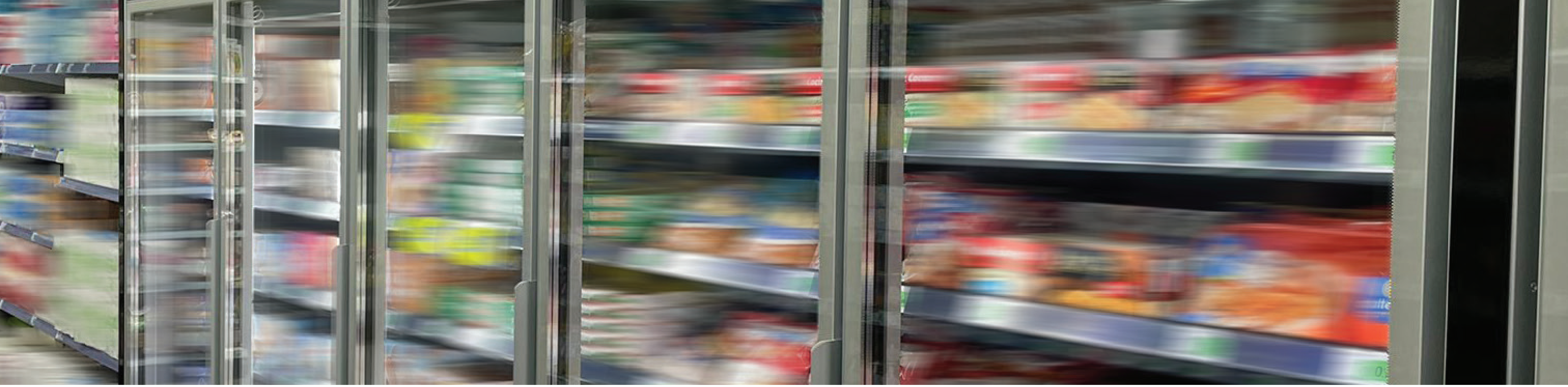
Enhancing Efficiency in Heat Recovery with A2L refrigerants

HEAT RECOVERY WITH OPTEON™ XL



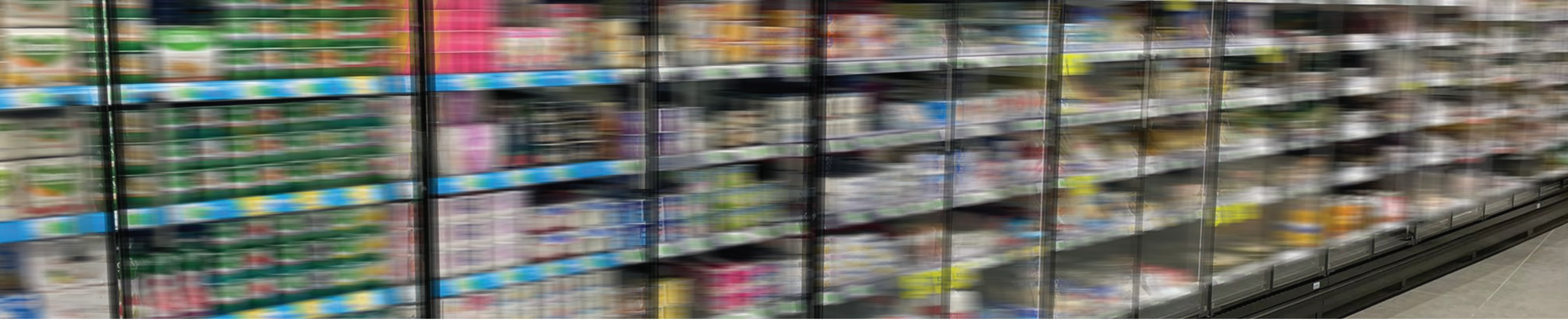
Heat Recovery and Low GWP A2L Refrigerants – a powerful combination for reducing emissions and costs in supermarket refrigeration

The rise of click and collect, a growing market for home delivery, increased demand for fresh food and perishable goods means retailers rely on efficient cold storage and display more than ever. Previously, proven performance has led to the increased use of low-GWP A2L refrigerants in cooling applications such as multi-compressor supermarket refrigeration to increase efficiency.

However, the focus for retailers is now broadening. Environmental standards such as the Kigali amendment to the Montreal Protocol and European F-Gas regulation mean retailers now have to balance sustainability targets with operational efficiency and concentrate on the total energy consumption. This has encouraged them to actively explore viable options and alternatives for reducing both energy consumption and total emissions in supermarket refrigeration.

To explore the efficiency of these alternatives, Chemours commissioned a study comparing HFO based refrigerants with R-744 in several different Heat Recovery scenarios for a typical retail area supermarket in two different climate conditions. The results clearly show that low-GWP HFO refrigerants used in a Heat Recovery system outperform other low-GWP options. Compared to a baseline R-404A with a gas boiler, the study found significantly lower 10-year total emissions and 10-year life cycle costs in most cases.

In the drive to reduce climate-changing emissions, the study proves that the use of low-GWP HFO refrigerant combined with Heat Recovery technology can reduce emissions and deliver a noticeable long-term cost-saving.



The heat is on for supermarket refrigeration

When it comes to supermarket refrigeration, the GWP of refrigerants has been the prime focus of environmental and emission legislation, such as the European F-Gas regulation and the Kigali amendment to the Montreal Protocol.

Recent studies conducted by, among others, Chemours have now demonstrated that this focus might need to change, as total emissions from refrigeration systems are much more heavily influenced by energy efficiency rather than its refrigerant direct emissions.

Engineers are now considering a bigger picture, as concentrating on cooling omits another large source of emissions - heating - which can no longer be isolated as a separate consideration. Capital expenditure fears about the cost of installing Heat Recovery systems are becoming outweighed by the advantages they offer. So, there is now a very real incentive to use Heat Recovery to achieve these goals.
Refrigerants such as R-454C and R-454A have already proved that low-GWP HFO refrigerants can deliver superior energy efficiency and lower 10-year total CO_2 equivalent emissions at a total life cycle cost very similar to traditional HFC systems. The question now is whether Heat Recovery – and consequent emission reductions – can be achieved at a reasonable cost using the same or similar low-GWP options.

Until now, little concrete evidence has been available that compared various options and technologies from a consistent approach, based on system costs and total emissions under the same operating conditions. Typically, the only information has compared individual cases with previous non-Heat Recovery options – the classic 'apples with oranges' scenario.

This begged a robust theoretical comparison of the available Heat Recovery technologies using different conditions that represented both a European moderate and a hot climate and then compared it to a benchmark – in this case, the energy production emissions and energy cost for scenarios in a country like France.

Arriving at our results

With the reduction of climate change emissions, the no.1 goal of legislation and targets now being introduced, the study decided to use total system emissions (TCO_2e) to compare the various technologies.

The two charts below demonstrate lower total emissions for a Heat Recovery plus low-GWP refrigerant set-up, compared to the R-404A & gas boiler. More specifically, depending on the configuration and technology in use, in the UK, the emissions will be decreased 11 to 70% (Figure 1), and in Spain the emissions will be decreased 13 to 58% (Figure 2).

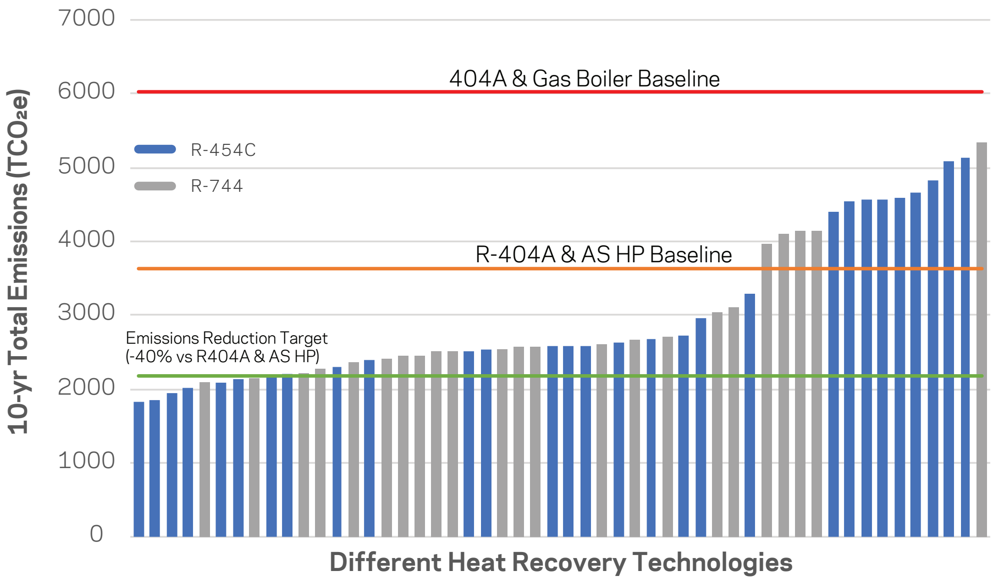


Figure 1 - Summary of 10-yr Emissions for Heat Recovery technologies at the mild UK climate conditions.

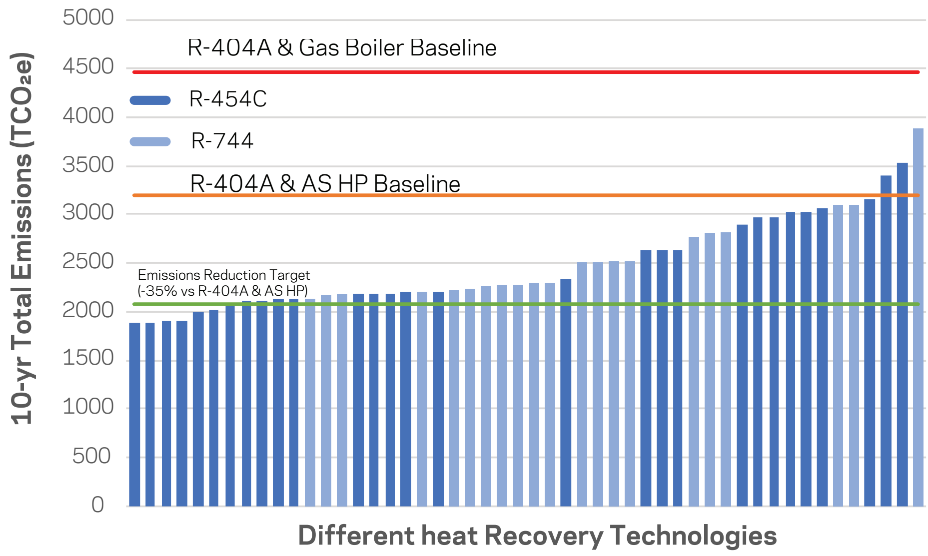


Figure 2 - Summary of 10-yr Emissions for Heat Recovery technologies at the hot Spanish climate conditions.

To limit the number of technologies being investigated, arbitrary emissions reductions targets were set to 40% (cooler climate) and 35% (warmer climate) below the R-404A & air source heat pump baseline values.

Applying these targets reduced the potential technologies to 9 for the cooler climate and 6 for the warmer climate. Table 1 below shows the different technologies which achieved the target emission reductions labelled by ID #.

ID #	Technology
1	R-454C - Gas - Partial Condensing - min. head equiv. ambient of 25 °C
2	R-454C - AS HP - Partial Condensing - min. head equiv. ambient of 25 °C
3	R-454C - Gas - AHU Mounted Condenser Coil - min. head equiv. ambient of 25 °C
4	R-454C - AS HP - AHU Mounted Condenser Coil - min. head equiv. ambient of 25 °C
5	R-454C - Gas - AHU Mounted Condenser Coil - min. head equiv. ambient of 25 °C HT packs / 30 °C LT packs
6	R-744 - AS HP - To Water (36/30 °C) - min. head equiv. ambient of 20 °C
7	R-454C - AS HP - AHU Mounted Condenser Coil - min. head equiv. ambient of 25 °C HT packs / 30 °C LT packs
8	R-744 - AS HP - To Water (36/30 °C) - min. head equiv. ambient of 25 °C
9	R-454C - AS HP - AHU Mounted Full THR Condenser Coil - min. head equiv. ambient of 30 °C

Table 1 - Identification number for the technologies achieving the target emissions reduction

The life cycle cost (LCC) of each potential solution which achieves the target emission reductions also acts as a factor in the selection of the best solution, however the lowest cost options are not necessarily the lowest emissions options as shown in the table below (Table 2).

Technology ID #	UK		Spain	
	UK 10-yr Emissions (TCO_2e)	UK 10-yr LCC (k£)	Spain 10-yr Emissions (TCO_2e)	Spain 10-yr LCC (k£)
1	2095	1484	1907	1434
2	1858	1523	1889	1430
3	2022	1594	1900	1521
4	1825	1630	1887	1517
5	2134	1650	2020	1571
6	2092	1671	-	-
7	1957	1684	2008	1568
8	2151	1694	-	-
9	2154	1769	-	-

Table 2 - Summary of 10-yr total emissions and 10-yr LCC for the technologies achieving the target emissions reductions

An established method widely used in scientific papers was therefore needed to evaluate which solutions provide emissions reductions at a reasonable cost. Calculation of the cost of abatement per Tonne of CO_2 equivalent emissions (TCO_2e) over a 10-year period is a method used to determine the most cost-efficient technology to reduce the environmental impact of a system. The relative emissions abatement cost can be calculated by using the following equation.

$$\textit{Abatement cost per } TCO_2e = \frac{LCC_{Alternate\ Technology} - LCC_{Baseline\ Technology}}{Emissions_{Baseline\ Technology} - Emissions_{Alternate\ Technology}}$$

A negative abatement cost indicates the system 10-yr LCC is lower than the baseline R-404A technology. This calculation in itself won't show which technologies deliver the largest emission reductions. However, given that the potential technologies under discussion have been chosen using the criteria outlined above, it does give an accurate reflection of which of these offers the best value for money in achieving those reductions as demonstrated in the figure below (Figure 3).

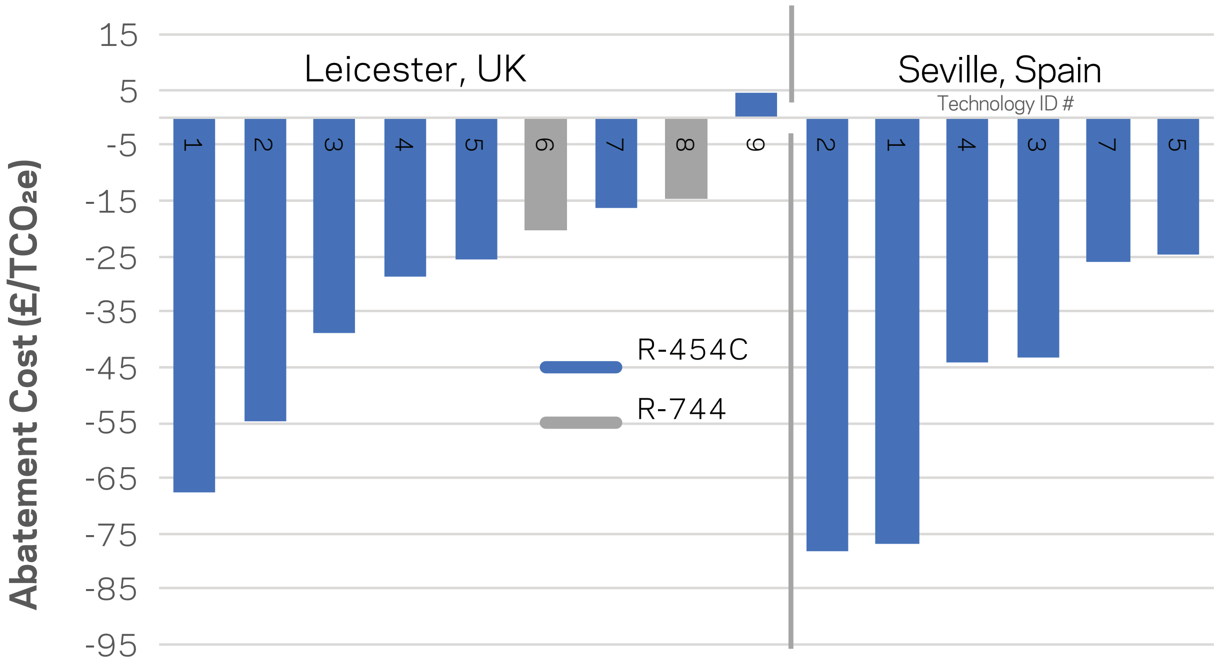


Figure 3 - Abatement cost by region and selected Heat Recovery technology

The results from the study were then benchmarked against power and emission costs from France - which already has a low emission factor. This gave a broader context for the results in terms of the impact on decarbonization and TCO_2e reductions, which you can see in the following chart. (Figure 4).

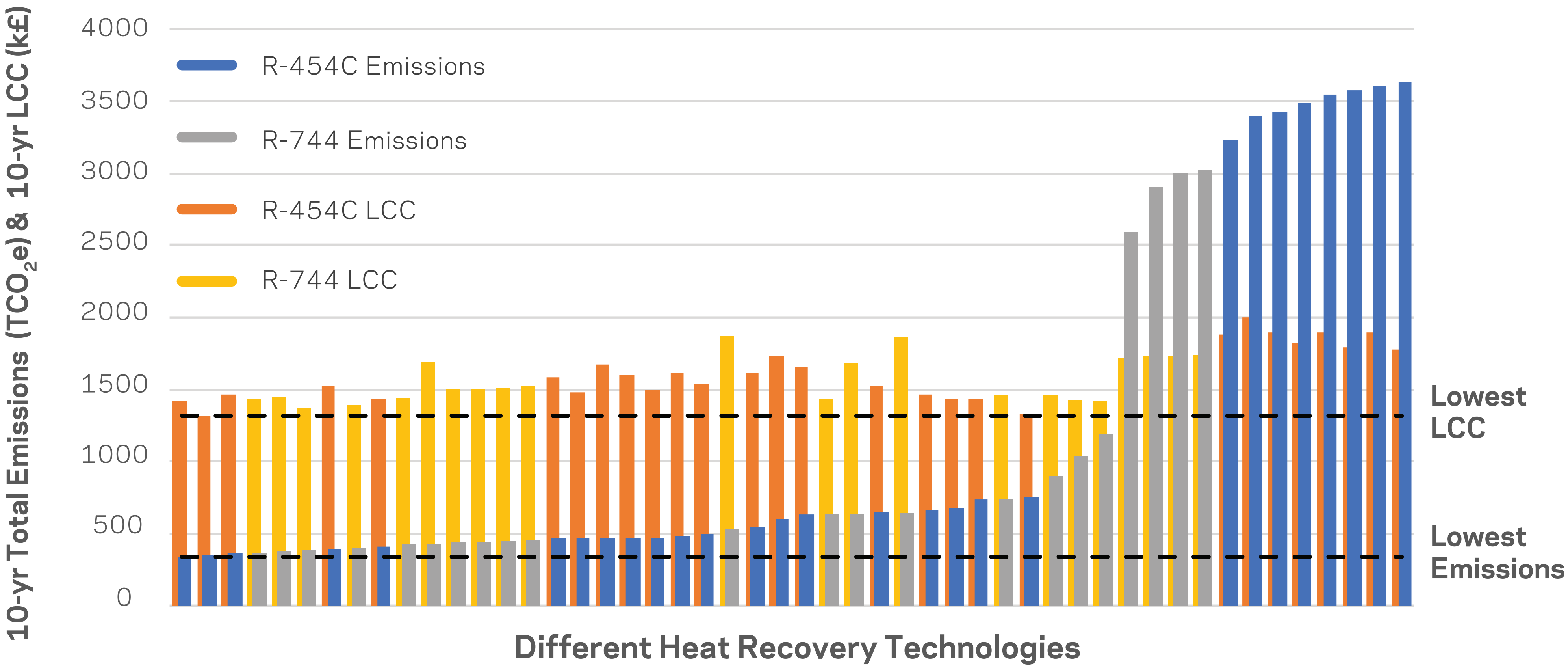


Figure 4 - Summary of 10-yr total emissions and LCC using French power generation emissions and cost data.

Conclusion

The results clearly show that the 10-yr total emissions from all Heat Recovery systems are significantly lower than the baseline R-404A with a Gas boiler. In most cases, the 10-yr LCC is also considerably less. To drill down into these results, technologies using the low-GWP HFO based refrigerant R-454C delivered the lowest 10-yr total emissions at the lowest 10-yr LCC in both the moderate and hot climates.

At current power generation emissions rates, technologies utilising low-GWP HFO based refrigerants such as R-454C offer the lowest total emissions in both the moderate hot climates considered. In fact, in the moderate climate, 9 different technologies (7 of which were using R-454C as the working fluid) saw at least a 40% reduction in emissions reduction compared to a R-404A refrigeration and air source heat pump heating baseline. In the warmer climate, 6 technologies (all R-454C) achieved at least 35 % emissions reductions.

It's worth bearing in mind that the Heat Recovery technology with the lowest abatement cost – in other words the most cost efficient - varies depending on the ambient conditions - although in both regions the partial condensing technology with a minimum head pressure equivalent to a 25 °C ambient was optimal. However, in the moderate climate if Gas was used as the supplementary heat source it proved most beneficial, in contrast to the hot climate where an air source heat pump provided the best solution.
The key issue based on these findings is whether a Heat Recovery system plus a low-GWP system delivers long term cost savings and emission reductions. The study results give a definitive answer. Combining the emissions reduction and LCC data to calculate a TCO_2e abatement cost showed that end users could achieve cost savings of up 79€-90€/TCO_2e reduction by installing a suitable Heat Recovery technology and using R-454C for their refrigeration needs.

Moreover, the study showed that 10-yr total emissions figures can be further reduced by taking advantage of low carbon energy generation sources, such as air source heat pump solutions. Technologies using R-454C as the working fluid still produced the lowest 10-yr total emissions at the lowest 10-yr LCC.

The results of this study clearly demonstrate that the low-GWP HFO based refrigerants such as R-454C can be incorporated into a Heat Recovery strategy and are capable of outperforming other low-GWP options such as R-744. This leads to the conclusion that serious consideration must now be given to the combination of low-GWP refrigerants and Heat Recovery systems in commercial refrigeration systems to meet sustainability targets while maintaining cost-effective operational performance that keeps food fresh.

Opteon™ XL
Refrigerants

Appendix

Study Scope & Assumptions

The study focused on a typical supermarket with a retail area of ~2300 m², 160 kW MT and 30 kW LT Refrigeration with either gas boiler or an independent air source heat pump for heating as the baseline technologies. The gas boiler efficiency used was 89%, which was considered to be a mid-range value. Coefficients of performance for the air conditioning / air-source Heat Pump units (Table 3) derived from manufacturers data and based on scroll inverter heat pump to water technology considering fans and ancillaries as well as compressors.

Two different geographical locations were considered - a moderate North European and a hot southern European climate. It was recognised that there is a requirement for space cooling of the retail area and therefore the cost and emissions from the air conditioning requirement was also taken into account.
The full study considered 3 different refrigerants, R-744, R-454C (GWP = 148) and R-454A (GWP = 239) but in this paper only the results for R-744 and R-454C will be presented. The AR4 GWP values (IPCC, 2014) were used as these are used for the European F-Gas legislation.

It was assumed that the heat exchangers would be ideally sized for the given conditions and the ancillary equipment which was common to all technologies (e.g. pumps) were not included. Where possible system performance data was calculated using manufacturers selection software and where this was not possible thermodynamic cycle calculations, assuming compressor efficiencies similar to known fluids, were used.

Table 3 - C.O.P. values used for the air conditioning & air source heat pump

Ambient / °C	Heating C.O.P.	Cooling C.O.P.
40	-	2.22
35	-	2.79
30	-	3.47
25	5.53	4.28
20	4.80	-
15	4.10	-
10	3.60	-
5	3.20	-
0	2.75	-
-5	2.50	-

Electricity cost (Eurostat, 2019) and power emissions factors (Defra, 2018 & AIB, 2017) published for both locations were used (Table 4). In addition, the low cost, low emissions figures from France were also applied to both sets of data to simulate the expected future improvements and to evaluate the impact of lower energy emissions on the overall results.

Table 4 - Energy costs and carbon dioxide emissions factors

Location	Cost		Emissions	
	Electric	Gas	Electric	Gas
Leicester	0.14 £/kWh	0.037 £/kWh	0.3072 kg/kWh	0.20437 kg/kWh
Sevilla	0.139 £/kWh	0.044 £/kWh	0.309 kg/kWh	0.20437 kg/kWh
France	0.106 £/kWh	0.05 £/kWh	0.053 kg/kWh	0.20437 kg/kWh

Refrigerant leakage (Meurer, 2011) rates were assumed to be 5% of the total charge per annum for the refrigeration systems and 2.5% of the total charge per annum for the air conditioning and heat pump systems. The working fluid for the air conditioning and heat pump systems was assumed to be R-454B (GWP = 466).

Configurations and conditions of the Heat Recovery technologies considered

Three basic configurations were considered for this study, namely, compressor discharge de-superheating (Figure 5), partial condensation (Figure 6) and air handling unit (AHU) mounted condenser/gas cooler (Figure 7).

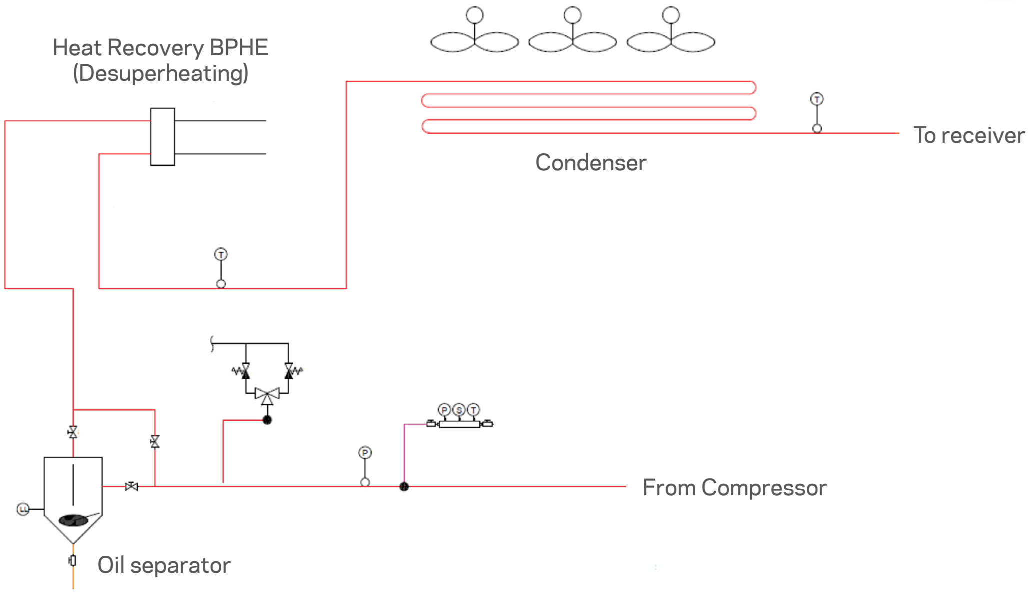


Figure 5 - Refrigeration Side P&ID Example for De-superheating (R-454C) / "To Water" (R-744

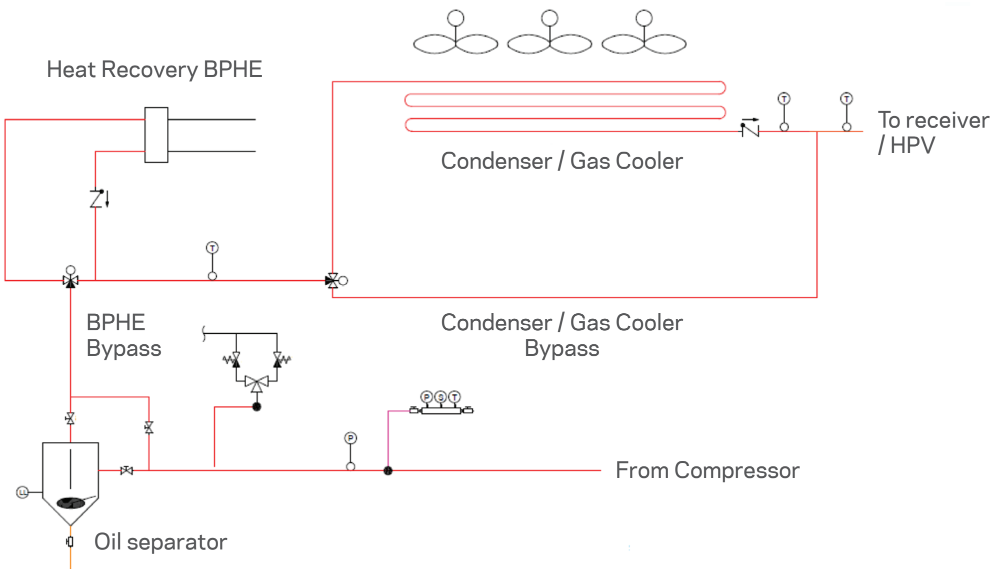


Figure 6 - Refrigeration Side P&ID Example for Partial Condensing (R-454C)

The available heat calculations for the brazed plate heat exchangers (BPHE) used in figures 5 & 6 were made using manufacturers software (SWEP, 2019), with a counterflow configuration to maximize the mean temperature difference across the heat exchanger enabling lower temperature approaches and condensing temperatures (R 454C) to be used to return an appropriate quantity and grade of heat.

The water temperature grades investigated were 45 °C flow / 30 °C return for de-superheating and 36 °C flow / 30 °C return for partial condensing. Both grades are considered for sensible cooling on R-744. These temperature grades are sufficient to transfer heat from emitters to air temperatures of 20 °C on and 28 °C off as per typical HVAC expectations. For the partial condensing technology, where an external ambient condition does not allow partial condensing to occur, only the de-superheating value is used. Table 5 summarizes the different conditions considered for the compared configurations.

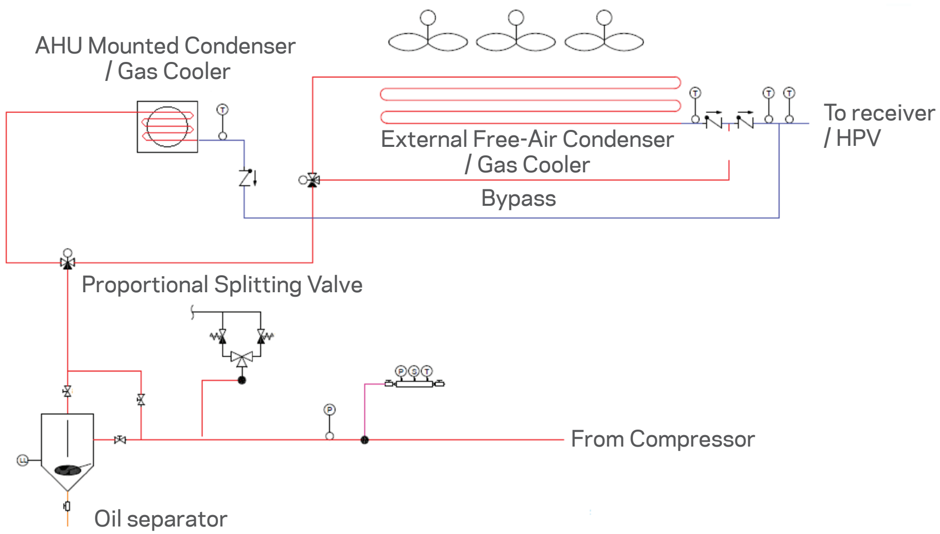


Figure 7 - Refrigeration Side P&ID Example for AHU Mounted Condenser (R-454C) / Gas Cooler (R-744)

Heat Recovery Technology	Refrigerant	Floating Head	Minimum Head Equivalent Ambient Temperature							Water Temperature	
			5 °C	10 °C	15 °C	20 °C	25 °C	30 °C	35 °C	36 °C	45 °C
Compressor Discharge De-superheating	R-454C	x			x	x	x	x			x
"To Water"	R-744	x	x	x	x			x		x	
"To Water"	R-744					x	x		x	x	x
Partial Condensation	R-454C	x			x	x	x	x		x	
Air Handling Unit Mounted Condenser	R-454C						x	x	x		
AHU Mounted Gas Cooler	R-744							x	x		

Table 5 - Ambient conditions and water outlet temperature scenarios used (x) for comparisons

The heating requirement for the store size considered in this study was determined using data gathered from a typical UK supermarket chain using a building heat loss figure of 246.6 kW. The design external air temperature for this heat loss figure is -2 °C, and the internal sales area temperature is 20 °C.

The "cold air spill", also referred to as net environmental cooling effect, from the chill cabinets was derived using the ISO 0 cabinet capacities multiplied by 0.75 for daytime operation (store open) and 0.7 for night-time operation (store closed using night blinds). The freezer cabinet capacity was multiplied by 0.25 for both day and night operation.

The heating load requirement was derived by applying constant net environmental cooling effects across all external ambient conditions, based on a constant heat load to the cabinets, and varying the building heat loss figure according to the external ambient temperature. The variation of building heat loss was obtained by linearly interpolating between the design temperature of -2 °C and 20 °C, where the heat loss was assumed to be 0 kW.

For external temperatures above 25 °C the building heat loss figure becomes a heat gain figure due to the external environment then being warmer than the internal environment. The heat gain for temperatures up to and including 25 °C is offset by the cold air spill from the cabinets. Beyond this, there would be a net cooling requirement for the building which must be served by air conditioning in order to maintain the 20 °C internal temperature. At 30 °C, this is ignored in the moderate climate, because of the relatively small net cooling requirement at that bracket, and the minimal number of hours spent at that bracket in that location (only 7 hrs). For the hot climate, air conditioning requirement was modelled from 30 °C up to the highest bracket of 40 °C.

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