Water	0.0%	11,178	2.49	10,060	2.76
		20-50 kW average: 20 kW	Hermetic reciprocating	On/off	Air	9.5%	45,873	1.97	41,286	2.19
					Water	0.0%	43,579	1.97	39,221	2.19
				2 speeds	Air	0.5%	43,579	1.97	39,221	2.19
					Water	0.0%	41,400	1.97	37,260	2.19
				VSD	Air	0.2%	41,286	1.97	37,157	2.19
					Water	0.0%	39,221	1.97	35,299	2.19
			Scroll	On/off	Air	1.1%	41,286	2.19	37,157	2.43
					Water	0.0%	39,221	2.19	35,299	2.43
				2 speeds	Air	0.0%	39,221	2.19	35,299	2.43
					Water	0.0%	37,260	2.19	33,534	2.43
				VSD	Air	0.0%	37,157	2.19	33,441	2.43
					Water	0.0%	35,299	2.19	31,769	2.43
			Screw	On/off	Air	0.0%	41,286	2.19	37,157	2.43
					Water	0.0%	39,221	2.19	35,299	2.43
				2 speeds	Air	0.0%	39,221	2.19	35,299	2.43
					Water	0.0%	37,260	2.19	33,534	2.43
				VSD	Air	0.0%	37,157	2.19	33,441	2.43
					Water	0.0%	35,299	2.19	31,769	2.43
			Rotary	On/off	Air	0.0%	41,286	2.19	37,157	2.43
					Water	0.0%	39,221	2.19	35,299	2.43
				2 speeds	Air	0.0%	39,221	2.19	35,299	2.43
					Water	0.0%	37,260	2.19	33,534	2.43
				VSD	Air	0.0%	37,157	2.19	33,441	2.43
					Water	0.0%	35,299	2.19	31,769	2.43

	Evaporating temp. (°C)	Cooling capacity (kW)	Compressor type	Compressor motor drive	Condenser cooling	Total market %	BAT extrapolated energy consumption per year (kWh)	BAT extrapolated COP	BNAT extrapolated energy consumption per year (kWh)	BNAT extrapolated COP
		>50 kW average: 50kW	Hermetic reciprocating	On/off	Air	3.0%	104,055	2.17	93,650	2.41
					Water	0.2%	98,853	2.28	88,967	2.54
				2 speeds	Air	0.2%	98,853	2.17	88,967	2.41
					Water	0.0%	93,910	2.28	84,519	2.54
				VSD	Air	0.1%	93,650	2.17	84,285	2.41
					Water	0.0%	88,967	2.28	80,071	2.54
			Scroll	On/off	Air	0.3%	93,650	2.41	84,285	2.68
					Water	0.0%	88,967	2.54	80,071	2.82
				2 speeds	Air	0.0%	88,967	2.41	80,071	2.68
					Water	0.0%	84,519	2.54	76,067	2.82
				VSD	Air	0.0%	84,285	2.41	75,856	2.68
					Water	0.0%	80,071	2.54	72,064	2.82
			Screw	On/off	Air	0.0%	93,650	2.41	84,285	2.68
					Water	0.0%	88,967	2.54	80,071	2.82
				2 speeds	Air	0.0%	88,967	2.41	80,071	2.68
					Water	0.0%	84,519	2.54	76,067	2.82
				VSD	Air	0.0%	84,285	2.41	75,856	2.68
					Water	0.0%	80,071	2.54	72,064	2.82
			Rotary	On/off	Air	0.0%	93,650	2.41	84,285	2.68
					Water	0.0%	88,967	2.54	80,071	2.82
				2 speeds	Air	0.0%	88,967	2.41	80,071	2.68
					Water	0.0%	84,519	2.54	76,067	2.82
				VSD	Air	0.0%	84,285	2.41	75,856	2.68
					Water	0.0%	80,071	2.54	72,064	2.82
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%	56,732	1.50	51,058	1.66
					Water	0.0%	53,895	1.50	48,505	1.66
			screw	-	Air	0.0%	56,732	1.50	51,058	1.66
					Water	0.0%	53,895	1.50	48,505	1.66
		>50 kW average: 50kW	scroll	-	Air	0.2%	148,868	1.43	133,981	1.59
					Water	0.0%	141,424	1.50	127,282	1.67
			screw	-	Air	0.0%	148,868	1.43	133,981	1.59
					Water	0.0%	141,424	1.50	127,282	1.67
	Medium temperature (-10°C)	0.2-20 kW		-	-	0.0%				
		20-50 kW average: 20 kW	scroll	-	Air	3.0%	37,157	2.19	33,441	2.43
					Water	0.0%	35,299	2.19	31,769	2.43
			screw	-	Air	0.0%	37,157	2.19	33,441	2.43
					Water	0.0%	35,299	2.19	31,769	2.43
		>50 kW average: 50kW	scroll	-	Air	0.9%	84,285	2.41	75,856	2.68
					Water	0.0%	80,071	2.54	72,064	2.82
			screw	-	Air	0.1%	84,285	2.41	75,856	2.68
					Water	0.0%	80,071	2.54	72,064	2.82