Improving freezing and refrigeration

In a nutshell

Summary				
Best practice is to improve the existing refrigeration and freezing equipment and procedures by: • appropriate temperature selection based on the needs of the products that are refrigerated or frozen, • precooling of hot/warm products before placing them into the cooling equipment, • minimising the volume of products or ingredients kept in cold storage, • avoiding temperature leakage e.g. via door seals, thanks to the use of high-speed doors and of air curtains, and to information and training of the staff, • systematically collect data on cooling loads, energy use and leakage rates and have in place a regular inspection and maintenance plan for the cooling equipment. When freezing and refrigeration equipment is upgraded or new facilities are designed and built, it is best practice to: • switch from hydrofluorocarbons (HFCs) to refrigerants with lower global warming potential (e.g. natural refrigerants), • agree a multi-year ‘leak-free warranty’ with the equipment supplier, • recover and reuse waste heat generated from the refrigeration unit or from other processes generating waste heat (e.g. production processes), • choose equipment, control systems and a plant layout (i.e. location and arrangement of the areas at different temperatures) that allow minimum energy consumption and avoid temperature losses and refrigerant leaks.				
Target activities				
All food and beverage manufacturing	Processing of coffee	Manufacturing of olive oil	Manufacture of soft drinks	Manufacture of beer
Production of meat products	Manufacture of fruit juice	Cheese making	Manufacture of bread, biscuits and cakes	Manufacture of wine
Applicability				
This best practice is applicable to all food and beverage manufacturers. Some limitations to the implementation of each of the measures listed above may arise from specific process or product requirements.				
Environmental performance indicators				

- Percentage use of refrigeration systems running on natural refrigerants compared to the total number of refrigeration systems (%)
- Coefficient of performance (COP) per single refrigeration system or for the entire facility
- Coefficient of system performance (COSP) per single refrigeration system or for the entire facility
- Energy efficiency ratio (EER) per single refrigeration system or for the entire facility
- Energy used for refrigeration per product unit per cooled area (kWh/m2/weight, volume or number of products)

Benchmarks of excellence

- Use 100 % refrigeration systems running on natural refrigerants in all sites.

Description

The use of refrigeration and freezing is widespread across the food and drinks supply chain, and especially in manufacturing, transport, bulk storage and retail. Although most of the cooling is used in refrigerators, freezers and cold stores, refrigeration is also commonly used for cooling and heating in air conditioning systems (Carbon Trust, 2011a). In Europe, 75 % of all industrial refrigeration capacity is installed in the food industry, equating to around 60-70 million cubic metres of cold storage for food (Masson et al, 2014). Cooling is among the most energy-intensive processes in the sector with up to 60% of a manufacturer's electricity used in refrigeration (Table 1), and up to 70% of the energy cost accounted for by refrigeration (Table 2).

Table 1: Importance of refrigeration related to total electricity use

Industry sector	Electricity used for refrigeration
Liquid milk processing	25%
Breweries	35%
Confectionery	40%
Chilled ready meals	50%
Frozen food	60%

Source: Carbon Trust Networks Project (2007)

Table 2: Importance of refrigeration related to total energy cost

Industry sector	Energy costs accounted for by refrigeration

Meat, poultry and fish processing	50%
Ice cream manufacturing	70%
Cold storage	90%
Food supermarkets	50%
Small shops with refrigerated cabinets	70% or over
Pubs and clubs	30%

Source: Carbon Trust (2011b)

Thus, any improvements to equipment, facilities, and management of refrigeration and freezing would substantially enhance the industry's environmental performance. This best practice describes what frontrunner food and drinks manufacturers do to optimise their cooling operations.

The Carbon Trust reports that typical sources of energy savings are good maintenance (25%), housekeeping and control (25%), and more efficient equipment (50%). In addition, up to 20% of such savings can be achieved through improvements that require little or no investment (Carbon Trust 2011b). Key opportunities include:

- *Smarter temperature selection.* For example, frozen food products must be kept below ?18°C, so to achieve this limit, manufacturers of such products will generally set their thermostats to ?23°C or lower allowing a safety margin. This buffer is selected to account for doors to the freezers being opened or perhaps for high ambient temperatures. But for every extra degree of cooling, significant additional energy is consumed, thus some frontrunners will accept a slightly warmer temperature, perhaps ?21°C. This is enabled by improvements to air curtains and freezer door seals, and acceleration of the opening and closing of freezer doors (British Frozen Food Federation, 2014, pers.comm.). Similarly, frontrunners will avoid grouping products (or ingredients) requiring different storage temperatures in the same cooling space as some of the goods will be kept at unnecessarily low temperatures.
- *Precooling of product.* Rather than placing recently heated products directly into a chiller, significant amounts of energy can be saved by allowing these first to cool in ambient conditions. Letting a soup at 100°C cool to 30°C before placing it in a (domestic) refrigerator can save up to 75% of the heat load (Carbon Trust Networks Project, 2007).
- *Minimising the volume of products or ingredients kept in cold storage* and thus the space which needs to be cooled. Under the principles of lean manufacturing, the inventory should be kept to a minimum. Not only is energy consumption in cooling minimised but other negative environmental impacts are reduced such as food wastage associated with expired products.
- *Avoiding temperature leakage* (e.g. by replacing leaking door seals).
- systematically collect data on cooling loads, energy use and leakage rates and have in place a regular inspection and maintenance plan for the cooling equipment

These principles can be applied retrospectively to existing cold stores through upgrades but the best results are typically achieved when new facilities can be designed and built from scratch. Key opportunities requiring significant investment include the following:

- *Switching away from hydrofluorocarbons* (HFCs) to natural refrigerants with lower global warming potential (GWP), especially ammonia and carbon dioxide but also some hydrocarbons used in modular packaging chillers.
- *Installing more sophisticated cooling systems.* The best example of this is seen in carbon dioxide-based cooling systems where 'transcritical' rather than 'subcritical' cooling is used (Star Technology Solutions, 2014, pers.comm.).
- Another potential approach to maintaining the best performance of cooling equipment is to agree a *'leak-free warranty'* with the equipment supplier, as evidenced by **Coca-Cola Enterprises** (CCE). Under this five-year agreement from 2009, two suppliers of Turbucor chillers at five manufacturing sites are responsible for repairing equipment, carbon off-setting the emissions and topping up refrigerants in the chillers in case of leakage (Coca-Cola Enterprises, 2014, pers.comm.). CCE decided against an immediate switch to natural refrigerants, and this warranty approach helps in the short term to reduce the risks posed by the release of high GWP refrigerant gases to the atmosphere.
- *Improving equipment and layout*, including investment in existing refrigeration plants and careful selection of new plants.
- *Recovery and reuse of waste heat.* This can be done in two ways:
    - Waste heat generated from the refrigeration unit can be used as a heat source; for example, to preheat water in order to reduce the energy use of the boiler (Carbon Trust, 2011b).
    - Waste heat from other processes can also be used for refrigeration, through the use of absorption refrigeration. This technique makes use of heat, instead of electricity, to provide cooling. Heat sources used in absorption refrigeration vary; examples are methane, solar energy or recovered waste heat (U.S. Department of Energy, 2012).

In addition, recently, interest in supercooling and superchilling has grown as alternatives to chilling and freezing. Both processes aim to improve shelf life, reducing energy consumption and increasing the food safety of the products stored thanks to temperatures ranging usually between -1 °C and -4°C. However, further research is required to make the technology more suitable for the preservation of food, investigating the quality and sensorial attributes of the stored products.

There are many examples of food and beverage companies moving towards natural refrigeration systems. For example, at **Unilever** almost all production facilities and cold stores use ammonia refrigeration systems. This is particularly suited for such use given ammonia's high efficiency in large-scale applications (Refrigerants, Naturally!, nd.). The new **Arla** dairy production facility in the UK includes an ammonia refrigeration system, with a cooling capacity of more than 7.5MW (Masson et al., 2014).

In the case of both new and old equipment, management of information on cooling loads, energy use and leak rates as well as regular inspection and maintenance of the cooling equipment are of primary importance to reduce energy use and cost. Some examples of this are provided below.

- *Compressors:* In refrigeration units compressors are used to raise the refrigerant pressure so that heat is ejected to ambient air, thus cooling the refrigerant. This is the most energy-intensive part of refrigeration systems. The higher the compressor temperature is set, the higher the energy required to run the system. Traditional condenser control systems are set at a fixed temperature, and therefore are set to run during the worst-case scenario, i.e. at the warmest time of the year. Changing the compressor control so as to reduce the temperature setting in cooler weather offers great energy-saving potential.
- *Condensers:* These are the parts of refrigeration systems which reject heat from the refrigerant. Energy savings can be achieved by simply keeping the condensers clean. Condensers that are blocked with debris must operate at a higher temperature to achieve the same results, thus consuming more energy (Carbon Trust, 2011b).

Environmental benefits

According to the Product Sustainability Forum, a UK initiative sponsored by WRAP (Waste & Resources Action Programme), the environmental savings potential from optimising refrigeration in the grocery supply chain is considerable (see Table 3).

Table 3: Environmental savings potential from optimising refrigeration in the grocery supply chain

	Refrigerant GHG emissions	Energy
Existing systems	50%	25%
New systems	>90%	40%

Source: Product Sustainability Forum (2013)

As mentioned above, such savings can be achieved through low-cost solutions involving better maintenance, housekeeping and control. For example, better temperature settings by separating products which need to be stored at different temperatures or by taking into account ambient temperature can result in a 4% energy saving for chill temperatures and 2% for low temperatures by increasing the temperature setting. For instance, where a Product A requiring 5°C is stored with Product B needing ?5°C, the freezer will be maintained at the 'lowest common denominator' of ?5°C. Thus, Product B will be kept 10°C cooler than necessary wasting perhaps 15% to 20% of power input (Carbon Trust Networks Project, 2007). The cleaning of the condensers results in energy savings of up to 10 % (Carbon Trust, 2011b).

Refrigerants which have been conventionally used to date have both high global warming potential (GWP) and ozone depleting potential (ODP). Therefore the release of these gases in the atmosphere through leakage or incorrect disposal has strong detrimental effects on the environment and climate change. Table 4 shows the GWP of conventional fluorinated refrigerants compared to that of carbon dioxide and non-fluorinated hydrocarbons. The data show that the natural alternatives presented have 20-year GWPs that are thousands of times lower than those of CFCs, HFCs and HCFCs. Another natural refrigerant available for use is ammonia; this has a GWP and ODP of zero. Moreover, ammonia refrigeration systems generally achieve higher energy efficiency than HFC equivalents (Masson et al., 2014).

Table 4: Global warming potential (GWP) of fluorocarbons and natural refrigerants (CO_2 and hydrocarbons)

Gas	Lifetime (years)	20 year	100 year	500 year
CO_2	1	1	1	1
CFC-11	45	6730	4750	1620
CFC-12	100	11000	10900	5200
HCFC-141b	9.3	2250	725	220
HFC-134a	14	3830	1430	435
Cyclopentane	weeks	<3	<3	<3

Isobutane	weeks	<3	<3	<3
Propane	months	<3	<3	<3

Source: Greenpeace (2009)

Side effects

Certain natural gas refrigerants may be toxic to humans, particularly ammonia which has the added risk of being flammable. However, the characteristic pungent odour of ammonia makes it easy to identify even in concentrations as low as 3 mg/m^3 of air. In addition, ammonia is lighter than air therefore it rises quickly (Eurammon, 2011).

Another environmental consideration is the negative impact of disposal of existing cooling systems when upgrading to new, more efficient, systems. These impacts may outweigh the improved efficiency offered by new equipment if premature disposal occurs or if the end-of-life treatment of the equipment is not managed properly. Determining the point at which it offers a net environmental benefit to switch to new equipment is not straightforward; although in general the older the equipment being replaced the more likely it is that the replacement makes good environmental sense.

Applicability

This best practice is applicable to all food and beverage manufacturers. Some limitations to the implementation of each of the measures listed above may arise from specific process or product requirements. For instance, ammonia is not compatible with copper so special motors and steel or aluminium piping may be required which in turn diminishes the advantages of enhanced heat transfer (Ansbro, nd). Carbon dioxide meanwhile, due to the fact that relative high pressures are required for it to function as a refrigerant, is better suited to lighter commercial applications and in vending machines (Staub, 2004).

Another issue is that the layout of existing facilities may preclude necessary changes to optimise cooling performance.

When manufacturers switch to natural refrigerants, certain types of equipment may be HFC-dependent and may no longer function. For example, when a new heat pump was installed at **Nestlé's** factory in Halifax, UK, which used ammonia as the refrigerant, the project team had to completely re-design the pump (Star Refrigeration, 2010)

Smart temperature strategies, such as the example given above of raising freezing stores to ?21°C, may not always be applicable; for instance, manufacturers of ice creams must maintain lower temperatures (e.g. ?25°C) to protect the quality of their product (British Frozen Food Federation, 2014, pers.comm.).

Another barrier is that many manufacturers may be unable to monitor energy consumption specific to their freezing and refrigeration equipment if electricity metering is on a site-wide basis. In rare cases frontrunners may install sub-meters on specific equipment but this tends not to apply to cooling technologies since these are 'closed systems' with no need to top up the refrigerant (British Frozen Food Federation, 2014, pers.comm.).

Transcritical carbon dioxide cooling systems have the drawback that they work best in cooler ambient temperatures and so are less applicable in warmer countries (e.g. southern Europe). In addition, there is a shortage of technicians skilled in servicing these systems which have more complicated controls (British Frozen Food Federation, 2014, pers.comm.).

As mentioned, **Coca-Cola Enterprises** (CCE) has agreed a leak-free warranty with the supplier of chillers. However, many manufacturers, especially smaller ones may not have the purchasing influence to demand such an agreement and even the soft drinks giant found that most suppliers would refuse to offer such a warranty, and only then for specific cooling equipment (Turbocor chillers) and for a limited period of five years (when the equipment has a life of 15 years or more). When the warranty expires in 2014/15, CCE will continue with the service contact and maintain the chiller to a high standard to minimise the risk of leakage (Coca-Cola Enterprises, 2014, pers.comm.).

Economics

Masson *et al* (2014) provide numerous examples of savings and paybacks from switching to natural gas refrigerants. For instance, the **Daniel Thwaites** brewery in the UK installed a reciprocating compressor using ammonia and as a result increased output from 310 kW to 400 kW with improved energy efficiency and saving around EUR 2,500 per week in electricity costs. The investment paid back in less than 18 months.

The new dual-function heating and cooling compressor installed in 2010 at **Nestlé's** Halifax plant reportedly consumes GBP 120000 (about EUR 155000) less electricity per year than the previous cooling only plant. The capital cost of the project will be recovered within four years (Star Refrigeration, 2010; Star Refrigeration, 2012).

Natural gases also have the advantage over HFCs of being cheaper. In the USA, both ammonia and carbon dioxide cost perhaps USD 1 per lb (about EUR 1.75/kg)[1] while R-134a[2], an HFC, costs USD 10 per lb (around EUR 17.50/kg) (Ansbro, nd; Staub, 2004). However, this consideration is perhaps less significant than others given that the gases are not consumables.

Illy reported investing EUR 400000 for the absorption cooling machinery installed in 2013. As mentioned above, this new technology results in savings of EUR 60000 per month when cooling is required, therefore the capital cost of the project will be recovered within five years. In addition, by collaborating with their suppliers, Illy secured a deal to pay for this equipment in instalments throughout the payback period (Illy, 2014, pers.comm.). Investment for the **Salcheto winery** geothermal plant was considerably lower, and amounted to EUR 40000 (Salcheto, 2014 pers. comm.).

The most efficient cooling equipment is not cheap. A capital investment of up to GBP 1 million (about EUR 1.3 million) is typical for a frozen food manufacturer seeking to upgrade its cold store. The life of the plant may be up to 20 years (British Frozen Food Federation, 2014, pers.comm.). When it comes to freezing, the amount a frontrunner is prepared to invest in cooling technology will depend on the value of its products and the speed with which it needs to be frozen. Those making seafood products with a relatively high unit value will typically use liquid nitrogen equipment able to freeze the product to ?200°C within seconds, while those making lower value items such as Yorkshire puddings will rely on ammonia as the refrigerant which may take 40 minutes to freeze the food. With products such as red meat, freezing times of up to two hours are acceptable (British Frozen Food Federation, 2014, pers.comm.).

Evidence does however suggest that significant energy savings can be realised without the need for such investments. Star Technology Solutions, a UK cooling systems supplier, participated in a study for the UK's Food Storage and Distribution Federation in which thirty facilities were visited to check for opportunities to improve energy efficiency. Most facilities could improve energy efficiency by up to 15% through such simple free or low cost measures as adjusting set points, timers, compressors or calibrating the duty sensors. The payback for some of these measures was immediate. In general, if the equipment has not been serviced in four or five years a servicing visit is likely to yield these savings. In cases where equipment needs to be replaced – perhaps as a result of the Montreal Protocol[3] – the difference in efficiency could be as high as 20-40% with paybacks of 3 to 18 months.

[1] The units conversion was performed on Google (25 September 2014)

[2] 1,1,1,2-Tetrafluoroethane

[3] Entering into force in 1989 and amended over subsequent years, the Montreal Protocol on Substances that Deplete the Ozone Layer is designed to reduce the production and consumption of ozone-depleting substances, notably chlorofluorocarbons (CFCs) widely used as refrigerants, in order to reduce their abundance in the atmosphere, and thereby to protect the earth's ozone layer. Under the Protocol, the removal of equipment using banned substances is staggered over several decades. More information is available here: http://ozone.unep.org/new_site/en/montreal_protocol.php.

Driving forces for implementation

Perhaps the greatest driver of change in the sector has been the much anticipated, and recently confirmed, EU rules for a 'fast phase-down' of HFCs (also known as 'F-gases') in new air conditioning and refrigeration equipment. The global warming potential (GWP) of F-gases are up to 23000 times greater than equivalent amounts of carbon dioxide. The new regulations, already informally agreed by EU ministers, will reduce the use of F-gases by 79% by 2030 (ClickGreen, 2014). From 2022, the servicing of equipment using F-gases will be prohibited. So, although the refrigerants themselves will not be banned immediately, if a leak occurred the machine could not be serviced. Many frontrunners who want to avoid the risk of a leak are already switching from F-gases to natural refrigerants.

Corporate responsibility may also be a factor. For instance, **Nestlé**'s decision to switch to natural refrigerants for all new factory process refrigeration equipment was part of a global commitment to reduce the environmental impact of its operations (Star Refrigeration, 2010). Although relating to point-of-sale, rather than manufacture, the 'Refrigerants, Naturally!' initiative should also be considered. Launched by **The Coca-Cola Enterprise**, **Unilever** and **McDonald's** and now including **PepsiCo**, the initiative promotes a shift to alternative HFC-free solutions for cooling technology that protect both the climate and the ozone layer (FoodDrinkEurope, 2012).

The use of more efficient cooling equipment is also driven by the need to cut costs. With energy costs rising inexorably, any opportunities to improve efficiency will be seized. However, an important caveat should be made here. While frontrunner manufacturers will invest in a certain amount of freezing and refrigeration equipment on site in order to protect the life of recently-manufactured products or frequently used ingredients, the principles of lean manufacturing favour minimisation of inventory (i.e. on-site storage). For this reason, frontrunners (or their retailer customers) will typically contract out the transport and storage of products to separate specialist companies. A manufacturer may run a cold store with a capacity of perhaps 500 pallets (e.g. **Aunt Bessie's** Yorkshire Puddings in the UK), but a specialist cold store may house 30000 pallets or more (e.g. **Reed Bordall** for frozen goods in the UK) (British Frozen Food Federation, 2014, pers.comm.). Due to the huge energy consumption of such operations, anecdotal evidence suggests that it is generally these contractors rather than manufacturers who are driving improvements (British Frozen Food Federation, 2014, pers.comm.).

Another important consideration relates to the scheduled upgrades of cooling equipment. Given the high capital cost of new cooling plants manufacturers are unlikely to replace recently installed machinery. But many cold stores in the industry are very old (up to 30 years old) so the need to install newer and more reliable equipment – and often to demolish the building and 'start again' - is a common pretext, if not a motivating factor, for upgrading to the latest technologies (British Frozen Food Federation, 2014, pers.comm.).

Reference organisations

- Arla – switch to an ammonia refrigeration system
- Coca-Cola Enterprise – introduction of a leak-free warranty
- Daniel Thwaites – installation of a reciprocating compressor using ammonia
- GICB winery – installation of an absorption chiller
- Illy – recovering heat from its coffee roasters for use in its plant heating system
- Mack – installing transcritical CO_2 chillers
- McDonald's – part of the 'Refrigerants, Naturally!' initiative
- Milka, part of Mondel?z International – switch to an ammonia refrigeration system
- Mlekpol – switch to an ammonia refrigeration system
- Nestlé – switch to an ammonia refrigeration system
- PepsiCo – part of the 'Refrigerants, Naturally!' initiative
- Salcheto Winery – installed a geothermal cooling system for chilling its cellar

- Unilever – switch to an ammonia refrigeration system
- Vlevico, part of the Colruyt group – switch to an ammonia refrigeration system

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