




COLD CHAIN TECHNOLOGY BRIEF

COLD STORAGE AND REFRIGERATED WAREHOUSE



Acknowledgment: 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 OzonAction and also several experts from the IIR commissions.

IIR-UN Environment Cold Chain Brief on Cold Storage and Refrigerated Warehouse



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2 The Cold Chain

Summary

Cold storage warehouses store food after production and before foods are transported and distributed to supermarkets or catering establishments. Food is stored either chilled or frozen and may remain in the store for periods of a few hours, days or even a year (for some fruits and vegetables) in chillers and up to several months in freezers. This sector has been shown to be one of the sectors of the cold chain where the temperature of products is well temperature-controlled. Energy usage is important to cold store operators as it is a high proportion of the overall operating costs. Cold storage warehouses traditionally have high usage of low global warming potential refrigerants.

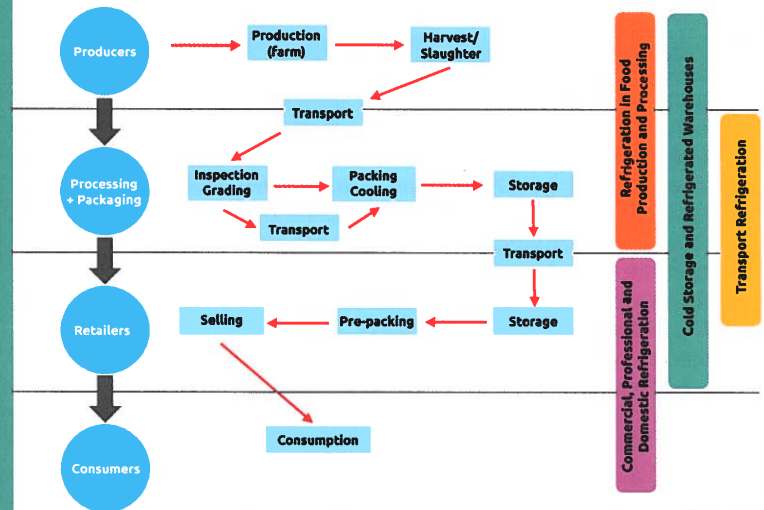
The “cold chain” refers to the various stages that a refrigerated product passes through, either until it is removed by a customer in a retail environment or unloaded from a delivery vehicle a few metres from its destination. From the moment a fruit or vegetable is harvested or an animal is slaughtered, 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.

1 Introduction

Once food is brought to the desired temperature after primary and secondary processing (food chilling/freezing or processing into a secondary product such as a meal), the storage and distribution stages of the cold chain should maintain food at a constant temperature. However, this is not always the case as food is often chilled or frozen in the storage chamber rather than being chilled or frozen in a dedicated blast chiller/freezer. Cold storage warehouses are usually considered within the industrial refrigeration sector. Such systems have heat extraction rates of up to 10 MW and generally operate as chillers or freezers. Generally most freezers operate between -22 and -26°C, although there are exceptions such as speciality ice cream freezers and niche products such as sushi which may be stored at -60°C. Food may be stored in freezers for several months. Storage times in chillers can vary considerably from a few hours or days to up to a year for certain fruits and vegetables. Chillers typically operate between -1 and 4°C, with some fruit, bakery and vegetable products being stored at between 8 and 12°C (UNEP, 2014¹).

¹UNEP, 2014. *Montreal Protocol on Substances that deplete the ozone layer. 2014 Report of the Refrigeration, Air Conditioning and Heat Pumps Technical Options Committee, 2014 assessment.*

The Cold Chain



©Diagram: Judith Evans and IIR

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 m³. 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 m² in operation and where 45% of the electricity consumed is used by refrigeration equipment (IIR, 2015²).

²IIR, 2015. *29th Note: The Role of Refrigeration in the Global Economy.*

I Fig. 1: Overall cold chain with the different components

3 Overview of Cold Storage and Refrigerated Warehouses

All chilled and frozen are stored in a cold store at least once during their journey from production to the consumer. Chilled stores generally maintain products at temperatures between -1 and 12°C whereas frozen stores generally maintain products at temperatures below -18°C. The cold store market is extremely diverse consisting of small stores with volumes of 10-20 m³ up to large warehouses with hundreds of thousands of cubic meters (Figure 2). All cold stores have the function of storing a product at the correct temperature and to prevent quality loss as economically as possible.



Fig.2

In chilled storage rooms temperature control is a food safety issue where increases in temperature may be detrimental to the safety and shelf life of the food. In frozen store rooms food safety is not an issue; assuming that the temperature in the room is maintained below -10°C, which is the temperature that is generally accepted as the minimum temperature for microbe growth. Food quality changes can however occur as in most instances food is stored above its glass transition temperature (temperature at which no further water can be frozen). For most food the glass transition temperature is below -30°C and most frozen storage facilities will operate at between -18 and -22°C (Nesvadba, 2007³). Temperatures in storage warehouses have been shown by Derens et al. (2007⁴) to be better controlled than any other sector of the cold chain (Figure 3).

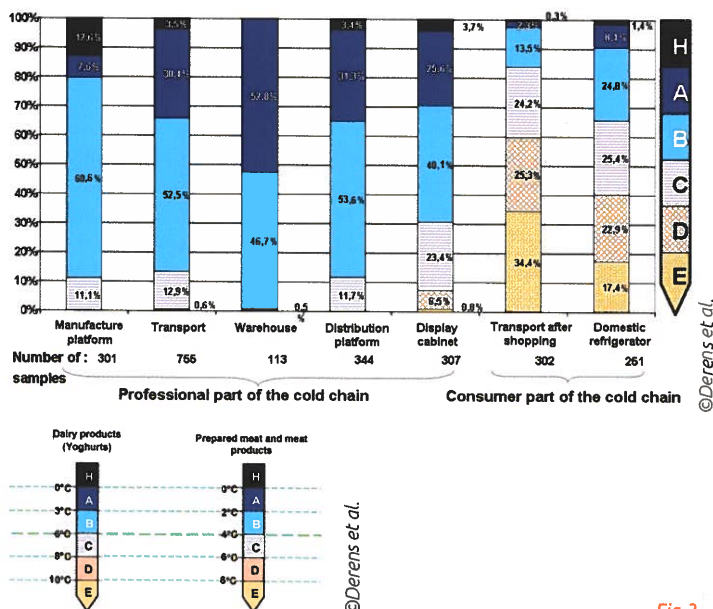


Fig.3

4 Current Issues and Market Trends

In cold stores reducing cost is a large driver. This can be achieved through reducing energy usage (and consequently indirect emissions) or by operating the store at times of lower energy tariffs (often termed 'load shifting'). The design of the store and how it is used are vitally important aspects of minimising energy use. Cold stores also contribute to direct emissions through loss of refrigerants and as such, the use of environmentally friendly low global warming potential (GWP) refrigerants is a significant issue in the current market.

4.1. Indirect emissions

Indirect emissions are affected by the cooling load, fuel mix of electricity generation, and efficiency of the plant. The heat loads on the room are dominated by transmission (through the walls and ceiling), infiltration through doors, fixed loads such as fans, floor heating (if relevant) and defrosts and heat loads from people and machinery (Figure 4).

Ideally the plant should be designed for maximum efficiency at the most common conditions. This requires knowledge of local seasonal ambient conditions (temperature and humidity) to define condensing temperatures (the refrigeration system condenser is generally located outside the building) and of usage patterns and heat loads on the store.

Cold storage rooms consume considerable amounts of energy. Within cold storage facilities 60-70% of the electrical energy can be used for refrigeration. In 2002 the IIR estimated that cold stores used between 30 and 50 kWh.m⁻³.year⁻¹ (Duiven and Binard, 2002⁵). More recent surveys carried out on a small number of cold stores have shown that energy consumption can dramatically exceed this figure, often by more than double (Evans and Gigiel, 2007, 2010⁶). These surveys also demonstrated that energy savings of 30-40%

³Nesvadba, P, 2007. Thermal properties and ice crystal development in frozen foods. In *Frozen Food Science and Technology*, edited by Evans, J.A. Blackwell Publishing.
⁴Derens, E., Palagol, B., Cornu, M., Guilpart J., 2007. The food cold chain in France and its impact of food safety. IIR ICR2007, Beijing, China.
⁵Duiven, JE, Binard, P., 2002. Refrigerated storage: new developments. Bulletin of the IIR, No. 2002-2.

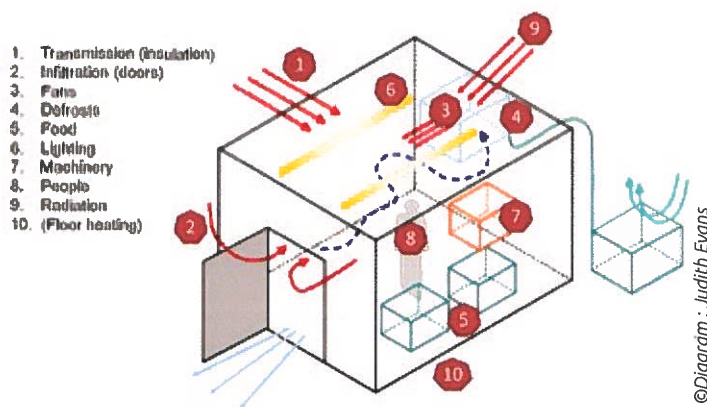


Fig.4

Fig.2: Typical cold stores: small (left), large (right)
 Fig.3: Temperatures throughout the French cold chain
 Fig.4: Heat loads in a refrigerated warehouse.

were achievable by optimising usage of the stores, repairing current equipment and by retrofitting of energy efficient equipment. However, cold store operators are often reluctant to install new equipment without sufficient information on savings that could be achieved.

There are few published surveys comparing the performance of considerable numbers of cold stores. Evans et al. (2015⁷) compiled data from 429 cold stores (167 chilled stores, 187 frozen stores and 75 mixed stores). The data collected covered 23 countries. Results from the survey are in Table 1. The survey demonstrates that considerable differences exist in energy consumption between cold stores. In many cases the best store could consume half the energy per cubic meter (also termed specific energy consumption, SEC) of the worst store. There may be many reasons for this that are not just due to poor efficiency. For example the store with the higher SEC may have higher usage and a different function than the store with the lower SEC.

4.2. Direct emissions

The scale of refrigerant leakage varies considerably between different refrigeration equipment types and from country to country. The leakage rates shown in Table 2, which are believed to be typical for the EU-15 region, are based on the UK Greenhouse Gas Inventory for 2007 (Defra, 2010⁸) and indicate significant variation between different types of equipment. Industrial refrigeration (that includes cold storage) had refrigerant leakage of 8% per year. Data on refrigerant emissions in developing countries is scarce but data from Giz (2017⁹) would indicate that refrigerant emissions can be about twice as high in developing countries as in industrialised countries.

Table 1: Range in SEC values for cold stores examined (Evans et al, 2015⁷).

		Chilled (kWh.m ⁻³ .year ⁻¹)	Frozen and Mixed (kWh.m ⁻³ .year ⁻¹)
All stores	Number of cold stores	167	262
	Mean	55.7	71.5
	Minimum	4.4	6.0
	Maximum	250.4	391.6
	Standard deviation	34.7	40.6

⁶Evans, J.A., Gigiel, A., 2010. Reducing energy consumption in cold storage rooms. IIR ICC2010, Cambridge, UK.

⁷Evans, J., Foster A., Huet, JM., Reinholdt, L., Fikiin, K., Zilio, C., Houska, M., Landfeld A., Bond, C., Scheurs, M., Van Sambeeck, T., 2015. Specific energy consumption values for various refrigerated food cold stores. IIR ICR2015, Yokohama, Japan.

⁸Defra, 2010. 2010 Guidelines to Defra / DECC's GHG conversion factors for company reporting: methodology paper for emission factors.

⁹Giz. 2017. <http://www.green-cooling-initiative.org/technology/chillers/green-cooling-potential/>.

Table 2: Typical refrigerant emissions by RAC sector (Defra, 2007⁸).

Type of Equipment	Typical Range in Charge Capacity (kg)	Installation Emission Factor (% of initial charge)	Operating Emissions (% of initial charge/year)	Refrigerant remaining at disposal (% of initial charge)	Refrigerant recovered (% of remaining charge)
Domestic Refrigeration	0.05 - 0.5	1.0%	0.3%	80%	99.0%
Stand-alone Commercial Applications	0.2 - 6	1.5%	2.0%	80%	94.5%
Medium & Large Commercial Applications	50 - 2,000	2.0%	11.0%	100%	95.0%
Transport Refrigeration	3 - 8	1.0%	8.0%	50%	94.0%
Industrial Refrigeration (inc. Food processing and cold storage)	10 - 10,000	1.0%	8.0%	100%	95.0%
Chillers	10 - 2,000	1.0%	3.0%	100%	95.0%
Residential and Commercial A/C including Heat Pumps	0.5 - 100	1.0%	8.5%	80%	95.0%
Mobile Air Conditioning	0.5 - 1.5	1.0%	7.5%	50%	88.0%

5 Current Refrigerants Used and Potential Alternatives

Refrigerant selection is an important issue in terms of environment, safety and sustainability. Within the food industry the majority of chilled/frozen stores use direct expansion refrigeration systems. Direct expansion systems consist of two heat exchangers (a condenser and an evaporator), a means to pump and raise the pressure of the refrigerant (compressor) and an expansion device plus associated control devices, storage vessels and safety devices. In larger plants pumped recirculation systems are common, often operating using ammonia (R717). In this system the refrigerant is contained in a large vessel termed a 'surge drum' and is pumped or fed by gravity to the evaporator(s).

Currently a large number of cold stores operate using ammonia as a refrigerant which has negligible GWP but is mildly flammable and toxic. To ensure safe operation it is vital that safety training and safe practices are applied when using a refrigerant such as ammonia. Training is seen as a key issue to facilitate transitions to low-GWP refrigerants where flammability and toxicity are issues that need to be dealt with. Often cost is the major consideration and there needs to be a move to lifetime costs which often favour systems that may have higher initial and maintenance costs but have lower energy costs.

In some instances cascade systems may be employed. The most common CO₂ cascade system incorporates CO₂ on the low temperature side operating below its critical temperature and ammonia on the high temperature side. This design can provide low temperature heating of hot water but is not suited for high temperature heating.

According to UNEP (2017¹⁰) industrial refrigeration accounts for approximately 2% of HFC consumption (in terms of CO₂-eq) and is projected to grow by approximately 6.7% annually between 2015 and 2050. There is an apparent move from ammonia to HFC refrigerants, especially in countries where there have been accidents or concern about safety (this is especially the case in Article 5 countries). Safety standards do exist through local regulation and ISO (International Organisation for Standardisation), IEC (I – E – C) and regional (such as European Norm, EN) standards. For industrial systems, ISO 5149 (2014) and EN 378 (2008/2012) cover design, construction and safety.

Smaller cold stores often operate on HCFC or HFC refrigerants and some newer stores operate on natural refrigerants (primarily CO₂, R744). In addition, although a relatively small proportion of the market, stores may operate on a secondary refrigerant (e.g. water, brine, glycols, silicon oils, or Flo-ice™) that is cooled by a primary centralised refrigeration system and then pumped to the cold store to extract heat. The advantage of such systems is that a flammable or toxic refrigerant can be used in the primary circuit which is isolated from the cooling process (therefore aiding safety) and the charge of the refrigerant in the primary circuit can be minimised.

Combined heat and power, polygeneration and trigeneration technologies where multiple energy inputs may be used to provide multiple energy outputs have potential to reduce energy consumption if the outputs can be put to use. The primary energy for such systems can include fossil fuels, biofuels and renewable energy and the energy outputs include heat, power and cooling. For traditional cold stores where refrigerated storage is the only function there may be little use for the outputs, although cold stores are often co-located or close to other production facilities which could benefit from the outputs.

Very occasionally absorption systems can be used in cold stores if excess heat is available to drive the system. Absorption systems vary the boiling point of a refrigerant by combining it with another fluid. For freezing this is usually ammonia-water. In the future greater use of heat reclaim may be justified and the use of energy grids and district thermal systems may be attractive and economic.

Although a number of novel refrigeration technologies are being developed (e.g. magnetocaloric, thermoelectric, thermoacoustic) these have limited apparent opportunities for cold stores. Most of these new technologies have been aimed at smaller refrigeration systems in the commercial and domestic markets.

Table 3: Summary of current and alternatives refrigerants

Cold Storage and Refrigerated Warehouses		
Size of store	Current higher GWP refrigerants (GWP kg•CO ₂)	Alternative lower GWP refrigerants (GWP kg•CO ₂)
Small store: less than 100 m ³	HFC-134a (1360), HFC-404A (4200), HCFC-22 (1810), HFC-410A (1920), HFC-407C (1920), HFC-507A (3990), HFC-422D (2470)	Wide range of HFO and HFO blend refrigerants, HC-290 (5), HC-1270 (1.8)
Large store: Larger than 100 m ³		Primary: R-744 (1), R-717 (0) Secondary: Brine, glycols, silicon oils

¹⁰UNEP, 2017. Montreal Protocol on Substances that deplete the ozone layer. UNEP, Report of the Technology and Economic Assessment Panel.

6 Development Perspectives and Challenges

There are many ways of operating or controlling food refrigeration that will save energy. Many cold store operators utilise control strategies to save energy. This can involve control of evaporator fans, the refrigeration system or of the temperature inside the cold room.

Reduction of energy consumption by cold stores should focus on three principal areas:

- Reducing heat loads on the store.
- Improved maintenance and usage operations.
- Improved operation/efficiency of the refrigeration system.

Any increase in the refrigeration system cooling temperature (evaporating temperature) or reduction in the heat rejection temperature (condensing temperature) will save energy. In many instances (especially in frozen stores) temperatures are kept lower than necessary to provide a safety margin in case of plant failure.

Often operators apply strategies to save money (not necessarily energy) by switching off the refrigeration systems during peak demand energy periods when energy is more expensive (energy can be 4 times more expensive at peak grid demand than at low demand times). During this period the temperature within the room is allowed to slowly increase and is then reduced once the cost of the energy returns to a lower level.

In the future the use of renewable energy sources such as wind, wave and solar are likely to play a role in reducing the environmental impact of the energy used by cold stores.

6.1. Technical challenges and potential

Energy is a major cost in the operation of food cold stores. Work from a number of energy audits has shown that considerable energy savings can be achieved in cold stores. In work carried out by Evans et al. (2014¹¹) reductions in energy consumption were identified by optimising usage of stores, repairing current equipment and by retrofitting of energy efficient equipment. Often these improvements had short payback times of less than 1 year.

Considerable work has been carried out in the UK and now extended to Europe to reduce refrigerant leakage (Cowan et al., 2010¹² and 2011¹³). Legislation, fiscal measures, new technologies, alternative refrigerants and other initiatives have all helped to drive significant improvements in refrigerant leakage. The European F-Gas Regulation (regulation 842/2006) ensures that installation, maintenance, service, (de)commissioning and disassembly of refrigeration systems containing or designed to contain HFCs can only be done by duly certified professionals. The Regulation requires regular leak checking by appropriately trained personnel. All of these obligations have been applicable since July 2009.

The implication of the F-Gas Regulations is a move to low GWP refrigerants. Ammonia is a widely used low GWP refrigerant in cold stores but requires high safety standards and refrigeration technicians to be fully trained. Many alternative low GWP refrigerants have issues related to high pressure or flammability. There are therefore increased issues surrounding safety and

training of refrigeration technicians to ensure that systems are applied and installed safely.

Use of heat reclaim in cold stores and greater integration between the store and 'local' amenities may become more economic in the future. Relatively low-grade heat can be reclaimed from the oil coolers of compressors and up to 60% of the compressor motor power can be absorbed in the oil. Systems have been developed that use heat from the compressor discharge or compressor oil coolers to pre-heat water in a boiler.

6.2. Related driving policies

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. 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 CO₂ (CH₄ 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.

¹¹ Evans, J.A., Hammond, E.C., Gigiel, A.J., Foster, A.M., Reinholdt, L., Fikiin, K., Zilio, C., 2014. Assessment of methods to reduce the energy consumption of food cold stores. *Applied Thermal Engineering* 62 (2014) 697-705.

¹² Cowan, D., Gartshore, J., Chaer, I., Francis, C., Maidment, G., 2010. REAL Zero – reducing refrigerant emissions & leakage - feedback from the IOR project, *Proceedings of the Institute of Refrigeration, Proc. Inst. R.* 2009-10. 7-1.

¹³ Cowan, D., Beermann, K., Chaer, I., Gontarz, G., Kaar, K., Koronaki, I., Maidment, G., Reulens, W., 2011. Improving F-Gas containment in the EU – results from the Real Skills Europe Project. *IRR ICR2011, Prague, Czech Republic.*

6 Development Perspectives and Challenges

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, 2014¹⁴) summarises the main international standardisation organisations and provides some examples of national and regional standards organisations.

The cold chain sector is one of the most important but overlooked business segments in terms of being addressed in a holistic approach. This is because it crosscuts with different economic, 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.

Conclusions

The cold storage sector is generally considered to be one of the best temperature controlled sectors of the food cold chain. The majority of stores use refrigerants with a low GWP and so the major source of emissions is from energy use. Energy usage in cold stores has been shown to vary considerably and many stores could reduce their energy consumption by applying good practice or efficient equipment and components.

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¹⁴UNEP, 2014. *International Standards in Refrigeration and Air-Conditioning. An introduction to their role in the context of the HCFC phase-out in developing countries.*