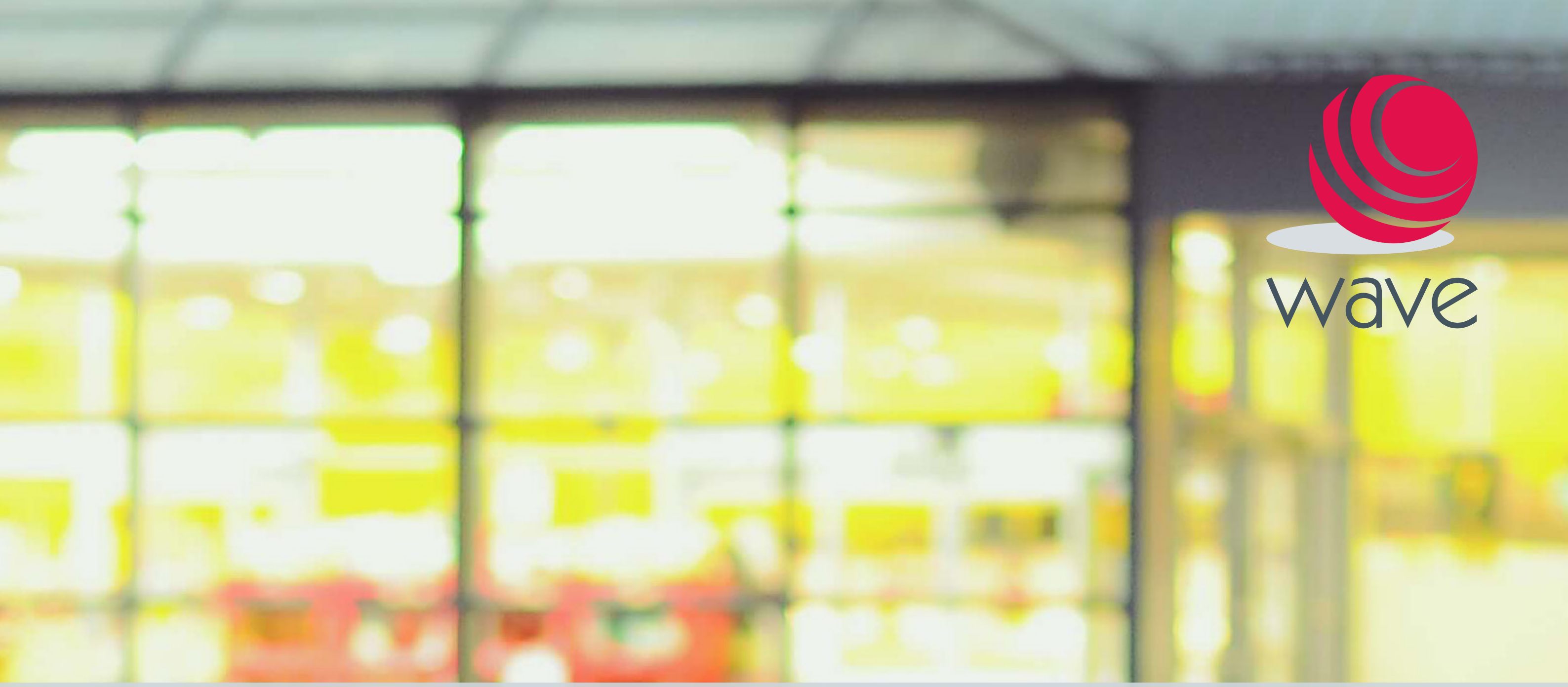

RETAIL REFRIGERATION
White Paper 2019

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ABOUT WAVE

WAVE Limited was established in 2015 to provide high quality, cost effective, independent refrigeration design management, technical analysis, and market awareness consultancy services to businesses who will require support to mitigate the impact of EU. 517/2014: commonly referred to as the F-gas Regulations.

The author of this paper is James Bailey, a time-served Mechanical Engineer and Chartered Engineer. During his career James has held various positions at leading UK engineering consultancy practices and possesses expertise and knowledge in retail refrigeration applications.

ABOUT THIS PAPER

This paper began its existence as a learning document for WAVE's first trainees and junior engineers in 2017. Over time as the detail developed, the author felt that the content may be of benefit to a wider audience connected with the refrigeration industry.

ABBREVIATION

BS	British Standard
C	Centigrade
CO2	Carbon Dioxide
COP	Coefficient of Performance
DX	Direct Expansion
EEV	Electronic Expansion Valve
EU	European Union
F-gas	Fluorinated Refrigerant Gases
GHG	Green House Gas
GSHP	Ground Source Heat Pump
GWP	Global Warming Potential
HC	Hydrocarbon
HFC	Hydrofluorocarbons
HFO	Hydrofluoroolefin
K	Kelvin
kg	Kilogram
kW	Kilowatt
kWh	Kilowatt Hour
LFL	Lower Flammability Level
LT	Low Temperature
MT	Medium Temperature
PRV	Pressure Relief Valve
RH	Relative Humidity
RHI	Renewable Heat Incentive
ROI	Return on Investment
SHR	Sensible Heat Ratio
TD	Temperature Difference
TEWI	Total Environmental Warming Impact
TEV	Thermostatic Expansion Valving Impact
WFD	Waste Framework Directive

WHITE PAPER AIM
&
BACKGROUND AND CHANGE

1. WHITE PAPER AIM

The aim of this paper is to inform, guide and provide advice to operators of supermarkets and convenience stores.

The following topics are addressed:

- Background and change – F gas phase-down
- Understanding emissions
- Refrigerant properties
- Best practice – refrigeration system control and containing refrigerants
- Refrigeration technologies
- Refrigeration energy initiatives
- Enhancement initiatives
- Good system design
- Greenhouse Gas Emissions
- Training
- Managing refrigerant

2. BACKGROUND AND CHANGE

The refrigeration industry has a significant carbon footprint and is one of the largest electricity users in the UK; accountable for c.4% of the UKs total energy consumption. Responsible for direct greenhouse gas (GHG) emissions (when allowed to leak to atmosphere), are hydrofluorocarbon (HFC) refrigerants.

European wide legislation EU. 517/2014; commonly referred to as the F-gas regulations will phase down the use of HFC refrigerants by 79% in stages between 2017 and 2030.

The 79% reduction is based on the CO2 equivalent of a refrigerant, and this is calculated from its Global Warming Potential (GWP). To mitigate the impact of the phase-down, low GWP refrigerants (both synthetic and naturally occurring) have and continue to be placed on the market

Further to the F-gas regulations, on the 15th October 2016, a deal struck by over 150 countries to cut HFCs in a complex amendment to the Montreal Protocol was made. The key agreements of this amendment are:

- The new agreement will see three separate pathways for different countries
- Richer economies like the European Union, the US and others will start to limit their use of HFCs within a few years and make a cut of at least 10% from 2019 – reaching 85% by 2036
- Some developing countries like China, nations in Latin America and island states will freeze their use of HFCs from 2024
- Other developing countries, specifically India, Pakistan, Iran, Iraq and the Gulf states will not freeze their use until 2028
- China, the world's largest producer of HFCs, will not actually start to cut their production or use until 2029
- India, will start even later, making its first 10% cut in use in 2032

Large end users operating in the retail arena are aware of the implications of legislation and are preparing for future change through developing & implementing alternative refrigeration technology. It can be considered accurate to state that many smaller retailers are not, and as we now arrive in 2018, where a 37% reduction in supply is up on us, the retail refrigeration sector will now have to face into a supply and demand crisis in respect to the phase-down and availability of many common refrigerants.

UNDERSTANDING EMISSIONS

Retail Refrigeration
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3. UNDERSTANDING EMISSIONS

CO_2 is colourless and odourless, and is naturally emitted from the earth's surface, as well as through the human function, respiration, and the plant function, photosynthesis. CO_2 is released during exhalation and is used by plants for photosynthesis, which yields glucose. Glucose is a carbohydrate that must be consumed by humans to have energy.

Aside from these natural processes, CO_2 is also emitted through the combustion or burning of fossil fuels such as coal, oil, and natural gas. Combustion occurs when vehicles are driven as well as when power and industrial plants are operating.

Combustion, otherwise known as burning, is the greatest source of CO_2 emissions globally. Typically, fossil fuels are burnt for electricity generation in homes, commercial buildings such as supermarkets, industrial uses, and transportation.

Though necessary to support the way we live and prevent untimely perishing of food, all refrigerants and their applications are carbon intensive. There are four key functions that contribute to CO_2 emissions in refrigeration:

- Combustion at facilities producing or extracting a refrigerant
- Transportation of a refrigerant to its source of use (these emissions are concerned with travel)
- Direct emissions caused through releasing refrigerant to atmosphere
- Indirect emissions that are a result of electricity generation in operating refrigeration systems

Indirect emissions in food retail are concerned with electricity generation of a refrigeration systems daily operation. Of the four carbon emitting entities that concern refrigeration, it is often the indirect emissions that contribute the highest level of emissions over a system life time.

The most commonly used refrigerants belong to the HFC family; those that are being targeted under a phase-down.

The current direction and trend in food retail is the adoption of naturally occurring refrigerants; CO_2 and HC's. CO_2 has a GWP of one, whilst HC's can have a GWP as low as three. In terms of CO_2, its GWP is almost 2000 times lower than the most commonly used HFC refrigerants.

It is clear why food retailers have been directed towards the use of naturally occurring refrigerants, however, long-term caution in terms of environmental impact and energy grid burden must be carefully considered as it quite plausible that future policies could target energy consumption.

REFRIGERANT PROPERTIES

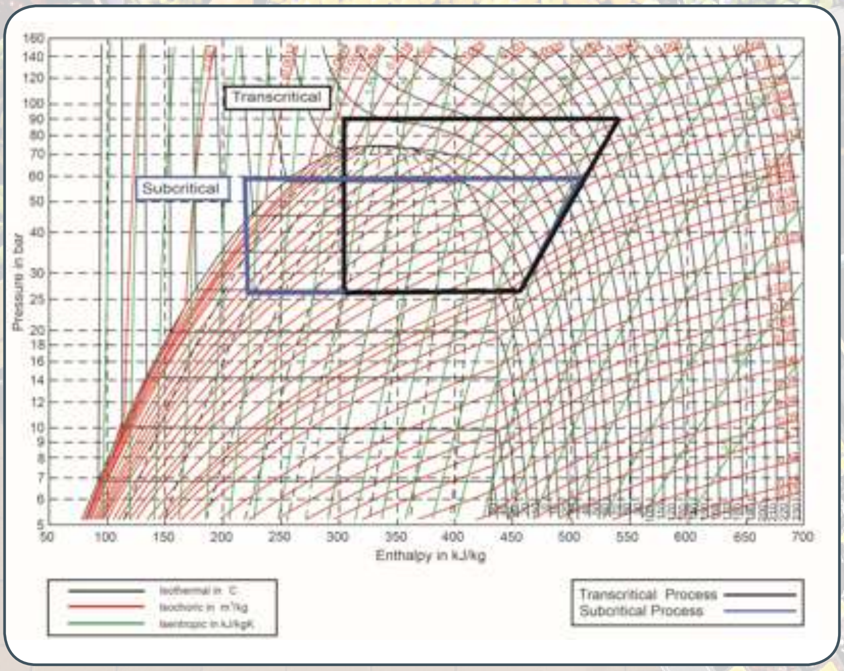
4. REFRIGERANT PROPERTIES

There are many thermodynamic properties that need to be considered when selecting a refrigerant. All refrigerants which damage the ozone layer have been banned in the UK, however many substances have a significant GWP that is released into the atmosphere through leakage. The GWP of a substance is expressed as the effect Carbon Dioxide has as a greenhouse gas.

The pressures contained within a refrigeration system are lower on the evaporating (cold) side of the system than in the condensing (hot) side of the system. It is desirable that the lower operating pressure is above atmospheric pressure to prevent any leakage within the low-pressure areas whilst preventing air and water vapour to mix with the refrigerant. A high vapour density entering the suction side of the compressor requires a smaller compressor swept volume than a refrigerant with a low density, as it is the mass flow rather than the volume flow which influences the system refrigeration capacity. The energy consumption of a refrigeration system can be influenced by the choice of refrigerant, those that require a large pressure ratio between the evaporation and condensing conditions require a higher compressor power input. Energy consumption varies from one refrigerant to another therefore it is desirable to select a refrigerant that consumes less energy. As a gas is compressed its temperature rises, the temperature is proportional to the pressure but is also influenced by its thermodynamic properties; some refrigerants have higher discharge temperatures than others used over the same pressure ranges. High discharge temperatures should be avoided as they can cause the refrigerant and oil to breakdown or cause a reaction resulting in the formation of acids or solids. High discharge temperatures can be useful though when recovering waste heat.

All compressors use oil to lubricate them, and some of this oil always leaves with the discharged high-pressure gas. As this gas is cooled and condenses, the oil is mixed with the liquid refrigerant and circulates through the system. When refrigerant enters the evaporator, the pressure is reduced, and it boils away at a low temperature and its pressure is reduced. It is essential that the refrigerant gas leaving the evaporator within the suction line allows the transportation of oil along the suction line walls back to the compressor. The selected refrigerant must not have any adverse reactions with the materials used within the system. In any refrigeration system water and air must be avoided. Water in refrigerant will freeze in the expansion valve resulting in the failure of the refrigeration plant, and it can also react with the refrigerant and oil to form acids that are drawn to the motor windings causing compressor failure. Non-condensable gases such as air will collect within the condenser and reduce the heat transfer surface area thus increasing the system pressure and energy consumption.

The pressure-enthalpy diagram below details a refrigeration cycle in both sub-critical (desired condition) and trans-critical operation (experienced with CO2 in higher ambient temperatures).



BEST PRACTICE / GOOD CONTROL

5. BEST PRACTICE / GOOD CONTROL

Refrigeration energy consumption typically accounts for 30-60% of an average retailer's total energy consumption. Installing basic mechanical systems that include efficient compressors, condensers and cooling fixtures will not guarantee optimum temperature control, performance or energy efficiency. This is due to refrigeration systems being dynamic; they do not often operate at their design load, thus creating inefficient part load operation (accounting for over 98% of a refrigeration systems annual run time).
To match refrigeration system capacity to actual operation, varying and dynamic refrigeration loads found in retail, the control system required to accomplish this task is of paramount importance.
The challenge for refrigeration system designers, manufacturers, and end users is to find effective ways to modulate key system components, and these are:

- Compressors
- Condenser fans
- Expansion valves

The aim of modulating these components is to achieve stable & reliable system operation, high system operating efficiencies, and closely control the refrigerated fixtures and products to achieve their desired temperatures.

5.1 KEY CONSIDERATIONS IN REDUCING REFRIGERATION SYSTEM ENERGY CONSUMPTION

Reducing refrigeration loads: The smaller the evaporator refrigeration load at the compressor, the lower the required mass flow rate and resulting compressor power will be.

Expansion valves: The expansion valve should precisely meter the refrigerant flow so that the refrigerant is completely flashed to vapour inside the evaporator. Whenever liquid refrigerant passes through the evaporator and into the return suction line before being completely evaporated (boiled-off), some refrigeration effect is lost, and non-useful refrigeration work is done. System efficiency is subsequently reduced, resulting in wasted energy. Additionally, even small amounts of liquid refrigerant in the suction line that reach the compressor suction inlet will cause substantial damage.

Return gas temperature: Lower suction return gas temperatures result in a higher density gas and this reduces the compressor power. This is a consequence and benefit of precisely metering liquid refrigerant into the evaporators by expansion valves - resulting in low return gas temperatures and "superheat" conditions. Compressor volumetric efficiency is increased by the lower temperature and this in turn results in a higher density suction gas flow. High return gas temperatures decrease system efficiencies and unnecessarily increase refrigeration energy usage.

Raising suction pressures: The higher the system suction pressures are, the lower the associated compressor power, thus increasing system efficiency.

Low discharge pressures: Refrigeration system condenser fans and other "high side" pressure control elements should be designed and operated in a manner that allows the lowest compressor discharge pressure possible for a given outside ambient air temperature.

Summary

Having introduced the effects that refrigeration system power consumption has on system efficiency, the following section explains how good refrigeration system control can deliver "optimal performance" to minimise refrigeration system power consumption.

5.2 REFRIGERATION SYSTEM CONTROL

Refrigeration System High Pressure Control

Many mechanical and electronic control systems cycle condenser fans to operate as "on" or "off" to maintain fixed high side condensing and operating pressures – this introduces system inefficiencies. To maximise efficiency, design condensing temperatures, when outdoor ambient temperatures permit, should allow the corresponding condensing pressures to drop (float) to lower levels.

A good refrigeration control strategy will allow a refrigeration system to take advantage of lower outdoor ambient temperatures to reduce refrigeration system compressor power. This can be carried out by floating the temperature difference (TD) between the outside ambient air temperature and condensing temperature – this ensures that the absorbed condenser fan load matches the external temperature and condensing requirement – as opposed to targeting and maintaining a fixed design condensing condition. This allows a refrigeration system to operate at the lowest condenser pressure possible with minimum required condenser fan power. This control is commonly referred to as "floating condensing pressure control" – as it measures and subsequently matches the outside ambient air temperature. Typically, floating condensing pressure provides savings of 7% over fixed pressure (maintaining a design target condensing condition). A consequential benefit of allowing the condensing pressure to float is that it reduces absorbed compressor power.

Compressor and Condenser Variable Speed Control

Traditionally, retail refrigeration system condenser fan and compressor controllers cycle fans and compressors "on" or "off" to match system refrigeration capacity to the actual load levels at any given time. Unfortunately, given the capacity steps available from this control methodology, it is rarely possible to deliver the exact amount of compressor and condenser capacity required for a given level of compressor and condenser loading. Varying degrees of uneven system operation often result, and a consequence is higher energy consumption due to poor control of the suction and condensing pressures. At worst this can cause excessive "start" and "stop" cycling of compressor motors and condenser fans. The application of variable speed drives to compressor motors and condenser fans, using varying speed algorithms, can eliminate these capacity matching problems; thus, reducing energy consumption. Benefits associated with compressors result from improved suction pressure control and compressor volumetric efficiency increases when operating at lower speeds. Savings from the application of variable speed control for compressor capacity can be between 7 to 12%.

Evaporator Control using Electronic Expansion Valves

High compressor suction pressures and lower suction return gas temperatures lower compressor power and refrigeration system energy usage. Therefore, it is paramount that the expansion valves that control the flow of refrigerant into fixture evaporator coils do so in a manner that results in the lowest gas superheat at the exit of the evaporator, without allowing liquid refrigerant to pass from the coil into the suction line. Inadequate refrigerant flow into an evaporator coil, as evidenced by high coil exit suction superheat temperatures, reduces evaporator coil heat transfer effectiveness and heat transfer rates; the consequential result of this is a larger temperature difference between the evaporator coil and the fixture air flow to remove the same amount of heat - thus increasing energy consumption.

Conventional mechanical Thermal Expansion Valves (TEVs) often exhibit these concerns and have numerous limitations; they must be set manually using a difficult process that is often not executed effectively. When setting TEVs, it is necessary to open-up the refrigerated fixture, disturbing its normal air flow and making proper valve setup almost impossible. Once a TEV is adjusted, any change in refrigeration system conditions including liquid pressure or sub-cooling, evaporator suction pressure, fixture load and airflow will result in the valve no longer being properly set and superheats that are either too high or too low. During cold weather, lower liquid refrigerant temperatures at TEVs can cause liquid refrigerant to flood through evaporator coils. During warmer periods when condensing and liquid temperatures rise, conventional TEVs can starve evaporators, which forces lower suction pressures to maintain fixture temperatures and hence higher compressor energy consumption.

Modern day electronic expansion valves (EEVs) and stepper motor valves alleviate these concerns as they are adaptable in respect to controlling the flow of refrigerant into a coil from dynamic system loads. They control the superheat at the exit of evaporator coils accurately under all system conditions and fixture loads. Unlike mechanical TEVs, where the operation is dependent on suction and liquid pressures as well as springs and capillary tubes for valve operation, the EEV requires little more than the sophisticated software algorithms within the valve controller to provide precise evaporator outlet superheat control under all conditions; thus, positively impacting on stability, performance and energy consumption of the refrigeration system.

5.3 SUPPORTING FURTHER ENERGY EFFICIENCIES

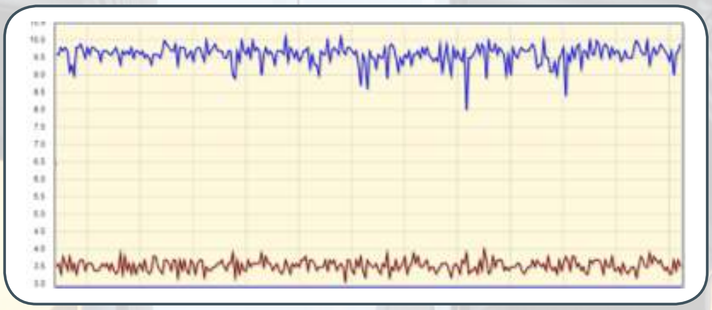
Liquid-Suction Sub-cooler

Though not directly linked to a refrigeration systems control algorithm, the use of a liquid-suction sub-cooler will present further energy efficiencies to a refrigeration system – the process of sub-cooling and its associated benefits will be automatically processed through monitoring system temperatures and pressures by a well-designed and controlled refrigeration system. A liquid-suction sub-cooler is installed with the aim of increasing the performance of the evaporator through lowering the refrigerant inlet temperature to the systems evaporators. Through heat exchange, the suction gas exiting the sub-cooler will be slightly higher than it was before entering – this presents a further benefit as the load at the compressors will be marginally lower thus reducing energy consumption further.

5.4 ANTICIPATED OPERATION

Liquid-Suction Sub-cooler

When following the principles of efficient refrigeration system design and control, the first thing that an engineer will investigate is whether the system is stable and efficient. A measure of this is high suction / low discharge pressures. The graph below details a 24-hour performance of an efficient refrigeration system.



Key:

- » Suction pressure (bar)
- » Discharge pressure (bar)

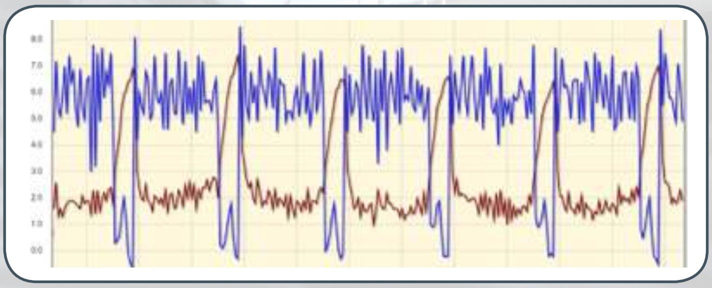
It is visible that the suction and discharge conditions are stable. The consequence of "floating condensing pressure control" is seen.

The graph below is a 24-hour measurement taken on a UK summer day.

Key:

- » Discharge temperature (°C)
- » Ambient temperature (°C)

It is visible that the discharge temperature is efficiently tracking the outside air temperature. The graph below is a 24-hour measurement of a display case – the control temperature and superheat values are recorded.



Key:

- » Control temperature (°C
- » Superheat (K)

It is visible that when in operation (outside of defrost), that the display case control temperature is stable (EEV control is metering with a level of expected precision) and that the superheat value is also stable.

5.5 SUMMARY

To enhance and maintain refrigeration system stability, reliability, performance and efficiency, control of the following key componentry should consider:

Evaporator Control

All componentry that directly control evaporators should be designed to directly measure evaporator pressure and temperature by means of a sensor, and automatically adjust the flow of refrigerant through the evaporator to maintain the refrigerated space within pre-defined operating limits.

Condenser Control

All componentry that directly control condensers should be designed to directly measure condenser pressure and temperature by means of a sensor, and automatically adjust the airflow across the condenser in a manner that maintains condensation at the rate required to maintain the thermal balance of the refrigeration system under different operating loads and weather conditions.

Compressor Control

All componentry that directly control compressors should incorporate automatic control algorithms to monitor the rate of change in system suction pressure or refrigerant temperature to prevent compressors from unnecessarily being controlled to load or unload in response to small fluctuations in cooling demand.

BEST PRACTICE / LEAKAGE

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6 BEST PRACTICE / LEAKAGE

For good leak testing to occur it is crucial to understand why leakage happens and the detrimental impact that it can have. Refrigerant leakage affects everyone from end users, industry stakeholders, and the public; leakage increases system operating costs (service, refrigerant, electricity, and downtime), power consumption, emissions, and adverse climate change, whilst reducing efficiency. Steps to minimise refrigerant leakage must begin with regular leak testing; end users have found significant benefits in exceeding regulatory minimum test periods. There are various leak testing methods and devices available. To ensure that they are effective it is recommended that checks to the operation and calibration are made after every 25 hours that the device has been in operation, avoid contaminating the detector with oil, replace the filter (if fitted) regularly, and use a reference leak to check the detector is working correctly.

If a leak detector cannot find a leak, the system charge should be recovered and pressurised with dry nitrogen. When checking system tightness, it is important to remember that a pressure of up to 10 bar g (150 psi) is usually sufficient to find leaks using a soap solution (though a trace gas would be recommended as a more accurate and modern day solution), any regulator fitted to a nitrogen cylinder must be in good condition and should not have an output pressure significantly higher than what is required. The regulator should be closed when it is fitted to the cylinder then slowly opened when all connections to the system are tight and the access valves are fully open.

Prior to commencing the refrigerant usage / F gas log should be reviewed to check where previous leaks have been found, the most appropriate leak detection method should be selected, and it is important that the test is carried out in a methodical, systematic manner whilst ensuring the entire system is checked.

To reduce leakage potential in existing systems it is important to ensure that pipework is not vibrating or chafing, and pipe clips should be adequate and in good condition. When tightening flanges, tighten the bolts evenly (to the correct torque), when replacing flared components, use flare adaptors opposed to manually made flares, and remove line tap valves from the system.

Overcharged systems increase the condensing pressure and reduce performance and efficiency, whilst presenting a greater leakage potential. Undercharged systems are less efficient, may not meet the load requirements and have higher running costs. Systems must be charged to a known weight – this is the most accurate method of achieving the correct charge. When charging to a full liquid line site glass, ensure there is a load on the system (this will prevent undercharging issues in higher load conditions).

6.1 IDENTIFYING REFRIGERANT LEAKS

Common leaks are listed below along with possible cause/s and solution/s:

Shut-off valves Possible causes include wear to the packing gland between the valve body and spindle shaft, overheating during installation and caps not being fitted. Solutions can include ensuring the gland is tightened (but not overtightened) and wrapping the valve with a damp rag while brazing.

Schrader valves Possible causes include valve cores being damaged during brazing, cores not being tightened correctly when replaced, deterioration of internal seals over time and caps not being fitted. Solutions can include removal of the core when brazing the fitting in, ensuring the valve body has cooled before replacing the core, using the correct tool to replace the core, and ensuring a cap is fitted.

Flare joints Possible causes include loosening of the flare nut due to thermal expansion and contraction, poor joint preparation, over tightening leading to damage at the copper flare face and the flare nut, and under tightening of the flare. Solutions can include the use of flare solder adaptors. If a flare must be made, cut the pipework with a pipe cutter and de-burr using the correct tool – use an eccentric flaring tool and ensure the correct length of pipe is protruding through the flaring block, checking the flare size ensuring that it does not foul the flare nut on the pipe, lubricating the flare and the use of a torque wrench to tighten the flare.

Mechanical joints and flanges Possible causes include incorrectly prepared joints, non-replacement of gaskets, uneven tightening of flanges, incorrect torque when tightening bolts, and incorrect materials and dimensioning. Solutions can include avoiding using PTFE on HFC refrigerants (use an appropriate thread seal), replacement of gaskets on flanges (remove all the old gasket material before applying the new one), tightening flanges down evenly applying the 'opposites' rule and using a torque wrench to carry out the final tensioning of flange bolts.

Pressure relief valves (PRVs) and fusible plugs (over-pressure protection) Possible causes include PRVs that do not reseat when the pressure drops following release (whilst leaks across the PRV seat can occur during normal operation), and fusible plugs (due to a wide temperature and / or pressure variations) weaken the bond between the solder core and the plug. Solutions can include leak testing the PRV outlet, where a PRV is leaking replace it with an equivalent rated device, the use of dual PRVs with a changeover valve where possible, using a bursting disc in conjunction with the PRV where possible, and where possible avoid using fusible plugs - replace them with a PRV.

Condensers (air-cooled) Possible causes include excessive air circulation, impact damage due to foreign bodies on the air stream, and vibration causing premature failure of the tube bundle. Solutions can include positioning condensers on a level base, repair or replace out of balance fans, checking the fin block for signs of oil, and when replacing a condenser, select it carefully – especially if it is going into an aggressive environment.

Line tap valves Possible causes include the poor fitting of the line tap onto the pipe, being fitted to poorly formed or flattened pipework, using an incorrect size line tap and loosening of the line tap valve due to movement or vibration. Solutions can include ensuring the correct size of the tap valve is being used, fitting a line tap to access a system and then braze a service access connector to replace it (do not leave the line tap valve on the system), and leak test any line taps found fitted and replace them where possible.

Pressure switches Possible causes include vibration causing the pressure coupler to split or damage to the switch, the pressure coupler chafing, rupture to the switch bellows due to vibration, failure of the flare connection, and poorly supported or fixed switches. Solutions can include using flexible couplers, ensuring couplers do not rub or chafe on other pipes or surfaces, ensure switches are correctly fixed and supported, the use of flare solder adaptors on the switch where copper pipe is being used, using dual bellow switches where possible, and connecting switches to minimise the transfer of vibration.

O-rings Possible causes include wear, hardening, flattening, and leakage after retrofitting (due to reaction to new oil and incorrect materials or dimensions). Solutions can include checking for roundness and flexibility (change seals rather than re-using existing ones), oil the seals before fitting them and ensuring replacement seals are suitable for the system oil and refrigerant.

Capillary tubes Possible causes include chafing due to insecure fixing and leakage where a capillary tube expansion device enters or exits a suction line. Solutions can include checking the capillary tube is firmly located and cannot chafe on any other material / surface.

Return bends on evaporators and condensers Possible causes include corrosion due to chemical action on return bends on evaporators or condensers (since the copper used in these heat exchangers can be thinner than normal copper pipework, a surface pinhole is likely to result in a leak in a relatively short period of time). Solutions can include leak testing return bends carefully, specifying materials which are less susceptible to damage – such as coated or electro plated fin blocks, and where chemical cleaners are used ensure they are totally washed off.

6.2 DESIGNING OUT LEAKS

First and foremost, a refrigeration system designer should consider, and where practical, eliminate potential leak points during the design process. Furthermore, it is essential that the system charge is kept to a minimum; consideration of plant location and pipework service routes are major factors in this. It is imperative that the number of mechanical joints and seals are kept to an absolute minimum. Consideration must be given to specifying adequate supporting, bracketing and fixing of pipework. Pipe sizing and fixing should consider and eliminate (where possible) the potential of liquid hammer and excessive vibration.

Uncapped valves can be a significant source of long-term, low level leakage. Valve caps should be specified as part of the design process and it is advisable that all caps are attached to the valve to ensure that they cannot be separated overtime.

Pressure relief is a system necessity and the devices exhaust must be adequately sized for the refrigerant. Dual port valves should be a designer's preference as rapid changeover is possible with minimal interruption to the system – guidance should be specified in terms of valve inspection, replacement and date.

The designers project scope of works should clearly state during installation that pipework and fittings are to be protected from dirt and moisture ingress, and that systems should be purged with nitrogen to prevent oxide build-up inside the pipework. The entire system should be properly evacuated with oxygen-free nitrogen to ensure minimal moisture content prior to strength and tightness testing.

Where possible the designer should specify a fixed leak detection system within a machinery plant room / refrigeration pack irrespective of regulatory minimum requirements; this will ensure that the impact of high level leaks is identified in a timely manner and kept to a minimum. This is advisable for both F-gas and non-F-gas refrigerants.

System commissioning should be considered as an integral part of the design process. To confirm that the system performs to the design it is vital that all refrigeration systems are strength tested as directed by BS EN-378: 2016. Prior to this test, and again as directed by BS EN-378: 2016, the system should undergo a leak tightness test. During this test all joints should be checked for tightness using an appropriate mobile leak detector; the test should last for a minimum of one hour, though for more complex systems it is advisable that the test lasts for 24 hours to ensure any smaller leaks that would only be identified by a small drop in pressure are identified. If leaks are found during the tightness test they must be fixed, and the test procedure should be repeated until satisfactory results are achieved.

REFRIGERATION TECHNOLOGIES

7 REFRIGERATION TECHNOLOGIES

7.1 INTRODUCTION

Alternative refrigeration technologies are rightly being encouraged and gaining in popularity – however, the uptake in next generation technologies amongst smaller and franchised retail outlets is believed to be very low, and this is a significant concern as these retail operations make up a significant portion of retail refrigeration.

Stakeholder training and knowledge in respect of alternative technologies, though continuing to improve is nowhere close to the industry knowledge of HFC refrigerant technology; this is a significant risk and industry challenge that must be overcome (highlighted in section 11).

The refrigeration technologies discussed in this section are:

» Trans-critical CO2

» Secondary Systems

» Ducted Air

» Water Cooled Integrals

» A2L Refrigerants

7.2 TRANS-CRITICAL CO2

The operating pressure of CO2 is considerably higher than traditional refrigeration systems.
Although there are significant concerns regarding system operating pressure and training, trans-critical CO2 exhibit the following benefits:

» Refrigeration plant configuration is like traditional HFC systems

» High grade of heat recovery is available

» Rapid temperature pull-down when charging the system

This section provides an overview on the CO2 covering:

» Properties

» Health & Safety

» Developments

Properties

CO2 is naturally a naturally occurring gas and is classified as being environmentally benign. It has a global warming potential of one. CO2 has some properties which may be unfamiliar to many engineers, the most obvious being the operating pressures in refrigeration systems; they can be as high as 100 bar. As an example, evaporating temperatures in a system operating at -10°C will be 26.5 bar; typically, the evaporating temperature in a HFC system is 3.5 bar. CO2 has a high triple point and a low critical pressure; at a temperature of -56.5°C / 4.2 bar, CO2 can exist in a liquid, vapour or solid state, it is the only refrigerant that has a triple point above atmospheric pressure. At pressures above 73.8 bar (trans-critical) the difference between liquid and gas phases cease to exist.

The triple point is unlikely to be a concern in a retail environment, but the trans-critical pressure corresponds to a saturated temperature of 31.6° bar, and this can easily be exceeded in higher ambient conditions, therefore traditional air-cooled condensers need to be replaced with gas coolers. Trans-critical operation requires an increase in compressor power, and discharge temperatures can easily exceed 100°C. A positive feature of trans-critical operation is that the heat rejected is released at a steadily decreasing temperature, while during sub-critical operation, condensing a large percentage is released at a constant temperature during the change phase. This can be used as a benefit to recover rejected waste heat as the average release temperature is considerably higher thus providing a high grade of heat.

CO2 when operating in lower ambient conditions; below the critical point occur for the vast part of the year. It is possible to maintain a sub-critical condition regardless of the ambient condition – a cascade or secondary type system will ensure this. CO2 operates with a high volumetric capacity; such characteristics benefit the system; components including pipe-work and fittings are much smaller when compared to other refrigerants. CO2 when in a vapour phase has a higher density than that of traditional refrigerants; therefore, the swept volumes of compressors for operation with CO2 are smaller, though the construction size is similar due to the construction having to cope with much higher pressures.

Health and Safety

When CO2 reaches ambient temperature within a refrigeration system, its pressure increases rapidly. A rise in pressure results in the activation of the systems pressure relief devices, which will result in a loss of system performance or potential system failure. CO2 must not be allowed to be isolated or trapped in any part of a refrigeration system due to its volatile characteristics. If its temperature is not maintained within its design envelope, the temperature / pressure will rise at a rapid rate. Appropriate pressure relief devices, by-pass lines that include suitably rated non-return valves must be considered on all system components that require servicing; these include evaporators, filters, driers, isolation valves etc.

CO2 occurs in the atmosphere at a concentration of 0.04% and is toxic in low concentrations. It can cause asphyxiation if a refrigeration system leak occurs in a confined area. At a concentration of 3%, CO2 is mildly narcotic and leads to a 100% increase in breathing rate. At 5% breathing becomes difficult, with headaches and sweating occurring following exposure of one hour. At 10% unconsciousness occurs in less than one minute; this can lead to death. It is recommended that CO2 leak detectors are in all plant rooms, areas containing header stations, cold-rooms and any low-lying area where CO2 can collect; leaking gas will be cold, and it has a higher density than air, therefore It is considered essential to install leak detectors in any public area where there is a leak potential.

Developments

Parallel Compression

Trans-critical CO_2 is not able to return into a liquid state at the outlet of a gas cooler as the pressure temperature relationship is dictated by external temperatures - the CO_2 remains as a compressed vapour. Without the phase change only sensible heat is removed. To return the vapour back into a liquid, the pressure of the vapour must be reduced, and this is done by a high-pressure expansion valve. Because of this expansion the subsequent proportion of un-useful flash gas vapour is significant (up to 35%). It is this un-useful flash gas that can be addressed by parallel compression.

Introducing this parallel compressor on to a rack system enables the CO_2 system to control the receiver pressure with this compressor and therefore decreases the compression ratio of the flash gas that is experienced when expanding it into a systems intermediate liquid receiver. Essentially the parallel compressor recycles the flash gas to the gas cooler directly from the intermediate liquid receiver (circa 8 bar higher), and it is this that results in a lower compression ratio than that of the main rack compressors. It is believed that the decreased compression ratio results in energy savings by up to 10%.

Parallel compression does not overcome the fundamental condensing inefficiencies of trans-critical operation - it acts to recycle the flash gas at a higher efficiency than the main refrigeration compressors can. It can generate complexities in rack design, build and system servicing, for these reasons some manufacturers may be reluctant to offer it as the efficiency savings can be considered marginal when compared to the additional cost and complexity.

Ejectors

Ejectors improve the efficiency of trans-critical CO_2 systems. They enable a system to achieve a pressure lift in the MT suction line as it raises the pressure from suction pressure to receiver pressure, thus decreasing the compression ratio necessary to compress the MT suction vapour. Ejectors work to recover the energy from the refrigerant that was introduced at the compressor. They do this by:

» Taking high pressure condensed / cooled trans-critical CO_2 vapour refrigerant and expanding it though a nozzle

» The accelerated flow of this vapour acts to force the flow of suction gas through another nozzle

» This combined flow then enters into a diffuser, where the vapour flow rate is reduced, this process raises the pressure of the mixture above the system suction pressure. The mixture is finally passed into a liquid separator

» The suction vapour pressure is higher than it was thus decreasing the compressor energy consumption

The processes of ejector technology are complex; however, it has significant potential. Research suggests that up to a 20% increase in system COP can be achieved. A down side to ejectors is that the nozzles must be 'dynamic' to allow them to change to suit the demands of system duty fluctuations.

7.3 SECONDARY SYSTEMS

Secondary coolant fluid systems employ a low charge primary circuit refrigerant to maintain a glycol cooling medium.

Propylene glycol continues to be the cooling medium of choice in industrial and process cooling applications as an environmentally sustainable solution. Propylene glycol has also been applied in retail refrigeration to varying levels of success – the variation often being an increase in energy consumption when compared to HFC systems. Energy consumption is a major concern with propylene glycol systems, namely due to its viscosity and required pumping load to circulate the fluid. Propylene glycols kinematic viscosity is c.7.5mm2 / sec in MT (chilled) applications. The alternative to propylene is ethylene glycol – until recently the refrigeration industry stayed clear of this fluid due to its high toxicity.

Recent developments have resulted in a non-toxic ethylene glycol being introduced. It has a significantly lower kinematic velocity of 5.94mm2/ sec, alongside an enhanced thermal conductivity.

Health & Safety

Hydrocarbons useful for refrigeration systems have a low GWP; the most obvious feature of them is that they are flammable and explosive. This imposes certain limits on their application; they are not suitable for circulation within branch and main type pipe work in a retail environment. For safety reasons a substance which is flammable, or explosive should not be used in systems where a significant volume extends into occupied areas.

System Control

Secondary systems can be considered a little more complex than traditionally configured refrigeration systems. This section introduces the system control of secondary systems.

Primary Circuit Control

The control of the system is governed by the glycol flow temperature set-point (c. -4°C in retail MT applications). Compressor loading is initiated when the required set-point temperature drifts – unloading occurs when the glycol flow temperature is satisfied. The control is intuitive in that it can monitor and maximise the timing that the system achieves temperature, and as such hold further compressors from starting – this function increases efficiency potential.

Condenser Control

In an optimum configuration secondary system are fitted with a split condenser coil – designed to allow 60% of the condenser to be shut-down and drained of refrigerant when the system detects low operating pressures. This section of the condenser remains dormant until the system detects higher system operating pressures where the coil is re-instated to allow normal condenser function.

Secondary Circuit Pump Operation

The secondary circuit employs a pump to circulate the glycol. Its operation can be controlled via an EC drive that through the control system detects the temperature difference between the glycol flow and return condition – when this TD closes there is a reduction in duty required (it is the display case solenoid valves closing that dictates this). This creates an increase in system pressure, and through slowing the pump the system allows the volume of glycol to be reduced to minimise energy consumption.

Heat Recovery

Secondary systems, through careful design can provide an effective source of heat recovery or heat generation through operating refrigeration compressors as heat pumps in low ambient conditions.

7.4 DUCTED AIR

Ducted Air is a paradigm changing food retail refrigeration concept. The Ducted Air system delivers low pressure cool air to display cases via ductwork. The cooling effect is generated away from the sales area in easy to understand, reliable and cost-effective plant.

Ducted Air systems have been found to reduce energy consumption and overall GHG emissions when compared to other types of refrigeration system at one major food retailer.

Ducted Air uses a unique and simple refrigerated display case that offers the following benefits:

- Drainage is not necessary – this eliminates water leakage potential
- Nuisance noise from display cases is eliminated as air distribution fans are not necessary
- There are no serviceable components - taking engineers away from the sales area
- Store involvement is reduced (de-merchandising) – saving money and disruption
- Cold aisle effect through trial and installation has been found to reduce - this reduces store heating and enhances the customer experience
- They are the only display case that eliminate direct CO2 emissions from a sales area
- Through research and analysis carried by a retailer adopting this technology it has been established that the life expectancy is double that of any other display case

From an installation perspective Ducted Air system offers the following benefits:

- Health & Safety – as it is ductwork that delivers the cooling effect to display cases and not pipework, hot works (brazing) are not necessary. This removes the risks associated with brazing including the use of oxy-acetylene
- Reduced installation time – Installation of pipework is time intensive, installing ductwork as an alternative reduces this significantly. Due to air being non-toxic and having a GWP of zero, there is no requirement for an expensive sales area leak detection system
- Reduced commissioning time - It is necessary to pressure test a completed pipework system prior to commissioning to ensure that it is leak tight; this is not required with Ducted Air. Eliminating system pressure testing alongside simpler plant commissioning enables Ducted Air to reduce commissioning by 48 hours – this means that food retailers can trade sooner than with any other refrigeration system

Ducted Air, like secondary systems are refrigerant agnostic; and any refrigerant can be used as the medium to cool the air.

Stakeholder training and knowledge in respect of alternative technologies, though continuing to improve is nowhere close to the industry knowledge of HFC refrigerant technology; this is a significant risk and industry challenge that must be overcome (highlighted in section 11).

7.5 WATER-COOLED INTEGRALS

Each display case has its own integral refrigeration system that can operate on any refrigerant (the condenser is in the form of a plate heat exchanger). The condensing medium is glycol and is a connected to a common circuit; a pump station circulates the glycol and condenses the refrigerant to each display case via the plate heat exchangers. The returning glycol passes through a dry air cooler before re-circulating through the system.

Advantages include:

» Contained and reduced refrigerant charge that make any potential leaks easier to identify

» The display case can use an extensive range of refrigerants

» Breakdowns are contained to each display case rather than a complete system

» Insulation is not required on the glycol pipe work and is flexible and more economical than traditional copper pipe

Disadvantages include:

» In the event of a leak on the glycol circuit, the entire refrigeration system is at risk

» As the dry air cooler is not changing the state of the glycol the surface area required to remove the heat is greater than that of a typical air-cooled condenser; the fans operate at a higher speed to compensate

7.6 A2L REFRIGERANTS

A2L refrigerants are low GWP synthetic refrigerants that have potential for use in all system types presented in this section.

Understanding A2L Refrigerants

A2L refrigerants exhibit low toxicity and are mildly flammable. In terms of toxicity, like HFCs, A2Ls have a permissible exposure limit of >400ppm and the related risk of accidents is low. In terms of an A2Ls flammability they typically require:

» Greater than 0.3kg/m^3 concentration in air to burn

» A heat of combustion of <19,000kJ/kg

» A burning velocity of <10cm/s

The effect of ignition from A2Ls is low (when compared to hydrocarbons) and they are difficult to ignite. It is necessary that components with ignition sources are avoided, and appropriate ventilation is provided where necessary as per guidance to relevant standards. E.g. BS EN-378: 2016: Refrigerating Systems and Heat Pumps.

In practical terms the quantity of an A2L would have to be greater than an A3 to create a flammable mix, as its flame when ignited travels at a slower rate. This has a positive impact on the maximum charge size of an A2L when compared to an A3 refrigerant. Please see refrigerant classification table below.

Classification	A (Low Toxicity)	B (High Toxicity)
1 (Non flammable)	A1: HFCs	B1: Rarely Used
2L (Mildly Flammable)	A2L: Low GWP HFC Replacements	B2L: Ammonia
2 (Low Flammability)	A2: Rarely Used	B2: Rarely Used
3 (High Flammability)	A3: Hydrocarbons (R290, R600 etc.)	B3: No Refrigerants

In considering an A2L it is essential that application type is considered and that the following mitigating factors are assessed and where appropriate investment made in the following:

» Flammability potential – consider suitable segregation, component choice and eliminating ignition sources where appropriate

» Install a suitable leak detection system

» In plant areas (rooms or containers) ensure a forced ventilation system is installed where required that activates upon detection of a leak

» As with any refrigerant – handle with care in a ventilated area with tools and equipment specific for the refrigerant

An advantage of A2Ls is that they operate very similarly to A1 HFC refrigerants. A2Ls may be more expensive than A1 (HFC) refrigerants initially, however this may be an acceptable trade-off when assessing their application against other alternative refrigerants.

Calculating the Allowable Charge Volume of an A2L

Important note: Please refer to BS EN-378:2016 for detailed guidance in respect to calculating allowable charge volumes of A2L refrigerants (the examples contained within this section have been provided using BS EN-367: 2016).

Lower flammability limit (LFL), is usually expressed in volume percent, and this is at the lower end of the concentration range over which a flammable mixture of gas or vapour in air can be ignited at a given temperature and pressure. The flammability range is determined by the upper and lower flammability limits. Outside this range of air / vapour mixtures, the mixture cannot be ignited (unless the temperature and pressure are increased).

This paper focusses on A2L – Chemours XL20 which has a given ASHRAE number of R454C. XL20 has an LFL 0.289 kg/m3 and a GWP of 148; though the methodology of assessment holds true to any A2L.

Calculating the maximum charge volume of a sealed integral display case (e.g. water or air cooled) would be identified as follows (room volume given for indicative purposes only):

20% x LFL x Room Volume
20% x 0.289 x (6 x 5 x 3.5 = 105m3)
Allowable charge = 6.07kg

In fulfilling the risk management obligations set-out by C.4, for A2L refrigerants, this may allow charge sizes up to ~60 kg in an occupied space.

This is calculated adhering to C.4 as follows:

m3b x 1.5 given as:

m3b = 130m3 x 0.289
= 37.57 kg x 1.5

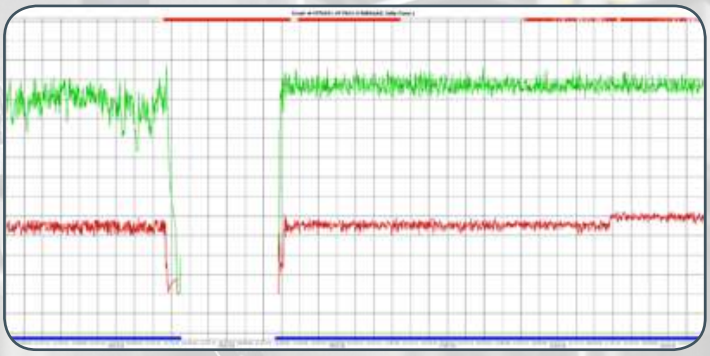
= 56.355 kg*

*** This paper does not offer guidance in respect to the risk management and allowable charge volume of A2L refrigerants; extensive professional dialogue and subsequent application guidance outside the intention and aim of this paper must be sought**

Summary

This section identifies that A2L refrigerants will be a viable HFC alternative in certain applications for retailers. Through greater knowledge and understanding A2L refrigerants, it may be possible to significantly expand their application in retail refrigeration.

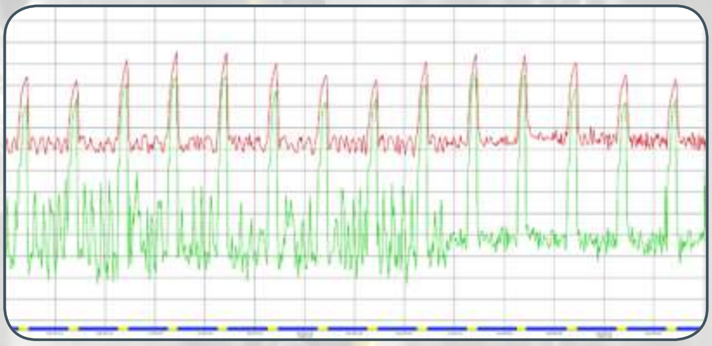
A controlled environment trial that is ongoing at the time of commissioning this report, identifies that the performance characteristics of A2L refrigerants in distributed DX systems is excellent. The refrigerant – R454A possesses a GWP of 238, and the graph below illustrates the plants suction and discharge stability enhancements when compared to the systems previous refrigerant R407A.



Key:

- Discharge condition
- Suction condition

Stability enhancements to the display case control and evaporating temperatures are also clearly visible in the graph below.



Key:

- Display case control temperature
- Evaporating temperature

REFRIGERATION ENERGY INITIATIVES

Retail Refrigeration
White Paper 2019

8 REFRIGERATION ENERGY INITIATIVES

This section presents available initiatives that are proven to reduce energy consumption and carbon emissions – that are readily available and applicable to any type of retail refrigeration system.

8.1 DISPLAY CASE SHELF EXTENSION GUIDES

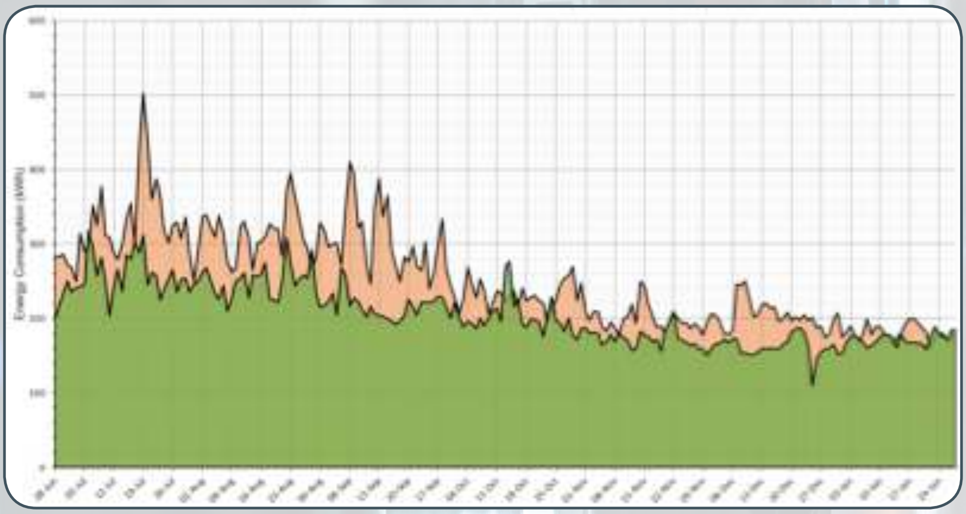
Refrigerated displays use an air curtain which is discharged across the open front a display case to keep the contents at a consistent cool temperature whilst minimising infiltration. However, a high percentage of cold air spills out of the front of the case into the store. This generates waste energy and is also the cause of 'cold aisle syndrome'. Display case shelf extension guides reduces waste energy and cold aisle syndrome through aerodynamically directing the air from the air-off into the air-return grille at the base of a display case.

Based on analysis and considering refrigeration energy savings only, where a comparison has been made against a 6-month period in 2016 and 2017 respectively, with annual energy use extrapolated, the return on investment of installing display case shelf extension guides is 3.14 years – based on a cumulative daily average kWh saving of 17%.

Shelf extension guides enhance display case air containment and improve 'cold-aisle syndrome', resulting in warmer chilled aisle temperatures. When considering the positive impact that this has on a stores heating requirement – in respect to a reduction the return on investment of installing shelf extension guides can be reduced to 2.82 years.

Store heating energy improvements are based on a 3% reduction in energy consumption per 1°C increase in cold aisle temperature (dependent on store size and refrigeration system).

The in store cold-aisle temperature improvements where Aerofoil shelf guide extensions have been installed is 3°C. The graph below identifies the energy savings pre and post installation of shelf extension guide technology:

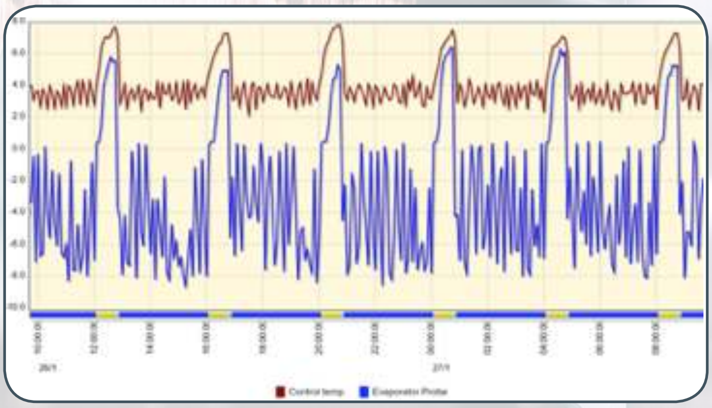


To further understand the energy benefits associated with shelf extension guide technology, the following graphs provide performance comparisons between a display cases with and without shelf extension guide technology.

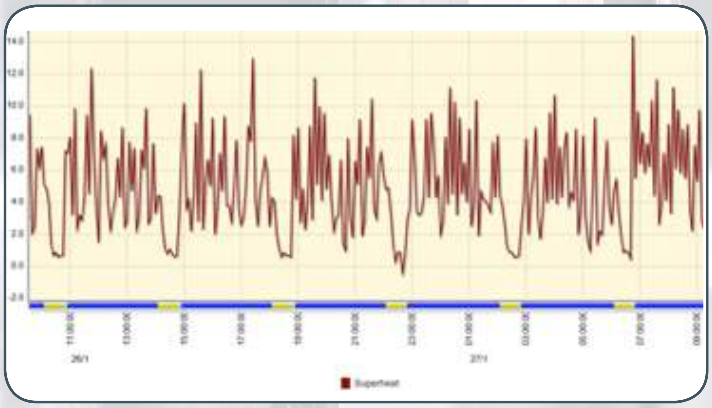
Three key performance functions are analysed:

- Control & Evaporating Temperature
- Superheat
- Air-on and Air-off Temperature

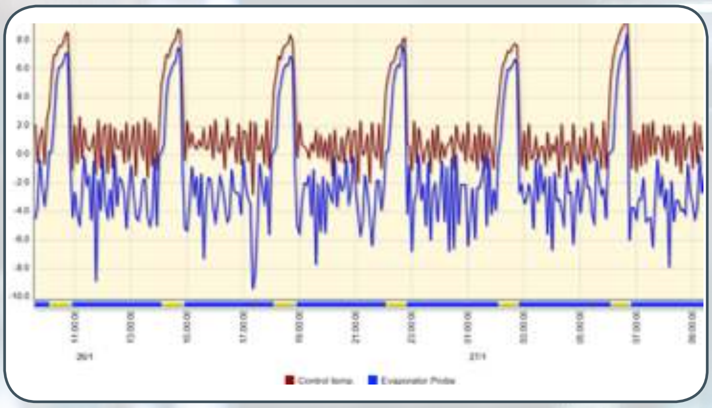
Control & Evaporating Temperature (no shelf extension guides):



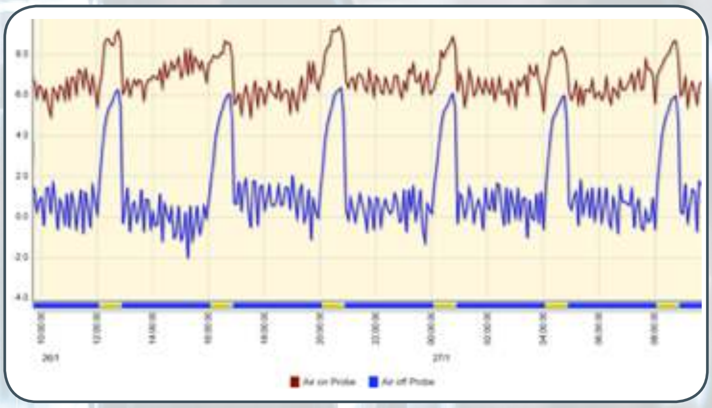
Superheat (with shelf extension guides):



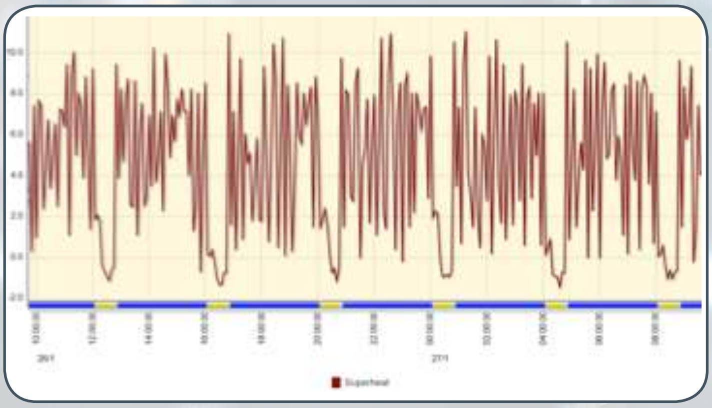
Control & Evaporating Temperature (with shelf extension guides):



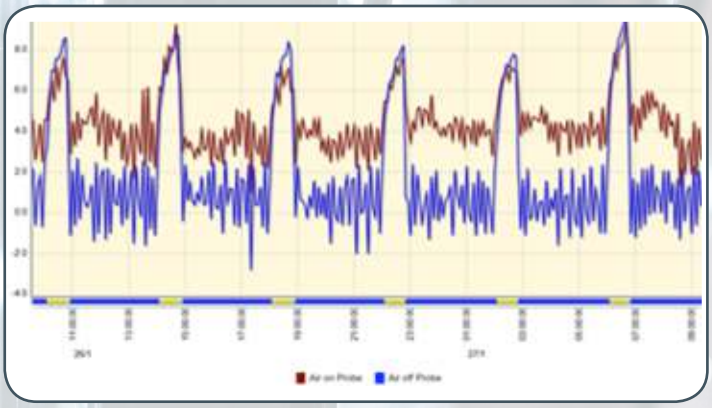
Air-on and Air-off (no shelf extension guides):



Superheat (no shelf extension guides):



Air-on and Air-off (with shelf extension guides):



Summary

Alongside and correlating to energy performance benefits, shelf extension guides provide the following display case performance enhancements:

» Enhanced stability / higher than target evaporating temperature

» Enhanced superheat control / valve performance

» Tightening band width; air-on and air-off temperatures

8.2 DOORS

Though considered a barrier to trade, without doubt the initiative with the greatest potential energy and carbon emission saving are MT display cases that utilise doors. In convenience stores where it can be argued that the trade barrier would be minimal due to the reduced likelihood of impulse purchases, system energy reduction of 40% could be achieved alongside a 25% reduction in refrigerant charge compared to open fronted display cases.

Retro-fitting doors to open fronted display cases is possible, however, it is crucially important to consider oil return. This is due to the pipework – specifically risers being sized on a duty match for open fronted display cases. Careful consideration must also be given pack control and display case evaporating temperatures.

8.3 TRANSDUCER CONTROL

The use of pressure transducers for evaporator control is beneficial for providing an accurate superheat reading. Superheat settings are not critical within a range of a couple of degrees either side of the required set point. All this will result in is that the coil performance may vary a few percent from the optimum output. Considering that the actual display case load is generally always significantly lower than the ISO 3 display case test condition.

For this reason, the use of a transducer for every case or even for every case run is not necessary. A single transducer somewhere on a system should be sufficiently accurate, bearing in mind that the maximum suction line pressure loss is designed to be lower than 2K at full design load (and therefore 2K would be highest variation in superheat). Under normal operating conditions the load will likely be half to two thirds the maximum design load and hence the pressure loss in the suction pipework will be much lower than 2K.

The use of a reduced number of pressure transducers and thermocouples will result in a capital saving. Many alarm & monitoring controls suppliers already incorporate this system control so correct commissioning is all that may be required.

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8.4 EET CONTROL OF ELECTRONIC EXPANSION VALVES

This control strategy uses the expansion valve opening to control the case or cold room temperature by the following method:
If the display temperature is higher than the set point the expansion valve pulses open longer and allows more liquid refrigerant to enter the evaporator and thereby provides a higher refrigeration effect. If the load temperature falls below the target the valve pulses less and reduces the flow rate.

In the instance for a sudden high load, such as may be encountered on re-starting the evaporator after a defrost, it is likely that the valve would open so wide that liquid flood back would occur. The control strategy therefore incorporates a safety back-stop to ensure that the superheat cannot fall below a minimum setting and the valve pulses will be reduced to ensure this.

There are several benefits to EET control:

- The case temperatures are controlled extremely accurately
- The load on the display cases only varies with the store ambient conditions, which change very slowly. With all case evaporators pulsing at a constant rate the load on the compressor pack is virtually constant
- If a pack is fitted with a variable capacity lead compressor it is possible for it to match the constant load and so the number of compressor starts, and stops is very low, maybe only one or two a day. Compressor starts result in a momentary high electrical load. It is also true, particularly with reciprocating compressors, that the highest wear rate occurs during staring as there is zero oil pressure
- If the evaporators are provided with the EET control strategy and pack with a variable capacity lead compressor is used, the whole system becomes very stable with virtually no variations in display temperatures, suction and discharge pressures and compressor capacities

Disadvantages of EET control are:

- Service engineers may be unfamiliar with the control strategy and need re-training to recognise and understand the system
- The control strategy cannot be used with condensing units. This is because the compressors have a constant capacity and if the load is lower than this then very low suction pressures and coil icing will result. Also, if the compressor shuts down on low pressure this will not prevent the expansion valve from continuing to pass liquid which would then flood the compressor on start up

Savings in the region of 2% to 5% is possible via EET control.

8.5 ADIABATIC COOLING

Adiabatic cooling of condenser air reduces the temperature of the air by evaporating moisture into the air and using the latent heat of evaporation to provide a reduction in the air temperature entering the condenser coil.

The amount of cooling available depends on the temperature and humidity of the ambient air. In hot, very dry conditions (32°CDB and 30%RH) the temperature reduction could be as high as 10°C.

In cool conditions and during wet weather there may be no cooling effect available.

Refrigeration systems are generally designed to have spare capacity even in maximum design ambient conditions and ISO3 store conditions of 25°C and 60% RH, and external ambient conditions of 32°C (Dry Bulb).

Because these design conditions only occur in very exceptional weather conditions; only a few hours per year, refrigeration packs rarely encounter more than 75% of their maximum design load and mostly operate at lower loads than this, particularly during night time when night blinds are in operation.

If the refrigeration load is 50% of the design load, the difference between ambient air temperature and the condensing temperature would also reduce; by 50%. Therefore, if the condenser was selected for a, 8Ktd, with 50% loading the condensing temperature could be reduced by 4°C until the minimum allowable condensing temperature is reached.

When the condensing temperature is at or near the minimum set point there is no significant energy benefit available from reducing condensing temperatures by using adiabatic assistance. The minimum condensing temperature setting for UK retail refrigeration systems is generally 20°C, and Wave estimate that adiabatic cooling could offer some potential saving in ambient temperatures above / around 18°C.

Local ambient temperature profiles vary with location. 18°C is achieved or exceed in SE England for approximately 1650hrs in an ‘average’ year, in Northern England only 550hrs per year and in Northern Scotland just 210hrs per year.

Potential Benefits

In a typical UK supermarket that has 300kW MT and 60kW LT load where applying traditional HFC refrigeration systems, typical calculated energy consumption values with and without adiabatic cooling are provided below:

» Store MT Projected Energy Consumption (No adiabatic) – 585,000 kWh

» Store LT Projected Energy Consumption (No adiabatic – 310,000 kWh

» Projected Store Refrigeration Energy Consumption (no adiabatic) – 895,000 kWh

» Store MT Projected Energy Consumption (With adiabatic) – 535,000 kWh

» Store LT Projected Energy Consumption (With adiabatic – 278,000 kWh

» Projected Store Refrigeration Energy Consumption (With adiabatic) – 813,000 kWh

The difference in annual energy consumption between systems with and without adiabatic condensing is 82,000 kWh. However, considering the available condensing surface area will increase away from design across most of the year, and that a 10°C reduction between adiabatic and air-cooled conditions is generally only going to be applicable in higher ambient conditions, it is sensible to anticipate the projected savings to be lower than those identified above (c.50%). In Trans-critical CO2 systems, the savings could be far greater as maintaining sub-critical operation for extensive periods could be achieved.

A further benefit of adiabatic cooling is that it will reduce the frequency of over temperature alarms for refrigerated display cases and plant.

Concerns

The following concerns should be considered prior to the installation of adiabatic cooling solutions:

» Additional water usage

» Water pumping power (where adiabatic solutions – e.g. multi-packs are served from a single supply; a supply pump is recommended)

» Water filtration – concerns surrounding 'hard' water that will result in water scale

» Selection and longevity of the mesh

» Longevity / servicing of the adiabatic nozzles – considering any propensity to block

» Longevity of the solenoid valves metering the adiabatic water usage

» Associated maintenance cost

8.6 GROUND SOURCE HEAT PUMP TECHNOLOGY (GSHP)

Introduction

The ground below the earth's surface can store vast quantities of heat energy. This energy can be harnessed to provide a heat source in winter, or a heat sink in summer. To transfer this energy from the ground, a GSHP system is employed as the heat transfer mechanism. GSHP technology is an increasingly popular and efficient means of providing heating and reducing cooling load within food retail stores. GSHP technology is also an attractive proposition in terms of reducing environmental carbon impact, whilst generating extremely high net savings; measured as the difference between the operating cost of conventional heating and cooling systems versus heating and cooling systems that employ GSHP technology. The net savings are not just a measure of the operating cost difference; they also include an annual RHI payment that is payable for twenty-years.

Background

GSHP technology has been popular in North America and Scandinavia for over twenty-years. They can be installed anywhere, using a borehole or other less common means; this report will focus on the application of borehole technology. Boreholes are drilled to an approximate depth of 80 meters and are used to harness heat in a series of deep underground pipes in a closed loop system that contains a water-glycol mix. It is this mix that is used to extract the stored energy within the ground. This energy can then be used to provide space heating, domestic hot water, and reversed to provide / reduce a buildings cooling demand. The only energy used by a GSHP is electricity to power the heat pump compressors and the circulation pumps which transfer heat energy from the ground into the building.

An important realisation of GSHP technology is that it negates any requirement for a natural gas supply.

GSHP technology require less maintenance than combustion-based heating systems, and they have a significantly longer life than those used in food retail. Unlike burning oil, gas, LPG or biomass, a heat pump produces no carbon emissions on site (and no carbon emissions at all, if a renewable source of electricity is used to power them). GSHP systems are the only renewable energy technology that can benefit from the thermal energy storage properties of the ground to recycle heat from summer to winter.

Renewable Heat Incentive (RHI)

One focus of this section is to present the benefits of the Renewable Heat Incentive (RHI). The fundamental basis is of financial encouragement to install GSHP technology in commercial buildings such as supermarkets or convenience stores. The RHI is administered by Ofgem. Owners (retailer end users) of renewable heat technologies apply to Ofgem who will pay tariffs, on a quarterly basis, over 20 years based on the total rated equipment capacity – in this assessment, it is based on a GSHP system that has a total output of 1050kW. Payment is made across two tariffs – one at £0.087 per kWh and one at £0.026 per kWh. Retail end users will need to provide information on the metered heat generated and satisfy Ofgem that the equipment is used to provide heating, and that the equipment is maintained according to the manufacturer's instructions.

Conventional Refrigeration and Heating Systems in Food Retail

Historically, refrigeration and heating systems employed in food retail stores have been independent entities. Significant heat is generated from a retail refrigeration process, and generally this is discharged to atmosphere via a bank of fans connected to an air-cooler condenser. This heat can be categorised as waste – however, it has significant heat energy potential. Cost effective harnessing / recovery of this heat energy remains difficult to achieve to an optimum level versus capital expenditure as the available heat is at its highest during summer; when there is the lowest demand for it to supplement or achieve a stores heating requirement. The heating of food retail stores is generally achieved by means of air conditioning in convenience stores, and gas fire heating systems connected to air handling units in supermarkets. In terms of the latter, centralised plant with distribution ductwork, supplies air that is distributed into the occupied space from high level diffusers. These systems typically utilise reverse cycle systems to heat and cool the store as required to maintain the required sales floor temperatures (typically 19°C for heating and 23°C for cooling).

Applying GSHP Technology in Food Retail

GSHP technology solution is made up of a primary circuit consisting of pumps connected to piping system inclusive of connections to the borehole pipe network, refrigeration plant and heat pumps. It uses a use a vegetable based non-toxic, biodegradable, food safe propylene glycol, mixed to 30% as the heat transfer fluid. The glycol circulates through the primary circuit and boreholes, and transfers energy with the surrounding temperature of the ground. The conditions of the ground present a stable, effective and consistent condensing medium that can be used to reduce load from the refrigeration systems condensing and compressor operating conditions. The performance of the heat pumps is assisted by the rejected heat from the refrigeration system. This heat is stored in the ground via the borehole piping network; this storage acts as a heat sink. As annual ambient temperatures vary, the storage and subsequent use of this energy is used to support the stores refrigeration and heating demands.

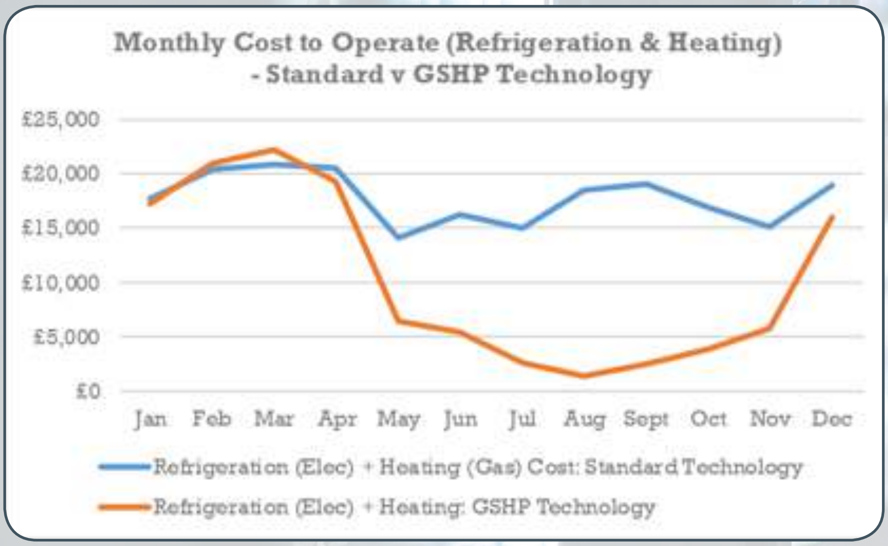
The secondary circuit provides heated fluid direct from the systems heat pump compressors (typically Bitzer screw compressors operating on R407F). This fluid is pumped to the stores air handling units (existing AHUs can be modified – detailed in the following section) and hot water storage / distribution plant.

The GSHP systems can be interfaced with any food retail refrigeration plant system – irrespective of refrigerant. Retrofit can take place and this involves the installation of an interface module that is connected to the plant systems discharge circuits (multiple plant systems can be connected to a single interface module). Standard refrigeration system condensers are still installed or retained in the case of retrofit – this is to ensure the refrigeration system remains operational in the unlikely event of a GSHP system failure. By taking the discharged refrigerant through the interface modules plate heat exchangers, heat is removed from the refrigeration system and transferred to the GSHP glycol pipe network circuit where the otherwise waste heat energy from the refrigeration system is subsequently stored in the ground.

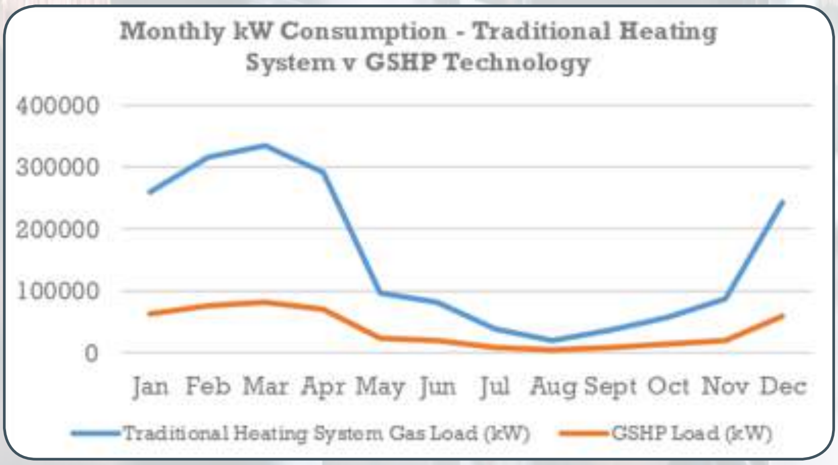
The plate heat exchangers within the interface module are staged to meet the seasonal dynamic demands and loads from the refrigeration system, and to suit the heat output for its desired purpose – heating / hot water.

Annual Energy Profiling

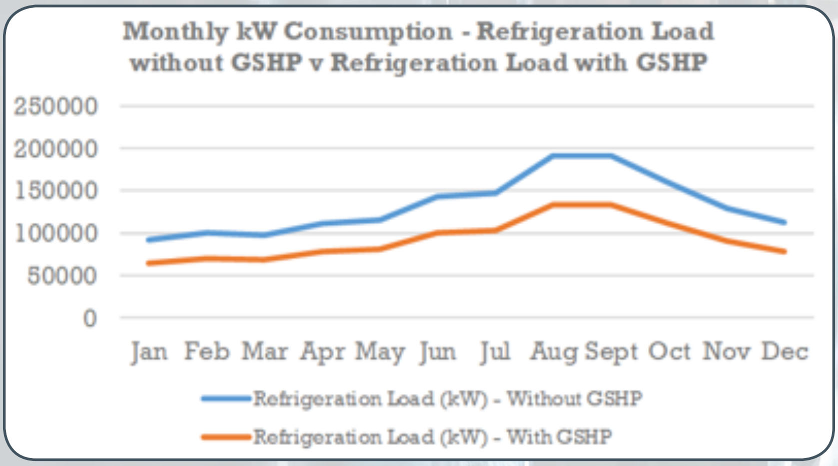
The graph below presents the monthly cost saving of retrofitting a GSHP system against conventional refrigeration and heating technology:



The graph below presents the monthly kW energy consumption of retrofitting a GSHP system against conventional refrigeration and heating technology:



The graph below presents the monthly kW energy consumption of retrofitting a GSHP system with conventional refrigeration technology – a conservative improvement of 30%* in energy consumption savings is projected:



Commercial

The total projected capital costs associated with the retrofit at a large UK supermarket is projected at £1.1m.

Based on a net annual saving of £217K, plus the following additional savings:

» Electricity demand side saving of £36K per year

» Carbon saving of £10K per year (based on £16 per Tonne of CO2)

» The grand total saving amounts to £264K per annum. Based on these projected savings, which can be considered conservative, the ROI would be 4.46 years

STORE ENHANCEMENT INITIATIVES

9 STORE ENHANCEMENT INITIATIVES

This section explores additional enhancement initiatives available to food retailers.

9.1 DEHUMIDIFICATION

Dehumidification is carried out where very low moisture content of air is required and where the environments relative humidity needs to be maintained. The term relative humidity is defined as the amount of water vapour in the air. Relative humidity is the percentage of water vapour in the air at a specific temperature; compared to the amount of water vapour the air can hold at that temperature. The most comfortable humidity level for any indoor space is between 30-50%.

Desiccant Dehumidification

Adsorption of water vapour in the air: humidity is reduced with an adsorbent material as silica gel or activated alumina. Adsorption is a physical process in where moisture is condensed and held on the surface of the material without any change of in the physical or chemical structure of the material. The dehumidifier working in this principle is referred to as a Desiccant Dehumidifier.

Background

All cooling coils with a surface temperature below the air dew point or wet bulb temperature condenser have a sensible heat ratio (SHR). This means that they condense water out to the air and the more they condense the greater the load on the case.

Modern day refrigerated display cases have smaller differences between evaporating temperatures and air onto the coil temperatures compared to previous generation cases. This is partly due to reduced air exchange with the store and to higher evaporating temperatures that reduce the SHR of the coil.

At the ISO3 test conditions of 25°C and 60% RH, the Latent cooling will be around 30% of the total case duty.

However, the temperature and humidity conditions near the display cases is usually very different from the ISO3 test condition in that it is often only around 15°C, and this will reduce the potential energy benefits from a low humidity in stores. However, in high humidity conditions dehumidification will present a significant refrigeration system energy saving.

Benefits

A significant advantage of in store dehumidification away from energy saving is equipment life enhancement. As moisture content in the air will be reduced through the dehumidification process, condensation within the display cases will reduce significantly and this will enhance life expectancy through removing a high percentage of corrosion potential generated by high levels of moisture content.

9.2 DESTRATIFICATION

The aim of destratification is to provide thermal air destratification of freely available warm high-level air and direct it effectively without causing a nuisance to customers, colleagues or disturbance to the performance of open fronted display cases.

Benefits

Typically, available heat at high level in a supermarket is 24°C. Destratification is a cost-effective means of utilising this heat to improve in store comfort conditions for customers and colleagues.

Typically, a degree improvement per 300mm from high level can be enjoyed for very little cost, and significantly lower than introducing supplementary heat sources for comfort heating purposes.

9.3 HEAT RECOVERY & HIGH COP HEAT GENERATION

The principle purpose of a refrigeration system is to remove heat to maintain a desired refrigerated condition. In a refrigeration cycle, this heat plus the energy used by the compressor, is rejected at a higher temperature, usually to waste. Heat is generally rejected at the lowest possible temperature to reduce the amount of power used by the refrigeration system. Meaningful heat recovery from refrigeration systems usually means that the systems condensing temperature is raised much higher than normal to make the recovered heat useful, however this makes the refrigeration plant much less energy efficient.

The problem with heat recovery is that it is at its optimum when there is the least requirement for it – in the summer months. When heat recovery would be useful the refrigeration system is not working as hard and the heat available for recovery purposes is low. Naturally it is possible to recover heat in colder periods; however, this is often at the detriment of raising the condensing temperature to higher levels to provide effective amounts of heat. The resulting effect is that under mid-season conditions the heat recovery system can use significantly more energy that is recovered. Another issue surrounding raising the condensing temperature is that it imposes additional wear and stresses on the systems compressors. Most systems that recover heat from refrigeration systems involve adding many additional controls and valves to the refrigeration plant making it much more complicated, unreliable and confusing to service and maintenance engineers.

A new initiative; 'HeatSuka' – interdependent refrigeration circuit system is installed via the refrigeration plant discharge line; a plate heat exchanger takes advantage of the refrigeration systems discharge condition and subsequently raises the temperature of the HeatSuka' refrigerant. As the condition of the refrigerant is now at a higher temperature, the HeatSuka compressor only uses additional energy for the required heating condition. This makes it a highly efficient way to recover heat. Additionally, it can make the main refrigeration plant more efficient because it reduces its condensing temperature and increases its sub-cooling. It has a very simple circuit and components that any refrigeration engineer should be able to understand.

HeatSuka overcomes common heat recovery problems:

» It is an easily understood technology that any refrigeration engineer can understand

» It can easily be fitted to new or existing systems

» It can provide heating to any temperature up to 75°C at a COP of 7 and above

» The main refrigeration plant continues to operate at its normal operating condition. In fact, if heating is still required in warm weather, say for washing down in a food factory, it may decrease the condensing temperature and increase the main systems efficiency

» As it only takes out the actual heat needed, it only uses the additional power needed to do this

» Provided there is sufficient heat available from the refrigeration plant, the efficiency of the HeatSuka is higher than all other conventional heating systems

GOOD SYSTEM DESIGN

10 GOOD SYSTEM DESIGN

This section presents the importance of good pipework design. Traditionally, performance charts and first principal calculations have been used to calculate refrigeration pipework and system losses to encourage efficiency. These calculations are time-consuming and often inaccurate.

The use of White Rose Software removes potential pipework design inaccuracies.

Refrigerating system design focuses on the four major components of the system:

» Compressor

» Condenser

» Evaporator

» Expansion device

The role of piping in the operation and efficiency of a vapour compression system is of critical importance. Therefore, an operational and efficient refrigeration system also depends on good piping design.

The correct or adequate design of a line for a given refrigerant mass flow rate is a trade-off between the initial costs; rise as the pipe diameter increases, and operating costs that decrease as the pipe diameter increases (this is due to the refrigerant pumping power decreasing).

There are also other important issues directly linked to the system pipework design:

» The pipework design must ensure that oil returns to the compressor - preventing excessive amounts of lubricating oil from being trapped in parts of the system (evaporators)

» Prevention of liquid refrigerant or oil slugs from entering the compressor during operating and idle time

» The system design must ensure proper refrigerant feed to evaporator and consider the importance of a clean and dry system

» Cost effectiveness, pressure drop, noise, and oil entrainment

Recommended (ASHRAE) design velocities in refrigerant lines are listed below:

Line Type	Refrigerant velocity (m/s)
Suction	4.5 - 20
Discharge	10 - 18
Liquid	< 1.5

The upper limits of velocity are linked to cost effectiveness, pressure drop and noise, whereas the lower ones to oil entrainment and fouling issues.

Of critical importance in designing a refrigeration pipework system is excessive pressure drop. In suction lines an excessive pressure drop will reduce system efficiency; it will cause the saturation pressure to decrease thus causing the saturation temperature to decrease. Liquid line velocities exceeding the recommended figure could result in possible liquid starvation at the expansion device.

Refrigerant line sizing – liquid lines

The liquid line connects the condenser with the expansion device/s has different considerations; the pressure drop does not impact on the energy efficiency since the aim of the expansion device is to reduce the pressure from the condensation one to an evaporation one. What must be avoided in the liquid line is the gas formation known as “flashing” that can be due to excessive pressure drops.

As a guide, the design of suction lines is different from that of the liquid lines; suction lines are guided by an energy efficiency consideration while liquid lines follow operational considerations.

Refrigerating systems are generally designed so that pressure drop in the liquid line from friction is not greater than that corresponding to about a 0.5 to 1K change in saturation temperature.

Liquid sub-cooling is the only method of overcoming liquid line pressure loss to guarantee liquid at the expansion device in the evaporator. If there is insufficient sub-cooling flashing occurs in the liquid line and degrades system efficiency; sub-cooling is generally achieved using part of the condenser.

The liquid line design procedure is the following: using the system capacity and the correct values for the considered fluid the nominal line diameter is determined. The total equivalent length from the condenser to expansion device or from receiver to sub-cooler must also be considered, this value is the sum of the straight pipe length and the equivalent length for fittings, bends and valves.

Refrigerant line sizing – Suction and discharge lines

Calculating suction lines can be considered more critical than liquid lines from a design and construction standpoint.

Refrigerant lines should be sized to provide a minimum pressure drop at full load, return oil from the evaporator to the compressor under minimum load conditions, and prevent oil draining from an active evaporator into an idle one.

The pressure drop in the suction line reduces the system’s capacity because it forces the compressor to operate at a lower suction pressure to maintain a desired evaporating temperature in the evaporator. The suction and discharge lines are normally sized to have a total pressure drop no greater than the equivalent of about a 2K change in saturation temperature (suction) and 1K change (discharge). For a given refrigerant mass flow rate and a temperature drop per unit of length, discharge lines are smaller than suction ones because the vapour density is higher, and the saturation temperature drop for a given pressure drop is smaller. Therefore, the temperature drop per unit of length for suction lines is greater than that of discharge ones.

The ASHRAE Handbook (for HFC refrigerants) recommend that such temperature drop be are 0.02 K/m for the discharge lines and 0.04 K/m for the suction lines.

The design procedure for calculating suction and discharge line sizes is calculated based on the given cooling capacity and refrigerant. It is of crucial importance to consider that losses are also attributed to pipework fittings, bends and valves.

Refrigerant line sizing – Oil management in refrigerant lines

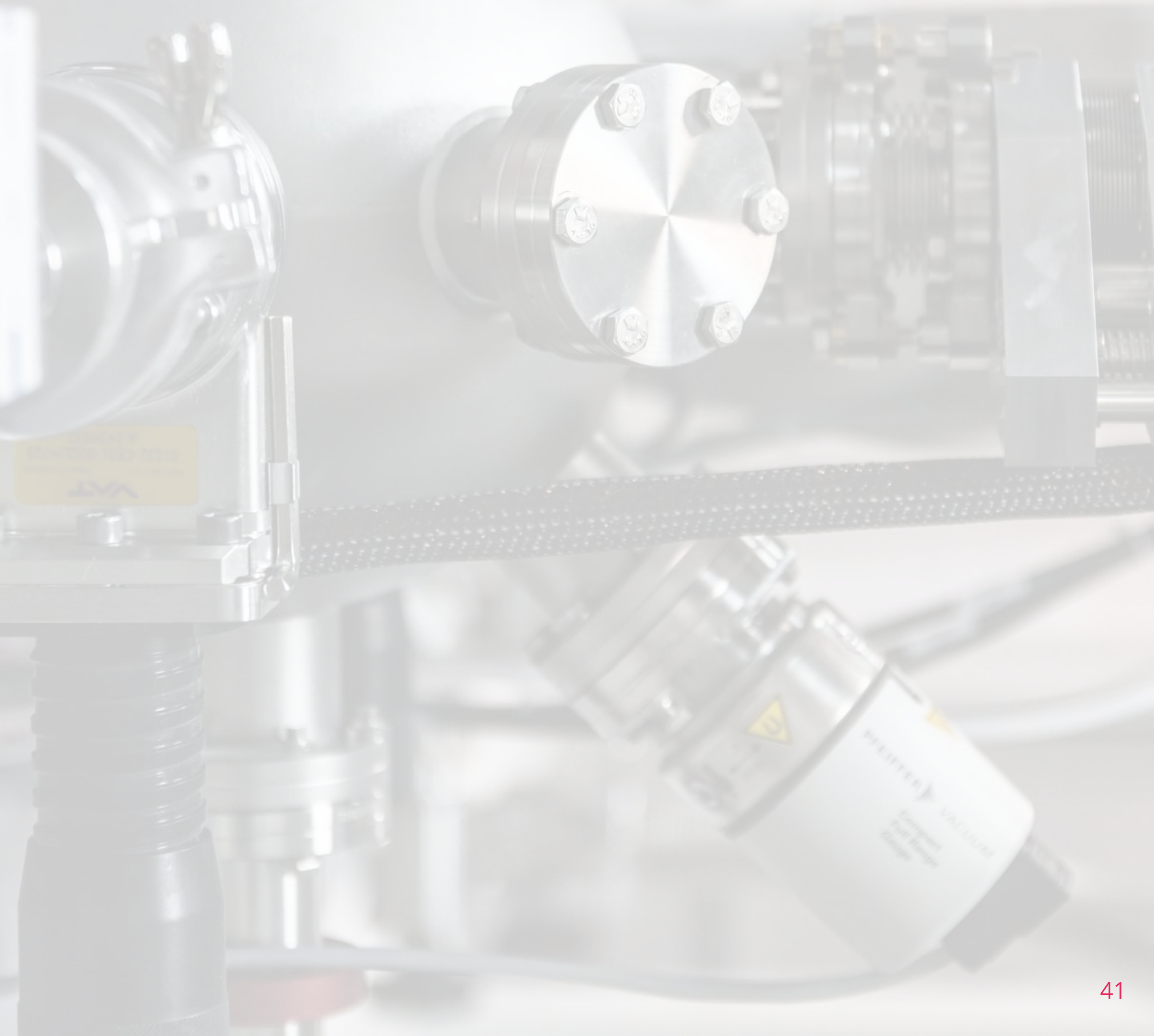
All refrigerant systems host a certain amount of oil used to lubricate the compressor and cool the electrical windings. It is common for compressors to lose some lubricating oil during normal operation. Because oil inevitably leaves the compressor with the discharge gas, refrigeration pipework systems must return this oil at the same rate at which it leaves. To reduce the amount of circulating oil, separators can be implemented in the system; unfortunately, they are not always 100% effective.

The systems suction line is critical from an oil return perspective. Therefore, this line must be verified for oil return in part load operation; the check is only necessary for risers with upward flow because the other lines are usually downward positioned and tilted of about 0.5% to exploit the gravity force (horizontal lines).

Considering the suction lines, many refrigeration piping systems contain a suction riser because the evaporator is at a lower level than the compressor. Oil circulating in the system can return up suction risers only by being transported by returning gas or by auxiliary means such as a trap.

The minimum conditions for oil transport correlate with buoyancy forces (i.e., density difference between liquid and vapour, and momentum flux of vapour). The principal criteria determining the transport of oil are gas velocity, gas density, and pipework internal diameter. Density of the oil/ refrigerant mixture plays a somewhat lesser role because it is almost constant over a wide range.

If a correctly sized suction riser imposes too great a pressure-drop at full load, a double suction riser should be used. The primary riser is sized to return oil at minimum load possible while the secondary riser is sized for satisfactory pressure drop through both risers at full load. A trap is introduced between the two risers; during part-load operation, gas velocity is not sufficient to return oil through both risers, and the trap gradually fills up with oil until the secondary riser is “sealed off”. The gas then travels up the primary riser only with enough velocity to carry oil along with it back into the horizontal suction main. At full load, the gas pushed away through the pipe the oil trapped in the bend enabling both risers.



SUMMARY

Retail Refrigeration
White Paper 2019

11 SUMMARY

Whilst end users of refrigeration need to introduce low GWP refrigerant technology to remain compliant to legislation, consideration must be given towards energy consumption in refrigeration systems.

GWP only considers the potential impact of leakage, and non-HFC refrigerants available to date may cause refrigeration systems to operate less efficiently, thereby consuming more electricity and resulting in potentially more GHG emissions polluting the environment.

Total Environmental Warming Impact (TEWI)

TEWI is the combination of direct and indirect emissions associated with refrigeration systems. TEWI is measured in Tonnes of CO2.

Direct emissions are concerned with the impact of refrigerant leakage. Refrigerant GWP is significant when assessing direct emissions – the lower the GWP, the lower the direct emissions (based on a like for like leakage rate).

Indirect emissions are concerned with the impact of electricity consumption.

Due to varying findings across the refrigeration industry, this paper does not provide any technology comparisons in respect to total system type GHG emissions. This is to remove any potential contention and dispute arising as the author accepts that findings will differ from one system user to another. What is considered as a benchmark comparison between technologies will vary.

The aim of highlighting GHG emissions and TEWI is to identify how crucial they are when selecting refrigerants and technologies.

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The aim of highlighting GHG emissions and TEWI is to identify how crucial they are when selecting refrigerants and technologies.

Training and Experience

Most retail refrigeration systems operate on HFC refrigerants; F-gases.

It is reported that there are over 160,000 certified F-gas technicians – where there is a legal requirement for formal registration. It must be assumed that an F-gas certified technician is competent HFC refrigeration technology. The EU is well underway in the phase-down of HFC refrigerants, and many large retail refrigeration operators are transitioning to alternative, non-HFC based refrigerants. Alarmingly, a report from the EU commission on the availability of training for service personnel regarding the safe handling of climate friendly technologies replacing or reducing the use of fluorinated greenhouse gases suggests that there is a significant gap between certified F-gas technicians and those who have certification / experience with alternative refrigerants as presented in this paper.

Please refer to the report from the Commission on availability of training for service personnel regarding the safe handling of climate-friendly technologies replacing or reducing the use of fluorinated greenhouse gases, accessed via the link - Commission Report.

Given the training and experience risks presented by alternative refrigerants, much more focus is required to ensure a transition on the reliance of HFC refrigerants can take place. Whilst larger retailers may have appropriate strategies in place to address the impact of the HFC phase-down, it is highly unlikely that any such strategy exists for most smaller retailers. Such retailers will likely rely on smaller contracting organisations to undertake the installation and maintenance of their refrigeration equipment; of which most systems will operate on HFC refrigerants. Proportionately it is these organisations and their respective technicians that make up most of the refrigeration industry.

Managing Refrigerants

As of 2020, new refrigerants with a GWP of >2500 will be banned. The most common refrigerant that will be affected will be R404A, and this has a GWP of 3,922.

In recent years, R407A, R407F, R448A and R449A have grown in popularity as a feasible drop-in replacement refrigerant for R404A (alongside being used in new refrigeration equipment). R448A and R449A became commercially available in 2017.

The GWP values of these four refrigerants are:

» R407A – 2,107

» R407F – 1,825

» R448A – 1,387

» R449A – 1,397

All four of these refrigerants exhibit similar performance characteristics as R404A, and their respective GWP values are much lower

It is essential that R404A is replaced to mitigate the impact of the forthcoming ban. However, considering the F-gas phase-down, a serious consideration must be given towards replacing R407A or R407F with either R448A or R449A. The retro-fitting of these two refrigerants that are compliant post-2020 will only serve to exacerbate F-gas supply and demand concerns throughout the EU. The only attributable benefit of retro-fitting such systems with R448A or R449A is reduced GWP (a slight energy benefit may also be achieved).