COLD CHAIN TECHNOLOGY BRIEF

COMMERCIAL, PROFESSIONAL AND DOMESTIC REFRIGERATION

Acknowledgement: This Cold Chain Brief was prepared by Judith Evans (IIR C2 Commission President), has been reviewed by Jim Curlin and Ezra Clark experts from the UN Environment

IIR-UN Environment Cold Chain Brief on Commercial, Professional and Domestic Refrigeration

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Summary

Due to the complex nature of the cold chain and the high temperature dependency of post-harvest or post-mortem deterioration in food, temperature control in the food chain is vital. Temperature control tends to become less well controlled at the retail/professional and domestic stages of the cold chain.
The food chain is responsible for greenhouse gas emissions through direct (refrigerant emissions) and indirect (energy consumption) effects. Published data for overall emissions for each section of a whole cold chain are relatively scarce. However, there is evidence to suggest that the retail sector has relatively high direct and indirect emissions compared to other sectors of the food cold chain. Domestic refrigeration has high overall indirect emissions (due to the large numbers of domestic refrigerators) but direct emissions are low due to low leakage of refrigerants and the use of low global warming potential (GWP) refrigerants. Refrigerant leakage is also low in the professional (catering) sector (for the same reasons) but there is evidence that indirect emissions are relatively high.

1 Introduction

The economic investment in food refrigeration technologies throughout the cold chain is tremendous in terms of refrigeration equipment worldwide. Refrigeration technologies are some of the most energy-intensive technologies used in the food supply chain and pose a number of sustainability-related challenges. Refrigeration accounts for about 35% of electricity consumption in the food industry (Guilpart, 2008[1]). Overall the cold chain is believed to be responsible for approximately 2.5% of global greenhouse gas emissions through direct (refrigerant emissions) and indirect (energy consumption) effects.

2 The Cold Chain

The "cold chain" refers to the various stages that a refrigerated product passes through, either until it is removed by a customer in a retail environment or unloaded from a delivery vehicle a few metres from its destination. From the moment a fruit or vegetable is harvested or an animal is slaughtered, the product starts to deteriorate. The deterioration of a product can be slowed by reducing the temperature at which it is stored. In fruits and vegetables, this slows down metabolic processes, which, in turn, slows spoilage. Reduced temperatures slow the growth of potentially harmful bacteria in animal products that are stored at frozen temperatures, allowing them to be shipped all over the world with minimal food safety risks. It is important that suitable temperature control be maintained from as soon as is feasible to as close as possible to consumption. From the raw materials stage to the various distribution storage facilities a commodity passes through, transport refrigeration keeps it at the temperature required to maximise storage life and quality for many days, weeks and months between cold storage facilities.

The Cold Chain

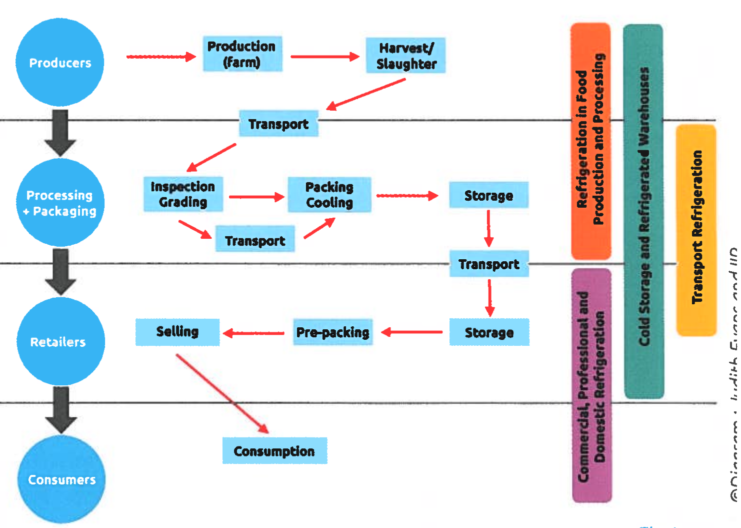

Fig. 1

The cold chain is often quite complex, with foods being chilled or frozen on more than one occasion. Worldwide about 400 million tonnes of food are preserved using refrigeration. The overall volume of cold stores (refrigerated warehouses) around the globe is about 600 million m^3. The IIR estimates that the total number of refrigeration, air-conditioning and heat pump systems in operation worldwide is roughly 3 billion, including 1.5 billion of domestic refrigerators. 90 million of commercial refrigerated equipment (including condensing units, stand-alone equipment and centralized systems) are operating in the world. There are also 4 million refrigerated road vehicles (vans, trucks, semi-trailers or trailers), 1.2 million refrigerated containers (reefers) and 477,000 supermarkets, with a footprint ranging from 500 to 20,000 m^2 in operation and where 45% of the electricity consumed is used by refrigeration equipment (IIR, 2015[2]).

3 Overview of Commercial, Professional and Domestic Refrigeration

Fig.2: Typical professional refrigerators.
Fig.3: Typical commercial refrigerators.
Fig.4 : Typical domestic refrigerators.

Commercial, professional and domestic refrigeration all occur at the later stages of the cold chain at the point where the retailer stores or the consumer purchases the food product. Commercial refrigeration encompasses supermarkets, convenience stores and bars and restaurants where food is on display for purchase by consumers. Smaller systems are integral units of usually less than 3 kW electrical consumptions but the sector also covers larger systems with multiple cabinets served by central refrigeration systems. Vending machines, water coolers, drinks fountain and small displays are considered as commercial refrigerators. Professional refrigeration encompasses restaurants, cafés and fast food outlets where food is stored before being prepared for the consumer. Professional cabinets are also sometimes found in supermarkets where they are used behind delicatessen displays for storage of food. Most of the appliances are solid door cabinets used for food storage (chilled or frozen) but blast coolers and freezers are also part of this sector. The vast majority of the cabinets sold are integral cabinets (plug in units with the refrigeration system on board) but remote units (where the refrigeration system is separate from the cabinet) are also available. Professional vaccine/blood/plasma units could be found in the pharmaceutical sector. Domestic refrigeration is used in consumers' homes to store food in chilled or frozen form. Domestic refrigerators are almost universally integral systems with an electrical consumption of around 20-150 W.

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Fig.3

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Current Issues and Market Trends

4.1. Temperature performance

Temperature is the prime factor controlling food quality and bacterial growth on foods. Generally, lower temperatures will achieve longer storage life. For chilled products there are minimum storage temperatures which are dependent on either the initial freezing point or a point where chilling injury occurs.

4.1.1. Temperature control in catering establishments

Limited information is available on temperature control in catering establishments. In Europe recent legislation has been applied to limit maximum temperatures and energy use in professional cabinets. Under the Ecodesign (Directive 2009/125/EC) and Energy Labelling (Directive 2010/30/EU) Directives most common types of chilled professional cabinets cannot be sold in Europe unless they achieve an internal temperature of between -1 and 5°C when tested in a laboratory at an ambient temperature of 30°C. Likewise frozen professional cabinets cannot be sold in Europe if they are unable to maintain temperature below a maximum of -15°C.

4.1.2. Temperature control in retail supermarkets

Temperatures in cabinets are specified by food safety regulations, standards, and by supermarkets' own specifications. However, differences between the recommended temperature and the real working temperatures can sometimes be observed. This can be due to variations in position of the control temperature probe(s), set up of the cabinet, or variations in the use of the cabinet.

Apart from the home, retail display is the weakest link in the food cold chain. Derens *et al.* (2007[3]) found that once food entered the supermarket the number of samples below 4°C (for meat) or 6°C (for yogurt) was less than 70%. This was further reduced to 16% during transport to the home and only recovered to 34% in the home. Mean food temperatures in chilled multi-deck cabinets in stores can vary greatly, with a study in the UK finding mean temperatures ranging from -1°C to 16°C (James and Evans, 1990[4]). This range causes food manufacturers problems when defining shelf life and results in shelf lives that are either unduly cautious or potentially risky. Individual cabinets are also often subject to large ranges in temperature and variations between locations within the cabinet (Evans *et al.*, 2007[5], Evans and Swain, 2010[6]). The ranges in temperature are partially encouraged by the test standards used to accredit cabinet performance where temperature ranges of 6, 8 or even 11°C are allowed.

4.1.3. Temperature control in domestic refrigerators

Temperature control of food in the home is vitally important. Evidence suggests that over 70% of food poisoning cases originate in the home and if food is stored in less than optimal conditions the potential for growth of pathogenic organisms exists. In the past decade there have been at least 15 surveys of temperatures in domestic refrigerators. The results are very similar, with overall mean temperatures ranging from 4.5 to 6.6°C and maximum temperatures from 11 to 14°C. These results imply that the average temperature of at least 50% of that the overall mean internal temperature of all refrigerators (671 appliances) was 5.3°C (Gemmell *et al*, 2017[7]). The maximum overall mean temperature in a single refrigerator was 14.3°C and the overall minimum mean temperature was -4.1°C. The overall mean temperature of freezers in the survey (745 appliances) was -20.3°C.

4.2. Energy consumption

4.2.1. Energy consumption in catering establishments

Professional cabinets used in catering establishment are reported to consume 12% of the refrigeration energy used in the sector. The average energy consumption claimed for chilled cabinets is 2,920 kWh per year and for frozen is 5,475 kWh per year (MTP, 2006[8]). There are few published data on energy consumption of professional cabinets in actual use. Unpublished data collected from real life usage of cabinets indicates that there are large differences in energy consumed by different cabinets. There are also large differences in the energy consumed by the same cabinet model in different locations, likely due to variations in usage and impact of local conditions such as ambient temperature, drafts from doors or proximity of warm appliances.

4.2.2. Energy consumption in retail supermarkets

Refrigeration is often the largest energy load in a supermarket. The energy consumption of supermarkets depends on business practices, store format, product mix, shopping activity and the equipment used for in-store food preparation, preservation and display. The annual electrical energy consumption can vary widely from around 700 kWh/m^2 sales area in hypermarkets to over 2000 kWh/m^2 sales area in convenience stores (Tassou *et al.*, 2011[9]). The refrigeration systems account for between 30% and 60% of the electricity used, whereas lighting accounts for between 15% and 25% and the HVAC equipment and other utilities such as bakery use the remainder. Gas is normally used for space heating, domestic hot water and in some cases for cooking and baking and will vary from zero in small stores such as petrol filling stations where gas is not used, to over 250 kWh/m^2 in hypermarkets. In some stores the gas energy consumption can be as high as 800 kWh/m^2. Tassou et al. (2011[9]) report energy use for varied supermarket sizes. In convenience stores the average electrical energy consumption of the stores using integral refrigeration equipment was approximately 300 kWh/m^2 higher than the stores using predominantly centrally located remote refrigeration equipment. Work carried out by Evans and Swain (2010[6]) showed that based on cabinets then on the market there were large overall differences in energy consumption between cabinet types and also between cabinets of each type when tested to EN23953 or EN441. Large energy savings could easily be achieved by selecting the best model within each cabinet type and by examining methods to reduce the range in temperature in cabinets. Many options are available to reduce energy consumption in supermarkets. In a study carried out by Evans et al. (2016[10]) 81 different technologies and their potential to save direct and indirect emissions in supermarkets were examined. Most of the carbon saving measures could be applied to currently installed cabinets and include cabinet doors, strip curtains, air deflectors/guides (all on open fronted cabinets) and improved fans. Additional options are available for new cabinets and these include optimisation of air flow in the cabinet, using high efficiency evaporators and micro-channel heat exchangers.

[3] *Derens, E., Palagol, B., Cornu, M., Guilpart J., 2007. The food cold chain in France and its impact of food safety. IIR IRC2007, Beijing, China.*
[4] *James, S.J., and Evans, J.A., 1990. Temperatures in the retail and domestic chilled chain. Processing and Quality of Foods. Vol. 3. Chilled Foods: The Revolution in Freshness. Elsevier Applied Science Publishers, London, 3.273-3.278.*
[5] *Evans, J.A., Scarcelli, S., and Swain, M.V.L., 2007. Temperature and energy performance of refrigerated retail display cabinets under test conditions. Int. J Refrigeration. Vol. 30 pp 398-408.*
[6] *Evans, J.A., and Swain, M.V.L., 2010. Performance of retail and commercial refrigeration systems. IIR ICCC2010, Cambridge, UK.*
[7] *Gemmell, A., Foster, H., Siyanbola, B., and Evans, J., 2017. Study of Over-Consuming Household Cold*

4.2.3. Energy consumption in domestic refrigerators

In Europe manufacturers have been reducing the energy consumed by domestic refrigerators and freezers since the instigation of energy labelling in 1995. There is substantial information on energy used by domestic refrigerators in Europe under test conditions as assessment of energy use is part of energy labelling. The test conditions do not include simulated usage as the tests are carried out with closed doors in a test environment. They therefore do not fully mimic real life energy usage. A recent study of refrigerators in the UK collected energy consumption data from 665 cold appliances (Gemmell *et al.*, 2017[3]). The overall mean annual consumption measured was 354 kWh/year, based on the entire monitored period of approximately 7 days. Although the energy efficiency of domestic refrigerators has improved considerably there are still options to reduce energy consumption through use of advanced insulation, compressor efficiency improvements, and optimisation of the refrigeration system operation/control and heat exchangers.

4.3. Refrigerant (direct) emissions

4.3.1. Refrigerant emissions in catering establishments

Data on direct emissions from catering cabinets are scarce. They are however, very likely to be similar to those from domestic refrigeration as the technologies used to produce the cabinets are similar. Emissions of HFCs from German commercial refrigeration between 1996 and 2002 were calculated by Schwarz (2005[11]). The emissions from catering cabinets estimated in the report were 1.5% which is similar to the IPCC (Intergovernmental Panel on Climate Change) estimates of 0.5-3% (IPCC, 2005[12]).

4.3.2. Refrigerant emissions in retail supermarkets

In larger remotely operated cabinets (operated from a central refrigeration plant) the direct emissions from the refrigeration system have a large impact. Emissions are largely attributed to HCFC and HFC refrigerant leakage. Leakage of refrigerant from supermarkets varies considerably. In industrialised countries integral cabinets have been shown to have minimal leakage (<1% per year) whereas leakage from remote refrigeration plant can vary from an average of 3% per year at best, to up to an average of 20-30% per year at worst. There is evidence that leakage rates can be reduced to low levels. This has been achieved through a change in management, system or technology and to better training, skills and qualifications of operators and maintenance teams. A number of options are available to reduce direct emissions from supermarkets. Evans et al. (2016[10]) showed that significant carbon savings could be achieved by reducing refrigerant charge, applying good refrigeration engineering practices, applying lower GWP refrigerants or by applying secondary fluids with centralised refrigeration systems. In order to achieve continuing reductions in refrigerant leakage it is necessary to gain a better understanding of where and why systems leak. Good maintenance records can help to identify high risk areas and components within systems and allow operators to prioritize their refrigerant containment activities.

4.3.3. Refrigerant emissions in domestic refrigerators

Evidence from sources such as Heap (2001[13]) and RAC (2005[14]) indicate that refrigerant losses from domestic refrigerators in industrialised are extremely low (less than 1% per year). Schwarz (2005[11]) estimated emissions of HFCs from German domestic refrigerators between 1996 and 2002 to be 0.3%, which is similar to the IPCC estimates of 0.1-0.5%. This assumes that refrigerant is removed and destroyed at end of life of the appliance. In developing countries where road conditions are often poor (this may cause pipes to fracture or pipe connections to becomes lose) and servicing and at the end-of-life are poorly controlled due to lack of regulation the leakage rates may be considerably higher. Giz (2017[15]) estimate that leakage rate over the life of an appliance may be 27% in developing countries.

[11]*Schwarz, W, 2005. Emissions, Activity Data, and Emission Factors of Fluorinated Greenhouse Gases (F-Gases) in Germany 1995-2002. Research Report 201 41 261/01 UBA-FB 000811/e.*
[12]*IPCC/TEAP, 2005. Special Report: Safeguarding the Ozone Layer and the Global Climate System. Chapter 4*

5 Current Refrigerants Used and Potential Alternatives

5.1. Refrigerants used in catering

Traditionally HFC refrigerants were used in catering cabinets. More recently a number of manufacturers have moved to R290 (propane), partly due to its low GWP but also because it is an efficient alternative.

5.2. Refrigerants used in supermarkets

Existing supermarket refrigeration systems are predominately based upon HCFC and HFC refrigerants, although use of R744 (CO_2) and hydrocarbons is increasing. Alternative systems such as secondary systems where a fluid such as glycol is cooled by a primary refrigeration system and then pumped to the cabinets are often used in Scandinavian countries. Other systems include the use of water to cool the condensers of integral cabinets and creating cold air in a central location that is then used to directly cool the cabinets (chilled cabinets only).

5.3. Refrigerants used in domestic refrigerators

Between 35% - 40% of domestic refrigerators operate on R600a, a hydrocarbon with a GWP of 3 (European Parliament Regulation No 517/2014, 2014[16]). Although flammable, R600a is an efficient refrigerant (Maclaine-Cross and Leonardi, 1996[17]). Generally refrigerators operating on a hydrocarbon will be helium leak tested prior to being charged with refrigerant at the factory. This has been shown to provide a high level of leak detection and there have been few instances of leaks of refrigerants in consumers' homes. All major European, Japanese and Chinese manufacturers produce refrigerators operating on R600a and the technology dominates the market in Europe, Japan and China. The 2010 Technology and Economic Assessment Panel (TEAP) Progress Report (UNEP, 2010[18]) reported that "It is predicted that at least 75 percent of global new refrigerator production will use hydrocarbon refrigerants in 10 years."

Table 1: Summary of current and alternative refrigerants

Commercial, Professional and Domestic Refrigeration		
Types of refrigeration	Current higher GWP refrigerants (GWP kg.CO_2)	Alternative lower GWP refrigerants (GWP kg•CO_2)
Commercial	Remote and integral: HFC-134a (1300); HFC-404A (3920), HCFC-22 (1810)	Remote: R-744 (1) Integral and secondary: HC-290 (5), HC-1270 (1.8) Remote and integral: wide range of HFO and HFO blend refrigerants
Professional	HFC-404A (3920),	HC-290 (5), HC-600a (20), wide range of

6 Development Perspectives and Challenges

6.1. Professional refrigeration

The fundamental design of professional refrigerated cabinets has changed little over the past 20 years. Major step changes that have improved efficiency have not occurred. Manufacturers have difficulty justifying the higher costs of energy saving components because users' emphasis is on the first cost of units rather than life cycle costing. Considerable energy savings are achievable using available technologies but one of the major issues is persuading end users to purchase the most efficient cabinets.

6.2. Commercial refrigeration

Considerable reductions in carbon emissions are possible from supermarket cabinets (Evans *et al.*, 2016). Much of the savings could be achieved by applying doors, strip curtains or technologies that reduce air infiltration to open fronted cabinets. Further reductions could be achieved by use of evaporator optimisation and new evaporator technologies. The use of alternative refrigerants with low GWP has considerable potential to reduce direct emissions. The main challenge is to apply these technologies economically and to achieve paybacks that are acceptable to the cost sensitive supermarket sector.

6.3. Domestic refrigeration

There is still evidence that temperatures in home refrigerators are higher than optimal. Over the past 30 years there have been a large number of surveys on temperatures in domestic refrigerators and all have concluded that few domestic refrigerators operate optimally in real life use by consumers. The energy used by domestic refrigerators has reduced considerably since energy labelling of appliances was introduced in the 1990's, but there is potential to improve food safety and quality through operation at more optimal temperatures (generally considered to be 0-5°C in the refrigerator and <-18°C in the freezer) which in turn may reduce food wastage and provide overall reductions in carbon emissions.

[16] *European Parliament. Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006, 2014.*
[17] *Maclaine-Cross, I.L. and Leonardi, E., 1996. Comparative performance of hydrocarbon refrigerants. IIR Commissions E2 E1 B1 B2 Melbourne. Australia.*

7 Technical Challenges and Potential

7.1. Professional refrigeration

Initial improvements in performance are relatively simply and involve use of the best components and technologies. In 2004, Pedersen[19] published a study showing improvements to cabinets which reduced energy use to 74% (chillers) and 47% (freezers) of original usage (from 6.26 kWh/day to 1.62 kWh/day for the chillers and from 8.53 kWh/day to 4.54 kWh/day for the freezers). The energy savings were achieved by changing the refrigerant, using energy efficient components and optimising heaters, door seals and the control system. The greatest savings were achieved by optimising the door seals, using DC fans and by using compressor discharge gas for evaporator water evaporation.

In the future further improvements will be required to achieve the 'best' energy labels. Technologies and systems such as inverter driven compressors, alternative defrosting methods and strategies, advanced control systems, removal of gasket and anti-condensate heaters, liquid line solenoids and advanced insulation will all play a part in future energy reduction strategies.

7.2. Commercial refrigeration

Technical challenges in commercial refrigeration involve the move to low-GWP refrigerants, and improving temperature control whilst also reducing energy consumption. Many of the issues are not just technical but also behavioural. For example there is a perception that a barrier between the shopper and the food may reduce sales and this has made supermarkets reluctant to apply doors to open fronted cabinets.

7.3. Domestic refrigeration

As with professional and commercial cabinets there are technical challenges to reduce energy consumption and ensure good temperature control. Although domestic refrigerators have undergone considerable energy reductions over the past 30 years there is still potential for further reductions. The primary challenge is applying new technologies economically.

7.4. Related over-arching issues

A number of common issues are relevant to commercial, professional and domestic refrigeration. Many very low GWP refrigerants are flammable or operate at high pressures. The uses of these refrigerants require designers and technicians to understand the safety issues and to ensure systems are designed and operated to ensure the safety of end users. This often involves training and knowledge of safety standards and their application.

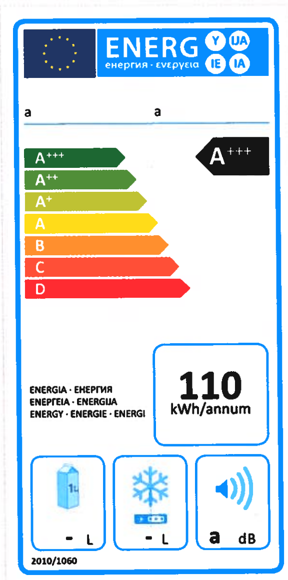
7.5. Related driving policies

The EU Ecodesign Directive (Directive 2009/125/EC) is a framework directive that obliges manufacturers of energy consuming products to reduce the energy consumption and sometimes also other negative environmental impacts occurring throughout the product life cycle. The Directive is complemented by the Enerfrigerated appliances and professional refrigerated cabinets are included under the directives. In the case of domestic appliances similar legislation is applied in almost all developed countries (Figure 5).

Refrigeration and Air Conditioning Industry witnessed considerable development and modernization in the last 3 decades partly as result to the international environmental policies where many refrigerants that have been used efficiently for decades, are held responsible to the Ozone Layer Depletion as well as Global Warming. The phase-out of ozone depleting substances (ODSs), under the Montreal Protocol, triggered significant changes in the industry moving towards alternative refrigerants and technologies that has zero-ODP (Ozone Depletion Potential).

In October 2016, the Kigali Amendment to the Montreal Protocol brought another dimension to the mandate of the Montreal Protocol by adding the control of production and consumption of hydrofluorocarbons (HFCs) under its mandate which will have major contribution towards the fight against climate change.

social and technical areas i.e. food industry, health, refrigeration, transportation, tourism, etc. The norms and directions for cold chain technology selection that has less environmental impact, energy efficient operation and affordable economics is scattered amongst different groups and entities within the same country. In September 2015, International Community adopted the 2030 Sustainable Development Goals (SDGs) stipulating Goal #2 «Zero Hunger» as the second global goal which needs to be achieved by 2030. This automatically means the urgent need to efficiently manage the portfolios of «Food Security» & "Food Waste" which depends on the cold chain capabilities. While this goal can be noted as the main goal with direct relation to cold chain, other goals are also connected to the cold chain business i.e. Goal #3: Health and Wellbeing, Goal # 9: Industry Innovation and Infrastructure, Goal # 12 Responsible Consumption and Production as well as Goal #13: Climate Action. Therefore, the integrated approach in addressing the cold chain challenges can lead to multi socioeconomic and environment benefits.



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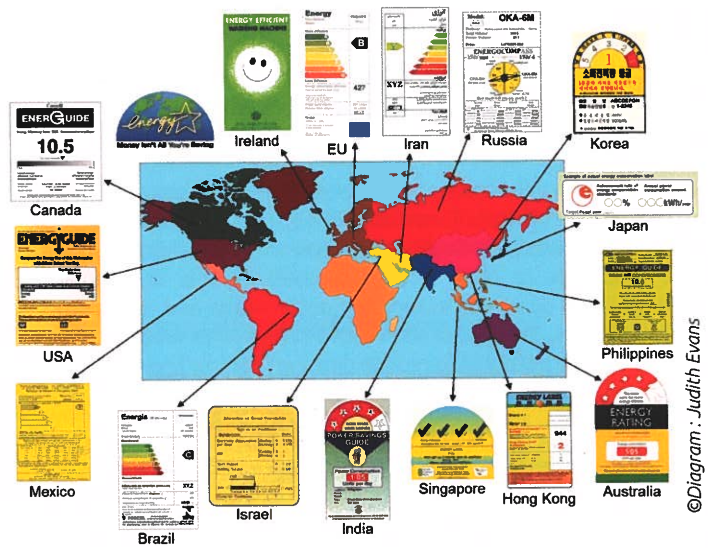

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Fig.5: European professional cabinet energy label (left), typical domestic energy labels from across the World (right)

Control of HFCs production and consumption will add to the climate benefits already achieved by the Montreal Protocol through the phase-out of ODSs including CFCs and HCFCs. The emissions of HFCs are also listed within the group of GHGs (Greenhouse Gases) under the Climate related conventions i.e. Paris Agreement and previously the Kyoto Protocol. However, actions to specifically control HFCs emissions within the climate regime are not yet set except for reporting requirements under the UNFCCC (UN Framework Convention on Climate Change).

The refrigerant climate impact of refrigeration equipment depends on direct and indirect effects. The direct effect is from its GWP (Global Warming Potential) and amount of a refrigerant emitted to the atmosphere (either from a leak, accident, or from improper handling or disposal). The indirect effect is associated with the energy consumed during the operation of equipment which, over its lifetime, occurs as a result of the CO_2 (CH_4 to lesser extend) produced by fossil fuel power plants, and is commonly greater than the direct effect. Minimizing direct and indirect impacts, of all types of refrigerants, emissions should be addressed through improved design, better field commissioning and maintenance practices, sound decommissioning procedures and enforcement to local relevant standards and regulations.

There are several principal organisations developing standards related to the refrigeration and air-conditioning sector. The UNEP International Standards in Refrigeration and Air-Conditioning booklet (UNEP, 2014[20]) summarises the main international standardisation organisations and provides some examples of national and regional standards organisations.

Conclusions

Commercial, professional and domestic refrigerators are the last stages in the cold chain where food is stored before consumption. The sectors are characterised by several challenges such as temperature maintenance and energy reduction. Commercial refrigeration also has higher emissions from refrigerants related primarily to the use of larger remotely operated refrigeration systems. All sectors have the potential for significant energy reduction.

[20] *UNEP, 2014. International Standards in Refrigeration and Air-Conditioning. An introduction to their role in the context of the HCFC phase-out in developing countries.*

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