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Evaluation of available Refrigeration Systems in the Retail Sector

by

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1. Introduction

The purpose of this paper is to present the energy performance and environmental impact of available refrigeration systems that have been installed in recent years at ASDA stores. The results are based on actual metered data and refrigeration gas loss records. Prior to presenting the results this paper will discuss refrigerants in terms of desirable properties, types and associated risks. The purpose of this is to identify the considered approach ASDA have taken in their implementation strategy, following this, the advantages and disadvantages of each system will be presented. The conclusion will share the benefits of a stake holder supported refrigerant containment strategy, adaptation of initiatives where energy savings are not only achievable but also fit the profile of a retailer's payback period, and the approach taken in evaluating alternative refrigeration system technology, opposed to implementing major change largely based on a paradigm that HFC refrigerants cannot be contained at a low level; how can the industry expect to contain a high pressure or flammable refrigerant if traditional HFC refrigerants cannot be contained.

All data is connected to ASDA and other retailer's data will most likely differ from that contained within this paper. The data is concerned with the energy performance and environmental impact of refrigeration systems ***only***.

2. Background of Industry Change

Following the Montreal Protocol many countries agreed that due to their ozone depletion potential (ODP), the use of certain refrigerants would be phased out, as a result work was undertaken to provide alternative chlorine-free refrigerants. Very few have been found suitable for use as single ingredients and the blending of various

HFC's has been carried out to provide compounds which closely match the properties of the superseded CFC and HCFC refrigerants. While such compounds perform well as refrigerants, they still pose a significant environmental impact as their effect on global warming is significantly higher than natural refrigerants; those produced for the purpose of refrigeration that also occur naturally in the atmosphere. R404A the most common of all HFCs has a global warming potential (GWP) of 3922 (IPCC 4^{th} assessment). Due to the significance of HFC refrigerants GWP, consideration of potential legislation, such as those adopted in some European countries that restricts the use of HFC refrigerants, ASDA took decisive action in 2008, the results of which are identified within this paper. Since 2008 alternative HFC refrigerants have become widely available these include R407A and R407F. This paper will present findings on the latter, its GWP is over 50% less than R404A but still significant if it is not contained.

3. Refrigerants

3.1 Desirable properties

There are a number of thermodynamic properties to be considered when selecting a refrigerant. All refrigerants which damage the ozone layer have now effectively been banned, 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, there is presently no legislation limiting the GWP of refrigerants; however this is possible in the future.

The pressures contained within a refrigeration system are lower on the evaporating side of the system than in the condensing 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.

3.2 Refrigerant types

Prior to installing alternative refrigeration systems an approach was taken to understand the benefits and limitations of available refrigerants.

3.2.1 HFC refrigerants

R404A and R407F are blends of various compounds, they have zero ODP and their GWP figures are 3922 and 1824 respectively. The boiling pressure allows their use in retail refrigeration systems; this can be as low as -40°C.

3.2.2 Hydrocarbon refrigerants

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. Small volumes are considered acceptable; domestic refrigerators widely use hydrocarbons, as do many integral refrigerated display cases in retail applications. Larger refrigeration systems can operate using hydrocarbons provided they are contained within a location restricted to trained personnel.

3.2.3 Carbon Dioxide (R744)

R744 was one of the earliest refrigerants, however since the introduction of CFCs its application fell out of common use. In the early 2000's it began to be considered again in retail applications due to its low GWP, interest has continued to grow and many systems have now been installed throughout the UK. R744 has some properties that can be unfamiliar to refrigeration engineers; the pressures in R744 systems can operate in excess of 100bar in trans-critical mode, evaporating pressures in a typical system operating at -10°C will be 26.5bar; a typical design pressure within the high side of a HFC system. Other notable considerations are the high triple point and low critical pressure, at a temperature of -56.5°C (triple point) the state of R744 becomes solid and at pressures above 73.834bar (trans-critical pressure) the difference between the liquid and gas phases cease to exist. The triple point is unlikely to be of concern to in a retail environment, but the trans-critical pressure is equivalent to 31.6°C and will be exceeded in higher ambient conditions. Trans-critical operation requires considerably more compressor power to maintain system performance.

An advantage of R744 systems is the small size of pipe-work when compared to similar HFC systems; this makes it much easier to run R744 services through ceiling voids. A disadvantage to R744 pipe work is that discharge lines are often constructed from steel with welded joints.

3.3 Health risks

3.3.1 HFC Refrigerants

HFC refrigerants can cause asphyxiation if a leak occurs within a confined space; it is therefore good practice to install refrigerant leak detection systems in plant rooms, cold rooms and other confined areas. Leaks can occur at very low temperatures and leaking gas is likely to collect in low areas.

3.3.2 Hydrocarbon Refrigerants

Hydrocarbons are flammable and there is potential for explosions. Systems using hydrocarbons should be provided with suitably rated electrical connections and be fitted with gas detection equipment that shut down the plant and ventilate the refrigerant safely to atmosphere. Hydrocarbons are unsuitable for use in public areas unless contained in integral type systems where the refrigerant charge is small.

3.3.3 Carbon Dioxide (R744)

Carbon Dioxide occurs in the atmosphere at a concentration of 0.04%, R744 can cause asphyxiation when a leak occurs in confined areas. At a concentration of 3% R744 leads to an increase in breathing rate, at a 5% breathing becomes difficult and at a 10% concentration unconsciousness can occur in less than one minute, with serious health implications including death for longer periods of exposure. It is therefore recommended that leak detectors are located in all plant rooms, cold rooms and in low areas as leaking gas will have a higher density than air. This paper recommends that refrigerant detectors are installed in public areas such as sales floors where there is a possibility of leakage.

4. Overview of systems installed at ASDA

4.1 Refrigerant R404A and R407F

R404A and R407F are employed in conventional direct expansion refrigeration systems.
Advantages include:

- Well known technology familiar to refrigeration engineers
- Low capital costs
- Good energy efficiency

Disadvantages include:

- High GWP
- Possible legislation may restrict the use of HFC refrigerants
- Adverse publicity from environmental organisations

4.2 R744

R744 is employed within a direct expansion refrigeration system; it includes a cascaded arrangement that provides a constant condensing medium for the low temperature system.
Advantages include:

- Small service sizes
- GWP of one
- Potential for efficient heat recovery
- Future proof
- Positive publicity

Disadvantages include:

- Very high pressures with potential safety implications
- Lower energy efficiency if isolated from the store heating requirements
- Higher capital cost
- Fewer qualified engineers

4.3 Secondary systems

A secondary system is employed using low charge primary chillers to cool a glycol type solution that is pumped around a conventional branch and main system.
Advantages include:

- Very limited primary refrigerant charge allowing the use of refrigerants which could not otherwise be considered in a retail environment such as Hydrocarbons and Ammonia.

Disadvantages include:

- Lower energy efficiency
- Large services
- Potential for corrosion damage in the event of a leak
- Fewer engineers are familiar with this type of system

4.4 Water-cooled integrals

Each display case has its own integral refrigeration system that operates on R404A (the condenser is 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 roof mounted dry air cooler before re-circulating through the system.
Advantages include:

- Contained and reduced HFC charge that make any potential leaks easier to identify (Hydrocarbons can also be used successfully in this type of application)
- 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:

- Lower energy efficiency due to individual systems, each system is mounted on top of the display case and is not easily accessible
- 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

5. Data

5.1 Energy consumption and environmental impact summary

Figure 1 identifies the 2011 energy consumption and environmental impact of the available refrigeration systems. Certain assumptions are made, these are:

1. With the exception of the R404A system, the TEWI figures are based on the 2011 average leak rate of 2.6%
2. The R404A system TEWI figure is based on the 2005 average leak rate of 22%
3. All systems follow the model store footprint, and are within 5% in terms of connected load at each store

	R407F system	R404A system	R744 system	Secondary system	Water cooled integrals
Total energy consumption in 2011 (kWh)	710,983	919,413	916,831	1,520,700	1,315,531
Life Time TEWI (Tonnes CO2)	6,055	17,669	6,893	11,433	10,027

Figure 1 – Energy consumption and environmental impact summary.

5.2 Annual energy consumption

Figure 2 provides the 2011 daily energy consumption of all systems with the exception of the R404A system. The data for this system has been extracted from 2005; the rationale behind this is to identify the improvements in HFC system design and energy initiatives between the two years. These improvements are identified in the conclusion.

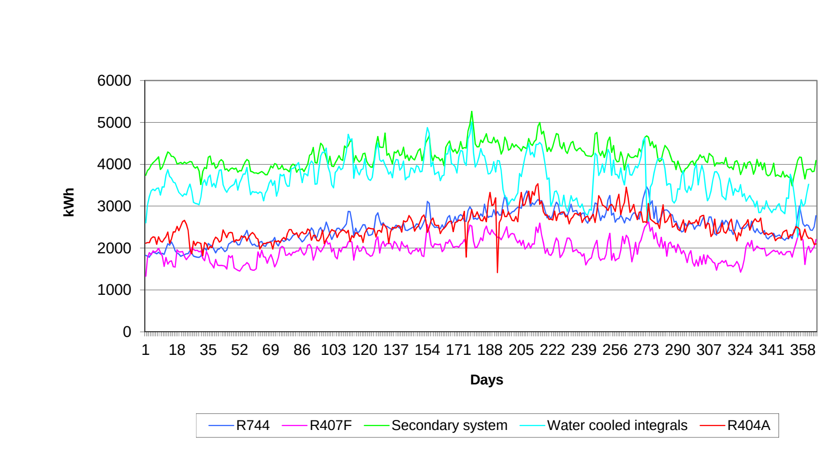

Figure 2 – 2011 Annual energy consumption.

5.3 Environmental impact

Figure 3 provides the systems environmental impact based on actual energy consumption and refrigerant leakage rates. The lifetime of each system is based on 14 years, and a CO² Emission Factor; ß (kg CO² / kWh) of 0.537.

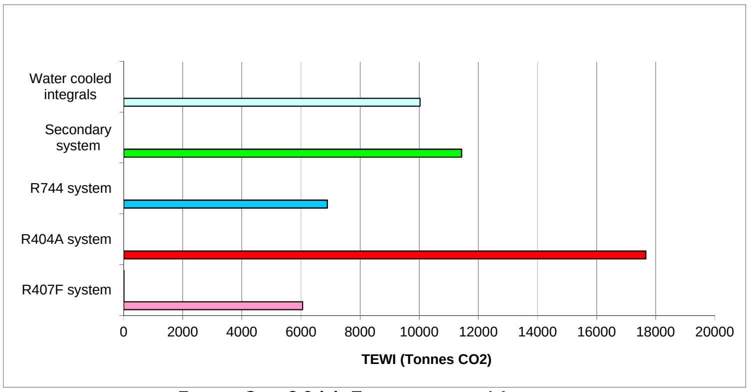

Figure 3 – 2011 Environmental Impact.

5.4 Refrigerant leakage

Figure 4 below identifies where refrigerant gas loss occurred during 2011.

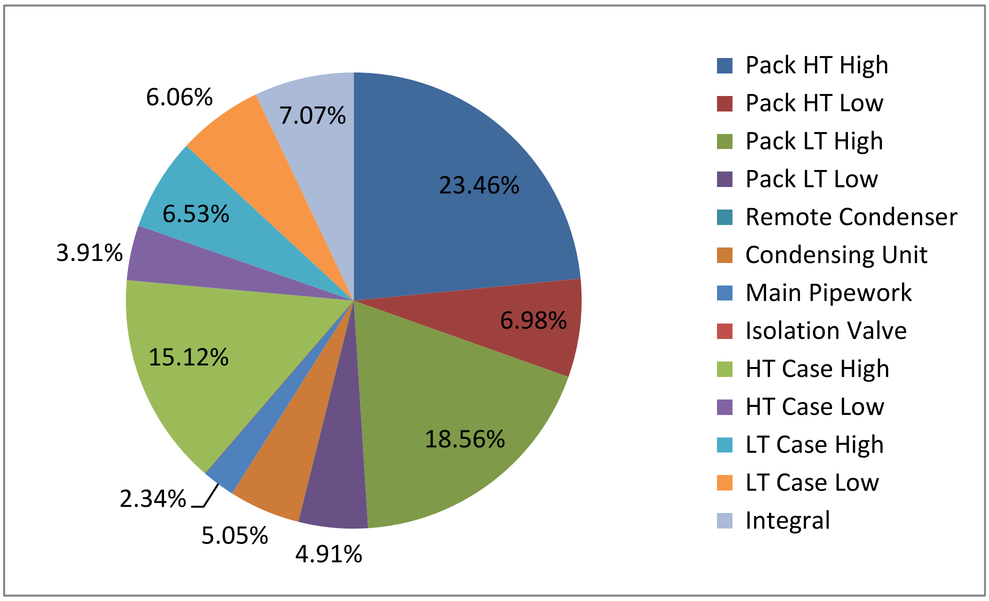

Figure 4 – 2011 Refrigerant leakage attribution.

The following conclusion details preventative maintenance recommendations based on the highest gas loss location identified above to further improve containment levels; the purpose is to support the RAC industry in identifying percentage attribution of gas loss within retail refrigeration systems.

6. Conclusion

6.1 Summary

Retail sector interest in natural refrigerants commenced in the early 2000s. It is appropriate to suggest that the benefit of natural refrigerants when compared to HFCs was greater. However it is visible from data within this report that embracing a gas loss strategy, combined with the use of R407F benefits the environment greater than any other technology due to its efficiency and reduced GWP. It can be argued that gas loss levels will deteriorate over time, in response to this, ASDA's open-book policy prove that this is not the case as their gas loss levels continue to reduce year on year.

Figures 5, 6 and 7 illustrate the impact of earlier data if each system type were adopted across the ASDA retail estate. The R404A data is based on 2005 energy and environmental impact data.

	R407F systems	R404A systems	R744 systems	Secondary systems	Water cooled integrals
Estate wide annual energy consumption (kWh)	268,040,591	346,618,701	345,645,287	573,303,900	495,955,187
Life Time TEWI (Tonnes CO2)	2,282,822	6,661,070	2,598,706	4,310,139	3,780,296

Figure 5 – Estate wide energy consumption and environmental impact summary.

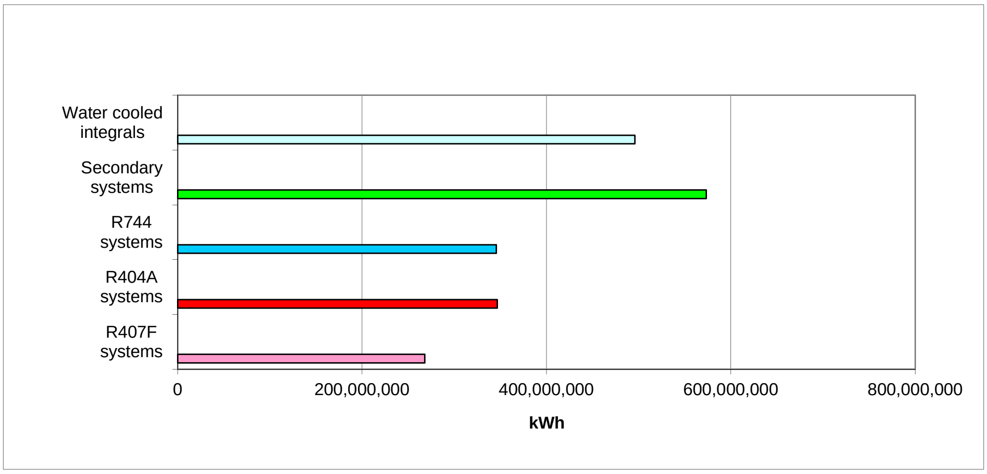

Figure 6 – Estate wide energy consumption.

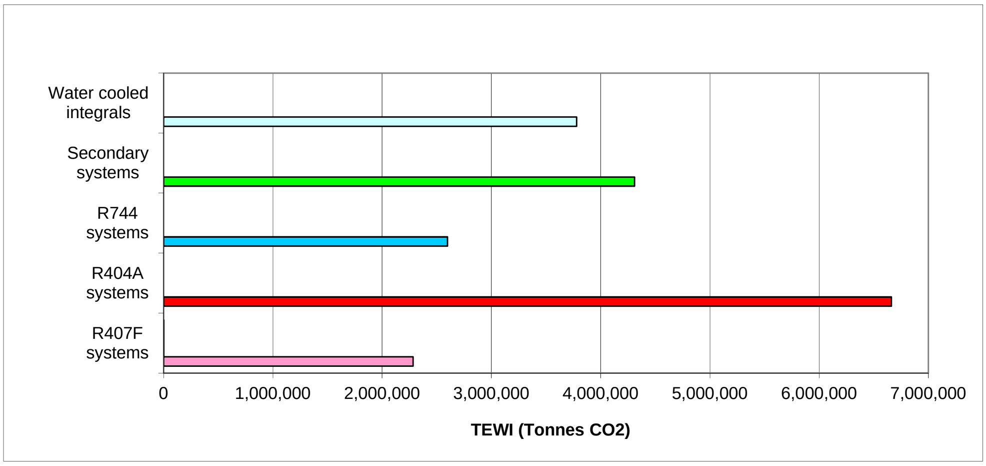

Figure 7 – Estate wide environmental impact.

The plethora of system types installed illustrate that ASDA embrace refrigerant technology, but decisions are always taken to support the wider business strategy of providing every-day low cost to its customers; reducing refrigerant gas loss supports this strategy whilst benefiting the environment. In the event of legislation that restricts the use of HFC refrigerants they are well placed to truly identify the most beneficial alternative refrigeration system to them, due to structured, considered and continuously monitored trial and evaluations.

6.2 Developments

Improved system design by ensuring refrigeration plant and display case distances are kept to a minimum, along with a zero tolerance approach to refrigerant gas loss have reduced carbon emissions and capital costs greatly. At component level the introduction of EC fan motors (opposed to fixed speed - "model" in 2005) to both display cases and condensers, Electronic Expansion Valves (opposed to Mechanical valves - "model" in 2005) to evaporators, Wier plate risers (introduced as "Model" in 2008) to display cases, Sliding lids (introduced as "Model" in 2011) to frozen food display case well sections, and the change to lower GWP refrigerant R407F from R404A have all contributed to a reduction in energy consumption.

Another alternative system is also under trail, it is an innovative concept that utilises air. The Simply Air system delivers forced air via a supply air fan through a specifically designed branch and main duct work system that is connected to the refrigeration fixtures, there are three modes of operation that provide cooling.

Recirculation mode
In recirculation mode, the plant operates as a standard refrigeration system to provide the necessary cooling effect. The supply air fan delivers refrigerated forced air that is provided from a direct expansion cooling coil. This occurs when the outside air temperature is higher than the return air temperature of 7°C.

Partial Cooling
In partial cooling mode, the outside air temperature is lower than the return air temperature of 7°C but higher than the supply air temperature of -3°C. The plant operates as a standard refrigeration system, however its load proportionally decreases dependant on the outside temperature being below 7°C.

Free Cooling
In free cooling mode, the outside air temperature is equal or lower than the supply air temperature of -3°C. When this occurs the plant does not operate as the compressors are cycled off and do not run.

In both recirculation and partial cooling modes, the plant operates as a standard direct expansion system. All plant loads operate; suction return gas is compressed, discharged and condensed back into a liquid refrigerant. However all refrigerant is contained to the plant and as such has a low volume charge. In free cooling mode the refrigeration plant does not operate and as such presents energy savings.

6.3 A shift in paradigm

The data contained within this paper disproves a paradigm that refrigerant cannot be contained. If traditional HFC refrigerants continue to leak at unacceptable levels, what chance does the RAC industry have if high pressure alternatives were the only refrigerant of choice? This paper does not intend to discredit any developments in refrigeration technology, its message is to highlight that the real issue of today, as it always has been is refrigerant containment. This paper proves that reducing refrigerant leakage is possible and that in doing so it provides tangible benefits. Advancements in technology will continue at pace and they need to be supported by the RAC industry, but containing refrigerant leakage must take priority. In the short term this paper identifies that irrespective of a retailer's refrigeration strategy it is possible to greatly reduce emissions by retrofitting systems operating on R404A with R407F.

This paper will now conclude in identifying methods of containment that can be readily adopted by the retail RAC industry. Refrigerant leak coding – It is clearly visible where leaks are attributed and this may be similar across all retailers. Referring to Figure 4, over 50% of leaks can be attributed to refrigeration packs. The high side of refrigeration plant is a major concern, however if OEM's were to incorporate a facility to replace discharge headers through designing and installing a by-pass arrangement, headers could be changed at periodic intervals to reduce gas loss significantly. This can be related to a car and its cam belt; nobody would hesitate in changing a cam belt at a periodic interval to prevent failure. Incorporating an interchangeable discharge header would add cost to the price of a refrigeration pack, however over time this may provide a return on investment through reduced leakage rates whilst also benefitting the environment.

The majority of retailers use a number of contractors to service and maintain their refrigeration equipment and the collation of gas loss data and attribution through a leak coding system can be time consuming, in response there are a number of independent third parties capable of providing this service and documenting leakage to provide effective analysis. Third party auditing of retailers existing equipment would successfully identify components that require periodic replacement or indeed removal from the system. Such items may include but are not restricted to plant services, pressure controls, flexible hoses, flare joints and shrader connections. At the manufacturing stage of plant and display cases, and site installation it is possible to carry out joint inspections, such inspections ensure penetrations to brazed connections are acceptable and will withstand the lifetime operation of the system.

This final message of this paper is not to accept refrigerant leaks, but to embrace a zero tolerance approach, and be involved in shifting the industry paradigm on containment as we do with developments in refrigeration technology.