THE EVOLUTION OF SUSTAINABLE REFRIGERATION AT ALDI STORES LIMITED

Conor EATON-SMITH

K2 Engineering (Cooling) Ltd
Burgh Heath, KT20 6AT, UK, Conor@K2cooling.com

ABSTRACT

Aldi, for over the last decade, has taken steps to improve sustainability with regards to refrigeration. The approach is one of evolution, rather than revolution, with a focus on incremental improvements, that which can be applied to most stores, rather than specific prestige flagship projects. This paper will detail the implementation of this doctrine from 2009, through to 2022, from changing refrigerants, the implementation of heat recovery and fully integrated cooling and heating systems, through to the selection of freezer cabinets, and closed-fronted cabinets. The implementation will be evaluated the results of the doctrine, and discuss the lessons learned, and potential pitfalls to be avoided.

Keywords: Refrigeration, Carbon Dioxide, COP, Heat Recovery, Heating, CoPh, Cabinets, Energy Efficiency.

1. INTRODUCTION

Aldi's focus on sustainability in refrigeration has taken two place distinct streams – improvements in system efficiency and direct refrigerant emissions, and secondly reduction in overall energy requirements via energy recovery and refrigeration and heating reductions.

The actions undertaken in the two streams can be summarised in table 1 below.

Table 1 Timeline of Sustainability Improvements

Year	Refrigeration Efficiency and Emissions.	Store Duty Improvements.
2009	Removal of T8 Shelf Lighting	Opportunistic Heat Recovery for Space Heating for all new stores.
2010	R407A used on all new remote refrigeration systems.	Fully integrated Refrigeration and Heating system trialed.
2011	Transcritical CO2 systems trialed	Fully integrated Refrigeration and Heating system specified on all new stores.
2014	R407F retrofit program. Specification of integrated control systems with associated benefits (e.g., Suction Pressure Optimisation, Adaptive Superheat)	
2015		Fully integrated hydronic systems trialed.
2016		Fully integrated hydronic systems specified on all new stores and major refits.
2017	Transcritical CO2 specified for all new stores and major refits.	Glass Doors and Shelf Edge Technology trialed.
2021	Parallel Compression	Closed Front refrigeration cabinets, with Auxiliary R290 Heat Pumps specified on all new stores.

2. MAIN SECTION

2009 - 2011 Opportunistic (Non-elevated) Heat Recovery for all New Stores

The recovery of waste heat for useful purposes had widespread application in Aldi during the late 2000s. Aldi shopfloors of the time were heated and ventilated using a single zone Constant Air Volume (CAV) system, utilising a ducted gas-fired air heater. With the refrigeration being provided by a single 60 kW MT R404A remote refrigeration system, it was relatively straightforward to install a pre-heating coil in the ductwork (see Figure 1 for an indicative sketch), which was connected to the refrigeration discharge line with the air-cooled condenser piped in series, with a bypass valve arrangement opening once heating demand had been satisfied. No additional controls required, nor were condensing pressure setpoints increased.

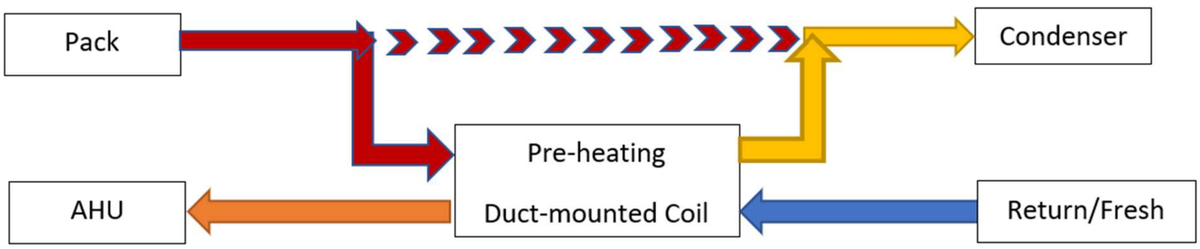


Figure 1 Indicative Heat-Recovery Sketch

This enabled Aldi to significantly reduce the annual consumption of natural gas for store heating, in the region of a 55% reduction annually.

Heat recovery from refrigeration can suffer from the fundamental issue that as the heating duty requirement increases, the available heat that can be recovered from the refrigeration cycle reduces. However, for retail refrigeration systems, especially with open front cabinets, there is constant (albeit varying) heating demand throughout the year, which can reward opportunistic (non-elevated) heat recovery on sites and combined HVAC&R schemes which can accommodate such approaches.

Table 2 Benefits and drawbacks of Opportunistic Heat Recovery

Benefits	Drawbacks
Effectively OpEx-free heating effects	Limited and varying useful heat capacity – prime heat generator still required.
Reduces carbon footprint	Return on Investment only feasible on certain refrigeration layouts.
Can be simple to implement	

2007 – Onwards Current Customer Facing Freezer Coldstore to Integral Freezers

Aldi's frozen food provision underwent a significant change from a frozen coldstore with customer-facing merchandising through glass doors, to integral sales floor cabinets, firstly with 'well' cabinets and then with half glass door 'Top boxes'. These integral cabinets have been periodically upgraded with various changes from R404A to R290, variable speed compressors, and automatic defrosting. Aldi and its consultancy teams have periodically carried out re-evaluations regarding the suitability of integral freezer cabinets.

Without factoring the intangible benefits that integrals provide retailers (e.g., resiliency to store-wide failure, adaptability) – these separate evaluations have shown that for the requirement – integral freezers can present a compelling efficiency case from chilled volume to energy consumption basis compared to the equivalent remote sale floor freezer provision, particularly due to the reduction in trim heating requirements (due to cabinet body forming the heat rejection surface).

As part of as HVAC&R scheme, integral freezers in the numbers used by Aldi, provide a usefully significant (5-10 kW) of internal heat gain, for a negligible cost, especially for open-front chilled cabinet stores, with the THR effectively repurposed for useful space heating all year round.

2009 - 2020 Fully integrated Refrigeration & Heating systems

Aldi installed their first integrated refrigeration & heating system in the UK, at their Edgbaston store. The refrigeration system effectively became a refrigeration system and an Air-Source Heat Pump (ASHP), by including two features.

- A single external air coil, with two separate circuits to provide heat rejection or to gather heat respectively (sometimes termed a "false load").
- A refrigeration pack designed so that 5 out of 6 compressors could transition between two suction groups – those being the sales floor refrigeration load, and the external air coil during ASHP function.

This configuration allowed the system to efficiently operate two separate duties and optimize each Saturated Suction Temperature (SST) throughout the annual operational cycle, whilst simultaneously minimising the plant requirement for the store, by enabling increased utilisation of refrigeration compressors, which could remain dormant for much of the year, thus negating the need to purchase additional ASHPs.

Additionally, as a fully integrated system – the Saturated Condensing Temperature (SCT) setpoint is dynamically floated as required, from typical heat rejection (20°C SCT) condensing temperatures up to maximum heating operation (46°C SCT) operation, depending on ambient or heat demand conditions. Whilst this will reduce the refrigeration CoP compared to a system that is only providing refrigeration, the increase in power is significantly less than the energy required for standalone heating. Consequently, this results in very high CoPh compared to other heat pumps, as the majority of work has already been done for useful refrigeration purposes.

$$Heat\ Recovery\ CoPh = \frac{Useful\ Heating\ Provided}{(Total\ Power\ Input - Required\ Refrigeration\ only\ Power)}$$

EQ.1

Such an approach allowed Aldi to reduce the carbon footprint of stores significantly, reduce project Total Expenditure (TotEx) with the elimination of natural gas infrastructure in store, and meet Local Authority planning requirements for Low to Zero Carbon (LZC) energy generation. Though there were drawbacks to this approach, predominantly the integration of the systems requires a multi-skilled and holistic approach throughout the product life cycle, and system malfunctions will impact both refrigeration and heating performance, these aren't prohibitive. This approach has been successfully adopted for over a decade, including through to the transition to R744 transcritical systems with the benefits and drawbacks summarised in Table 3.

Table 3 Benefits and Drawbacks of Fully Integrated Refrigeration Heating Systems

Benefits	Drawbacks
Reduction in project TotEx. Increases in the refrigeration package are offset by the reductions in other project packages.	Integrated systems are complex and can require involved management to ensure service partners are sufficiently trained.
Reductions in operational and embodied carbon footprints due to reduction in consumption of natural gas or electricity for heating processes.	Heating operation is secondary to refrigeration – which can result in a cold store under system malfunction conditions or low refrigerant levels
Significant reduction in Carbon footprint available (depending on carbon intensity of electricity and heating fuel).	Manufacturers need to have fully assessed the requirements of both heating and refrigeration in their systems otherwise efficacy can be limited.

2009 – 2017 Replacement of R404A with Lower GWP Alternatives

In parallel with new heating strategies, Aldi has reduced their refrigerant emissions liability, by adopting alternative HFC refrigerants which have a lower GWP, when the adoptions became practicable. Table 4 shows the top-level differences between the refrigerants historically used on the Aldi estate.

Table 4 Comparison between Aldi refrigeration types

Refrigerant	R404A (-2015)	R407A (2009 -)	R407F (2014 -)	R744 (2017-)
GWP (AR4 Values)	3922	2107	1825	1
Nominal CoP[i]	2.23	2.32	2.34	1.86
Heat Recovery CoP[ii]	2.46	2.51	2.51	2.64

For MT systems, changing from R404A to R407A and R407F for new stores and retrofits offered the potential for significant energy savings in addition to direct carbon savings. In the main, this process was painless and effective, but there were two significant points at which care is required by stakeholders. Firstly, to realise any improved CoPs, requires systems to be recommissioned appropriately, especially as the R407 range of refrigerants has significant glide. Midpoint conditions used for design, need to be carried over to commissioning.

Secondly, the differences in operating pressures could result in unanticipated problems. Table 5 shows that whilst R407A can be used for a plant designed for R404A for a 32°C design ambient temperature with no significant changes, and have a wider potential operating envelope, R407F cannot be so readily placed into such systems. R407F has a lower maximum condensing temperature than R404A for a 24.8 bar PS system, (albeit not a significant reduction). More problematically with a design condensing temperature of 46°C, R407F has a significantly higher operating pressure which can bring it into conflict with backup control setpoints and mechanical switches.

Table 5 Comparison in operating pressures and temperatures between R404A, R407A, and R407F

Refrigerant	R404A	R407A	R407F
Saturated liquid pressure at 55°C bubble point (bar g)	24.8	25.0	26.2
Saturated gas pressure @ 46°C midpoint (bar g)	20	20.2	21.1
High-Pressure Safety Switch setting for 24.8 bar PS systems (0.9 x PS) (bar g)	22.3		
Maximum possible midpoint condensing temperatures for above (°C)	50.5	52.1	50.2

This potential unhelpful interaction in high ambient temperatures or periods of high heating demand in the case of combined refrigeration and heating systems can be eliminated with the appropriate design pressure for the application. In many cases, manufacturers and installers were not aware of the changes in design pressures, which raises the importance of design reviews and the re-familiarisation of standards.

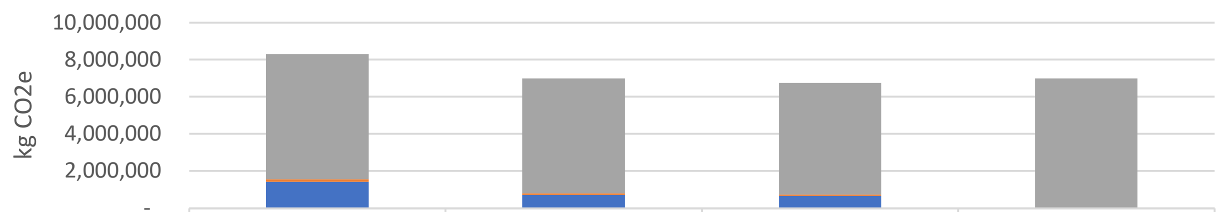
2015 – Onwards - Hydronic system trials and rollouts.

As Aldi stores increased in number and type, the existing CAV systems would not be suitable for new projects. These would be unable to meet the new Part L Building Regulations in a cost-effective manner[iii], with the increase in heating duty requiring a larger system as to not compromise efficacy. Additionally, aiming to reduce the effect of refrigerant leaks (with a mind towards Carbon dioxide as a potential replacement), Aldi trialled and specified hydronic heating systems such as an underfloor heating system for the salesfloor and amenities area, or where not feasible (e.g. refits, developer shell), ceiling hung LTHW cassettes, for all new stores and significant refits.

Whilst there may be a nominal reduction in heating efficiency due to an additional heat transfer penalty – underfloor heating does provide specific benefits for refrigeration heat recovery, primarily much lower fluid return temperatures than typical air-to-air or water-to-air systems, which can significantly increase the heat recovery CoPh compared to other methods of heat recovery, in addition to the HVAC specific benefits of underfloor heating.

2016 – Onwards – Transitioning to a Carbon Dioxide future

Moving forward to 2016, Aldi made the decision to transition to natural refrigerants, with R744 providing remote MT refrigeration having trialled systems from 2011. To evaluate this approach from a sustainability standpoint, a dynamic model is used to compare[iv] different refrigerants on 60 kW MT refrigeration systems (in practice, installed systems have varied between 60 – 150 kW total capacity and by compressor technology) shows the impact of this adoption on refrigeration only systems and can be seen in Graph 1 over a 10-year life cycle.

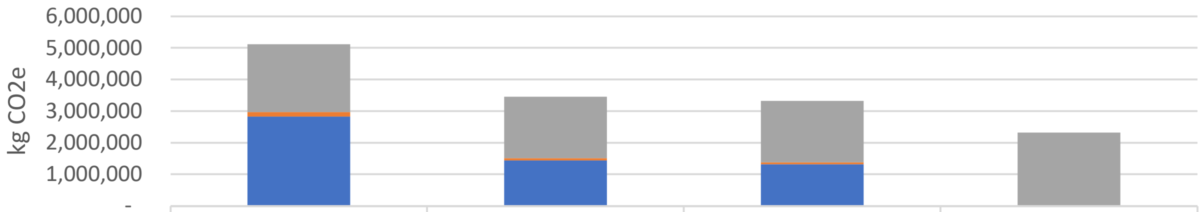


	R404A - 60 kW MT	R407A - 60 kW MT	R407F - 60 kW MT	R744 - 60 kW MT
Indirect	6,749,796	6,199,464	6,030,252	6,980,940
Recycle	141,192	72,000	65,664	720
Leakage	1,411,920	720,000	656,640	360

Graph 1 Lifetime equivalent CO2 emissions in ‘ideal’ conditions

Under relatively 'ideal' conditions'[v] for high and interim medium GWP refrigerants (for example systems are modelled with a 5% Annual Leakage Rate (ALR)), and not accounting for heat recovery activities, we can see that R407F would offer a 3.3% reduction in lifetime emissions compared to R744 (assuming the same compressor type) and 19% compared to R404A.

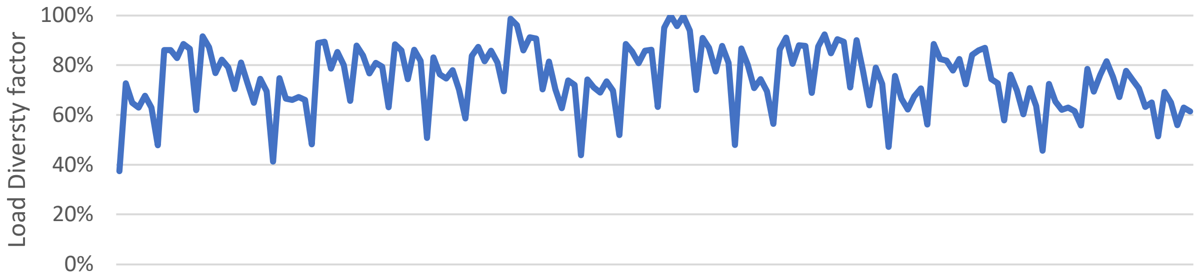
However, if different and arguably more representative conditions[vi], including a 10% ALR, current carbon intensity figures for the UK national grid, and load diversity factors allowed for, the carbon footprint changes significantly as shown in Graph 2.



	R404A - 60 kW MT	R407A - 60 kW MT	R407F - 60 kW MT	R744 - 60 kW MT
Indirect	2,150,232	1,946,664	1,947,024	2,320,092
Recycle	141,192	72,000	65,664	720
Leakage	2,823,840	1,440,000	1,313,280	720

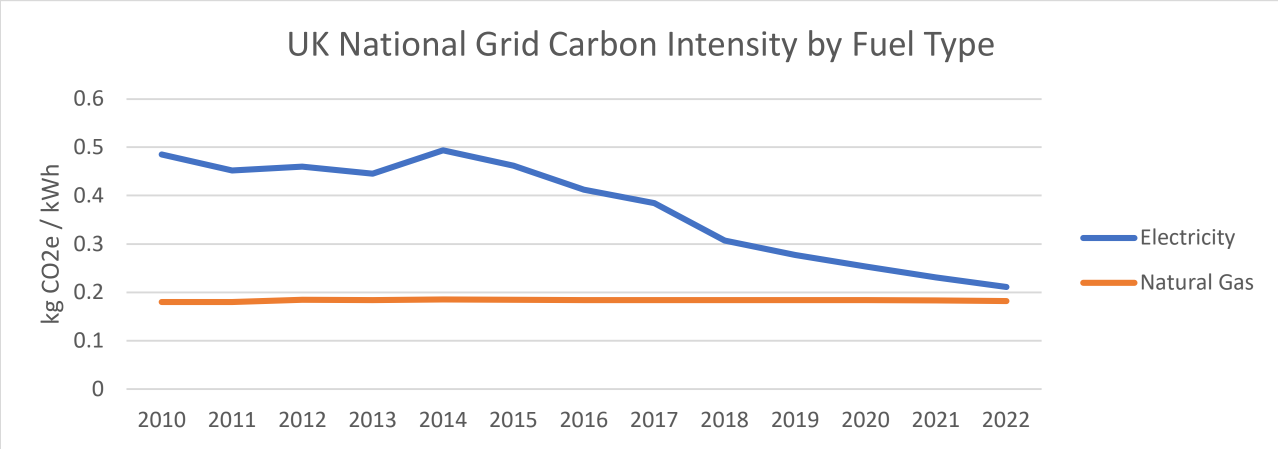
Graph 2 Lifetime equivalent CO2 emissions in representative conditions.

With a diversified weekly load profile as shown in Graph 3 and a more representative leakage rate, R744 offers a significant reduction in carbon footprint and shows a greater relative impact of refrigerant leakage.



Graph 3 Pack Calculation Pro Supermarket MT Load Profile (Weekly)

With the reduction in carbon intensity of electricity generation, as shown in Graph 4, the relative impact of direct emissions will likely continue to increase, as indirect emissions trend towards Net Zero.



Graph 4 Trend of UK Carbon Intensity by Fuel Type (including Transmission and Distribution losses)

Additional onsite electricity generation (i.e., solar photo-voltaic resulting in a blended electricity rate with a lower carbon intensity) will reduce indirect carbon emissions further, further increasing the relative impact of high GWP refrigerant leakage. Under current plans, Aldi intends to be completely free of fluorinated gases by 2030. At the time and now in retrospect, the choice to adopt R407A/F in the interim was very positive, as table 6 summarises.

Table 6 Benefits and drawbacks of interim HFC refrigerants compared to R404A

Benefits	Drawbacks
Significant reductions in direct refrigerant emissions, which might be 40-60% of total warming impact.	Full recommissioning of the system is necessary to reach full efficiency.
Improvements in energy efficiency available.	Different operating pressures can lead to unintended consequences.
Limited CapEx impact compared to R404A.	

The transition to R744 when load diversity and the decarbonisation of UK electricity infrastructure is accounted for, in addition to specific requirements such as store heating – transcritical R744 has enabled a significant reduction in carbon footprint compared to other options. Planning conditions which refer to a particular BREEAM rating, are much more easily met with R744, specifically POL-01 “Impact of Refrigerants”.

A factor not always considered when calculating the direct warming effect of high GWP refrigerants is the effect of unforeseen catastrophic loss of refrigerant. Such losses could have rather large effects, with one recent catastrophic loss at a Scottish abattoir contributing 87% of all HFC released in Scotland during 2021, and potentially 0.87% of all of Scotland’s GHG emissions for the year from one event[vii]. Extending the 60 kW MT system hypothetical example, the potential annual release of various refrigerants from catastrophic losses from a thousand store estate can be estimated, as shown in Table 7.

Table 7 Estimating the effects of catastrophic refrigerant leaks

Refrigerant	GWP (AR4)	Refrigerant Charge (kg)	Annual Probability of Catastrophic leak	Systems on Estate	Annual Warming Impact (kg/CO2e)
R404A	3922	60	1%	1,000	2,353,200
R407F	1825	60	1%	1,000	1,095,000
R448A	1387	60	1%	1,000	832,200
R454C	148	40	1%	1,500	88,800
R744	1	60	1%	1,000	600

The potential warming impact from catastrophic leaks should be factored into models (actual estate-wide annual leakage rates would appear to be most suitable). In the case of R404A, the effects of this rate of annual catastrophic release would be the equivalent warming impact of the lifetime warming impact (using the model from Graph 2) for nearly 6 modelled stores. For R744, the increase in warming impact is insignificant.

Aldi's experience with its first-generation rollout of transcritical refrigeration equipment highlighted the importance of appropriate compressor selections. A tranche of dual temperature 75 kW pack systems was delivered with a 2 MT & 1 LT compressor configuration. These systems performed well in general, but in stores which could not utilise the integrated refrigeration & heating system – these systems had a sub-optimal performance at low load conditions and impinged on suction pressure optimisation, due to a relatively high minimum capacity of the packs.

2020 – Onwards - Closed Fronted Display Chilled Display Cabinets and Heating System Refinements

After several previous trials, including shelf edge technology, in 2020 Aldi carried out a widespread trial of doored chilled display cabinets, with the intention to roll out the doors in all new stores pending the success of the trial. Adopting doored cabinets comes with the benefits of reducing overall refrigeration duty significantly, and improved evaporating temperatures. With the adoption of R744, Aldi stores had been serviced by two dual-temperature transcritical booster packs, each providing approximately 50% of the store's refrigeration and heating duty. The adoption of doors required a different approach to the refrigeration systems.

Firstly, practical considerations drove the reduction in system requirements down to one main MT system and a condensing unit per coldstore, a cost reduction which offset the increased doored cabinet's CapEx. Secondly, with such a reduction in refrigeration load, the false load of an integrated refrigeration and heating system was much larger proportionally than previous and the system was in danger of becoming a relatively inefficient heat pump with a secondary refrigeration function rather than vice versa.

The required changes enabled Aldi to take several opportunities to further increase the overall efficiency of the store in addition to the duty reductions presented by doored cabinets. Removing the false load from the refrigeration system (but retaining the boosted heat recovery), and supplementing with a number of R290 Air to Water auxiliary heat pumps firstly provided an overall improvement in seasonal CoPh for heat pumping. Secondly, removing the false load operation allowed the suction pressure optimisation software routines to be operational constantly, rather than potentially inhibited during heat pump operation.

Thirdly, with the change in pack systems – Aldi was able to specify the use of parallel compression on the transcritical systems. Historically in the UK, parallel compression for transcritical CO2 for refrigeration systems hasn't offered an attractive return on investment, but for systems which adopt heat recovery – a much larger proportion of the time is spent in transcritical operation than would otherwise be. Additionally, parallel compression allows for the "load" compressors (as opposed to the "Flash Gas" compressor) to have a significant reduction in swept volume. For refrigeration packs which are limited by compressor numbers – parallel compression has the welcome consequence of improving suction pressure performance at low loads. For a given 60 kW system [viii]– the differences in system characteristics can be quite stark, as table 8 shows, although designers can find some benefits with a parallel compressor optimised for part-load flash gas generation, with the disparity below reducing, (albeit with resultant part-load efficiency increase).

Table 8 Flash gas to Parallel Compression Comparison

Flash gas Management	Total compressor displacement (m3/h)	Nominal Full Load Current (A)	Nominal CoP at design conditions	Minimum Capacity (kW)
Flash gas Bypass	31.5	76.7	1.59	20
Parallel Compression	24.3	65.4	1.8	10

When retrofitting doors or new refrigerated display cabinets to existing stores, care must be taken with regards to the system's minimum capacity, as noted previously, failure not to do so will impinge on cabinet performance due to sub-optimal suction pressure control. Depending on the system configuration, one might need to carry out a compressor reconfiguration on-site (particularly on systems with fewer capacity stages).

From a wider store perspective – it should be noted that open-fronted cabinets do provide additional useful functions – specifically maintaining comfortable sales floor temperature in summer and year-round dehumidification. If doors are to be retrofitted – designers should assess if the existing or proposed HVAC systems are able to cope with the change in design environmental conditions. Cabinet doors will provide a visible warning of insufficient humidity control – as condensation forms on the outside of the door of the refrigerated display cabinet.

3. CONCLUSIONS

2022 – Onwards

Aldi continues to evaluate approaches to optimise total expenditure, with improvements to system efficiency and performance at the forefront of considerations - whether new compressor and ejector technology for transcritical carbon dioxide – through to regular re-evaluations on existing doctrines, to implementing automated system performance and efficiency KPI reporting - Aldi has gone through a sea change in refrigeration technology and process and is well placed regarding sustainable practices for now and into the future.

The question that Aldi will look for the next answer to - is what is the next sea-change in sustainable refrigeration, in a competitive marketplace?

ACKNOWLEDGEMENTS

The author would like to acknowledge the help of Aldi Stores Ltd, David Ringham of K2 Engineering (Cooling) Ltd, and Paul Dunna of Building Management Technology for their assistance in drafting this paper.

---

[i] -10°C Saturated Suction Temperature (midpoint), 20°C Suction Return Temperature, 0 K subcooling,
HFC Compressor: Bitzer 4CES-6Y. :45°C Saturated Condensing Temperature
R744 Compressor: Bitzer 4JTE-10K. 90 bar(a) Gas Cooler Pressure with 35°C Gas Cooler Outlet).

[ii] -10°C Saturated Suction Temperature (midpoint), 20°C Suction Return Temperature, 0 K subcooling,
HFC Compressor: Bitzer 4CES-6Y. :46°C Saturated Condensing Temperature 10 K Subcooling
R744 Compressor: Bitzer 4JTE-10K. 75 bar(a) Gas Cooler Pressure with 25°C Gas Cooler Outlet) - Flash gas Bypass

[iii] Part L of the Building Regulations required Ventilation systems to incorporate heat recovery.

[iv] Using IPU *Pack Calculation Pro* v. 5.2.3.0 64 Bit.

[v] 20 K Suction Superheat, 10 K useful superheat, 10K condensing temperature difference, annual ambient profile for Birmingham, constant load profile, 60 kg/kW charge, 5% annual refrigerant leakage rate, life span 10 years. Electrical Carbon intensity of 0.485 kgCO_2e/kWh (2010 GHG Conversion Factors - Department for Business, Energy & Industrial Strategy).
R404A – 4 off. Bitzer 4CES-6Y @ -10°C evaporating temperature dewpoint
R407A – 4 off. Bitzer 4CES-6Y @ -8°C evaporating temperature dewpoint
R407F – 4 off. Bitzer 4CES-6Y @ -8°C evaporating temperature dewpoint
R744 – 4 off 4JTC-10K @ -9°C evaporating temperature dewpoint
Lead Compressors VFD speed controlled.

[vi] Load Profile "Supermarket Medium Temperature", 10% annual refrigerant leakage rate, Electrical Carbon intensity of 0.2117 kgCO_2e/kWh (2022 GHG Conversion Factors - Department for Business, Energy & Industrial Strategy).

[vii] "Perth abattoir leaked emissions equal to 41,892,750 Big Macs" https://www.thecourier.co.uk/fp/business-environment/environment/3718642/slaughterhouse-gas-leak-questions-remain/

[viii] Nominal 60 kW system at -8°C SST, 5 K useful superheat, 5 K non-useful suction superheat. 93.7 bar(a) Gas Cooler Pressure, 38°C Gas Cooler Outlet, intermediate pressure 40 bar(a). Minimum Condensing temperature 12°C, 2 K sub cooling.
Compressors automatically selected by Bitzer Software v.6.17.8 rev2725
Flash gas Bypass System 1 off. 4HTE-15K (VFD), 3 off.4MTE-7K.
Parallel Compression 1 off. 2KTE-5K (VFD), 2 off.4MTE-7K, PC Compressor 1 off. 4MTE-10K (VFD)