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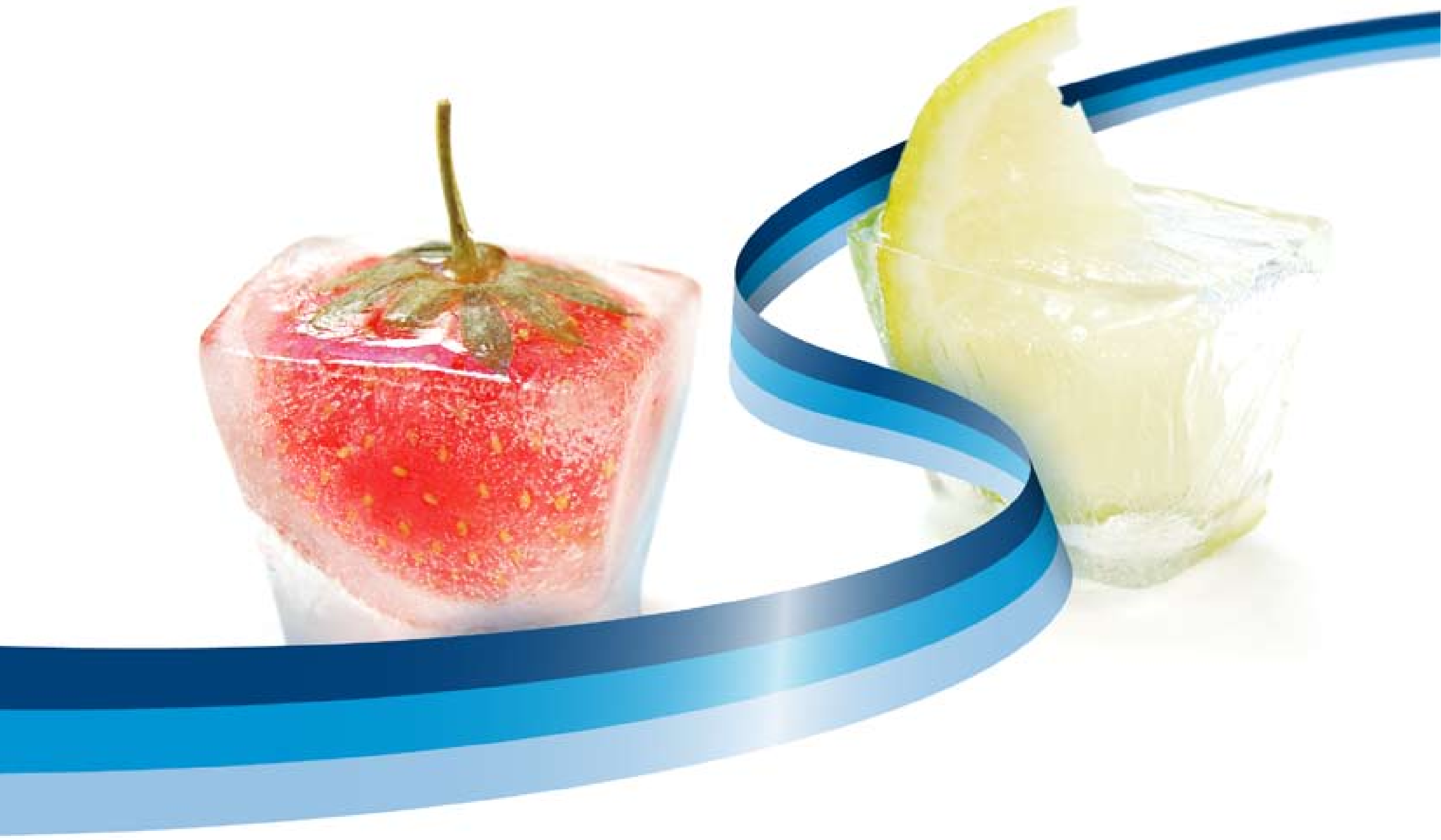
British Refrigeration Association

Refrigeration Road Map



Contents

Introduction

Reducing energy use makes perfect business sense; it saves money, enhances corporate reputation and helps everyone in the fight against climate change.

The Carbon Trust provides simple, effective advice to help businesses take action to reduce carbon emissions, and the simplest way to do this is to use energy more efficiently.

This Refrigeration Road Map introduces the main energy saving opportunities for refrigeration use in the retail sector and demonstrates how simple actions save energy use, cut costs and increase profit margins.

Refrigeration Road Map

The Refrigeration Road Map was developed to identify technologies that can be implemented by retailers to enable them to save energy and CO_2e.

Application timescale

2010 Short Med

CO_2 saving potential

Technologies available now to retrofit

- Refrigerant change to R407A
- Training
- Cleaning and maintenance
- Re-commissioning
- Floating head pressure
- Store temperature
- Doors on cabinets
- Store dehumidification
- LED lights
- Evaporator fan motors
- Suction pressure control
- Occupancy sensors and controls – cabinet lighting
- Curtains (strip)
- Condenser fans
- Cabinet lighting (non-LED)
- Night blinds
- Set-point
- LPA
- ASH controls
- Riser or weir plate
- Covers
- Loading – volume
- Loading – duration and temperature
- Defrost controls
- Store light (LED and fluorescent)
- Radiant heat reflectors
- HCs (integrals MT)
- HCs (integrals LT)

Technologies available for store refit

- Cabinet selection
- Secondary systems (with NCs)
- CO_2 refrigeration technology
- Borehole condensing
- Dynamic demand
- Occupancy sensors and controls – doors
- HFO-1234yf in MT pack
- R134a in MT pack
- Ground source
- Pipe insulation/rifling/reduced pressure drops
- Anti-fogging glass
- Air curtain optimisation
- Evaporative condensers
- Back panel flow
- High-efficiency evaporators and condensers
- Refrigeration system contamination
- SLHE
- Nanoparticles
- Heat pipes and spot cooling
- Anti-frost evaporators
- Dual/triple air curtains
- Centrifugal fans
- Economisers
- Electronic expansion valves
- Tangential fans
- Reflective packaging
- Insulation e.g. VIPs
- Supercooling/chilling of food
- Off-cycle losses
- Cabinet location
- Desuperheating/heat recovery
- Variable speed drives (integral)

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Long term 2020+

Technologies available for new stores/concepts

- Internet shopping
- Supermarket cold store
- Vending cabinet concepts
- Water loop systems
- Polygeneration
- Adsorption
- Absorption
- Novel building fabric
- High-efficiency compressors
- Centralised air distribution
- Store light (natural)

Potential future technologies (alphabetic)

- Acoustic refrigeration
- Air cycle
- Ammonia (sealed hermetics)
- Automation
- Electro caloric
- Eutectic packaging
- Hydraulic refrigeration
- Leasing concepts
- Magnetic
- New food
- Optical cooling
- Peltier
- Pulsed electrical thermal de-icers
- Stirling cycle variations
- Thermionic refrigeration
- Vortex tube cooling
- Water

Introduction to the Refrigeration Road Map

Background

Retail food outlets in the UK are responsible for around 3% of total electrical energy consumption and 1% of total greenhouse gas (GHG) emissions, with major retail food outlets alone responsible for around four million tonnes (Mt) of CO_{2e} annually. A large proportion of these emissions can be attributed to refrigeration and, therefore, improving the efficiency and reducing emissions from refrigeration units could provide significant carbon savings.

All retailers face a similar number of key decision points along the route to carbon reduction in refrigeration. The Carbon Trust, The Institute of Refrigeration and the British Refrigeration Association have worked together to produce a 'Refrigeration Road Map' for reducing carbon emissions in retail refrigeration applications. The Refrigeration Road Map has been developed to assist supermarkets, contractors and equipment manufacturers to identify the technologies most likely to reduce CO_{2e} emissions in supermarket refrigeration systems. These groups will be able to use it to identify their company's current status, and to clearly see what the next steps are for their business. This could include actions such as basic improvements in leakage monitoring, new approaches to design and installation, the introduction of alternative refrigerants, or the creation of zero carbon stores. The Refrigeration Road Map provides information on the technologies that are most likely to save carbon emissions, and prioritises them in terms of carbon saving potential, relative cost and limits to commercial maturity.

The technologies included in the Refrigeration Road Map have been divided into three sub-groups:

- Technologies currently available for retrofit in supermarkets
- Technologies that could be installed during a store refit
- Technologies that could be implemented in a new build supermarket.

Each technology has then been benchmarked against a baseline supermarket scenario to show its relative carbon saving potential. In addition, a number of potential future technologies have also been identified. These technologies are discussed within this report, but have not been evaluated for their CO_{2e} saving potential as there is currently insufficient evidence to attribute carbon savings to them at this stage in their development.

This report accompanies the Refrigeration Road Map and is split up into a number of sections:

- How the Refrigeration Road Map was developed.
- How the Refrigeration Road Map should be used.
- The presentation format for the Refrigeration Road Map.
- The baseline supermarket used for making carbon calculations.
- The Refrigeration Road Maps for the three technology subgroups (retrofit, refit and new store), together with an explanation of each technology.
- Details on other future potential technologies that could save carbon but are not currently considered viable in the short to medium-term.

How was the Refrigeration Road Map developed?

The Refrigeration Road Map has been developed using information obtained from a range of sources, including published literature and consultation with industry. This information has been used to identify the carbon emissions savings, relative cost and limits to commercial maturity of a range of technologies.

For the purposes of the Refrigeration Road Map the term 'technology' has been used to cover both technical options and non-technological behavioural changes such as training and maintenance improvements.

Each technology included in the Refrigeration Road Map has been compared to a 'baseline', or typical supermarket, and the relative CO_{2e} savings compared. It has also been evaluated for the time required for the technology to be implemented, and the relative payback period has been identified. For the purposes of the Refrigeration Road Map, the time to implementation has been defined as the time taken from making a decision to purchase a technology up until the point of installation and use in the supermarket. An assumption has been made that technologies can be applied without delay in current commercial timescales.

The analysis undertaken considered the potential to reduce the energy consumed by the refrigeration system and cabinets, and does not include store construction, lighting or air conditioning, apart from where these technologies impact on, or are used by, the refrigeration system or cabinets. In addition, energy usage has been defined as the energy used within the supermarket only, and does not include any energy associated with the manufacture or transportation of the technologies.

It should be noted that all savings have been calculated for each individual technology and that there may be interactions between technologies in cases where more than one option is implemented (see Appendix 1 for more details). Therefore, it should not be assumed that the CO_{2e} savings shown for each technology will be cumulative. In all payback calculations, a cost for energy of £0.12 per kilowatt hours (kwh) has been used. It has been assumed that all refrigeration in the benchmark store is operated using electricity. When converting energy into CO_{2e} emissions, a conversion factor of 0.544 kg CO_{2e}/kWh has been used.

Abbreviations

ASH	Anti-sweat heaters
CO_{2e}	Carbon dioxide equivalent
COP	Coefficient of performance
EC	Electronically commutated
ECM	Electronically commutated motors
EEV	Electronic expansion values
FGD	Full glass door (cabinet)
GHG	Greenhouse gas
GWP	Global warming potential
HC	Hydrocarbon
HFC	Hydrofluorocarbon
HFO	Hydro-Fluoro-Olefin
HGD	Half glass door (cabinet)
HVAC	Heating ventilation and air conditioning
LED	Light emitting diode
LPA	Liquid pressure amplification
LT	Low temperature
MT	Medium temperature
NIST	National Institute of Standards and Technology
PSC	Permanent-split-capacitor
SLHE	Suction liquid heat exchanger
tCO_2	Tonne carbon dioxide
TDA	Total display area
TEC	Total energy consumption
TEV	Thermostatic expansion valve
TEWI	Total equivalent warming impact
VIP	Vacuum insulated panel
VSD	Variable speed drive

The baseline supermarket

The baseline store used for the Refrigeration Road Map is a typical supermarket of 5,000m^2 sales area (equivalent to a large supermarket or small hypermarket). However, the information in the Refrigeration Road Map can be applied (in terms of CO_{2e} savings rank order but not absolute CO_{2e} savings) to any supermarket above 2,000m^2 (as above this size energy usage is relatively linear with the size of the store).

The baseline supermarket refrigeration system energy was defined as the energy used to operate the refrigerated display cabinets and included energy used by the refrigeration system packs and energy used by the cabinet components (i.e. fans, lights, heaters and controllers).

Direct emissions

Supermarket refrigeration systems generate greenhouse gas emissions directly, through refrigerant leakage.

R404A is the dominant refrigerant used in supermarkets and has therefore been used as the refrigerant in the baseline supermarket. The refrigerant charge for the baseline supermarket is assumed to be 400kg.

Leakage of refrigerant from supermarkets has been assumed to be <1% per year for integral cabinets and 20% for remotely operated cabinets. For technologies involving the replacement of the refrigerant in the remotely operated refrigeration plant, it has been assumed that repairs carried out during the replacement would reduce leakage to 10% per annum.

Indirect emissions

Indirect emissions originate from the energy used by supermarket cabinets, and the refrigeration systems used to providing cooling for the cabinets.

The energy used in the baseline supermarket has been divided into energy used by remotely operated freezer and chiller cabinets, and energy used by integral freezers and chillers. The energy used by the remotely operated cabinets has been further sub-divided into energy used by the low and medium-temperature packs (for freezers and chillers respectively) and the direct energy used for services to the cabinet (lights, fans, defrost heaters, anti-condensate heaters etc). This is shown in *Table 1*.

Table 1 Breakdown of refrigeration energy consumption for a typical supermarket

	Low-temperature (freezers) (%)	Medium-temperature (chillers) (%)
Refrigeration pack	23	35
Direct	21	9
Integrals	3	9

A further sub-division has been made in order to account for variations in heat loads on the different retail display cabinets. The heat loads used are based on published literature and are presented in *Table 2*.

Table 2 *Heat loads for various retail display cabinets from literature*

	Infiltration (%)	Radiation (%)	Conduction (%)	Fans (%)	Lights (%)	Anti-sweat heaters (%)	Defrost (%)
Low temperature[1]							
Full glass door	23	37	15	5	6	4	10
Well	24	43	17	5	0	4	7
Half glass door	23	37	15	5	6	4	10
Medium temperature							
Produce[1]	77	8	2	5	8	0	0
Dairy[1]	78	9	3	5	5	0	0
Meat[1]	80	10	3	5	2	0	0
Delicatessen[1]	50	25	10	5	10	0	0

How should the Refrigeration Road Map be used?

The aim of the Refrigeration Road Map is to provide supermarkets with a comprehensive overview of available technologies and options for consideration in reducing their emissions.

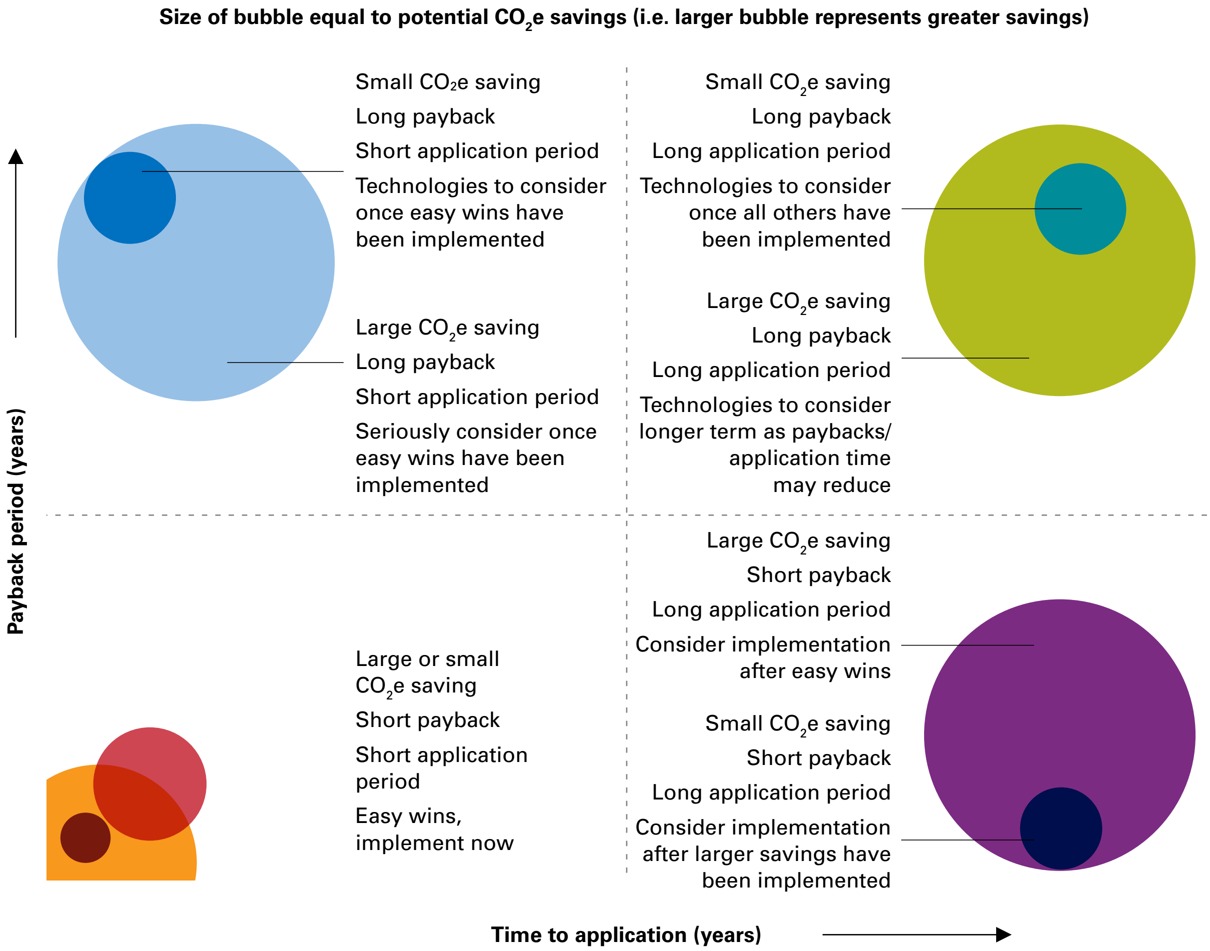
It is intended to assist in the selection of appropriate technologies, and to give an overview of each technology and its application. However, it is not intended that the Refrigeration Road Map is a list of all technologies that a supermarket should implement. End users, designers and contractors should therefore use the Refrigeration Road Map to help guide them towards choosing the most appropriate technologies for their particular application.

The Refrigeration Road Map was derived from detailed analysis of each technology and the results displayed visually using a series of bubble charts. These show the CO_{2e} savings potential, payback period and application time for the technologies examined. The size of the 'bubble' represents the level of CO_{2e} saving associated with a technology per annum, for the baseline supermarket (i.e. the larger the bubble, the larger the saving).

Figure 1 (overleaf) shows how these 'bubbles' are typically mapped on a graph, to show technology application time and payback period. The largest savings that can be applied now, or in the near future, are shown by the largest bubbles nearest the axis origin. Bubbles further away from the axis origin will take longer to apply, or will have a longer payback period. It should be noted that, depending on the size of the bubble, these technologies may still be worth considering if they can achieve large CO_{2e} reductions.

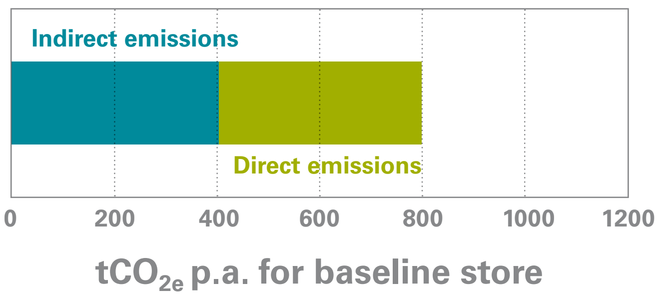
[1] ASHRAE Refrigeration Handbook 2001.

***Figure 1** Refrigeration Road Map bubble map schematic*



This report presents an overview of each of the technologies included in the Refrigeration Road Map.

Beside the information provided on each technology, a summary of the CO_{2e} emissions is presented.



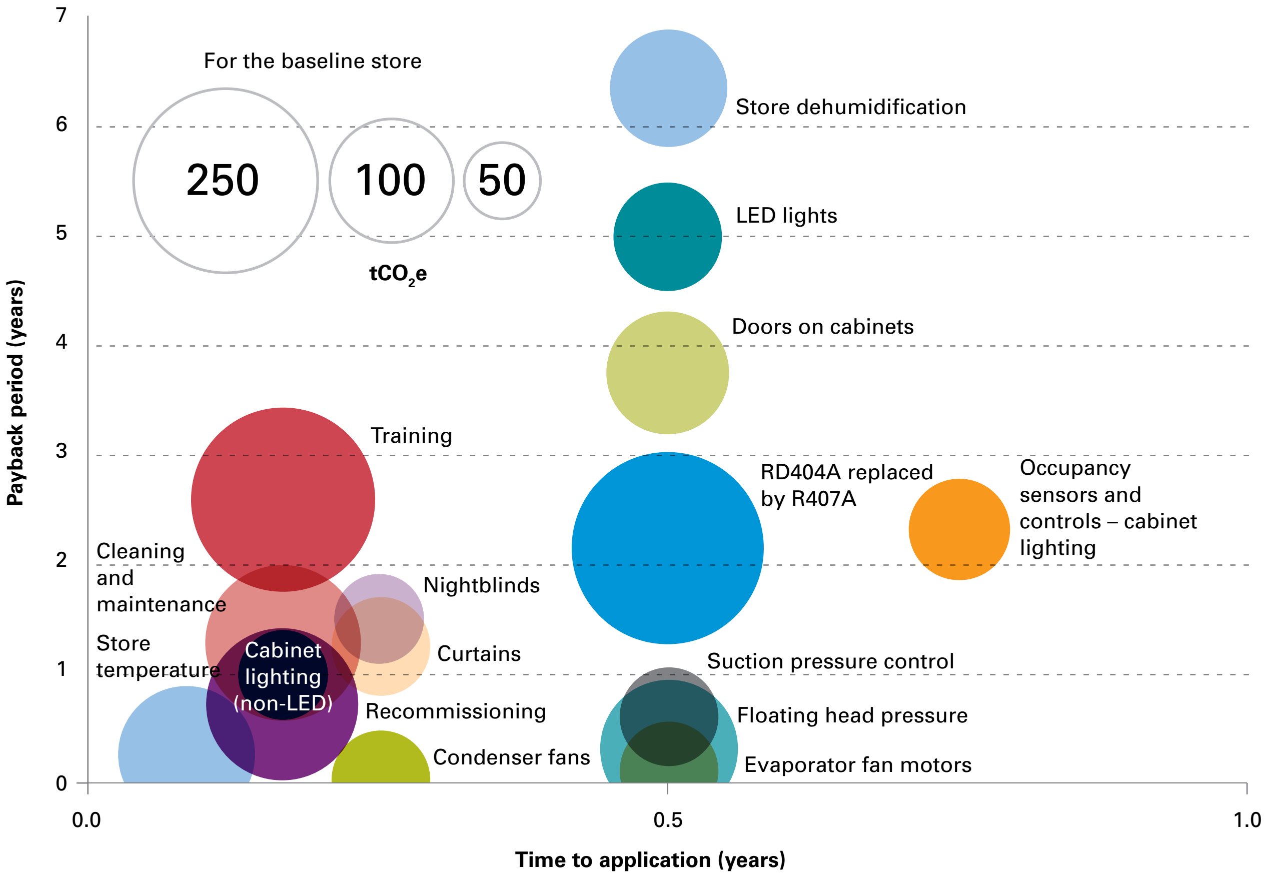
Less quantifiable factors are assessed as having a high (H), medium (M) or low (L) impact on uptake of each technology and are presented in a summary table beside the information on each technology.

Barriers to staff / customers	H	H=major barrier
	M	M=partial barrier
	L	L=no barrier
Availability barriers	H	H=prototype/demonstrator only
	M	M=limited availability
	L	L=available
Limits to commercial maturity	H	H=lack of maturity
	M	M=intermediate
	L	L=mature
Ease of use and installation	H	H=major issues
	M	M=partial
	L	L=simple
Technology interdependence	H	H=high (i.e. interaction with another technology)
	M	M=some
	L	L=none
Maintainability	H	H=major issue
	M	M=some problems
	L	L=no issues
Legislative issues	H	H=major (issue now)
	M	M=could be an issue in near future
	L	L=no impact

CO_{2e} saving options that can be retrofitted

Retrofit options have been divided into those that save less than, and more than, 50 tonnes of CO_{2e} per annum for the typical baseline store.

Figure 2 *Technologies that can be retrofitted with potential to save >50tCO_{2e} pa*

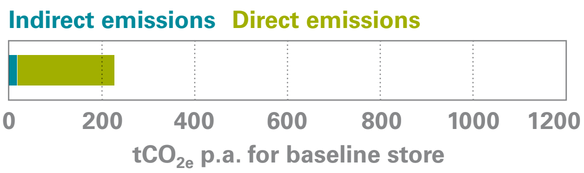


Retrofit options saving more than 50tCO_{2e} per annum

Figure 2 shows retrofit options that can save more than 50tCO_{2e} per annum. These technologies are described in more detail below.

1. Refrigerant change to R407A

Refrigerant replacement can have a significant impact on the direct emissions associated with refrigeration.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	M

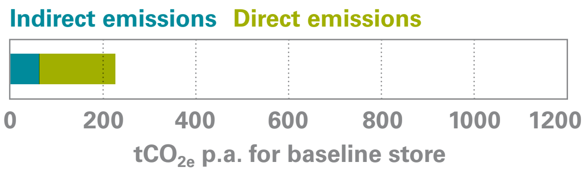
R407A has a lower global warming potential (GWP) than R404A (2100 versus 3922)*. By replacing R404A with R407A a supermarket can reduce the direct emissions associated with its refrigerant use by almost half. An additional advantage is that R407A operates at a lower pressure than R404A and this means that its leakage will inherently be slightly less when compared to R404A. Maintenance work to identify and repair leaks is generally also carried out during replacement of the refrigerant and will reduce leakage of refrigerant.

The legislation associated with refrigerants is continually evolving and, as a result, the use of R407A should be reviewed in the light of any changes in legislation.

See also maintenance (page 12).

2. Training

Providing appropriate training to supermarket staff and refrigeration engineers can lead to significant emissions savings as a result of reduced refrigerant leakage and improved energy efficiency.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	L

Training can cover many aspects of refrigeration, including the installation and maintenance of refrigeration plant and the use of cabinets in supermarkets.

There are potentially large-scale savings associated with training available in tackling refrigerant leakage, with countries such as Sweden and the Netherlands reporting excellent results. In the UK, this issue is being tackled through training initiatives such as RealZero (www.realzero.org.uk).

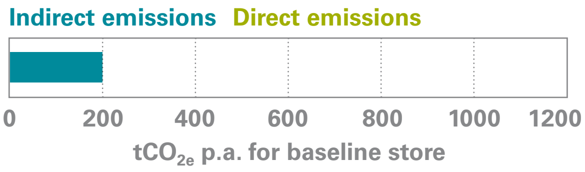
In other areas such as commissioning and installation of plant, and the use of cabinets, training is relatively limited. This can vary from training in-store staff to operate cabinets in a more energy efficient manner to advising commissioning engineers on the best way to set up and operate a cabinet. Although training can deliver significant savings in direct and indirect energy there are no formal training courses in the UK.

See also re-commissioning (page 12), loading – duration and temperature (page 22), and store temperature (page 13).

* These figures are taken from the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, and are the most up-to-date GWPs available for refrigerants.

3. Cleaning and maintenance

Maintenance and cleaning of cabinets and refrigeration plant is an important aspect of energy minimisation and leak reduction.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	M
Maintainability	M
Legislative issues	L

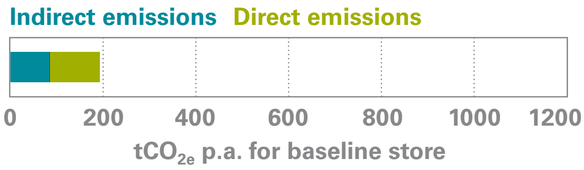
Maintenance and cleaning covers a variety of activities, including cleaning of condensers and evaporators, replacement of door gaskets and seals, and minimising refrigerant leakage. Leakage has a direct effect on CO_{2e} production.

Dirt and debris build-up on external heat exchanger surfaces and can have a dramatic effect on heat transfer if not removed. Poor maintenance can increase condensing temperature or reduce evaporating temperature by several degrees, resulting in an increase in energy use of between 2% and 10%.

Refrigerant loss is a major cause of direct emissions and system inefficiency. When refrigerant charge becomes critically low-energy use can increase by between 11% and 15%. Undercharged systems need to operate for longer in order to achieve the same cooling capacity, and systems that have lost refrigerant are likely to operate at higher suction temperatures. This can cause a reduction in compressor efficiency and higher discharge temperatures, often leading to oil breakdown and overheating problems that generate acid formation in the compressor.

4. Re-commissioning

Re-adjusting settings on cabinets and refrigeration plant can result in substantial energy saving benefits.



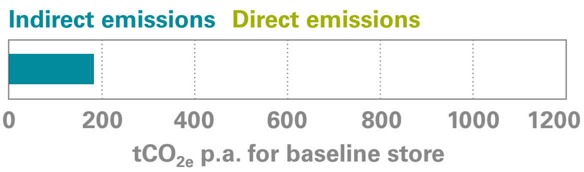
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	L
Technology interdependence	M
Maintainability	L
Legislative issues	L

Often over time cabinet and refrigeration system control settings have been adjusted away from their original levels. Substantial energy savings from re-commissioning and 'locking down' refrigeration and cabinet controllers can achieve energy savings of 15%. Re-commissioning can be implemented rapidly with short paybacks.

See also training (page 11).

5. Floating head pressure

There is considerable potential to save energy by allowing head pressure to fluctuate in line with ambient conditions, down to a minimum safe level.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

In the past, supermarkets have tended to maintain head pressure at a constant level either to ensure consistent operation of expansion valves, or to enable refrigerant gas to be used to defrost evaporators.

Reducing the head pressure set point from 15.1 bar to 12.0 bar will result in energy savings of more than 22% in the summer. These savings will increase during winter operation where ambient temperatures are lower. Leakage of refrigerant will also be reduced as a result of pressure reduction.

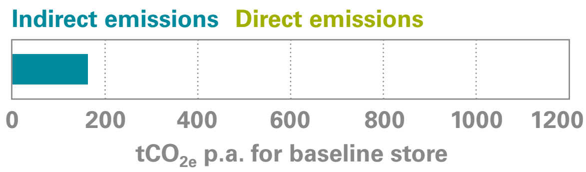
To float head pressure, the condenser fans are usually required to operate continuously instead of cycling on and off. This consumes more condenser fan energy but is more than compensated by the much larger decrease in compressor energy use. There are also other related benefits in reducing compressor operating pressure ratios in terms of reduced wear on compressor parts.

Reducing condensing pressure may have an effect on cabinet expansion valves. Thermostatic expansion valves (TEVs) operate less well at low-pressure differences and may need to be replaced with electronic expansion valves (EEVs). Alternatively liquid pressure amplification (LPA) could be considered to raise liquid line pressures.

See also cleaning and maintenance (page 12), liquid pressure amplification (page 20) and electronic expansion valves (page 38).

6. Store temperature

Store temperature has a major influence on the energy consumption of retail cabinets.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	L

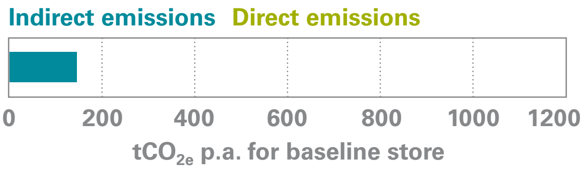
Store temperature is greatly influenced by air spillage from open-fronted cabinets and infiltration through doorways. In most cases this means that stores are too cold without additional heating in winter, and in summer are too hot without some form of mechanical cooling (although this is often from ambient air make up).

Considerable opportunities exist to reduce store temperatures in winter and raise them in summer. In winter this would have an added benefit for display cabinets, as they would require less energy to achieve the same level of temperature control, and therefore refrigeration pack energy would be less. This should save approximately 10% of the energy used by the baseline store. Conversely, in the summer it may increase the energy used by cabinets.

Store temperature reduction has been trialled by Tesco at its Cheetham Hill store. Altering the acceptable temperature levels from 19°C-21°C to 18°C-24°C has allowed the air conditioning system to operate using a natural ventilation mode for longer periods, with modelled energy savings of 28% on air conditioning energy.

7. Doors on cabinets

Adding doors to open-fronted cabinets can save 20%-50% of the refrigeration energy used by the cabinet.



Barriers to staff/customers	H
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

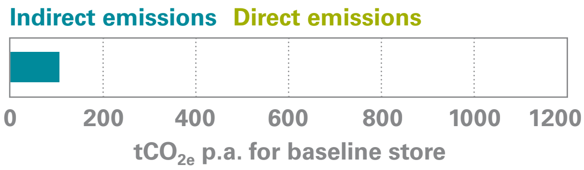
The installation of doors is a simple option to reduce infiltration into open-fronted chilled cabinets. Although in the past supermarkets believed that doors would have a negative impact on sales, this view is now changing and they are beginning to trial this technology. Controlled trials have shown that compared to the baseline store, energy savings of 12%-30% can be achieved, depending on the cabinet type and the efficiency of the cabinet prior to fitting doors. The levels of energy saving claimed vary considerably and must be related to the level of use of the cabinet. Cabinets with doors undergoing higher usage have been shown to save little energy when compared to an open-fronted cabinet, but generally the doors do show some benefits during periods of low store usage.

Most cabinet doors have highly insulated glass doors with low emissivity coatings. However, anti-sweat heaters are usually still required, and these add to the energy demand of the cabinet.

It should be noted that, by adding doors, cabinets are likely to require re-commissioning, and the chilled refrigeration pack will require resetting to ensure that the highest possible energy efficiency gains are achieved, and to avoid product freezing.

8. Store dehumidification

Dry store air can reduce the energy consumed by open cabinets through reducing the latent load on the refrigeration system.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

This will lead to less condensation and frost formation, reductions in defrost cycles, decreases in anti-sweat heater energy requirements and improvements in the temperature stability of products.

Store dehumidification has been trialled in the US. In one trial, lowering relative humidity from 55% to 35% was shown to reduce compressor power by 20% and defrost duration by 40%[2]. In another US study, a 5% reduction in humidity reduced the total store energy load (display cases, air conditioning and lighting) by 5% [3,4].

Store dehumidification has not been widely implemented in Europe. In the only published study in Europe it was shown that a flat optimum could be achieved when the relative humidity was at 45%[5]. Dehumidification is likely to produce the largest energy savings in stores with low ceilings as less energy is required for dehumidification.

[2] Evans, J.A., Russell, S.L., James, C. and Corry, J.E.L. (2004) Microbial contamination of food refrigeration equipment. Journal of Food Engineering 62, 225–232.

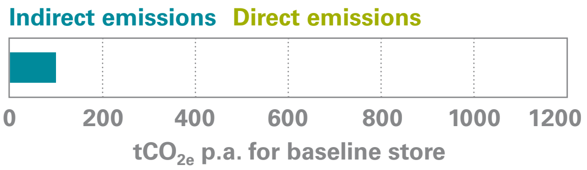
[3] Faramarzi, R.T., Sarhadian R. and Sweetser R.S. (2000). Assessment of Indoor Relative Humidity Variations on the Energy Use and Thermal Performance of Supermarkets' Refrigerated Display Cases. Energy efficiency in buildings, Aceee.

[4] Howell, R.H., Rosario, L, Riiska, D. and Bondoc, M. (1999). Potential savings in display cased energy with reduced supermarket relative humidity. 20th International Congress of Refrigeration, Sydney, Australia, IIR/IIF.

[5] Orphelin, M.M., D. and D'Alanzo, S.L. (1999). Are There Optimum Temperature and Humidity Set Points for Supermarkets? American Society of Heating, Refrigerating and Air-Conditioning Engineers, Chicago; IL.

9. LED lights

LED lights reduce heat loads on cabinets. They can also reduce the energy consumed by cabinet lighting by up to 66% when compared to conventional fluorescent lighting fixtures, and 40% when compared to T8 fluorescent lamps.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

LEDs have a number of benefits, such as longer shelf life (up to 50,000 hours versus 18,000 hours for fluorescent lamps in low temperature environments). They can also be switched on instantaneously and dimmed unlike traditional fluorescents. This makes them ideal to be used with lighting controls to switch off or dim cabinet lights during closing times or when no customers are present.

LEDs have the potential to save 6-7% of the energy used by the baseline store. A number of supermarkets are now trialling linear strip LED lighting fixtures for frozen food display cabinets. Although LEDs have shown energy savings, these sometimes have not been a true like for like comparison as lighting levels have been reduced after the LEDs were fitted.

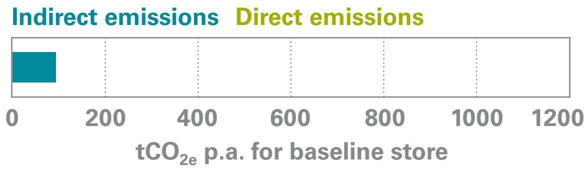
LED technology is continuing to develop and further efficiencies should be expected in the next few years.

See also cabinet lighting (non-LED) (page 18).

> One case study where LED and occupancy sensors were applied reported a saving of 2,659 kWh per year for a typical five-door cabinet. This gave a payback based on energy savings of 6.3 years. If maintenance savings were also factored in, the payback was reduced to 5.4 years[6].

10. Evaporator fan motors

Recent dc motor technology has produced fans that are 70%-75% efficient.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Fan energy can be a significant part of the energy used by cabinets, and fan use also presents a significant heat load that needs to be removed by the refrigeration system. Overall savings of approximately 6% can be achieved compared to the baseline supermarket.

Traditionally, evaporator fans had shaded pole motors that were 17%-30% efficient. Shaded pole motors can be replaced by either electronically commutated motors (ECM) or permanent-split-capacitor (PSC) motors, both of which offer a higher energy efficiency.

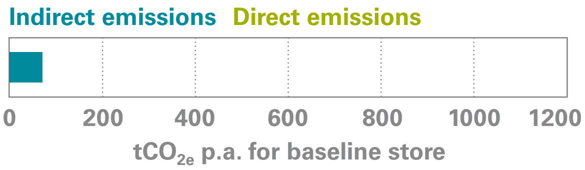
> ECM fans have been shown to produce 67% energy savings over conventional shaded pole motors[7].

[6] US DOE, 2009. Demonstration Assessment of Light-Emitting Diode (LED) Freezer Case Lighting. U.S. DOE Solid State Lighting Technology Demonstration GATEWAY Program.

[7] Karas, A., Zabrowski, C. and Fisher, D., (2006). GE ECM Evaporator Fan Motor Energy Monitoring, FSTC Report 5011.05.13, Fisher-Nickel Inc., California http//:www.fishnick.com/publications/appliancereports/refrigeration/GE_ECM_revised.pdf.

11. Suction pressure control

In supermarket trials, suction pressure control has shown a 10%-30% saving on refrigeration pack energy.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	L

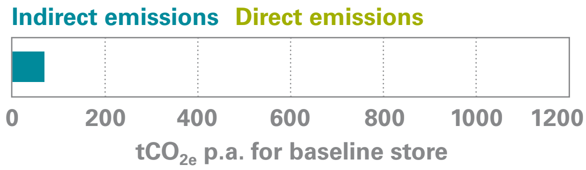
Suction pressure control (sometimes referred to as floating suction pressure control) adjusts the refrigeration pack suction pressure to the maximum necessary to maintain the cabinets at the correct temperature.

The system controls the operation of the refrigeration system compressors by monitoring the performance of the cabinets. Although systems vary in their control methodology, they generally identify the worst temperature performing cabinet connected to a refrigeration pack, and then adjust the suction pressure accordingly.

Although not widely applied in supermarkets, suction pressure controls have short payback periods of less than eight months and are relatively simple to apply. They have the potential to save approximately 6% of the baseline store energy.

12. Occupancy sensors and controls – cabinet lighting

Occupancy sensors and controls have the ability to sense customer movement and to switch cabinet lighting on or off. Depending on the level of supermarket usage, this technology could save up to 40% on the energy used for lighting.



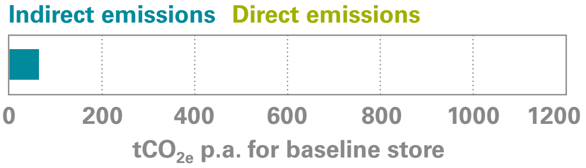
Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	H
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

During certain periods of the day, supermarkets experience a low number of customers. During these periods cabinet lighting could be switched off. If this was exploited to its maximum effect, approximately 5% of the energy of the baseline supermarket could be saved.

Although supermarkets do not currently utilise occupancy sensors, there is considerable potential in stores with a variable trading profile to implement this technology. It is readily available and could be transferred from other areas of the cold chain (e.g. cold storage) where it is currently used. Lighting occupancy sensors are particularly compatible with LEDs as they can be rapidly switched on and off, unlike more conventional fluorescent lighting.

13. Strip curtains

Strip curtains reduce the infiltration of ambient air into open-fronted cabinets, and can save up to 30% of the energy used by the cabinet.



Barriers to staff/customers	H
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	M
Maintainability	M
Legislative issues	L

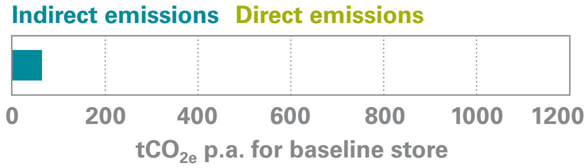
Strip curtains consist of transparent, flexible strips that cover the front of open-fronted cabinets. Like doors, curtains are perceived to create a barrier between the food and the customer. They also tend to slightly reduce visibility of the food and require a level of maintenance to keep them clean and tidy.

For this reason, curtains have not been widely used in larger supermarkets. However, they are a simple and effective means to reduce infiltration, can be fitted more rapidly than doors and have a shorter payback period. Strip curtains are only practically applicable to meat and dairy multi-deck cabinets and therefore they could save approximately 5% of the energy used in the baseline supermarket.

See also doors on cabinets (page 14) and night blinds (page 18).

14. Condenser fans

Using dc motor technology, energy consumed by condenser fans can be reduced.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Condenser fans can benefit from the same dc motor technology developments as evaporator fans. They can also be operated at variable speeds to increase chiller coefficient of performance (COP) in certain operating conditions.

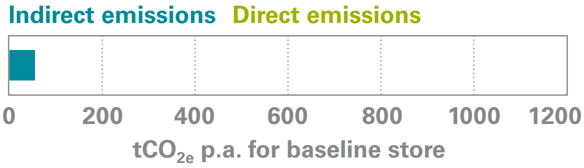
To achieve maximum COPs the condensing temperature set point can be adjusted based on the chiller load together with the outdoor temperature, rather than on the outdoor temperature alone. This then enables the condenser fans to be operated at the right speed to minimise the sum of compressor electric input and fan electric input. Depending on the operating conditions, savings of up to 5% could be made on the energy consumed by the baseline supermarket.

> Research has shown that, depending on the operating conditions, the COP could increase by 4.0%-127.5% and the chiller electric demand could drop by 3.8%-52.8% when variable speed condenser fans were fitted[8].

[8] Yu, F.W. and K.T. Chan (2006). "Advanced control of heat rejection airflow for improving the coefficient of performance of air-cooled chillers." Applied Thermal Engineering 26(1): 97-110.

15. Cabinet lighting (non-LED)

More efficient lighting could reduce energy use by up to 35% when compared to standard fluorescents.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Although lighting levels in cabinets have been reduced in recent years, there is still potential to install more efficient lighting systems. Internal loads from lighting can be reduced through the use of more efficient lighting fixtures and electronic ballasts, for example, T5 instead of T8, T10 or T12 fluorescent tubes.

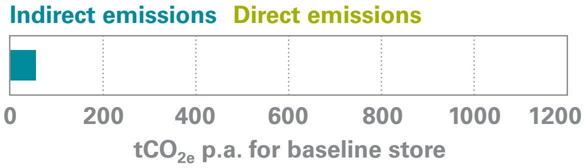
There are also opportunities to reduce the level of lighting within a cabinet without reducing visual display, through more intelligent fitment of appropriate lighting. Cabinet lights outside of the refrigerated area will reduce cooling load and often the lights will function better (and be brighter).

The use of high-efficiency non-LED lights is a good short-term alternative to LEDs, and provides a slightly lower efficiency, but shorter payback alternative, to LEDs. Energy savings of 4-5% could be achieved in the baseline store if more efficient lights were fitted to all cabinets.

See also LED lights (page 15).

16. Night blinds

Well-fitting night blinds can reduce the energy used in open-fronted cabinets by up to 35%.



Barriers to staff/customers	M
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	L
Maintainability	M
Legislative issues	L

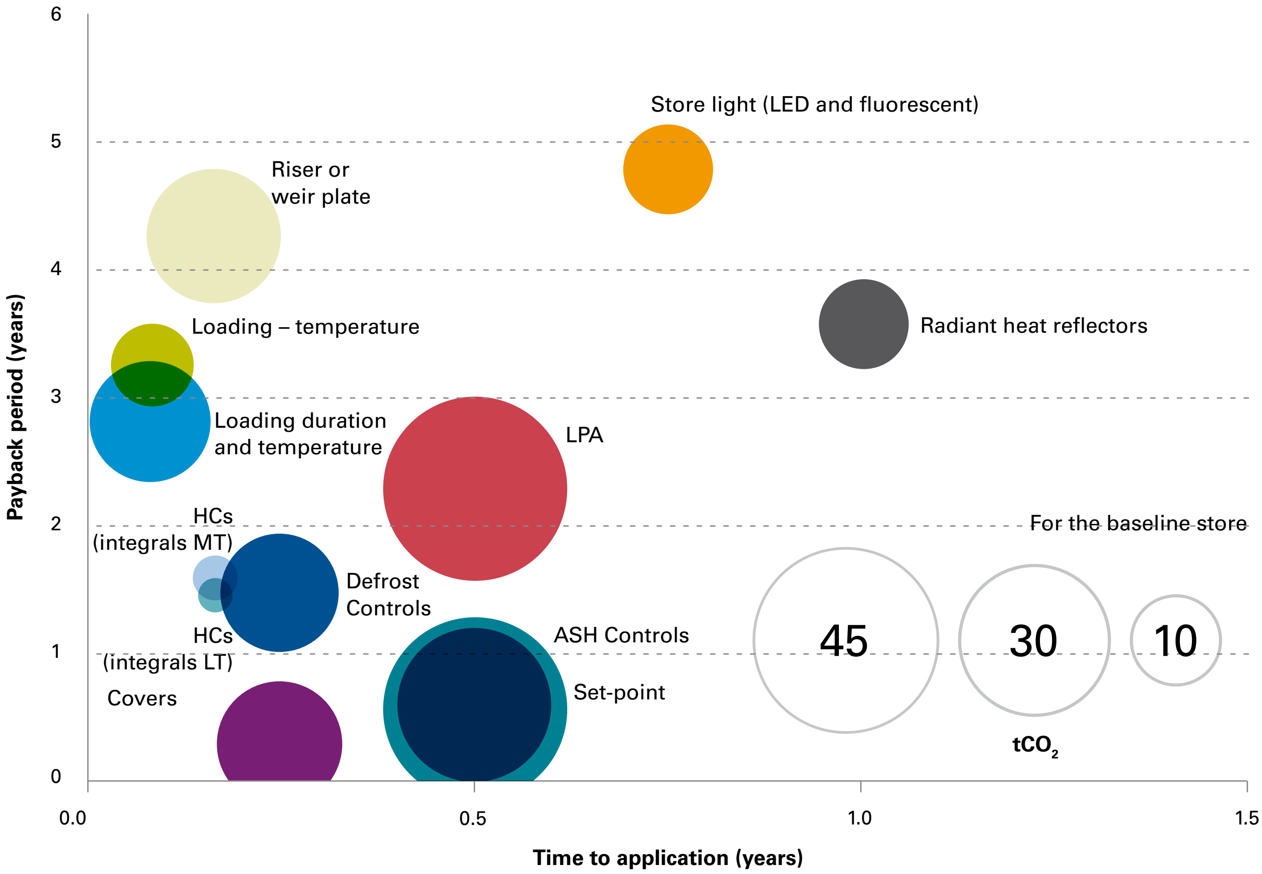
Night blinds can only be applied on cabinets where the store is closed for a part of the day, and so are not appropriate for all supermarkets. The level of energy savings achieved is a function of the ambient temperature, the quality of the blind and its fitting on the cabinet, and the on-off operational cycle of the blind. Overall savings of around 4% could be achieved if blinds were well fitted and used in the baseline supermarket.

It is essential that night blinds are well fitted. Poorly fitted blinds can reduce the energy savings that could be achieved by up to 50% and also lead to raised temperatures of food within the cabinet.

Night blinds are not always popular with larger stores as they are considered to interfere with cabinet loading during the night. However, it is possible to purchase versions that automatically operate at set times, thereby reducing the need for staff to operate the blinds.

See also strip curtains (page 17), covers (page 21) and doors on cabinets (page 14).

Figure 3 Technologies that can be retrofitted with potential to save <50tCO_{2e} pa

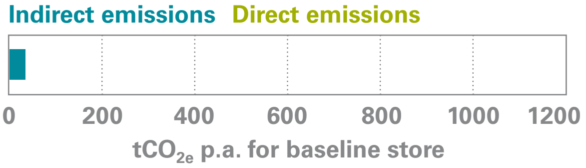


Retrofit options saving less than 50tCO_{2e} per annum

Figure 3 shows options that can save less than 50tCO_{2e} per annum. The technologies that can be retrofitted to achieve this reduction are described below in order of their CO_{2e} saving potential per annum for the baseline store.

17. Set-point

Energy benefits can be achieved through checking set-point temperatures to ensure that individual cabinet temperatures are set at the correct level.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	M
Maintainability	L
Legislative issues	M

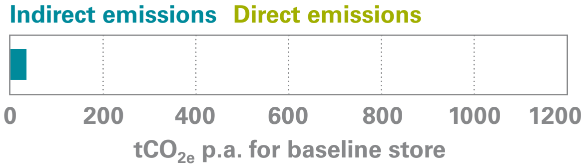
Temperatures in cabinets are specified by food safety regulations, standards, and by supermarkets' own specifications. However, differences between the recommended temperature and the real working temperatures can sometimes be observed. This can be due to variations in position of the control temperature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

Re-commissioning cabinets can generate energy savings in the region of 3% in the baseline supermarket. Increasing the set-point temperature of a cabinet can further reduce energy used by cabinets. Reducing the set-point by 1°C will typically achieve savings of between 3%-5%. However, care needs to be taken to ensure that food temperatures are not adversely affected. Examples to date have shown that if air temperatures within a display cabinet are allowed to vary, but average temperature of food is maintained at a set level, that energy consumption can be reduced but food quality loss is slightly higher[9].

See also re-commissioning (page 12).

18. Liquid pressure amplification

LPA is not yet implemented extensively in supermarkets but has been reported to achieve energy savings of 20% in other applications.

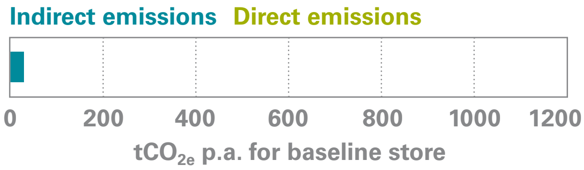


Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

LPA is best applied in situations where head pressures are allowed to fluctuate. Levels of savings may be less in supermarkets than in other food cold chain applications (in the region of 3% of the energy used by the baseline supermarket), and payback times are therefore relatively long.

19. Anti-sweat heater controls

Anti-sweat heater (ASHs) controls can save 7% of the total energy consumption of freezer cabinets.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

ASHs heat glass doors on cabinets to prevent condensation. ASH controls save energy by reducing the amount of time the trim heaters run, and by also reducing the heat added to the cabinet from the heaters that the refrigeration system then needs to extract.

[9] Cai, J., Jensen, J.B (2008). On the trade-off between energy consumption and food quality loss in supermarket refrigeration systems. 2008 American Control Conference, Vols 1-12. New York, Ieee: 2880-2885.

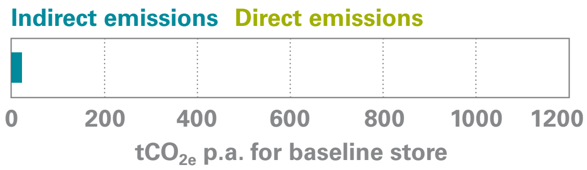
Compared to the baseline supermarket energy, savings of approximately 2% can be achieved by utilising ASHs on glass door cabinets.

ASH control is quite common in supermarkets. ASH controls can operate in several formats. They can reduce or turn off anti-sweat heaters based on the amount of condensation formed on the door of a glass door cabinet. Alternatively, they can sense the relative humidity in the air outside of the display case and reduce or turn off the glass door and frame anti-sweat heaters in response to the level of humidity in the supermarket. Standard glass doors on low-temperature reach-in display cases can be replaced with special glass doors that require minimum to no ASH. Doors are also available that prevent condensation from occurring within the frame assembly.

See also doors on cabinets (page 14).

20. Risers or weir plates

Risers or weir plates have variable energy benefits, but can reduce heat extraction rates by up to 7%.



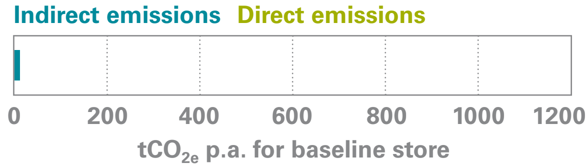
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	L

Risers or weir plates consist of a strip of material, usually transparent Perspex, that is added to the front of the well in open-fronted multi-deck cabinets. The aim of the riser is to reduce infiltration by reducing the length of the cabinet air curtain. This can often have a positive effect on temperatures within the cabinets, as air is allowed to collect in the well area to help maintain temperature of food in the well, which is often at the warmest temperature in the cabinet. Compared to the baseline supermarket, risers can save 1%-2% of the energy consumed.

See also air curtain optimisation (page 31).

21. Covers

Covers can reduce energy consumption and lower food temperatures in cabinets.



Barriers to staff/customers	H
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	L
Maintainability	M
Legislative issues	L

Covers for chilled and frozen cabinets can consist of either solid covers used during non-trading periods, or transparent covers ('bubble lids') that remain in place during trading and non-trading periods. Solid covers require some level of staff interaction to fit and remove the covers. Bubble lids generally consist of a rigid transparent material that fits across the display window of a horizontal cabinet and incorporates holes for access to food. In all cases the cover reduces cabinet heat loads.

Night covers reduce the air temperature inside cabinets by 5-6°C and generate more homogeneous food temperatures compared to cabinets without night covers. In addition, the cooling load and difference between the return and supply air were markedly lower. The percentage of latent heat to the total heat transfer was also decreased from 54% to 44%. Due to the limited opportunities to apply covers, their energy saving across the baseline supermarket is limited to approximately 1%.

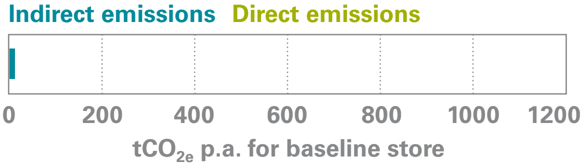
> Field measurements illustrated that night covering of display cases and deep-freeze display cases reduced the energy consumption of the cabinets by 10-20%.

Both solid and bubble lids can be simply retrofitted to open topped cabinets and provide a relatively inexpensive and simple means to reduce energy.

See also night blinds (page 18) and strip curtains (page 17).

22. Correct cabinet loading volume

Overloading display cabinets decreases product quality and increases energy use by as much as 10%-20%.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	M
Maintainability	L
Legislative issues	L

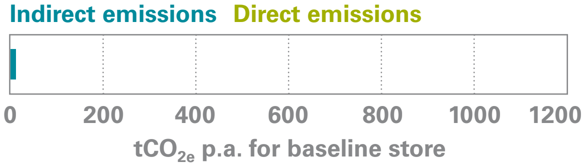
Cabinet loading has a major impact on air infiltration into open-fronted cabinets. In supermarkets, shelves are often overfilled or partially filled. This allows more air to be infiltrated into cabinets. Therefore, fully loading shelves is likely to improve the efficiency of cabinets, and any means to ensure that shelves remain fully stacked should lead to energy efficiency benefits.

Improved loading of cabinets is a relatively simple energy saving option that requires training of supermarket staff. Energy savings of approximately 1% could be achieved in the baseline supermarket by applying better loading procedures.

See also loading – duration and temperature (this page, right) and training (page 11).

23. Loading – duration and temperature

Reduced loading times will minimise infiltration and reduce heat gain to food, saving energy.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	L
Technology interdependence	M
Maintainability	L
Legislative issues	L

The time taken to load food into cabinets with doors affects the amount of air infiltrated into the cabinet, and the heat gained by food whilst at ambient temperatures. Extended door openings can also increase the number of defrosts as well as the use of cabinet heaters to prevent condensation build up on doors.

Loading times can be minimised through pre-merchandising of food so that larger quantities of food can be placed into the cabinet quickly. Staff training can also help to minimise the time spent loading cabinets.

The temperature at which the foodstuff is loaded into cabinets influences the performance and energy consumption of the equipment. Thermal gains can be minimised during loading by reducing loading time and by transferring food from storage to the cabinet in insulated containers.

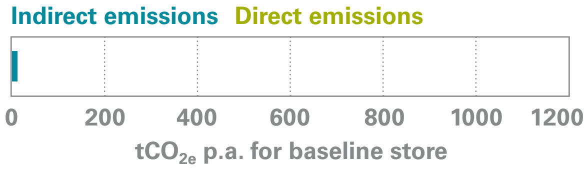
Eliminating temperature gains during loading could reduce energy in the baseline supermarket by approximately 1%.

Most food in supermarkets is pre-cooled prior to loading, but there are examples where items such as drinks are loaded from ambient temperature. In these instances, the drinks could be cooled more efficiently in a cold room or similar, prior to loading in the display cabinet.

See also training (page 11).

24. Defrost controls

Minimising the number of defrosts saves energy.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Defrost controls minimise the number of defrosts needed by a cabinet. This has the effect of reducing direct energy consumption, and also leads to reduced heat gain in the cabinet. Defrost controls are generally applied to frozen food cabinets where electric defrosts are required to melt ice that has built up on the evaporator. Most chilled cabinets operate on passive or 'off-cycle' defrosts, and therefore this technology is only appropriate for frozen food cabinets. Overall savings of around 1% on the baseline supermarket could be achieved by implementing defrost controls.

Defrosting the evaporator only when necessary can save considerable amounts of energy. Most conventional defrosts are scheduled at pre-set times (every six to 12 hours is typical) and this can result in unnecessary defrosts, excess energy use and increase in product temperatures. During a defrost the 'useful' energy is used to melt the ice on the evaporator but as the ice built up on an evaporator is rarely evenly distributed, a great deal of energy is used to heat the evaporator block. This excess heat then needs to be removed once the refrigeration system begins operating, and has been found to account for around 85% of the energy used in the defrost[10].

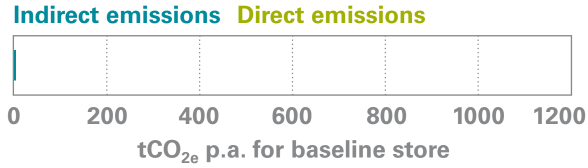
> A defrost on-demand system has been trialled by JTL Systems and has achieved savings of 9% on frozen cabinets in a real store evaluation.

A defrost on demand system is an additional part of a supermarket controls system and therefore is relatively simple to install and operate.

[10] Lawrence, M and Evans J.A. (2008). Reducing the number of defrosts safely. International Journal of Refrigeration 31, 107-112.

25. Store light (LED and fluorescent)

Store lighting is a source of radiant heat gain by cabinets.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

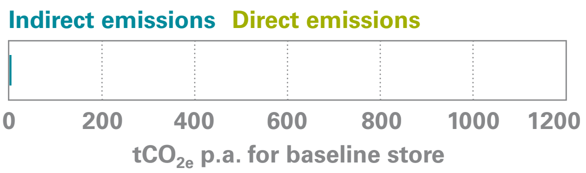
Lighting plays an extremely important role in food display in supermarkets. Some of the energy used in lighting finds its way into the display cabinets, which increases the refrigeration system load and energy consumption.

The majority of lighting fixtures in stores use fluorescent lighting. A number of technologies exist to minimise radiant heat gains from lights. These include the use of low radiant heat output lights such as LEDs and dual level switching to allow lights to be turned off during low traffic hours. Savings on the baseline supermarket of up to 1% could be achieved by reducing radiant heat gains to cabinets from lighting.

See also LED lights (page 15), cabinet lighting (non-LED) (page 18) and radiant heat reflectors (page 24).

26. Radiant heat reflectors

Radiant heat reflectors can reduce radiant heat gains in open-top freezer cabinets by approximately 25%.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	H
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

Radiant heat load is most significant in frozen retail cabinets (see *Table 2*, page 7). Methods to reduce the radiant load, using reflective canopies, have been shown to be successful, but are rarely implemented in supermarkets.

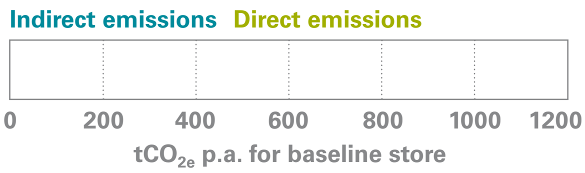
Trials have shown that reflecting night blinds and reflecting ceilings and canopies lowered temperatures and temperature gradients within cabinets. Using reflective mirrors above frozen well cabinets showed that product temperatures could be reduced by 5°C. [11]

As well as reducing radiant heat gains, radiant heat reflectors may allow evaporating temperatures to be increased with associated additional energy benefits. Savings compared to the baseline supermarket of around 1% could be achieved if radiant reflectors were used for frozen cabinets.

See also store light (natural) (page 47).

27. Hydrocarbons (chilled integrals)

A number of trials have demonstrated energy savings of 10%-15% when using R290 (propane) in integral cabinets.



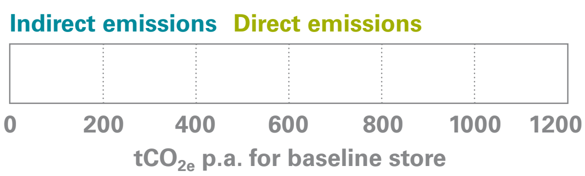
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	M

Hydrocarbon (HC) refrigerants are beginning to be widely applied to integral (stand-alone) cabinets. The advantage of HC cabinets lies primarily in their reduced energy consumption, as leakage from integral cabinets is low and therefore there is little advantage in the application of a low GWP refrigerant. Although the energy saving potential of integral HC cabinets alone is relatively large, the usage of integral cabinets in the majority of supermarkets is currently low. Therefore, the overall energy saving that can be achieved over the whole supermarket is relatively small.

See also hydrocarbons (frozen integrals) below).

28. Hydrocarbons (frozen integrals)

See also hydrocarbons (chilled integrals) (above).



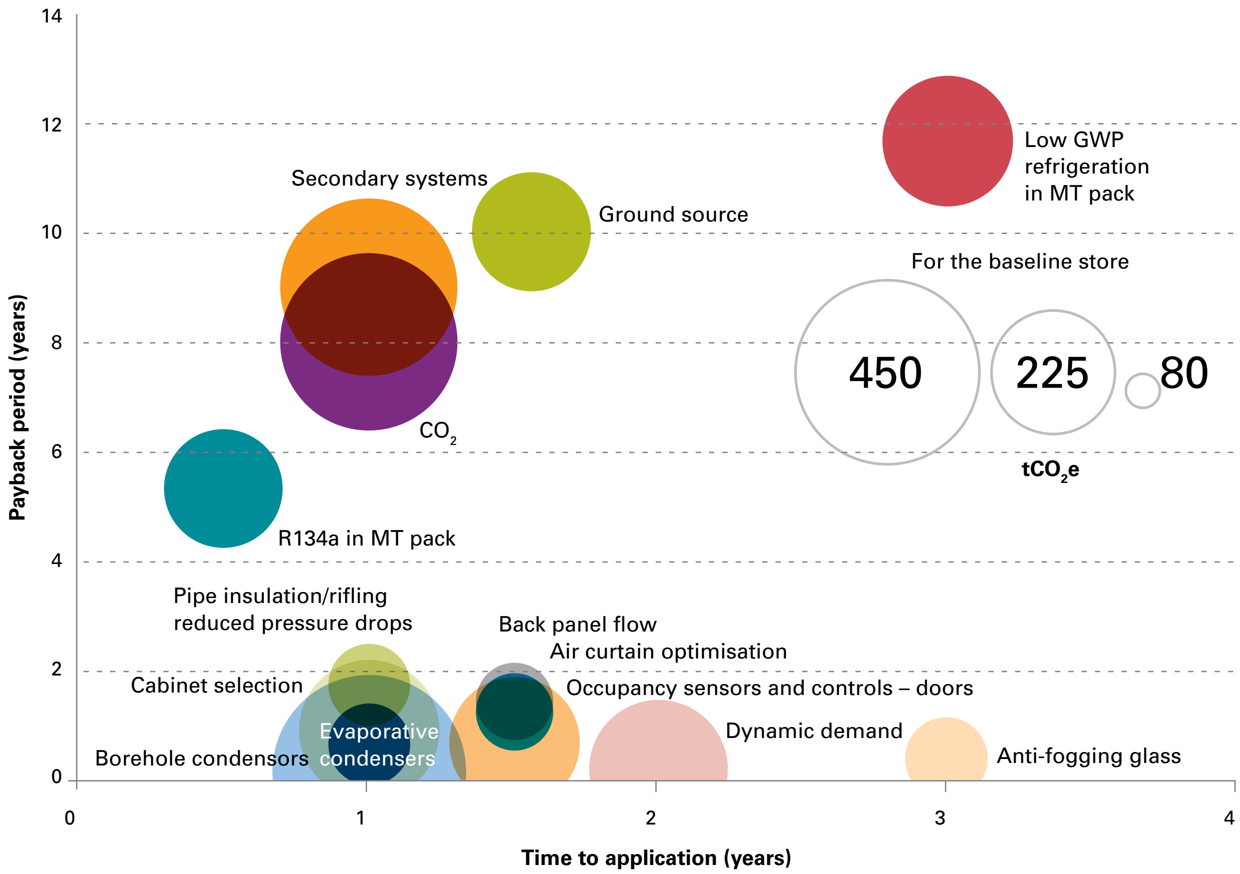
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	M

[11] Hawkins, A.E., Pearson, C.A. and Raynor, D. (1973). Advantages of Low Emissivity Materials to Products in Commercial Refrigerated Open Display Cabinets. Proc Inst of Refrig.

CO_{2e} saving options that can be implemented during a store refit

Store refit options have been divided into those that save less than, and more than, 50tCO_{2e} per annum.

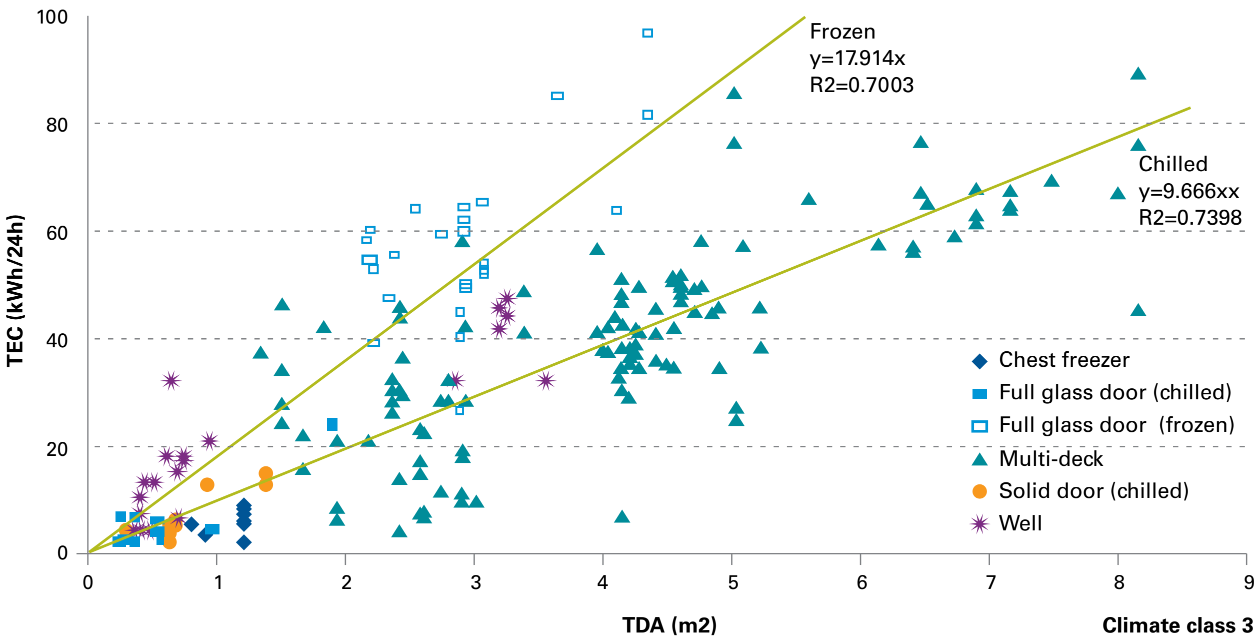
Figure 4 *Technologies that are available during a store refit with potential to save >50 t CO_{2e} pa*



Store refit options saving more than 50tCO_{2e} per annum

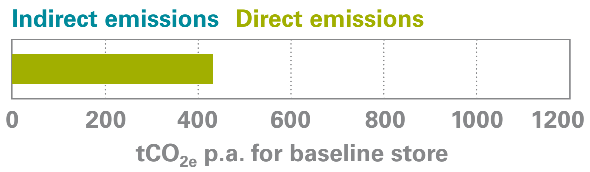
Figure 4 shows options that can save more than 50tCO_{2e} per annum for the baseline supermarket. The following sections describe these technologies in more detail.

Figure 5 *Relationship between TDA (total display area) and TEC (total energy consumption) for all chilled and frozen cabinets*



1. Cabinet selection

Selecting the best performing cabinet can save substantial amounts of energy.



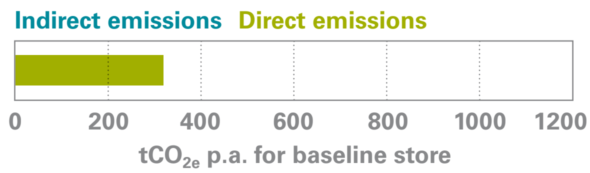
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	M

There are large differences between the energy efficiency of different cabinet types. Careful selection of cabinets can enable substantial energy savings to be made[12], and further savings could be made if the function of the cabinet is also considered. For example, a chest freezer with a glass lid is substantially more efficient than a full glass door (FGD), or well cabinet *(Figure 5)*. By applying best technology cabinets and assuming they are connected to an efficient refrigeration system, energy savings of 30% could be achieved in the baseline supermarket.

Schemes such as Eurovent and the UK Enhanced Capital Allowance (ECA) scheme compare performance data from cabinets under standard test conditions (currently EN23953) and can help in selecting the most efficient cabinet.

2. CO_2 refrigeration technology

CO_2 refrigeration technology has considerable potential to reduce direct CO_2 emissions as the GWP of CO_2 is equal to 1.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	M

CO_2 (R744) systems are beginning to be installed more widely. Significantly reduced total equivalent warming

[12] Evans J.A. and Swain M.V.L. (2010). Performance of retail and commercial refrigeration systems. IIR, ICCC, Cambridge 29-31 March.

impact (TEWI) values are achievable when the leakage from a conventional R404A system is greater than 2.65% per annum[13].

CO_2 systems can be applied in sub or trans-critical modes. The majority of CO_2 systems have been applied in sub-critical mode where the refrigerant is in a 'cascade' arrangement with ammonia, HCs or hydrofluorocarbons (HFCs). This enables the primary circuit to be contained in a plant room. If a high GWP refrigerant is used in the primary circuit it is generally part of a factory assembled chiller that tends to have less leakage than an on-site built system.

The use of CO_2 transcritical systems negates the need for another refrigerant, for both the low and medium-temperature refrigeration requirements in the store. This can simplify system installation, but the very high pressures involved in the system impose specific design, control and safety challenges.

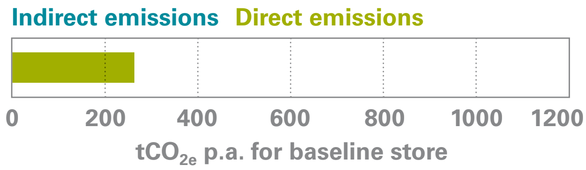
The performance of CO_2 refrigeration systems strongly depends on the system configuration and location. Variable levels of energy saving have been reported. The efficiency of transcritical systems is especially dependent on the system operating in sub-critical mode for part of the year and therefore trans-critical systems tend to be more efficient in colder climates. Potential energy savings can be made if heat is recovered as part of a trans-critical cycle and used for heating or desiccant cooling. However, heating is generally required in the winter when the heat recovery options are limited.

To date, the capital cost of CO_2 systems has been higher than the capital cost of R404A systems, due to the higher cost of the major components (often because the systems were prototype developments). As such, the cost of the systems is likely to reduce through wider application and the mass production of components.

See also desuperheating/heat recovery (page 41).

3. Secondary systems

Secondary systems use a contained primary refrigeration system (usually in a plant room), that is used to cool a pumped secondary fluid. These secondary fluids are generally brines or glycol-based fluids, but can be CO_2 or ice slurries.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	M
Legislative issues	M

Secondary systems have refrigerant emissions of 2%-4% of charge per year[14], due to reduced refrigerant piping lengths and number of connecting joints[15]. Although fluorocarbon-based refrigerants can be used as the primary refrigerant, the use of flammable and/or toxic refrigerants can be considered due to the plant being located in a controlled access room away from the customer sales area.

Energy usage of secondary systems is mixed and depends very much on the design of the system. Careful design is needed to minimise energy consumption, and secondary systems are generally more expensive than conventional direct expansion refrigeration plant.

[13] Rhiemeier, J-M, Harnisch, J, Ters, C, Prof. Kauffeld, M, and Leisewitz. A. (2009). Comparative Assessment of the Climate Relevance of Supermarket Refrigeration Systems and Equipment. Environmental Research of the Federal Ministry of the Environment, Nature Conservation and Nuclear Safety Research Report 206 44 300 UBA-FB 001180/e.

[14] Little A.D., Inc. (2002), Global Comparative Analysis of HFC and Alternative Technologies for Refrigeration, Air Conditioning, Foam, Solvent, Aerosol Propellant, and Fire Protection Applications, report for the Alliance for Responsible Atmospheric Policy, Washington, D.C., 21 March.

[15] Bivens, D and Gage, C. (2004). Commercial Refrigeration Systems Emissions. Paper presented at the 15th Annual Earth Technology Forum, Washington, DC. 13-15 April.

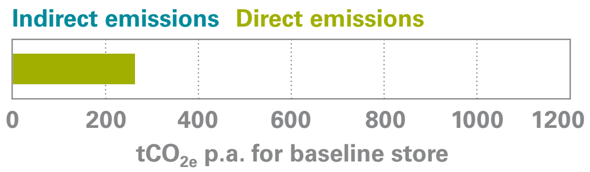
Reported data from 77 supermarket secondary loop systems showed that installed costs were 15-35% higher than direct expansion systems, and energy consumption was 5%-20% higher[16].

Other studies have shown that in some instances refrigeration system energy consumption can be reduced by using a secondary system. In one example at Loblaws supermarket in Canada, a secondary system was expected to produce energy savings of 18% in refrigeration and heating, and a 73% reduction in CO_2e emissions.[17] Another US study showed 4.9% savings in real life usage[18].

Another study in a Fakta store in Beder, Denmark, resulted in energy consumption of a propane/ CO_2 and propylene glycol secondary system being similar to eight other Fakta supermarkets operating on conventional R404A systems[19].

4. Borehole condensing

The use of boreholes for cooling condensers can save at least 30% of the energy used by the refrigeration system.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	H
Technology interdependence	L
Maintainability	M
Legislative issues	M

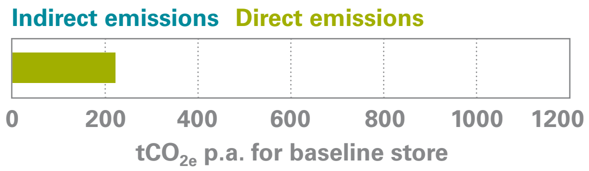
Ground coupled cooling systems can be either open loop or closed loop systems. In open loop systems, water within the ground (from a borehole) is used directly to provide cooling. In closed loop systems, heat exchangers are constructed within the ground to extract the cold energy (see ground source, page 30).

Open loop systems can require less energy input compared to traditional refrigeration systems, as the water temperature in the condenser is normally lower than an air cooled condenser system. However, the cost to install the system is high compared to installing an air cooled condenser. Typically, this type of system would increase COP by around 50% at full load conditions, however, the saving at part load conditions would be less. Estimated overall energy savings for the baseline supermarket are 15-20%.

The use of borehole water for reducing condensing temperature has been used in a small number of applications where borehole water is easily accessible. The viability of open loop systems will depend on the availability and access to the aquifer. A ready reckoner identifying the availability of ground water is detailed in CIBSE technical memorandum TM45[20]. Responsibility for the management of groundwater resources lies with the Environment Agency and any groundwater scheme needs to comply with its rules.

5. Dynamic demand

Dynamic demand balances loads on the grid to enable more efficient electricity generation.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	H
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	M

A cabinet fitted with dynamic demand reduces its electricity demand in response to changes in the system frequency (i.e. power imbalances on the grid). This allows retail cabinets to play a role in overall system balancing.

[16] Haaf, S. and Heinabokel, B. (2002). Alternative Refrigerants for Supermarket Refrigeration Installations, DKV-Tagungsbericht (Proceedings), Volume 2, Issue Pt. 2, pp 29-42, 2002.

[17] Pajani, G., Giguère, D., Hosatte, S. (2004). Energy efficiency in supermarkets – secondary loop refrigeration pilot project in the Repentigny Loblaws, CANMET Energy Technology Centre – Varennes, Natural Resources Canada, Report Ref. CETC-Varennes 2004- (PROMO) 170-LOBLA2, 5 pgs.

[18] Faramarzi, R. T. and Walker, D.H. (2004). Investigation of Secondary Loop Supermarket Refrigeration Systems. PIER. California, US: 76.

[19] Christensen , G. K. and Bertilsen, P. (2004). Refrigeration systems in supermarkets with propane and CO_2 – energy consumption and economy, www.aiarh.org.au/downloads/2004-02-02.pdf.

[20] CIBSE, TM45: Ground water cooling systems, Published January 2008.

Provided sufficient appliances apply dynamic demand, electricity generated by the grid can be balanced and generated more efficiently.

The CO_{2e} savings provided by dynamic demand come from more efficient electrical grid generation and are not likely to reduce actual energy consumed by the supermarket. However, the technology may reduce energy costs, as energy purchased outside of peak energy demand periods is on a cheaper tariff.

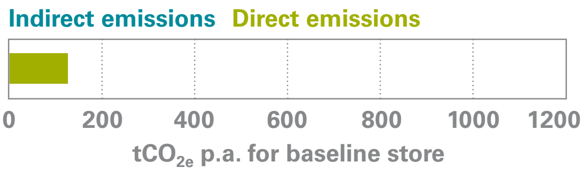
To date, the use of dynamic demand has been mainly targeted at domestic refrigeration. The technology is currently not used in supermarkets and it is expected to take several years before it becomes commercially available.

The Centre for Sustainable Electricity and Distributed Generation (SEDG) carried out a study to model the carbon saving potential for domestic refrigerators. The results indicated that a single refrigerator incorporating dynamic demand could potentially abate between 17kg and 44kg of carbon dioxide per annum, dependent upon the precise mix of coal, gas, nuclear and wind used to generate the energy.

The use of dynamic demand may potentially affect temperature control in supermarket cabinets, and therefore technologies such as phase change materials (PCMs) may be required to stabilise temperature during the dynamic demand period.

6. Occupancy sensors and controls – doors

Novel occupancy sensors may enable supermarkets to install automatic doors on cabinets, that allow customers easy access to food.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	H
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

The application of doors to open-fronted cabinets is perceived to create a barrier between customers and the food. This barrier can be removed through the use of proximity sensors that open doors when customers are close to the cabinet. Proximity sensing technology is relatively well developed, but little used in supermarkets.

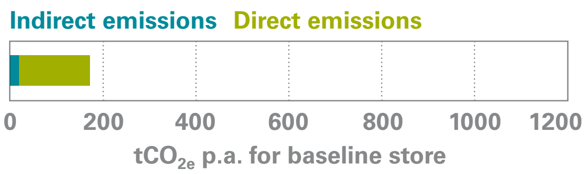
One cabinet manufacture (ISA) has developed a cabinet with short retractable blinds that cover each shelf. These roll up when customers are close to the cabinet.

The potential benefits of using proximity sensors are dependent on the cabinet use. The benefits should be similar or should outweigh the use of doors on open-fronted cabinets, as it is not necessary to fully open all the cabinet if shorter retractable blinds are applied. Energy savings of 15% could be achieved in the baseline supermarket if proximity sensors were applied to open-fronted cabinets.

See also doors on cabinets (page 14).

7. Low-GWP refrigerant in the medium temperature pack

Low GWP refrigerants are being developed. These can reduce direct emissions from supermarkets.



Barriers to staff/customers	L
Availability barriers	H
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	L
Maintainability	M
Legislative issues	M

A number of low-GWP refrigerants are currently under development or are near commercialisation. The hydro-fluoro-olefin (HFO) most likely to be commercially available in the short term is HFO-1234yf. HFO-1234yf is a low-GWP refrigerant that is planned to be widely used in automotive air conditioning. HFO-1234yf has a GWP of four and can therefore potentially reduce direct emissions from a refrigeration system if used instead of a higher GWP refrigerant such as R404A.

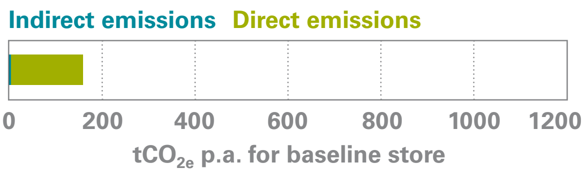
HFO-1234yf is a direct replacement for R-134a and only suitable for medium temperature systems. It is mildly flammable (classified as A2) and, for this reason, supermarkets may be reluctant to use it in a centralised system.

HFO-1234yf has not yet been widely tested in practical use, and therefore there is limited knowledge of its potential to break down if applied to systems that are not entirely clean. Although the potential CO_{2e} savings from the application of HFO-1234yf are relatively large, there is still a lack of detailed knowledge on the use of the refrigerant and therefore results from trials are required before it is likely to be applied in supermarkets.

See also R134a used in medium temperature (chilled) refrigeration pack (below).

8. R134a used in medium temperature (chilled) refrigeration pack

R134a has a lower GWP than R404A (1,300 versus 3,780). Therefore, by replacing R404A with R134a the level of direct emissions from refrigeration plant can be reduced by one third.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	M

R134a is a lower GWP refrigerant than R404A and operates at a lower pressure. Refrigerant emissions from a R134a refrigerant plant will therefore be less than from a R404A plant.

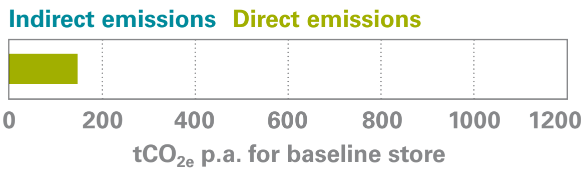
R134a has been proposed as the high stage of an R134a/CO_2 cascade and compressors have been specifically developed for this purpose. The reduction in direct emissions is the primary reason for using R134a and the technology has been retrofitted into supermarkets in Germany, Austria and Switzerland where TEWI reductions of 20% are predicted by models.

R134a is an HFC. The legislation associated with refrigerants is continually evolving and, as a result, the use of R134a should be reviewed for any changes in legislation.

See also low GWP refrigerant in the medium temperature pack (page 29).

9. Ground source

The ground can provide a valuable free resource for heat rejection.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	H
Technology interdependence	L
Maintainability	M
Legislative issues	M

The ground offers an excellent resource for cooling. From a depth of 4m to 200m, the ground temperature is relatively constant in the UK, at around 12°C. Therefore, the ground can be used as a heat sink for refrigeration system condensers.

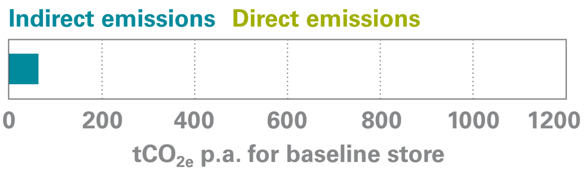
Ground cooling can be a good alternative to borehole cooling in instances where an aquifer is unproductive in terms of groundwater production, where the water quality may be unsuitable for cooling, or the extraction costs may be too high. A closed loop system can be used in the ground to produce lower condensing temperatures and this will have a direct impact on system COP. The improvement in COP depends upon size of the closed loop heat exchanger, which can be relatively expensive to install. A saving of around 5-10% should be achievable in the baseline supermarket.

Closed loop heat exchanger systems can be installed either vertically or horizontally. Vertical loops are more expensive to install, whereas horizontal loops require a large footprint for installation. Many supermarkets have large car park areas, which could potentially be used for horizontal loop heat exchangers.

See also borehole condensing (page 28).

10. Pipe insulation/rifling/reduced pressure drops

Supermarket refrigeration systems have long pipe runs and any improvements made to these systems can have a significant effect on energy efficiency.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

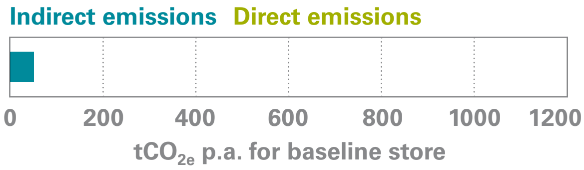
Pressure drops in refrigeration pipework should be avoided as they can have a substantial effect on COP. In general, pressure drop in the compressor suction line has a greater effect on COP than the same pressure drop in the compressor discharge line. For example, at low temperatures a 2K drop in the suction temperature would reduce the COP by approximately 7%, whereas a 2K temperature drop in the discharge line would reduce the COP by approximately 4%.

Pipework insulation is also important to reduce heat loads on the refrigeration plant, particularly in the suction line to the compressor. Energy benefits will be dependant on the length of the suction line but should be in the region of 5% in the baseline supermarket.

Pipe rifling is relatively common in cabinet evaporators and is claimed to maximise heat transfer and reduce energy consumption.

11. Anti-fogging glass

Novel surface coatings are now becoming available that can prevent condensation on glass doors in cabinets.



Barriers to staff/customers	L
Availability barriers	H
Limits to commercial maturity	H
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

When doors on cabinets are opened, the inner surface of the glass is usually below the dew point of the ambient air and this causes condensation on the glass surface. New coatings eliminate or reduce the need for heating of glazing surfaces to prevent or remove condensation.

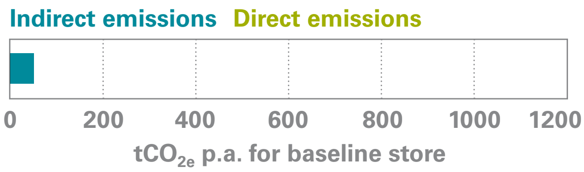
These surface coatings consist of a three-dimensional matrix of negatively-charged, 'water-loving' polymer chains, intermingled with a mixture of glass nanoparticles and tiny air bubbles. The coatings strongly attract the water droplets and force them to form much smaller contact angles with the surface. As a result, the droplets flatten and merge into a uniform, transparent sheet rather than forming countless individual light-scattering spheres.

A number of research teams have been developing this technology and application times are expected to be short. Energy savings of around 5% can be expected in the baseline supermarket.

See also ASH controls (page 20).

12. Air curtain optimisation

There is a considerable energy benefit in improving the performance of air curtains in open-fronted cabinets.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

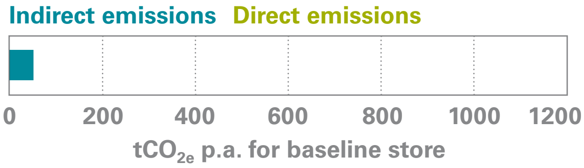
Infiltration loads on open-fronted cabinets are the highest cabinet heat load. In recent years, significant research has been carried out to improve the performance of air curtains. By implementing best technology air curtains, the energy in the baseline store would be reduced by 5%.

A major study funded by the US Department of Energy carried out to understand infiltration and the key variables affecting infiltration has shown reductions in infiltration of 18%. This was achieved with an opening height to discharge air curtain width ratio of 16, a linear velocity variation across the discharge air curtain width, a Reynolds number at air curtain of 4,500, an aligned discharge and return air grille, no back panel flow, and a throw angle of zero.[21]

See also back panel flow.

13. Evaporative condensers

Evaporative condensers can reduce condensing temperature, leading to energy savings.



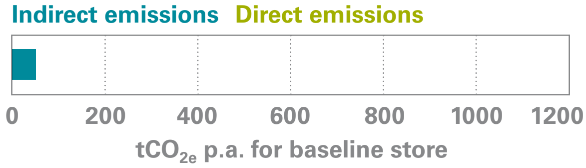
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	H

Evaporative condensers use water sprayed over a specifically designed condenser, so that heat is rejected at the wet bulb temperature of the air (rather than at the dry bulb temperature). This reduces condensing temperature and therefore saves energy.

Evaporative condensers have higher maintenance costs than conventional condensers and require any water to be dosed to eliminate the Legionella bacteria. They do, however, have the potential to save around 5% of the energy used in the baseline store.

14. Back panel flow

The design of the rear cabinet duct and perforations of the back panel play an important part in creating even air flow within the cabinet.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

The air flow from the perforated back panels in open-fronted cabinets has a dual function: to provide cooling for the products at the rear of shelves, and to support the flow of the vertical air curtain at the front of the cabinet.

Air in the rear duct of the cabinet is often non-uniform and this can greatly affect the effectiveness of the back panel flow. By improving the design of the rear duct, improvements in air flow and the temperature of the air flowing over each shelf can be achieved. Energy savings of up to 4% should be achievable in the baseline store if the back panel air flows were optimised.

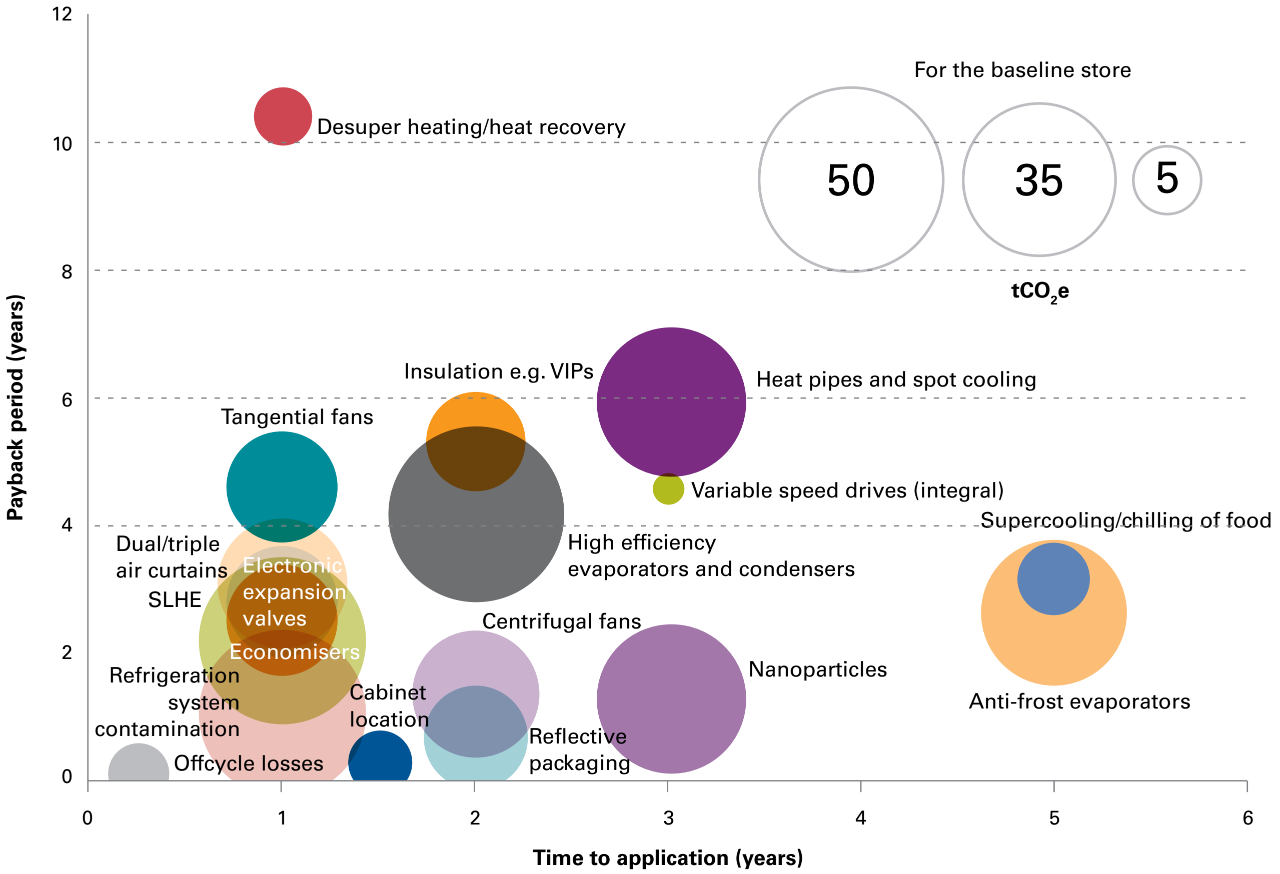
See also air curtain optimisation (page 32).

The use of evaporative condensers in supermarkets in the US has demonstrated an 8.2% saving on refrigeration system. [22]

[21] Faramzi, R (2007). Investigation of Air Curtains in Open Refrigerated Display Cases – Project Overview, Presentation at PAC meeting, Dallas, Texas, 29 January 2007.

[22] Walker D.H. and Baxter V.D. (2003) Analysis of Advanced, Low-Charge Refrigeration for Supermarkets. ASHRAE Transactions, CH-03-1-1.

Figure 6 Technologies available during a store refit with potential to save <50tCO_{2e} pa



Store refit options saving less than 50tCO_{2e} per annum

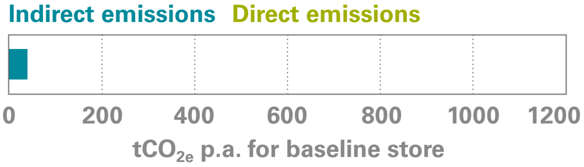
Figure 6 shows technology options that can save less than 50tCO_{2e} per annum for the baseline supermarket.

The performance of a supermarket integral multi-deck cabinet as improved by modifying the air flow in the rear duct and at the discharge grille. After modifications the temperatures were reduced by 3˚C and overall energy savings of 5.8% were achieved.[23]

[23] Foster A.M, Madge M. and Evans J.A. (2005). The use of CFD to improve the performance of a chilled multi-deck retail display cabinet. International Journal of Refrigeration, 28(5); 698-705.

15. High-efficiency evaporators and condensers

Efficiency improvements and refrigerant charge reductions can be achieved through the use of more efficient micro-channel heat exchangers.



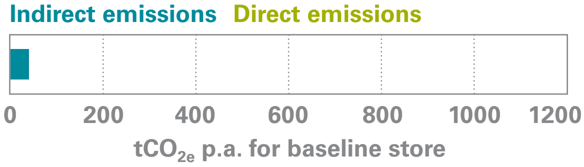
Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

An efficient evaporator or condenser will lead to an increase/decrease in the evaporating/condensing temperature and pressure, and will lead to a reduction in the compressor power consumption. The use and understanding of transport phenomena in micro-channel heat exchangers is still developing and is currently a topic under research[24].

Currently these types of heat exchanger are expensive and have long paybacks compared to conventional heat exchangers used in condensers and cabinets. They do, however, have the potential to save 3-4% of the energy used in the baseline supermarket and, with further developments, this could be greater. Micro bore heat exchanger technology is continuing to be developed and costs are likely to reduce as demand increases and production costs decrease.

16. Refrigeration system contamination

It is estimated that internal contaminants can reduce system efficiency by as much as 50%[25].



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

Refrigeration systems can become contaminated during use and this can have a large effect on system efficiency. Contamination can occur inside the components and pipes of a refrigeration system, or on the outside of heat exchangers.

Contamination can originate from a number of sources but generally is a result of poor installation or maintenance of the refrigeration system. The most serious contaminants are water, non-condensable gasses and oil. Water combines with oil to form acids that can harm metal components, such as motor windings. It can remove copper ions from pipework, and these can then be deposited on hot surfaces causing bearing seizure and, ultimately, compressor failure. Over time, water and oil form a sludge that can block filters and oil flow passages. Water can also freeze in valves and pipes and block the flow of refrigerant. Non-condensable gasses usually originate from air that has not been completely evacuated from the system prior to charging with refrigerant. In rare cases, air can enter the refrigeration system through leaks in the pipework if the low pressure side of the system is below atmospheric pressure.

System efficiency could be reduced by approximately 5% if the refrigeration systems contain 5% non-condensables.

[24] Shiferaw D., Mohamed M.M., Karayiannis T.G. and Kenning D.B.R. (2009). Flow Boiling of Refrigerants in Small to Micro Diameter Metallic Tubes. Proc. Inst. R. 2009-10. 4-1.

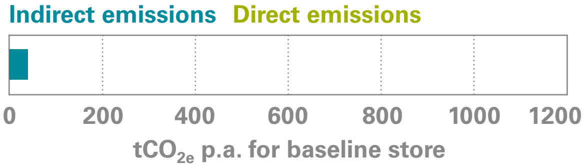
[25] Jones, D. and Harkins, V.P. (2005). Maintaining energy efficient cooling. Energy efficient cooling, RAC seminar, 28 September 2005.

Contamination can be avoided by effective installation and maintenance of refrigeration systems and training of installers and service engineers.

See also cleaning and maintenance (page 12).

17. Suction liquid heat exchanger (SLHE)

The use of a SLHE can save 4.5% of the total energy consumption (TEC) for a typical open chilled vertical multi-deck.

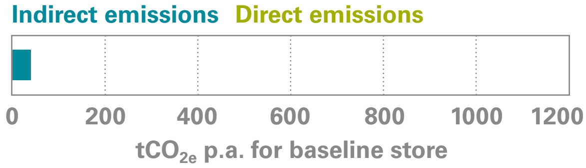


Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Suction liquid heat exchangers effect heat exchange between the suction and liquid lines. They can increase system performance by sub-cooling liquid refrigerant and preventing flash gas formation at the inlet to the expansion valve. In addition, they help to ensure that all refrigerant is evaporated before returning to the compressor. Suction-liquid heat exchangers increase the temperature of the refrigerant and reduce volume of refrigerant pumped by the compressor. Therefore, their installation is not an energy efficient option for all refrigerants.

18. Nanoparticles

National Institute of Standards and Technology (NIST) has shown that dispersing low concentrations of copper oxide nanoparticles (30 nm) in a common polyester lubricant, and combining it with R134a, improved heat transfer by between 50% and 275%.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Nanofluids are engineered colloidal suspensions of nanoparticles (1-100 nanometres (nm)) in a base fluid. The size of the nanoparticles imparts some unique characteristics to these fluids, including greatly enhanced energy, momentum and mass transfer, as well as reduced tendency for sedimentation and erosion of the containing surfaces. To enhance heat transfer, nanofluids were developed, based on mainly copper and aluminium nanoparticles of above 20nm in size[26]. Nanoparticles have a high thermal conductivity and, hence, should improve the heat transfer near the laminar sub-layer. Recent experimental work at NIST (USA) with varying concentrations of nanoparticle additives indicated a major opportunity to improve the energy efficiency of large industrial, commercial cooling systems.

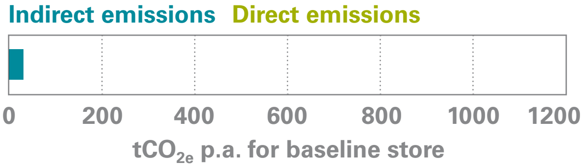
Nanoparticle additives are available commercially but have received little testing in supermarkets. Savings in energy of up to 18% in non-supermarket applications are claimed by manufacturers. Due to a lack of independent test data from supermarkets, it is difficult to gauge the energy saving potential of nanoparticles. The additives are also claimed to have a cleaning function on the refrigeration system and to be effective in returning the performance of systems to the level they were at installation. Due to the limited information on nanoparticles in supermarket systems further evidence is needed to fully quantify their benefits.

See also cleaning and maintenance (page 12).

[26] Eastman J.A., Choi S.U.S, Li S., Thomson L.J., Lee S. (1996). Enhanced Thermal Conductivity Through The Development of Nanofluids, Proceedings of the Symposium on Nanophase and Nanocomposite Materials II.

19. Heat pipes and spot cooling

Heat pipes and spot cooling technologies provide an opportunity to reduce the range in temperatures within individual cabinets.



Barriers to staff/customers	L
Availability barriers	H
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	M
Maintainability	L
Legislative issues	L

In most supermarket cabinets, temperatures of products vary according to their position within the cabinet. In chilled cabinets, centre product temperatures often vary between -1 and 7°C. In frozen cabinets, centre product temperatures vary between -15 and -30°C. Reducing the temperature of the maximum temperature food has the potential to reduce the overall range in food temperatures. This would have the effect of not only stabilising food temperature and extending the shelf life of foods, but would enable evaporating temperature to be increased with the associated energy savings. Overall savings of 2-3% should be achievable in the baseline supermarket if evaporating temperatures could be increased by 1-2°C.

Several methods have been proposed to reduce the range in temperatures within a cabinet.

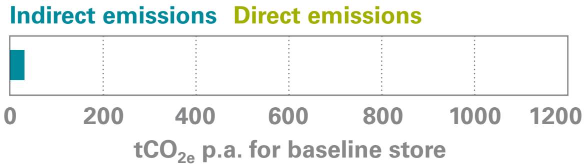
Linde proposed a method using chute shelves to create sequential air curtains. The work demonstrated that it was possible to keep product temperatures within a 1°C to 2°C range whilst reducing the heat extraction rate by 6%[26].

The use of heat pipes in cabinet shelves has been used to increase heat transfer between the rear and front of the shelf.[27 28]

Currently there has been limited commercial development of heat pipes and spot cooling technologies for retail cabinets. Further development is required before the technology could be applied.

20. Anti-frost evaporators

Hydrophobic surface treatments on evaporators have been shown to be a more efficient means of defrosting.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

Hydrophilic or hydrophobic coatings are a means of reducing the frosting behaviour of evaporators. The amount of residual water on the surface-treated heat exchangers has been shown to be smaller than that of a bare heat exchanger. This reduces direct energy required for defrosts and heat load on the refrigeration system. Overall savings in the baseline supermarket of 2% could be achieved with enhanced anti-frost evaporators.

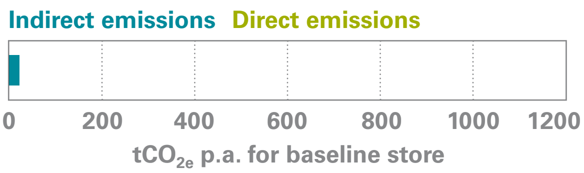
The technology is still undergoing development and would be applied to evaporators in new cabinets and is unlikely to be suitable for retrofitting to current cabinets. Currently, hydrophobic surface treatments for evaporators are too expensive to be commercially viable, but further improvements in their performance and manufacture are expected in the future.

[27] Schuster, M. and Krieger, T. (2007). Open vertical cabinet (multi-deck) with Sequential air curtain for better temperature and merchandizing performance. The 22nd IIR International Congress of Refrigeration. Beijing, China. August 21-26.

[28] Wang, F., Maidment, G.G., Missenden, J. and Bailey, C. A Novel Superconductive Food Display Cabinet. IOR Proceedings Volume 101 (2004/5).

21. Dual/triple air curtains

In open-fronted multi-decks, 60-80% of the heat load is through the open front of the cabinet.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

Reducing infiltration into the open front of cabinets can significantly reduce energy consumption. This is a complex area, and air curtain turbulence is important in controlling infiltration. Reducing turbulence from 10% to 3% will reduce infiltration by 8%. This can be achieved by optimising the design of the discharge air grille and could achieve overall energy savings in the baseline store of 1-2%.

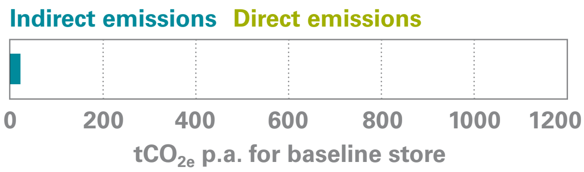
Dual and triple air curtains can be used as a means to reduce infiltration. When a multiple, rather than a single, air curtain is used, the innermost curtain is normally the coldest, with the second one being slightly warmer. If a third outer curtain is employed, it is normally at ambient temperature, and used to reinforce the jet inertia and reduce the 'cold feet effect' in the store aisles.

The use of dual air curtain cabinets has increased over the past few years. Although such a cabinet is not in itself a guarantee of high efficiency, there is some evidence to suggest that it may be easier to produce a high-efficiency cabinet with a dual or triple curtain, as a result of a more robust design. At present it is still possible to purchase a single air curtain cabinet that is equally efficient to a dual or triple air curtain. However, the potential for further design improvements in dual/triple air curtains means that this picture is expected to alter in future.

See also air curtain optimisation (page 31).

22. Centrifugal fans

EC fans have been developed recently that could be used in retail cabinets. These are claimed to save between 21.5% and 54% of the energy of a standard fan in non retail cabinet applications.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

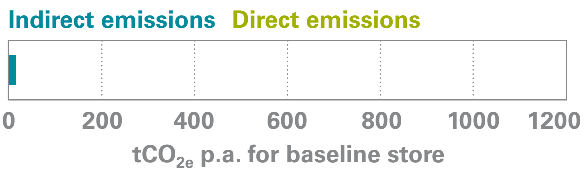
In the past backward-curved centrifugal fans were commonplace in refrigerated display cases, but went out of favour due to cost and were replaced by axial fans. Centrifugal fans can be aerodynamically efficient and have excellent pressure-handling capability. They have some applications in retail display cabinets due to the narrow profile of the impeller and their inherent characteristic of turning the air through 90 degrees. Recent developments in EC centrifugal fans technology have raised the possibility of these fans once again being used in retail cabinets.

The energy saving potential of these fans is rather unproven in retail cabinets, but could be between 1% to 2% of the energy used by the baseline store.

See also evaporator fan motors (page 15).

23. Economisers

In smaller systems the use of economisers on compressors can provide considerable energy savings.



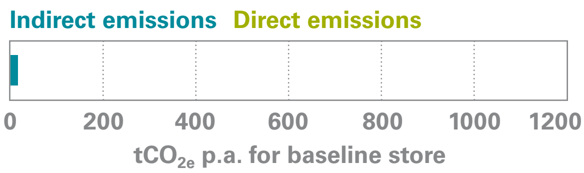
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

In an economiser a portion of the condensed liquid will be vaporised and injected into an intermediate vapour injection port on the compressor. This has the effect of subcooling the liquid leaving the condenser and increasing the enthalpy gain across the evaporator as well as providing intermediate cooling in the compressor. The heat exchanger needs to be sized to provide the correct intermediate pressure and temperature, and thus optimise the capacity gain.

Scroll compressors with economiser ports have been available for 10 years and are now starting to become widely applied on low-temperature systems. Savings of 20% energy in pack energy can be made using economisers in systems, but this would probably be less in supermarkets due to the long pipe runs. Overall savings of 1-2% of the baseline store energy should be achievable.

24. Electronic expansion valves (EEVs)

EEVs allow engineers to optimise cabinet superheats more rapidly and can provide better superheat control.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

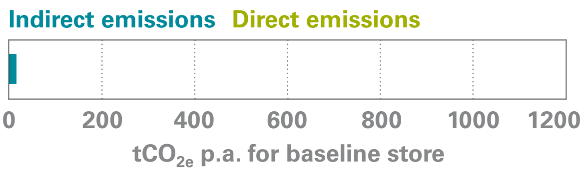
On larger supermarket cabinets the expansion device is usually a TEV or an EEV. EEVs are claimed to enable better evaporator superheat control and therefore to enable more efficient usage of the evaporator. This is only true if the TEV is not correctly set or the pressure difference across the TEV changes significantly from the design condition.

EEVs, unlike TEVs, can cope with partial load capacities down to 10% of full load. Therefore, they can continue to operate when the condensing temperature floats down due to low ambient temperature. Although EEVs have been shown in some instances to reduce energy consumption, the savings are low when compared to an optimised TEV.

See also floating head pressure (page 13).

25. Tangential fans

Tangential fans can provide more even air flow in cabinets and have been shown to produce overall energy savings of 2%[29].

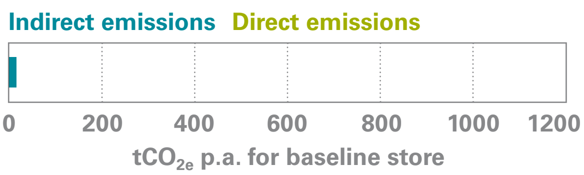


Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

Tangential fans are already used in some retail display cabinets. They tend to be more compact than axial fans allowing more space for air to be distributed within the cabinet. The claimed energy savings are probably achieved by more even distribution of cooling within the cabinet and the associated ability to increase evaporating temperature. Although tangential fans appear to have advantages, they are more difficult to clean in comparison to axial flow fans.

26. Reflective packaging

Reflective packaging has the potential to reduce radiant heat gains, especially in freezer cabinets.



Barriers to staff/customers	L
Availability barriers	H
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	M
Maintainability	L
Legislative issues	L

For reflective packaging to be effective the food must be packaged in a low emissivity material for the technology to be fully effective all food in a cabinet must be packaged with a similar low emissivity packaging (otherwise the food not packaged in low emissivity wrapping will be at a higher temperature).

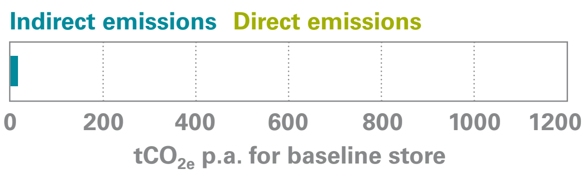
> In trials where food was wrapped in plain metal foil with an emissivity of 0.05 the temperature of food in a freezer was reduced by between 6 °C and 15°C and the temperature gradient reduced by 9°C. Although energy in these trials was not measured (the aim was to improve product temperature) the opportunity to raise evaporating temperature by around 10°C in freezers would result in energy savings of 10-20%. [30]

Currently very few foods are wrapped in reflective packaging. For the technology to be fully implemented food packaging would need to be changed and applied by food manufacturers. If this was implemented on all frozen cabinets in the baseline store, the overall energy savings would be 1-2%.

See also radiant heat reflectors (page 24).

27. Insulation e.g. VIPs (vacuum insulated panels)

In frozen cabinets the heat load across the insulation can be as high as 17% of the total heat load, and therefore improved insulation solutions are an effective way to improve efficiency.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	L
Maintainability	M
Legislative issues	L

[29] Faramarzi, R. Sarhadian, R. Coburn, B. Mitchell, S. and Lutton, J. (2000). Analysis of energy enhancing measures in supermarket display cases. ASHRAE Annual Meeting, Anaheim.

[30] Hawkins, A.E. Pearson, C.A. and Raynor, D. (1973). Advantages of Low Emissivity Materials to Products in Commercial Refrigerated Open Display Cabinets. Proc Inst of Refrig.

The heat load across the insulation of retail cabinets varies and is higher in frozen cabinets than open-fronted chillers *(Table 2).* Insulation performance can be improved by either increasing the insulation thickness or by reducing the thermal conductivity of the insulation. This would have the effect of reducing energy used in the baseline store by 1-2%.

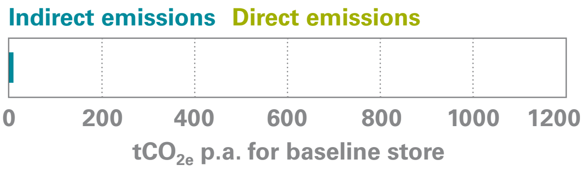
Decreasing the thermal resistance of the insulation will improve the thermal properties of the insulation. This can be achieved by the formation of smaller cells within the foam insulation structure and better cell-size consistency.

Alternatively, VIPs are another advanced insulation technology. VIPs can have mid-panel thermal conductivities as low as one-fifth of those of conventional polyurethane[31]. Depending upon application, this can translate to enhanced energy efficiency, improved temperature control or reduced insulation thickness. Certain limitations on performance of the panels has so far restricted uptake to niche applications. These limitations include durability, edge effects where heat is conducted through the metalized foil outer, especially at the corners and the integrity of the panels[32]. However, if these could be overcome VIPs have huge potential to save energy in commercial and retail appliances.

Improved insulation technologies are available but currently have only been applied to refrigeration cabinets where the additional cost for the technology can be justified. It is expected that as further uptake occurs costs for the technologies will reduce.

28. Supercooling/chilling of food

Supercooling and superchilling have considerable potential to maintain food quality and safety whilst retaining food at higher than 'normal' storage temperatures.



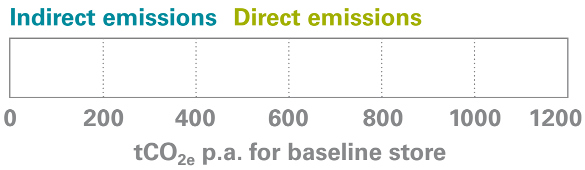
Barriers to staff/customers	L
Availability barriers	H
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	M
Maintainability	L
Legislative issues	L

Supercooled and superchilled foods are stored at temperatures around their initial freezing point and therefore can be stored at higher temperatures than equivalent frozen foods. In superchilling, ice crystals are formed, whereas in supercooling they are not. The technologies only save energy if they replace frozen foods and therefore their energy saving potential is rather limited.

Both technologies are likely to require stable temperature control at a level that is generally lower than conventional chiller cabinets. Although fish and meat have been superchilled and been shown to have extended storage life, both technologies require further development and it is likely that specialised retail display cabinets will need to be developed. Therefore this is not a technology likely to be in applied to supermarkets in the short term.

29. Off-cycle losses

Off-cycle losses can significantly increase energy in small integral cabinets.



Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	L
Technology interdependence	L
Maintainability	L
Legislative issues	L

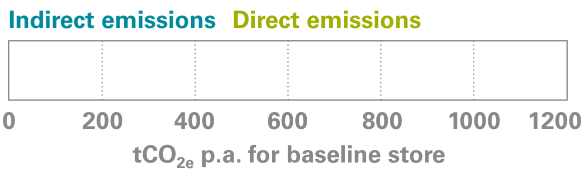
Off-cycle losses occur when refrigerant gas migrates across the capillary tube and condenses in the evaporator when the compressor is non-operational. On smaller capillary based systems, off-cycle losses can be considerable. By fitting a liquid line solenoid valve, energy savings of as much as 44% can be achieved. The overall savings across a whole supermarket are, however, rather limited due to the low number of integral cabinets used by large supermarkets.

[31] Wu J-W, Sung W-F and Chu H-S (1999). Thermal conductivity of polyurethane foams, International Journal of Heat and Mass Transfer, 42:2211-2217.

[32] Brown T., Swain M.V.L and Evans J.A. (2007). Use of vacuum insulated panels to improve performance of refrigerators and insulated shipping containers, The 22nd IIR International Congress of Refrigeration, Beijing, China, 21-26 August.

30. Cabinet location

Locating display cabinets in a cool area and not in direct sunlight will keep energy consumption low.



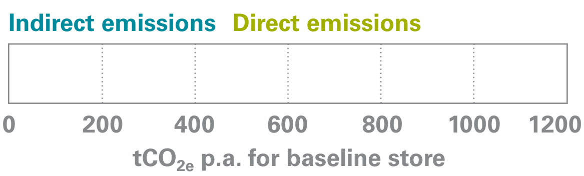
Barriers to staff/customers	M
Availability barriers	L
Limits to commercial maturity	L
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

Cabinets near natural lighting have worse performances due to radiation, and those located near an external environment are affected by high temperatures, humidity and wind. Air-conditioning inlets can interfere with the air curtain of some open refrigerated cabinets and impair their performance.

Severe draughts can have a serious effect on open-fronted cabinets and can increase energy consumption by up to 95%. The number of cabinets located close to doors in supermarkets is relatively low and therefore energy savings are low.

31. Desuperheating/heat recovery

Heat recovery from refrigeration systems can be used for hot water or space heating in supermarkets.



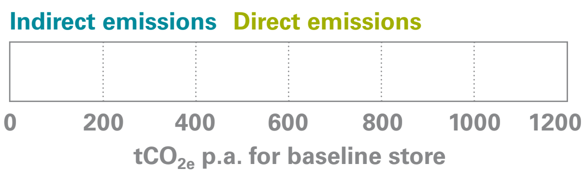
Barriers to staff/customers	L
Availability barriers	L
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	H
Maintainability	L
Legislative issues	L

Floating head pressure control reduces opportunities for heat recovery from desupe heating the compressor discharge gas or from condenser heat reclaim.

Many supermarkets in Sweden utilise heat recovery from condensers as one way to increase the overall energy efficiency of the supermarket. The obvious drawback is that the condensation temperature must be kept at a level where heat can be transferred to the heating system of the supermarket. This increases energy consumption of the refrigeration system, but at the same time leads to a reduction of energy consumption for the heating system. An alternative way to recover heat at low head pressures may be to use a heat pump to upgrade the reject heat for heating and hot water purposes.

32. Variable speed drives (integral)

Variable speed drives (VSDs) have the potential to operate compressors down to 20% speed and save 9-11% of the energy used by the compressor.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

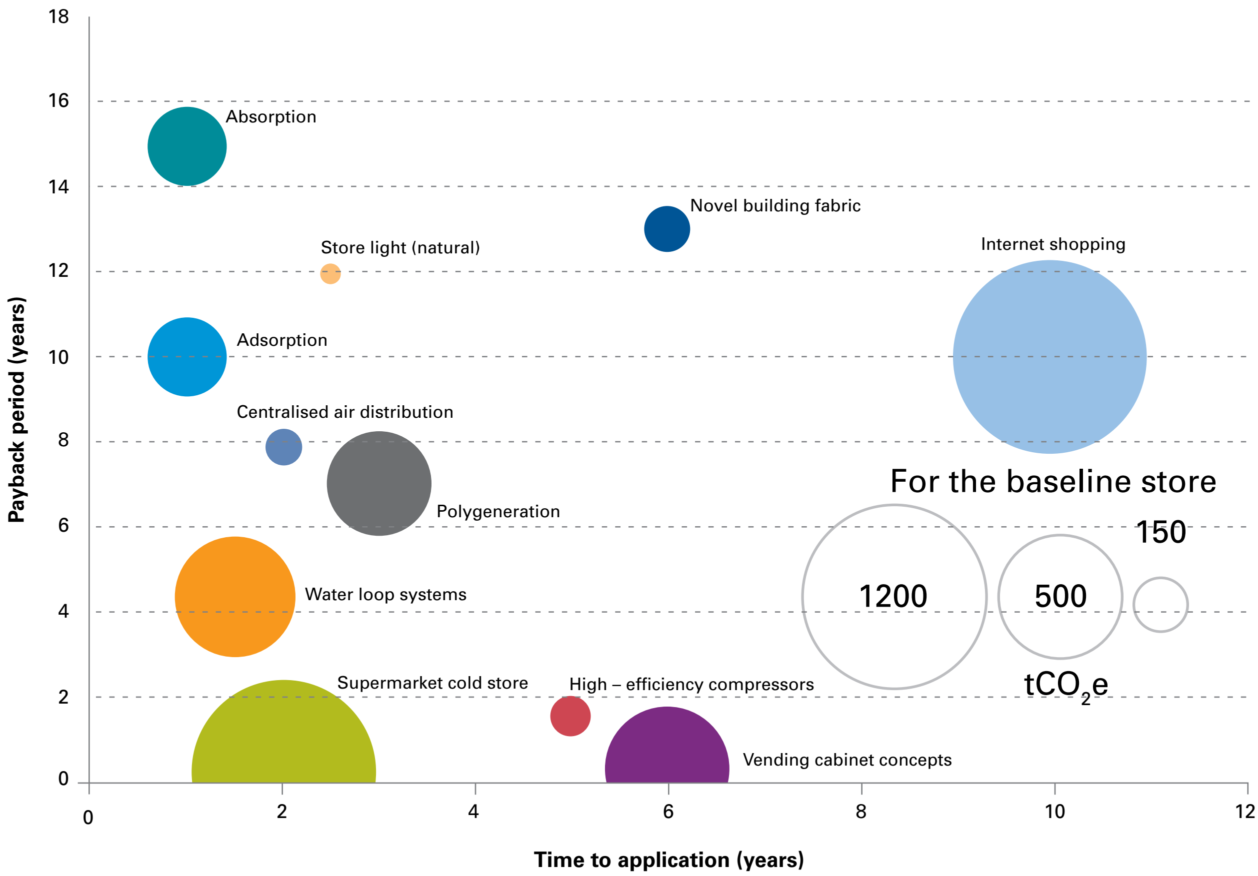
By using VSDs overall savings of around 9-11% can be achieved when compared to on-off compressor control. Generally, if a constant-speed compressor operates above 80% of its capacity, it will be more efficient; whereas if it operates below 80% of its capacity the VSD compressor is likely to be more efficient.

Considerable future potential exists for the use of VSDs on integral cabinets. However, currently, energy savings for a large supermarket are limited due to the small number of integral cabinets installed.

CO_{2e} saving options available when designing a new store/ retail concept

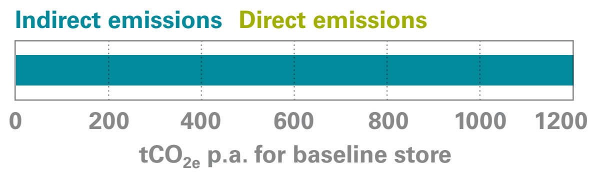
Technologies that could be applied when designing a new supermarket are presented in *Figure 7*. These are described below in order of CO_{2e} saving potential for the baseline supermarket.

Figure 7 *Technologies that are available when designing a new store/retail concept.*



1. Internet shopping

Internet shopping is already a growing part of supermarket sales.



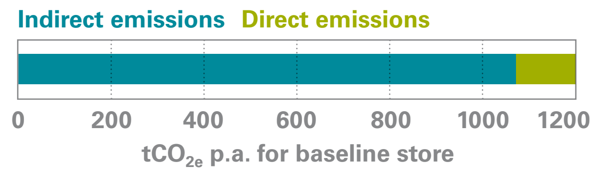
Barriers to staff/customers	M
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

The further development of internet shopping has considerable potential to reduce store refrigeration energy as food is maintained in efficient centralised cold stores. However, to fully develop the technology a large and highly efficient infrastructure would need to be developed to cater for the level of demand and this is likely to take at least 10 years to fully implement.

To achieve maximum CO_{2e} reductions all food would need to be stored in efficient cold stores and an efficient and coordinated delivery service would need to be developed to minimise emissions from delivery vehicles. The technology is reliant on extensive use of the internet and full access to all consumers. There is also a non-technological barrier as not all consumers may accept internet shopping.

2. Supermarket cold stores

Compared to cold stores, supermarket cabinets use at least two to three times more energy per cubic metre than a poorly performing comparably sized cold store.



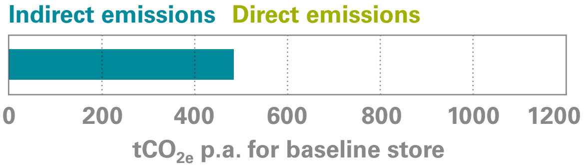
Barriers to staff/customers	M
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	H
Technology interdependence	L
Maintainability	L
Legislative issues	L

Using semi-open cold stores to replace display cabinets is an option that has been used in discount warehouses and cash and carry type outlets in the UK. It has also been applied to supermarkets in Europe. It therefore makes sense to utilise cold stores where customers can walk through and select goods. There would be additional benefits of enhanced temperature control and possibly extended storage life of foods.

However, although this is an extremely energy efficient option, the use of cold stores has potential safety problems (ice, water on the floor) and is unlikely to create the same marketing opportunities for supermarkets that display cabinets are able to provide.

3. Vending cabinet concepts

The use of vending cabinets to store food is an alternative that could save considerable amounts of energy if applied in supermarkets.

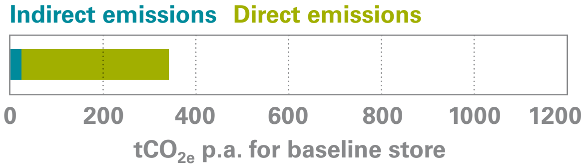


Barriers to staff/customers	H
Availability barriers	H
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	L
Maintainability	H
Legislative issues	L

Infiltration, radiant heat gains and heat loads from defrosts and heaters are a major load on display cabinets *(Table 2)*. A large proportion of this heat load could be removed if food was no longer placed in open-fronted cabinets. The application of vending cabinet technology requires further development to make cabinets user friendly and to educate consumers in their use.

4. Water loop systems

Using a water loop to cool an integral cabinet condenser enables high GWP refrigerants to be minimised in supermarkets.



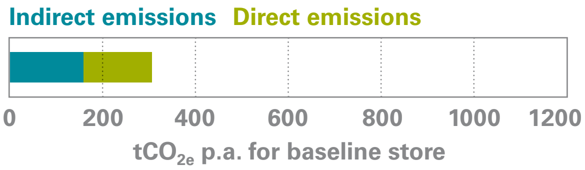
Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	H
Technology interdependence	M
Maintainability	M
Legislative issues	M

Supermarkets such as Waitrose are currently trialling the use of HC integral cabinets where the condenser is cooled by a water system pumped around the store. This is particularly attractive as the integral cabinets operate on a low GWP refrigerant and integrals have been shown to have low leakage of refrigerant. The condensing temperature is also maintained at a low level and the system has a relatively high COP compared to a conventional direct expansion-type supermarket refrigeration system. It is also flexible and requires minimal commissioning and set up as the cabinets are constructed and tested by the manufacturer prior to delivery to the supermarket.

Results from trials still need to be obtained to fully quantify the potential of this technology.

5. Polygeneration

Polygeneration uses multiple energy inputs to provide multiple energy outputs.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

The primary energy can include fossil fuels, biofuels and renewable energy, and the energy outputs are generally defined as energy that is useful in an activity. In retail, the outputs are generally electricity or heat transfer at different levels suitable for cooking, chilling or freezing.

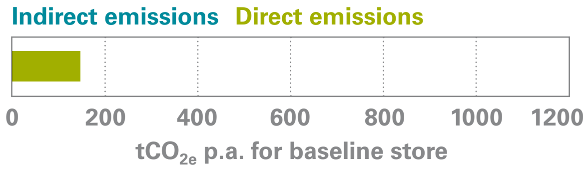
Trigeneration is the most common form of polygeneration so far investigated for supermarkets. Trigeneration systems produce heating, power and refrigeration. In a trigeneration system all or some of the heat is used within an absorption cycle to generate cooling. Although not so common, adsorption systems can also be used in trigeneration.

Waste and by-products can be used to generate thermal energy and power by either direct combustion, thermal gasification or anaerobically treated to give biogas. These technologies are not common, but anaerobic digestion of biodegradable food waste is probably the most promising option. The biogas that is rich in methane can be burnt and used directly or used in a gas engine or turbine as part of a combined heat and power (CHP) system.

See also adsorption (right) and absorption (page 46).

6. Adsorption

Adsorption systems are driven by heat and so if waste or solar heat is available they are an attractive option for supermarkets.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

Adsorption systems use the adsorption and desorption of a refrigerant to create cooling. Unlike absorption and vapour compression systems, adsorption is an inherently cyclical process and multiple adsorbent beds are necessary to provide approximately continuous capacity. Adsorption systems require large heat transfer surfaces to transfer heat to and from the adsorbent materials which automatically increases their size and cost.

Adsorption systems commonly use water, methanol and ammonia as the refrigerants and adsorbents such as zeolites, active carbon, silica gels and salts in mesopourous silica or alumina[33]. They have capacities between 70kW and 1,300kW capable of being driven by low grade heat at 50 to 90°C with COPs of around 0.65. Research and development is also under way to produce systems for refrigeration applications and prototypes for temperatures down to -25°C. At present, there are no low (freezer) temperature absorption refrigeration systems of large enough capacity available off-the-shelf.

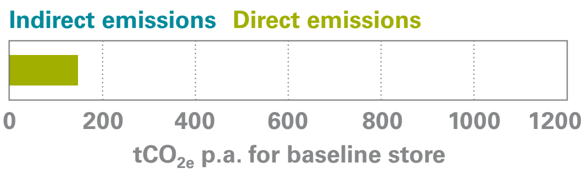
Solar adsorption refrigeration devices have the potential to meet cooling demand at certain times of year. They are also noiseless, non-corrosive and environmentally friendly. Various solar powered cooling systems have been tested extensively; however, these systems are not yet ready to compete with vapour compression systems.

See also absorption (page 46) and polygeneration (left).

[33] Critoph R E and Zhong Y (2005), Review of trends in solid sorption refrigeration and heat pumping technology, Proc. ImechE, Vol. 219, Part E, J. Process Mechanical Engineering.

7. Absorption

Like adsorption systems, absorption systems are driven by heat.



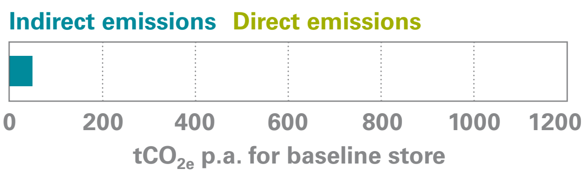
Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	M
Legislative issues	L

Absorption cycles are usually based on lithium bromide (LiBr) or ammonia and water and, depending on the cycle, can generate cooling down to -40°C. They have relatively low COPs but are heat driven and therefore applications are most appropriate where there is a source of waste heat.

See also adsorption (page 45) and polygeneration (page 45).

8. Novel building fabric

The use of novel materials such as those incorporating phase change materials could be a means to even out summer/winter variations in heating, ventilation and air conditioning (HVAC) heating/cooling demand.

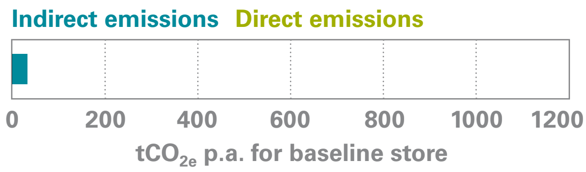


Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	M
Maintainability	L
Legislative issues	L

Building fabric can influence refrigeration energy by affecting heat gain/loss to the building and consequently the ambient temperature inside the supermarket (see also store temperature). In summer supermarkets require cooling, and in winter they require heating. If some of this imbalance could be evened out through the use of novel building materials the need for additions heating or cooling could be minimised.

9. High-efficiency compressors

Overall compressor efficiencies are usually at best between 70-75%. Some further improvements in efficiency are technically possible.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	M
Technology interdependence	L
Maintainability	L
Legislative issues	L

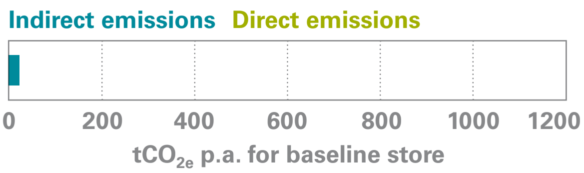
In supermarkets in recent years the trend has been towards the use of scroll compressors due to their lighter weight and ease of replacement by maintenance engineers in the event of failure. Scroll compressors in medium temperature applications offer efficiencies comparable with the best reciprocating semi-hermetic reciprocating types. In low temperature applications liquid injection cooling is required and efficiency can be lower than well-engineered semi-hermetics, but the use of economisers more than compensates for this.

Recent developments in compressor technology have used magnetic bearings and high-speed synchronous permanent magnet direct drive motors to produce a high-efficiency oil-free compressor for chiller applications. The Danfoss Turbocor compressor can operate on R134a and has high efficiency across a range of operating conditions[34].

[34] Conry, R. (2009). A brief overview of the Turbocor compressor – the Road to Discovery. Proc. Inst. R. 2009-10. 1-1.

10. Centralised air distribution

Dusting air directly to cabinets is a novel means to cool chiller cabinets.

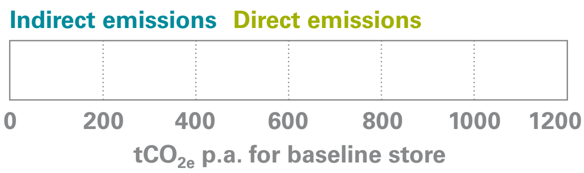


Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	M
Ease of use and installation	H
Technology interdependence	H
Maintainability	M
Legislative issues	L

The use of ambient air to cool chiller cabinets has received limited application. The system requires air to be ducted to and from the cabinets from either a central chiller system or from outside when ambient conditions are suitably low. The efficiency of the system relies totally on the number of days when ambient temperature is sufficiently low to provide chilling to the cabinets. One of the main advantages of the system is the centralised refrigeration plant which can be easily maintained and direct emission minimised. In addition the display cabinet no longer requires an evaporator and this frees up space within the cabinet that can be used for storage or to improve air circulation.

11. Store light (natural)

A number of new supermarkets have been designed to maximise day lighting through light pipes in the sales areas, maximising light from the store façade and by building glazed sections into the roof. If these features reduce radiant heat to cabinets, there are energy saving benefits for the refrigeration plant.



Barriers to staff/customers	L
Availability barriers	M
Limits to commercial maturity	H
Ease of use and installation	H
Technology interdependence	L
Maintainability	L
Legislative issues	L

Installation of these technologies in the Tesco Cheetham Hill store has shown that there is significant potential to reduce energy consumption in retail food stores through the use of day lighting by up to 25% of lighting energy requirements.

The main barriers to the wider application of day lighting, however, is the requirement to satisfy the new building regulations in terms of the overall thermal performance of the building fabric, the high cost of the first store design to incorporate day lighting and the requirement to have consistent levels of illumination on certain types of food and non-food products. Integration of day lighting with artificial lighting should be able to satisfy both energy and merchandising requirements at acceptable additional capital cost, but detailed research and development is required to reduce the impacts and maximise the benefits of day lighting in retail food stores.

See also store light (LED and fluorescent) (page 23).

Future technologies

There are a number of future refrigeration technologies that present potential carbon savings but are not currently sufficiently developed to be quantified. These technologies are described in this section (in alphabetical order).

Acoustic refrigeration

Acoustic refrigeration uses sound waves to produce cooling. The technology is currently less efficient than vapour compression technologies but potential improvements are possible. There are a number of prototype systems reported. Penn State University has developed a demonstrator acoustic refrigerator for storage of ice cream which is currently undergoing further development with the view to future commercialization[35].

Air cycle

Air is a natural refrigerant and environmentally benign. The use of air as a refrigerant has been demonstrated in chiller and freezer cabinets using components from the aircraft industry. The cycle has a key advantage over conventional supermarket refrigeration systems in terms of direct emissions as air is a natural, safe and benign refrigerant with a GWP of 0. The system has other advantages, including operation at low pressures (3-4 bar absolute) and the ability to use heat from the compressor for space or water heating. Currently equipment availability and costs limit the use of the technology.

Ammonia (sealed hermetics)

Ammonia is an environmentally benign and efficient refrigerant that has been used extensively in large vapour compression systems. However, due to safety concerns, it has had limited use in supermarkets. The use of ammonia in small systems using hermetic or semi-hermetic compressors to minimise the ammonia charge, reduce the risk of leakage and increase system reliability is being developed. Several compressor concepts have been tested in recent years, including a hermetic ammonia scroll compressor, which is currently undergoing further development. It seems rather unlikely that supermarkets would accept ammonia as a refrigerant in distributed systems, however, the application of this technology in leak-tight integral cabinets would present savings in terms of energy and leakage.

Automation and vending type cabinets

Automation and robotics have received little attention in supermarkets. The possibility of incorporating robotic picking of food has some possibilities, particularly if combined with vending-type concepts. By containing food in a sealed enclosure and using a robot to select items, heat loads on cabinets could be almost eliminated. However, the technology minimises retail interaction between the customer and the food and these issues would need to be overcome to gain acceptance from customers.

Electrocaloric refrigeration

Electrocaloric cooling uses the ability of a material to change temperature by applying an electric field. An electrocaloric device has two thin films separated by a vacuum layer. If a voltage is passed across the gap, the most energetic electrons on the negative side 'jump' across to the positive side. As the electrons leave the negative side it gets colder. Potentially such a device can be thermodynamically very efficient and could outperform classic direct expansion refrigeration systems. The electrocaloric effect has been known for many years; however, until recently only small temperature differences have been possible. In 2006 researchers from Cambridge University reported the giant electrocaloric (GEC) effect, whereby temperature changes of around 10°C can be efficiently achieved. Currently, the thin films used are expensive, but current research is investigating the potential for new materials[36].

Eutectic packaging

Food undergoes unwanted warming during loading and storage in retail cabinets. The use of advanced packaging that utilises phase change materials (eutectics) could have potential to even out these fluctuations and allow evaporating temperatures to be raised. Such technology uses micro and nanoencapsulated phase changing materials contained in the food packaging. Substantial challenges exist and are being researched to develop the technology. However, it is not anticipated that these types of packaging materials will be available for five to 10 years.

[35] Poese M.E, Smith R.W.M, Garrett S.L, van Gerwen R. and Gosselin P. (2004). Thermoacoustic refrigeration for ice cream sales, 6th IIR Gustav Lorentzen Natural Working Fluids Conference, Current applications and opportunities, 29th August to 1st September, Glasgow, UK.

[36] Mischenko, A .S., Zhang Q, Scott J.F., Whatmore R.W. and Mathur N.D. (2006), Giant Electrocaloric Effect in Thin-Film $PbZr_{0.95}Ti_{0.05}O_3$, Science 311 (5765): 1270–1271.

Hydraulic refrigeration

The hydraulic refrigeration system (HRS) is a vapour-compression system that accomplishes the compression and condensation of the refrigerant by entraining refrigerant vapour in a down-flowing stream of water and utilising the pressure head of the water to compress and condense the refrigerant. There are several advantages of hydraulic refrigeration including efficiency (especially at part-load conditions), no usage of high-GWP refrigerants or lubricants, simplicity and low maintenance and high reliability. Disadvantages include physical size of the components and the large vertical extent of the down pipe that is necessary for the compression and condensation process of the system. Systems are currently under development and commercial availability is relatively long term.

Leasing concepts

Refrigeration system leasing has been proposed as a concept in other areas of the food cold chain. The basis behind the technology is that a company leases the refrigeration system to a supermarket and is responsible for its maintenance and operation. The leasing company are responsible for providing refrigeration or air at set temperatures but can operate the plant as they see fit to achieve minimum energy usage.

Magnetic refrigeration

Technologies such as magnetic cooling have potential advantages such as no harmful refrigerants and potentially high efficiencies above those of vapour compression technologies. Magnetic refrigeration takes advantage of the magnetocaloric effect: the ability of some metals to heat up when they are magnetized and cool when demagnetized. The majority of prototypes developed have been based on the use of gadolinium magnets that are quite expensive. More recent work has looked for new materials that are cheap, have suitable transition temperatures and exhibit a large magnetocaloric effect.

New foods (less refrigeration)

Proponents of GM foods claim benefits can include longer shelf lives than conventional foods. Longer shelf life means that some foods (most likely fruit and vegetables) may not need refrigeration in the store.

Some conventional products do not need refrigeration if they are cured or dried. Certain processes such as irradiation or high pressure processing have been expounded as a way to increase shelf life of meat with minimal refrigeration. There is therefore a possibility that some, if not all, foods may require less or no refrigeration in the future.

Optical cooling (heavy-metal-fluoride glass doped with ytterbium)

Laser, or optical, cooling is based on a principle known as anti-Stokes fluorescence and occurs when the amount of energy emitted by a solid, when exposed to an energy source, is more than the energy it absorbs. A laser aimed at certain materials will excite the materials' atoms to a higher energy state. These excited atoms absorb a little extra energy from the heat of the surrounding material. When they produce photons, the photons are of a higher energy than the initial laser energy and this radiation of energy cools the material.

Optical cooling has been developed at Los Alamos when researchers used laser light to cool a glass compound doped with ytterbium (Yb), a rare earth element. Significant improvements in the technology have occurred with sample temperature being able to be reduced by up to 47°C.

Peltier

Peltier, or thermo-electric (TE) devices, are lightweight, small, and inexpensive and do not utilise high-GWP refrigerants. TE devices are limited by their low efficiencies (approximately one-third those of a vapour compression system) but do have some advantages in terms of direct emissions, reliability, quiet operation and also may be useful for spot cooling.

Pulsed electrical thermal de-icers

Recently, work by the Thayer School of Engineering at Dartmouth has shown that thin, electrically-conductive films applied to surfaces and heated with millisecond-long pulses of electricity can make ice melt from surfaces. Called thin-film, pulse electro-thermal de-icers they create a thin layer of melted water on a surface that melts ice efficiently. If this technology can be economically applied to evaporators it has potential for low energy and efficient defrosting.

Stirling cycle variations

A number of Stirling cycle variations exist. The Ericsson is a double-acting Stirling-type engine in which the displacer piston also acts as the power piston. The cycle has been demonstrated to have a relatively high efficiency but requires further development.

Gifford-McMahon cycle coolers use helium gas as the working fluid and were primarily developed for cryo pumping. Cryo pumps are commercially available and are used in medical applications.

The Vuilleumier cycle machine resembles a duplex Stirling machine. The main difference being the use of pistons by the duplex Stirling system to maintain large pressure differences in the cylinders, while the Vuilleumier machine uses displacers in the cylinders for small pressure differences. The cycle has been used traditionally for obtaining liquid nitrogen or liquid oxygen. However, recently a Vuilleumier cycle heat pump for air conditioning temperatures has been developed.

The Malone cycle applies liquids to Brayton or Stirling cycles. Liquid CO_2 has been used in these cycles, mainly with applications in defence cooling.

Thermionic refrigeration – Borealis chip

Novel thermionic technology developed by Borealis Exploration Ltd uses a vacuum diode that pumps heat from one side of a chip to the other to provide localised cooling and refrigeration. These chips are claimed to deliver up to 70-80% of the maximum (Carnot) theoretical efficiency, significantly higher than vapour compression efficiencies. Initial commercialisation is thought to be in aircraft due to the small size, low weight and low power advantages of the chip[37].

Vortex tube cooling

The vortex tube is also known as the Ranque-Hilsch vortex tube and is a mechanical device that separates a compressed gas into hot and cold streams. It has no moving parts. Vortex tubes have lower efficiency than traditional air conditioning equipment. They are commonly used for inexpensive spot cooling, when compressed air is available.

Water

Water has been used commercially in industrial chillers at facilities such as Legoland in Denmark. Water systems operate under a vacuum and require large volume flows of water to be compressed using turbo compressors with relative high-pressure ratios. Therefore, systems tend to be rather large and have some design challenges.

[37] Ying-Feng Pang, (2002). Integrated Thermal Design and Optimization Study for Active Integrated Power Electronic Modules (IPEMs). MSc thesis, Faculty of the Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Appendix 1
Summary of technologies

Page no.	Technology (alphabetic)	Energy saving application	Total indirect saving (MWh p a)	Indirect CO_{2e} saving (tonnes p a)	Direct CO_{2e} saving (tonnes p a)	Total CO_{2e} saving (tonnes p a)	Pay back (yrs)	Application (yrs)	Barriers to staff /customers	Availability barriers	Limits to commercial maturity	Ease of use and installation	Technology interdependence	Maintainability	Legislative issues
									H=major barrier, M=partial barrier, L=no barrier	H=prototype/demonstrator only, M=limited availability, L=available	H=lack of maturity, M=intermediate, L=mature	H=major issues, M=partial, L=simple	H=high (i.e. can only apply with another technology or can be affected by application of another technology), M=some, L=none	H=major issue, M=some problems, L=no issues	H=major (issue now), M=could be an issue in near future, L=no impact
46	Absorption	MT packs	0.0	0.0	156.0	156.0	15.0	1.0	L	M	M	M	M	M	L
45	Adsorption	MT packs	0.0	0.0	156.0	156.0	10.0	1.0	L	M	M	M	M	M	L
31	Air curtain optimisation	MT cabinets infiltration	134.1	72.9	0.0	72.9	1.1	1.5	L	M	M	M	M	L	L
31	Anti-fogging glass	LT FGD/HGD ASH heat load, ASH energy	136.4	74.2	0.0	74.2	0.4	3	L	H	H	M	M	L	L
36	Anti-frost evaporators	LT defrost energy, defrost heat load	57.7	31.4	0.0	31.4	2.6	5	L	M	M	M	M	L	L
20	ASH controls	ASH heat load	55.3	30.1	0.0	30.1	0.6	0.5	L	L	M	M	M	L	L
32	Back panel flow	MT pack (ex deli)	104.5	56.8	0.0	56.8	1.4	1.5	L	M	M	M	L	L	L
28	Borehole condensing	MT, LT pack	480.2	261.3	0.0	261.3	0.9	1.0	L	M	M	H	L	M	M
18	Cabinet lighting (non-LED)	Lighting all cabinets, lighting heat load	251.1	68.1	0.0	68.1	1	0.2	L	L	L	M	L	L	L
41	Cabinet location	Infiltration of cabinets close to doors (10%)	8.9	4.9	0.0	4.9	0.3	1.5	M	L	L	M	L	L	L
26	Cabinet selection	All refrigeration energy	828.0	450.4	0.0	450.4	0.2	1.0	L	L	L	M	M	L	M
47	Centralised air distribution	MT pack	52.9	28.8	0.0	28.8	7.9	2.0	L	M	M	H	H	M	L

37	Centrifugal fans	Fans all cabinets, fan heat	43.7	23.8	0.0	23.8	1.4	2.0	L	M	M	M	L	L	L
12	Cleaning and maintenance	MT, LT pack	160.1	87.1	104.0	191.1	1.3	0.2	L	L	L	L	M	M	M
26	CO_2 refrigeration technology	MT, LT pack	0.0	0.0	312.0	312.0	8.0	1.0	L	M	M	M	M	M	M
17	Condenser fans	MT, LT pack	133.6	72.7	0.0	72.7	0.1	0.3	L	L	L	M	L	L	L
21	Covers	Frozen well and deli cabinets	33.9	18.5	0.0	18.5	0.3	0.3	H	L	L	L	L	M	L
17	Curtains (strip)	MT dairy/meat infiltration	142.0	77.2	0.0	77.2	1.2	0.3	H	L	L	L	M	M	L
23	Defrost controls	LT defrost energy, defrost heat load	28.6	15.6	0.0	15.6	1.5	0.3	L	L	M	M	L	L	L
41	Desuperheating/heat recovery	MT, LT pack	8.0	4.4	0.0	4.4	10.4	1.0	L	L	M	M	H	L	L
14	Doors on cabinets	MT dairy/meat infiltration	236.7	128.7	0.0	128.7	3.7	0.5	H	L	M	M	M	M	L
37	Dual/ triple air curtains	MT dairy/meat infiltration	47.3	25.7	0.0	25.7	3.1	1.0	L	M	M	M	M	L	L
28	Dynamic demand	All refrigeration energy	414.0	225.2	0.0	225.2	0.2	2.0	L	M	H	M	M	L	M
38	Economisers	MT, LT pack	32.0	17.4	0.0	17.4	2.6	1.0	L	L	M	M	L	L	L
38	Electronic expansion valves	MT, LT pack	32.0	17.4	0.0	17.4	2.8	1.0	L	L	L	M	L	L	L
32	Evaporative condensers	MT, LT pack fan heat load, fan energy	131.3	71.4	0.0	71.4	0.6	1.0	L	L	L	M	M	M	H
15	Evaporator fan motors	MT, LT pack	163.7	89.1	0.0	89.1	0.1	0.5	L	L	L	M	L	L	L
13	Floating head pressure	MT, LT pack	320.2	174.2	0.0	174.2	0.3	0.5	L	L	L	M	M	L	L
30	Ground source	MT, LT pack	240.1	103.6	0.0	130.6	10.0	1.5	L	M	M	H	L	M	M
24	HCs (integrals LT)	LT integrals	1.7	0.9	0.2	1.1	1.4	0.2	L	L	M	L	L	L	M
24	HCs (integrals MT)	MT integrals	2.0	2.0	0.2	2.2	1.6	0.2	L	L	M	L	L	L	M
36	Heat pipes and spot cooling	MT, LT pack	64.0	34.8	0.0	34.8	5.9	3.0	L	H	H	H	M	L	L
29	Low-GWP in MT pack	MT pack	19.3	10.5	155.9	166.4	11.6	3.0	L	H	H	H	L	M	M
46	High efficiency compressors	MT, LT pack	80.0	43.5	0.0	43.5	1.6	5.0	L	M	M	M	M	L	L
34	High efficiency evaporators and condensers	MT, LT pack fan heat load, fan energy	91.1	49.6	0.0	49.6	4.2	2.0	L	M	M	M	M	L	L
39	Insulation e.g. VIPs	LT pack conduction	23.5	12.8	0.0	12.8	5.3	2.0	L	M	H	H	L	M	L
43	Internet shopping	All refrigeration energy	2208.0	1201	0.0	1201	10.0	10.0	M	M	M	M	L	L	L

15	LED lights	Lighting all cabinets, lighting heat load	178.7	97.2	0.0	97.2	5.0	0.5	L	L	M	M	L	L	L
22	Loading – volume	MT, LT pack	32.0	17.4	0.0	17.4	1.3	0.1	L	L	L	L	M	L	L
22	Loading – duration and temperature	Infiltration, MT, LT pack	30.7	16.7	0.0	16.7	2.8	0.1	L	L	L	L	M	L	L
20	LPA	MT, LT pack	80.0	43.5	0.0	43.5	2.3	0.5	L	L	L	M	M	L	L
35	Nanoparticles	MT, LT pack	64.0	34.8	0.0	34.8	1.3	3.0	L	M	M	M	L	L	L
18	Night blinds	MT dairy/meat infiltration	118.3	64.4	0.0	64.4	1.5	0.3	M	L	L	L	L	M	L
46	Novel building fabric	All refrigeration energy	110.4	60.1	0.0	60.1	13.0	6.0	L	M	M	M	M	L	L
16	Occupancy sensors and controls – cabinet lighting	Lighting all cabinets, lighting heat load	143.8	78.2	0.0	78.2	2.3	0.8	L	M	H	M	M	M	L
29	Occupancy sensors and controls – doors	Infiltration multi-decks	208.9	113.7	0.0	225.2	0.6	1.5	L	M	H	M	M	M	L
40	Off-cycle losses	Integrals	9.3	5.1	0.0	5.1	0.1	0.3	L	L	M	L	L	L	L
31	Pipe insulation/rifling/ reduced pressure drops	MT, LT pack	144.1	78.4	0.0	78.4	1.7	1.0	L	L	M	M	M	M	L
45	Polygeneration	All refrigeration energy	276.0	150.1	156.0	306.1	7.0	3.0	L	M	M	M	M	M	L
30	R134a in MT pack	MT pack	9.7	5.3	130.0	135.3	5.3	0.5	L	L	M	M	L	L	M
11	R404A replaced by R407A	MT, LT pack	48.0	26.1	228.0	254.1	2.2	0.5	L	L	M	M	L	L	M
24	Radiant heat reflectors	Radiant, well	16.4	8.9	0.0	8.9	3.6	1.0	L	M	H	M	M	M	L
12	Re-commissioning	All refrigeration energy	364.3	198.2	0.0	198.2	0.7	0.2	L	L	M	L	M	L	L
39	Reflective packaging	Radiant, LT pack	29.3	15.9	0.0	15.9	0.7	2.0	L	H	H	H	M	M	L
34	Refrigeration system contamination	MT, LT pack	80.0	43.5	0.0	43.5	1.0	1.0	L	L	M	M	M	L	L
21	Riser or weir plate	MT infiltration except deli	34.8	18.9	0.0	18.9	4.2	0.2	L	L	L	L	L	L	L
27	Secondary systems	MT, LT pack	0.0	0.0	312.0	312.0	9.0	1.0	L	M	M	M	L	M	M
20	Set-point	MT, LT pack	80.0	43.5	0.0	43.5	0.5	0.5	L	L	L	L	M	L	M
35	SLHE	MT, LT pack	80.0	43.5	0.0	43.5	1.7	1.0	L	L	L	M	L	L	L
14	Store dehumidification	Infiltration all cabinets	136.9	115.5	0.0	115.5	6.3	0.5	L	L	M	M	M	L	L
23	Store light (LED and fluorescent)	LT, MT radiant	17.4	9.5	0.0	9.5	4.8	0.8	L	L	M	M	L	L	L
47	Store light (natural)	LT, MT radiant	7.0	3.8	0.0	3.8	12.0	2.5	L	M	H	H	L	L	L

13	Store temperature	LT infiltration, radiation, conduction	279.4	152.0	0.0	152.0	0.3	0.1	L	L	L	L	L	L	L
16	Suction pressure control	MT, LT pack	160.1	87.1	0.0	87.1	0.5	0.5	L	L	L	L	L	L	L
40	Supercooling/chilling of food	LT pack (25%)	15.9	8.6	0.0	8.6	3.2	5.0	L	H	H	H	M	L	L
43	Supermarket cold store	All refrigeration energy	1932.0	1051	78.0	1129	0.2	2.0	M	M	M	H	L	L	L
39	Tangential fans	MT, LT pack	32.0	17.4	0.0	17.4	4.6	1.0	L	L	M	M	M	L	L
11	Training	MT, LT pack	160.1	87.1	156.0	243.1	2.6	0.2	L	L	L	L	L	L	L
41	Variable speed drives (integral)	Integrals	2.5	1.3	0.0	1.3	4.6	3.0	L	M	M	M	L	L	L
44	Vending cabinet concepts	Infiltration, radiant all cabinets	868.5	472.4	0.0	472.4	0.3	6.0	H	H	H	H	L	H	L
44	Water loop systems	MT, LT pack	48.0	26.1	312.0	338.1	4.3	1.5	L	M	M	H	M	M	M

The Carbon Trust is a not-for-profit company with the mission to accelerate the move to a low carbon economy. We provide specialist support to business and the public sector to help cut carbon emissions, save energy and commercialise low carbon technologies. By stimulating low carbon action we contribute to key UK goals of lower carbon emissions, the development of low carbon businesses, increased energy security and associated jobs.

We help to cut carbon emissions now by:

- providing specialist advice and finance to help organisations cut carbon
- setting standards for carbon reduction.

We reduce potential future carbon emissions by:

- opening markets for low carbon technologies
- leading industry collaborations to commercialise technologies
- investing in early-stage low carbon companies.

www.carbontrust.co.uk
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ACT ON CO_2 is the Government's initiative to help individuals understand and reduce their carbon footprint. Visit http://actonco2.direct.gov.uk for more information.

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