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HFO Behaviour in Components and Systems

Paper 1 – Site trial results

Why this topic?

- The industry needs to understand more about how new refrigerants behave in practice in terms of performance, reliability, leakage and system adaptions.
- This paper provides details and results of tests and trials carried out on various systems found in an actual retail environment.
- It offers insights into how this data can be used to develop strategies around the reduction of the environmental impact of retail refrigeration related to future refrigerant use.

1 Introduction

Changes in legislation, as well as a desire to improve the 'green' credentials of refrigeration systems over the years has led to the birth and death of various refrigerant gases. A long enough career in the refrigeration industry has allowed many of us to work through changes from CFC's, to HCFC's, to HFC's finally leading to Natural refrigerants. Through each of these changes the industry is left struggling to make the decision which gas to select and ultimately what needs to change in the systems to allow us to transition to these new gases. To facilitate these retrofits we have had to, in some instances, change oils, upgrade condensers, add vapour injection and in the case of 'naturals' replace some of or all of the existing system.

In recent years a new molecule was discovered which has led to the birth of HFO's as a refrigerant family. This new family of refrigerants offer low GWP's and improved efficiencies but come with a 'mildly flammable' sting in the tail and a whole new flammability category to deal with them. This has led to these refrigerants being blended with other refrigerants to remove the 'mildly flammable' tag while maintaining GWP's that keep them available under the updated F-Gas regulation until 2030.

Whilst this paper will not delve too deeply in to the chemistry of these refrigerants, it aims to give the details and results of the tests and trials carried out on various systems found on in an actual retail environment. It will also seek to offer guidance on how this data is used by retail end users to form future strategies around the refrigerants they use and how they help to satisfy their 'Corporate Social Responsibility' statements.

The Immediate issue to address for supermarkets

Changes to the F-Gas Regulation in 2015 have created immediate issues with certain HFC refrigerants being banned in certain applications, and future production of HFC's being phased down. See below a summary of impact for supermarket systems:

Ban effective from 1st Jan …	Application	Ban effective for refrigerants with a GWP greater than …
2015	Domestic fridges, freezers	150
2020	Commercial fridges, freezers	2500
2020	Moveable room air conditioning	150
2022	Commercial fridges, freezers	150
2022	Central plant greater than 40 kW cooling capacity in Commercial supermarket applications Except as the high stage of a cascade	150
2025	Single split air conditioning with less than 3kg charge	750

End users need to address all of these in one way or another but the two that really stand out and are being addressed by this paper are:

Ban effective from 1st Jan …	Application	Ban effective for refrigerants with a GWP greater than …
2020	Commercial fridges, freezers	2500
2020	Most stationary HFC equipment	2500

This ban has very wide implications to the HFC R404a (GWP of 3922) and means that we all need to be working on and developing strategies to make sure we have as little of this left by 2020 as possible. This will mean trialling new refrigerants with new and existing equipment and making sure we understand all the implications of the changes.

What refrigerants are we trialling?

We have chosen to go with blends as we do not want to have to deal with the mildly flammable issue at this stage. We will investigate this further when the new version of EN378 is issued and we have more guidance on charge sizes.

R449a – HFO Blend (GWP 1397) – Non Flammable (A1)
R513a – HFO Blend (GWP 631) – Non Flammable (A1)

What equipment have we trialled it in?

Trial One:

Remove R404a from chilled integral display cases and replace it with R449a (XP40). Testing product temperatures and performance in an EN23953 laboratory.

Trial Two:

Using the data from 'trial one' remove the R404a from circa 40 chilled integral display cases and replace it with R449a for a longer term study. This is ongoing.

Trial Three:

Remove the R404a as the primary refrigerant in a CO_2 cascade system and replace it with R449a (XP40). This is ongoing.

Trial Four:

Remove the R134a as the primary refrigerant in a CO_2 cascade system and replace it with R513a (XP10). This is ongoing.

What are we looking for?

Sometimes when trials of this nature are carried out, the focus on the science and technicality of the refrigerant and its exact performance at a spot condition with each individual tiny component, detracts from the bigger picture. End users are typically interested in these questions:

- Are the products in the cabinet and cold rooms still at the required temperatures?
- Are the refrigeration systems still reliable?
- Have we increased the energy signature of the system?
- Is the new refrigerant readily available?
- Are they causing any new leaks?
- How much of the system did we need to change to allow the new refrigerant in?
- How much does the new refrigerant cost?

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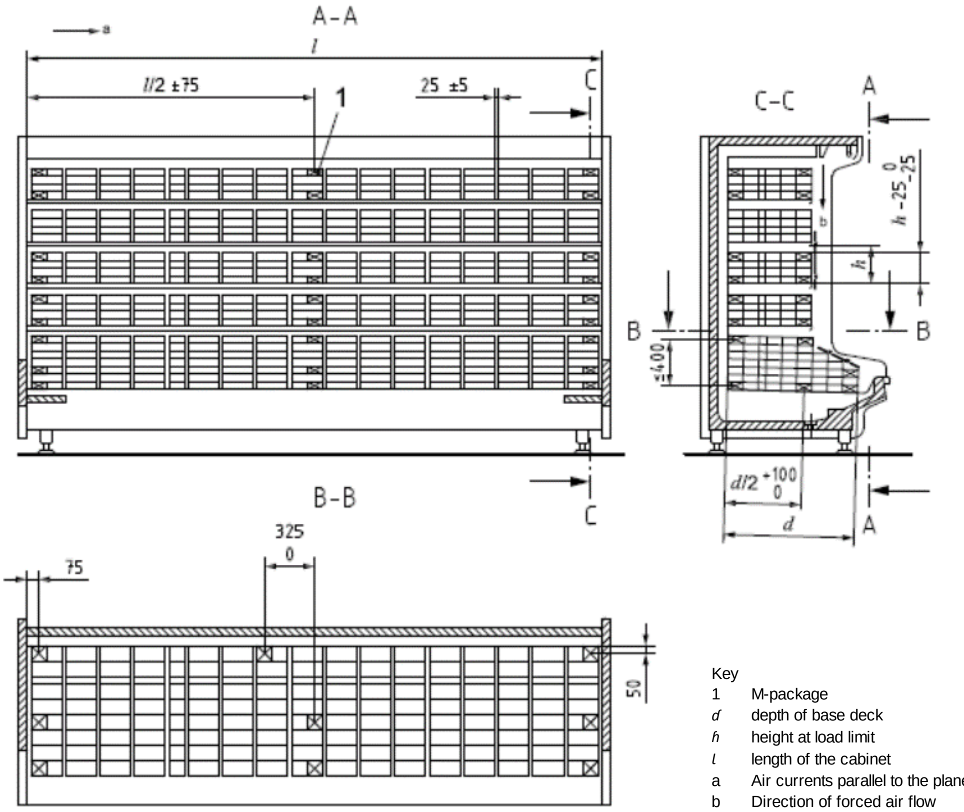
2 Trial One

This trial is by far the most important one. By changing the fluid in the evaporator and introducing one that has a glide, you have the potential to change the temperatures you see within the case. As a retailer you have to ensure that the products you sell are held at the temperatures laid out via legislation and by your Food Technicians. To that end is important to test the case in a controlled condition, to a recognised standard, operating on the fluid that the case will eventually run on.

For the purpose of this trial we are testing to the temperature and environment condition 0M1 in line with EN23953. 0M1 asks for conditions of 20°C ambient with a Relative Humidity of 50%, and M packet temperatures of >-1°C / <+5°C. However, typically you may test to 3M1 (same M packet temperatures but a 25°C ambient with 60%RH) as well, but as this does not reflect the store conditions the integrals operate in so we chose, in this instance, not to do it.

We base lined the case while it was still running R404a as its refrigerant and then duplicated the test once we had carried out the gas change.

The test M packets are placed around the cabinet as per the diagram below:



Key
1 M-package
d depth of base deck
h height at load limit
l length of the cabinet
a Air currents parallel to the plane of the opening (opening in longitudinal direction)
b Direction of forced air flow

There are three suppliers of this type of cabinet and so all three were tested. Each cabinet is a twin compressor 6 foot cabinet, but they all use different compressors and evaporator coil configurations so it was important that all three were understood.

The results for the temperatures came in as follows:

	Mean Pack Temperature	Room Temperature degC	Room RH %	DEC (kWhrs/24hrs)	Energy Decrease over R404a
Barker R404a / Manufacturer 1 – R404a	3.11	20	50%	37.17	
Barker XP40 / Manufacturer 1 – R449a	3.39	20	50%	31.68	-14.77%
Manufacturer 2 – R404a	4.86	20	50%	19.3	
Manufacturer 2 – R449a	5.05	20	50%	18.73	-2.95%
Manufacturer 3 – R404a	3.38	20	50%	37.49	
Manufacturer 3 – R449a	3.15	20	50%	36.55	-2.51%

The test generates a lot more data than is represented above but largely speaking, as a retailer this is the information that we need to know. The trial shows us that there is very little difference to temperature and there is an energy saving to be had (under test conditions) by making the change.

We were obviously keen to understand what was it about Manufacturer 1's case that created such a big saving and why the Manufacturer 2's case didn't use as much energy in the first place. With the Manufacturer 1's case, the twin compressor arrangement is on a 'staged' on / off and we think we may have been on the crossover over point meaning less compressor starts. We are still working to understand Manufacturer 2's case. However, from the tests we have run and the data we have gathered we can answer two major questions:

- Will it affect the temperature we store food at? - NO
- Will the change increase the cabinet energy signature? – NO

3 Trial Two (On Going)

Now we have been through trial one, there is confidence that a trial can take place in a live store environment without putting customers at risk. We nominated four stores using integral chilled cabinets and set about changing the refrigerant from R404a to R449a.

The case manufacturers were as follows:

Case Manufacturer	Qty
Manufacturer 1	5
Manufacturer 2	4
Manufacturer 3	28
Total	37

The cabinet manufacturer split wasn't ideal, but we wanted to find four stores in one region that were keen to get behind the trial. Also, from a service and maintenance perspective we wanted to be sure that we kept them in one region as we didn't have any R449a in other regions and the engineers may not have had it on their van in the case of an emergency.

None of the cabinets were in Warranty so this trial did not pose a risk in terms of spare parts.

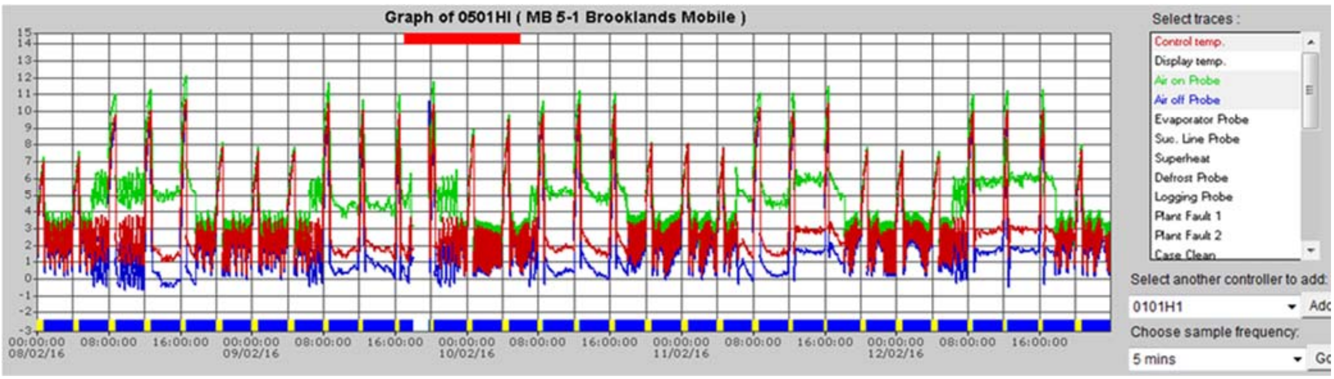
The gas changes were done in accordance with gas suppliers instructions except for one store. In that store we carried out a very 'quick and dirty' change. We didn't change filters and strainers etc, we simply reclaimed the R404a and put the system on 'vac', held it for a couple of minutes then recharged it with R449a. We wanted to make sure that if corners were cut during a roll out you wouldn't get any issues, and also learn if you could swap gases after a catastrophic gas leak as part of a future roll out initiative.

We completed a data sheet for each of the cases to see how it all behaved and gathered all the pertinent data to allow us to assess them. We did not bother with energy tests on these trials as it requires very detailed regression to account for all variables and even then you can't be certain you are correct. However, once we have a years' worth of data, we will try and see what we find.

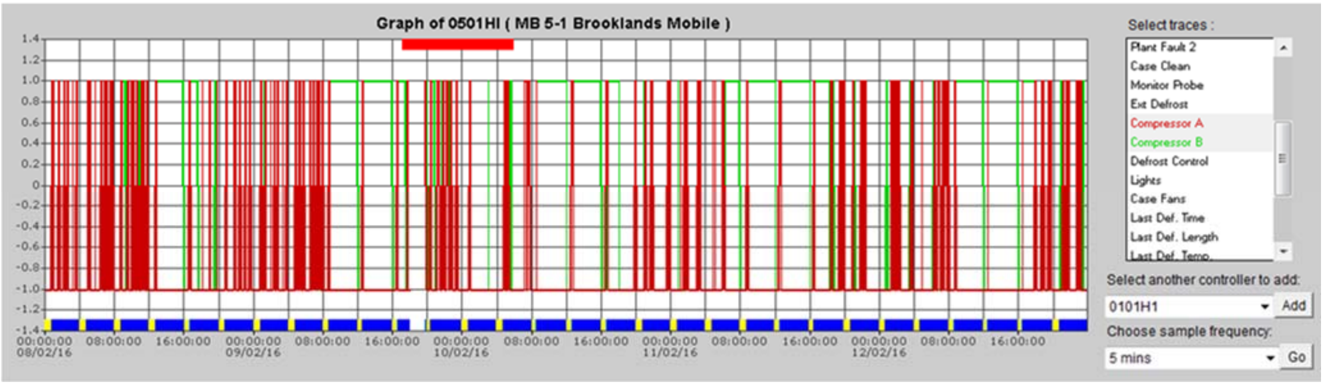
All the data sheets showed similar patterns as shown below on this Manufacturers 3's from one site:

Date / Time	09-02-2016 / 19.30		
Ambient Temp °C	20		
Reclaimed Refrigerant	R404A	Charge (kg) 680g/740g *(2 x 875g detailed on manufacturer data plate)*	
New Refrigerant	XP40 (R449A)	Charge (kg) 900g/900g	
New Refrigerant ID Labels Fitted	Yes		
Compressor			
	Pre-Works (R404A)	Post-Works (XP40 (R449A)	
Suction Temp °C	16c/21c	16c/15c	
Suction Pressure (bar)	4/3.9	3.5/3.4	
Discharge Temp °C	58c/60c	55/56	
Discharge Pressure (bar)	no access	no access	
Motor Amps	7.6/5.6	8/6.3	
Evaporator			
Air On Temperature °C	4.4	3.9	
Air Off Temperature °C	0.5	0.4	
Superheat (K)	22/27	22/22	
Genearl Comments	Dual Circuit Cabinet		

See below a graph showing five days' worth of data for the same case (the red block at the top is when the change was carried out):



We can see a very slight increase in the 'air on' and 'air off' trace, but the 'control temperature' hasn't really changed. However, from these graphs below you can see that compressor 'A' is cycling a lot less and the reduced number of starts could well explain the energy saving

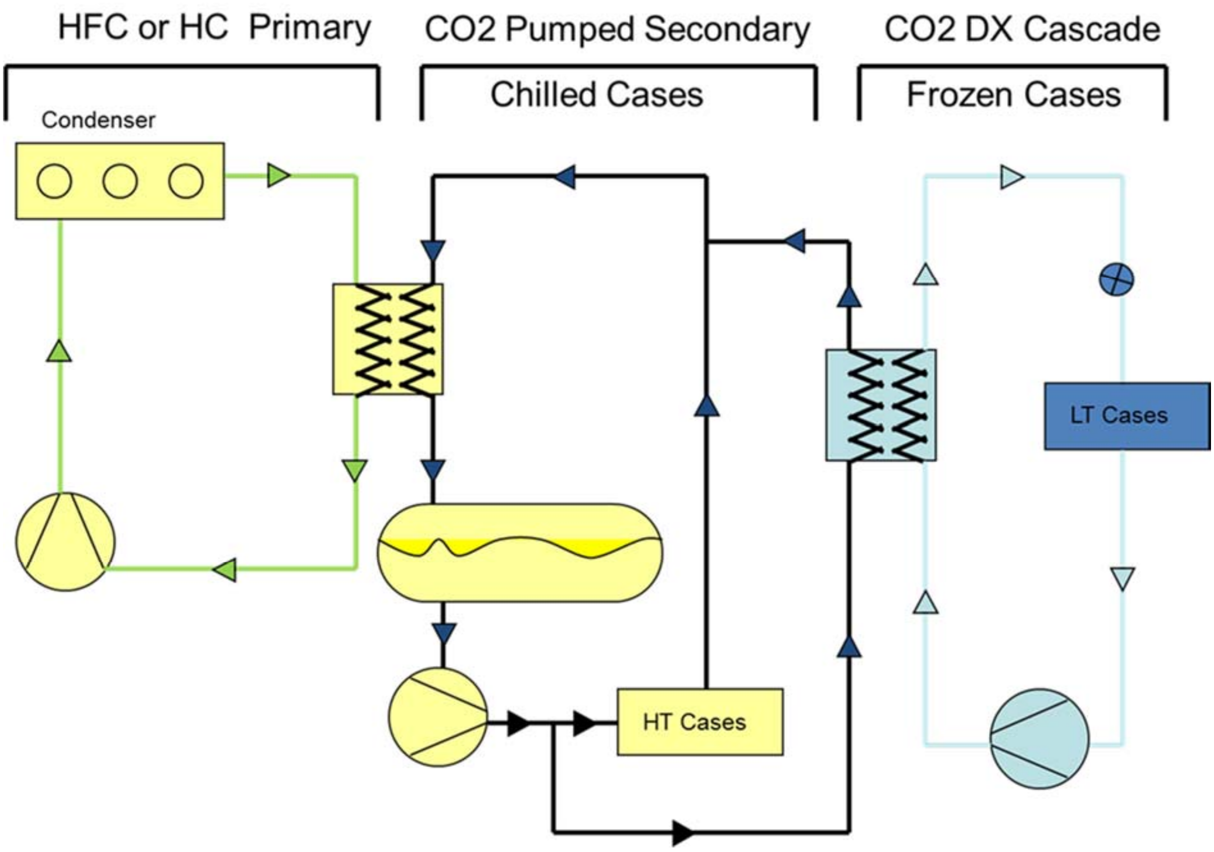


We are just over one month in to this trial at the time of writing this paper and to date we have not experienced any leaks or failures that could be attributed to the refrigerant. We have had fan motors, probes and lamps fail and a couple of water leaks, but none of these are because of the refrigerant. Some of the cases on this trial are 15 years old and have been refurbished more than once in line with the retailer's Carbon reduction policies, so the mechanical failures experienced are what we expect with an ageing asset.

We will now allow these cases to run for a year while we continue to monitor their performance paying particular attention to leaks or compressor faults. However, early indications seem very positive.

4 Trial Three and Four (On Going)

Over the last few years we have installed circa 100 Pumped CO_2 systems to cool its chilled and frozen fixtures. With the exception of four Hydrocarbon trials, all the primary systems are either on R404a or more recently R134a.



The last of the trials wanted to see how these systems behaved if we swapped the R404a for R449a and the R134a for R513a.

Again all trials were carried out in line with the refrigerant manufacturer's instructions. The only thing different about this trial was that we implemented a 'disaster recovery' protocol in case it didn't work or we couldn't control the system on the new refrigerant.

The main concern we had was the glide in the R449a as we had previously tried R407a in one these systems and had problems with liquid flooding back to the compressors as we have very short suction lines.

Both stores have now been completed and it is fair to say, they pulled straight down to temperature as soon as they were recommissioned. We have not experienced any liquid flood back at all. However, the pack that was moved to R449a wasn't running as smoothly as it had been previously and appeared to be loading up the compressors a little more.

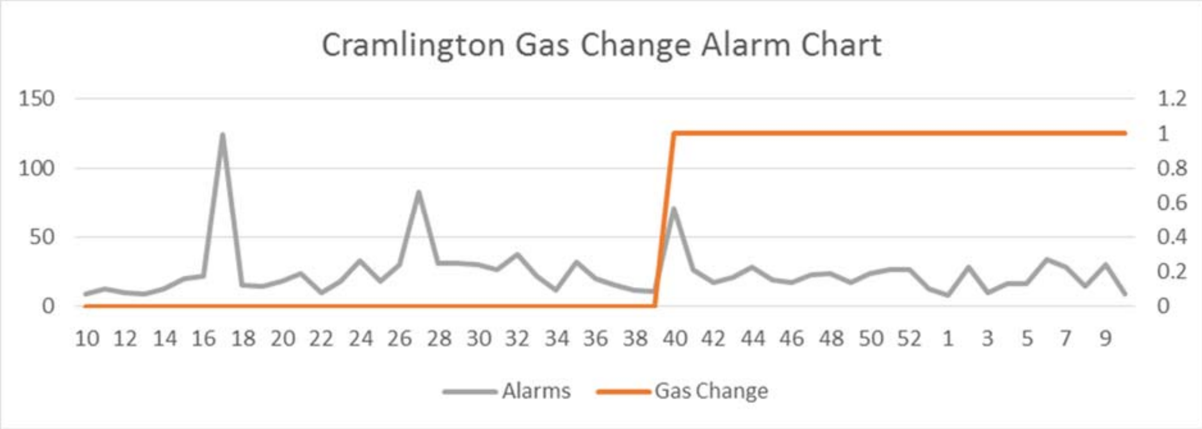
Average Comp 1 VSD % Before:	45.37
Average Comp 1 VSD % After:	50.44

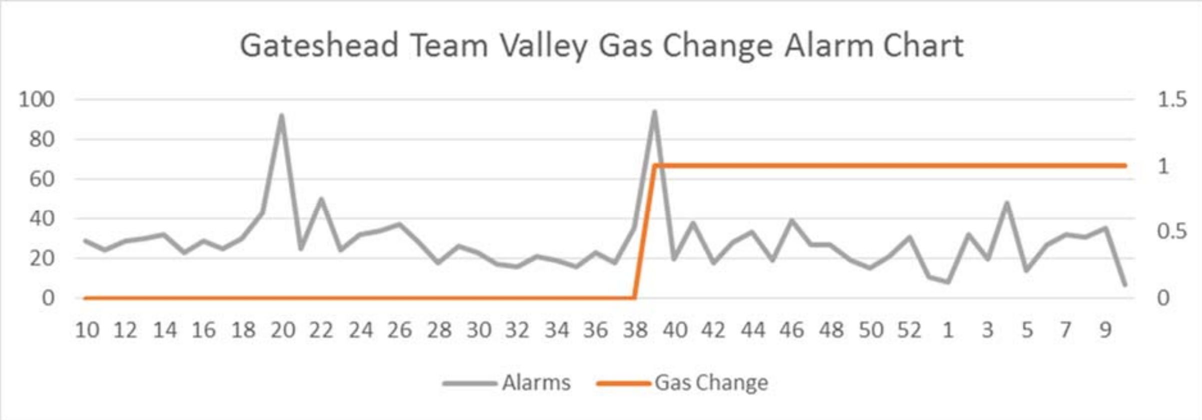
Average Compressor Stages Running Before:	2.79
Average Compressor Stages Running After:	2.96

Upon investigation it appeared to be that we needed to apply an 'offset' as the pressures that the system transducers saw did not reflect the temperatures that that pack controller translated them to. Once this change had been made the system seemed to settle back down again.

We had no such problems on the R513A store.

From an alarm point of view, neither site has shown a significant change at the time of writing this paper and neither have experienced a gas leak of any sort.





As with the integral cabinet trials, nothing at this stage indicates that there are any operational issues in using HFO blends. So the next stage of the trial is to let the systems run throughout the course of the year, experiencing a good mix of ambient profiles.

5 Overall Conclusion

The short answer to this is "it all appears to be good!!"

Having worked through numerous refrigerant changes in the past, the primary concern outside of the environment, is always reliability. Reliability has always seemed to stem from either liquid flooding back to the compressors as expansion valves need adjusting or a sudden abundance of leaks. After some very minor tweaks this change has gone very smoothly. It is however early days in this trial and we will now leave these systems to run for 12 months to get a full view of what they are like to live with.

6 So What Now?

The final part of the trial once you have carried out the 'Post Implementation Review' is what do you do with all the data? How do you turn it in to a statement / proposal that a retailer can get behind?

Let's assume this fictitious table below represents a supermarket's F-Gas data base:

F-Gas Data Base to Date

Gas Type	Refrigerant	Quantity (Tonnes)	CO2 Conversion of Entrained Volume (Tonnes)	Quantity Leaked (Tonnes)	C02 Conversion (GWP)	C02 Emissions (Tonnes)	Percentage Leaked
HFC	R134A	30.00	42,900.00	0.30	1430	429.00	1.0%
HFC	R404A	72.00	282,384.00	6.30	3922	24,708.60	8.8%
Grand Total		**102.00**	**325,284.00**	**6.60**		**25,137.60**	

And as a result, we change the refrigerants in their entirety to the refrigerants we have trialled:

F-Gas Data Base after the Gas Change

Gas Type	Refrigerant	Quantity (Tonnes)	CO2 Conversion of Entrained Volume (Tonnes)	Quantity Leaked (Tonnes)	C02 Conversion (GWP)	C02 Emissions (Tonnes)	Percentage Leaked
HFC	R513a (XP10)	30.00	18,930.00	0.30	631	189.30	1.0%
HFC	R449a (XP40)	72.00	100,584.00	6.30	1397	8,801.10	8.8%
Grand Total		**102.00**	**119,514.00**	**6.60**		**8,990.40**	

You can then make a global statement:

Food Retailer to Reduce the Carbon Effect of Leaks by 65% by 2018

However, this doesn't feel that ambitious, so you can now start to play with the table and the data behind it to incorporate leak reduction as well as conversions of certain stores to HFC free technologies. This then allows you to build a good, more stretching strategy to enable you to make a statement that the retailer can get behind and is able to budget for and ultimately deliver.

For Example:

Food Retailer to Reduce the Carbon Effect of Leaks by 80% by 2020

About Paul Alway

Paul is a highly experienced refrigeration engineer with over 20 years of service in the refrigeration industry covering manufacturing, wholesale, consultancy and subcontracting. He joined the engineering team at Tesco in late 2011 to help facilitate the move to DX Transcritical CO_2 systems and improve the reliability of the existing CO_2 estate. In late 2012, Paul was approached by Marks & Spencer and joined the team in early 2013 to continue to develop the natural refrigeration solutions and build on the goal to be HFC free.

Discussion report (Alway and Atkins papers combined)

David Gibson commented that the author had used 1.5K subcooling in the thermographic picture and asked what the subcooling would have been if R404a had been used? How much subcooling are you loosing?
Nick Atkins replied that the TD they are working on is not sufficient to measure the actual subcooling. This is only an estimate. It depends on drainage on the condenser. It is likely that you will loose 2K in a condenser of operating TD for subcooling. The 1.5 was only an estimated figure not an actual measurement.

David Gibson noted that a subcooling coil was recommended for new equipment. What about retrofits?
Nick replied that this was not generally necessary. Perhaps if a supermarket was operating with 8 K it should be considered, but engineers should be able to manage that. For medium to small system that tend to operate on larger TDs the amount of subcooling is not significant.

Andrew Gigiel asked about the process of reducing the refrigerant charge during testing which had been shown on the graph. The tests had shown the same results for both refrigerants but why had the system been overcharged?
Nick responded that there was surplus charge in the receiver in order to cope with all of the conditions that the test system would be subject to. During the operating tests they pushed components to their maximum charge condition. But during the discharging exercise, the system wasn't being placed under the worst operating condition, which would have been pushing the superheat on the cooler to a lower level than you would normally use, with a high condensing temperature and a low evaporating temperature. The same conditions were used for both of the refrigerants tested.

Colin Vines asked between the two refrigerants one needed two turns on the valve and one needed three. Did you have any thoughts as to why…
Nick said they hadn't investigated that any further.

John Austin Davies by webinar asked whether the authors had any advice on which refrigerant to choose R448A or R449A as they seem very similar?
Paul Alway responded that they had started with one and will probably progress to the other, as the results were very similar across both refrigerants. At the moment R449 seemed to offer a saving in one case.. Industry would have to try them both and consider availability and price. To a certain extend it depended on how the market responds and if everyone make the same choice this would bring the production costs down. Paul had been happy to share his results, but this only represents one supermarket, and there are a lot more systems with R404A out there. Colin confirmed that both price and availability were essential considerations.

Colin Vines asked why there were such significants differences in results between the three cases used in the first paper?
Paul said that this was probably down to design issues. One of the cases had a second compressor that didn't start as much as the others due to design, and its base load was drawing less energy. We think that in changing the refrigerant it just tipped it over into using the second compressor. All of the cases are on control circuits and they get a lot of information about performance. They were continuing to monitor and review long term results of comparisons of the three cases to identify the impact of compressors not running as much.