Eco-Efficiency Comparison of Supermarket Architectures

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Commercial refrigeration has been under scrutiny by politician and regulators around the world, because of the use of high GWP (Global Warming Potential) fluids like R-404A and because of high leak rates. In Europe the F-Gas Regulation has a ban on high GWP refrigerants, and also a phase down on the use of HFCs based on their CO_2 equivalent. The use of refrigerants with low GWP will provide a future-ready solution. To respond to the challenges of the F-Gas and to reduce energy consumption in commercial refrigeration, many new architectures are under investigation and development.

Current solutions available that can be used to help the commercial sector meeting Fgas targets, are twofold. For existing R-404A systems, retrofitting with a lower GWP refrigerant is the quickest, most economical and environmentally friendly solution. For new build, several architectures are being explored. The combination of R-744 with newly developed HFOs and HFO blends offers added benefits of safety and performance.

Eco-efficiency is one of the best basis to compare various architectures in terms of not only environmental, but also economic impact.

Eco-efficiency concept

Many metrics have been developed to measure carbon footprint of refrigeration systems. GWP, used by many legislators for its simplicity, is a measure of the direct impact of emissions on the environment. Depending of the system leak rate, GWP can only capture 10 to 35% of the total environmental impact.

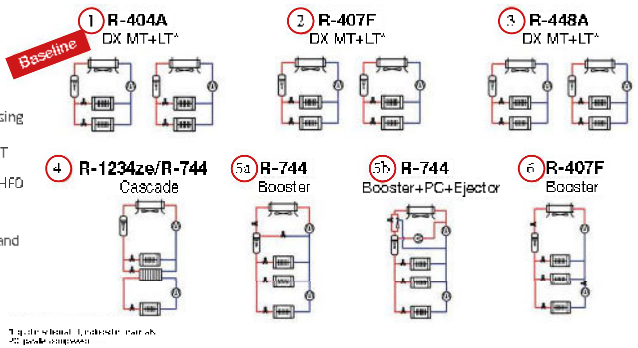
TEWI (Total Equivalent Warming Impact) is the measure of the direct and indirect impact being the indirect energy usage to drive the refrigeration system. Unlike GWP, TEWI can capture up to 95% of the environmental impact. The residual impact can only be captured through a comprehensive LCCP (Life Cycle Climate Performance) analysis; but this involves making several assumptions, like embedded energy to produce components and fluids, transport and assembly of the equipment, service and maintenance, disposal, etc., which make the approximation difficult and not always more accurate.

A shortfall of all these metrics is their one dimensional nature. It is always possible to reduce environmental impact of any system by using better performing components, larger condensers, ejectors etc... in short, it is always possible to improve environmental impact by spending more money on a given system. The system total cost is therefore an important parameter that should be taken into account when comparing system environmental performance. **The Eco-Efficiency, is a two dimensional metric that takes into account the environmental impact of the system and its total cost.**

Commercial Refrigeration Architectures

The drive behind development of new architectures is to reduce supermarkets' carbon footprint and ensure compliance with regulations. For a comparison, six architectures have been selected as they represent some of the main stream systems used today and new ones that are based on low GWP refrigerants.

1. Centralised DX (direct expansion) using R-404A for both low (LT) and medium temperature (MT)
2. Centralised DX, similar to system 1 but using R-407F
3. Centralised DX, similar to system 1 but using R-448A (Solstice® N40)
4. Cascade system using DX R-1234ze for MT and sub-critical DX CO_2 for LT. Heat rejection from the LT CO_2 side is cascaded into the MT HFO system
5. a) CO_2 booster for colder region
   b) CO_2 booster with parallel compression and ejector for warmer region
6. R-407F booster



Hypothèses

Comparison is based on a typical 2,000m² supermarket, with loads of 68kW for MT and 18kW for LT. Two distinct European regions are considered: colder, represented by Hamburg (Germany), and warmer, represented by Seville (Spain). Temperature bin data have been obtained from meteorological database for 2016. For each location, monthly day time and night time temperatures were identified. Nominal supermarket loads were associated to day-time temperatures. The night time refrigeration loads were taken as half the nominal loads in order to account for the reduced energy losses during non-trading hours.

For electrical consumption the following components were considered: compressors, condensers fans, air cooler fans, display cabinets fans, display cabinets light, defrost heaters (only in LT units), defrost heaters assumed working 4 times per 24 hours, each defrost cycle 30 minutes. The electric power cost used 0.097€/kWh and the resulting CO_2 emission at the power generation plant is 0.43kg/kWh.

A critical parameter to the study is the CAPEX, or initial cost of the system. A detailed Bill of Material was developed for each system to include compressor racks, heat exchangers, system components (pipes, valves, insulation, initial refrigerant charge, hangers, and solders). Installation costs also included, based on normalised tabulated hours for assembling standard refrigeration system components (HEX, racks, pipes, insulation, cable ducts, system commissioning etc.). Another component of the total cost, is the operating cost (OPEX), which was based on regular maintenance work (oil, filter change, minor repairs). The analysis is done over the 15 years lifetime of the unit, assuming a yearly leak rate of 15%.

Results

All architectures were simulated using in-house system simulation complemented with third party software for compressor selection and heat exchangers sizing.

Derived results are shown on the eco-efficiency chart shown in fig (1a&b) for both Hamburg and Seville respectively, as a % on R-404A system baseline.

ECO-EFFICIENCY CHART FOR HAMBURG AND SEVILLE

Fig 1a

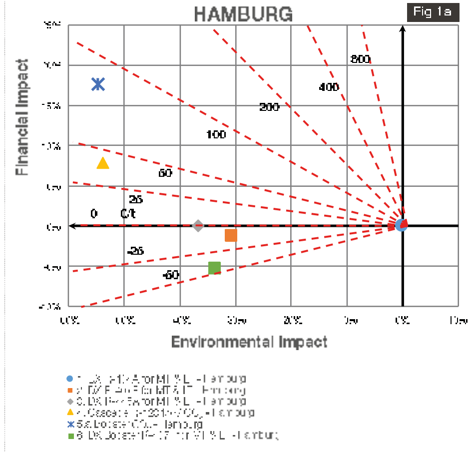
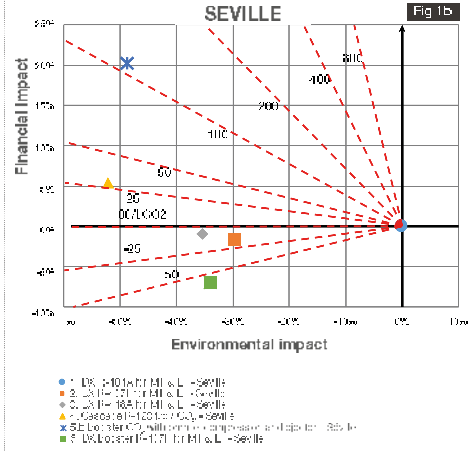


Fig 1b



All alternatives show reduction in environmental impact versus baseline R-404A, but with different financial impacts.

Architectures 2&3 are very similar to the base line with only refrigerants being different. The refrigerant environmental impact is shown to be an important one. R-407F and Solstice® N40 have been adopted by many supermarkets already because of their lower GWP and also the energy savings demonstrated in many applications, both in MT and LT: both show reduction in environmental impact, with similar to lower total cost. The cascade HFO/CO_2 and CO_2 systems achieve the lowest environmental impact. This is due mainly to the lower direct impact as the refrigerants used have ultra-low GWPs. The cascade system shows very promising performances both environmental and economic.

The dotted red lines represent constant €/tonCO_2 removed. The R-744 architecture 5a&5b show important reduction in environmental impact, but it is at the expense of an important financial impact. Both R-744 systems reduce the CO_2 at a cost of 80 to 110 €/tonCO_2.

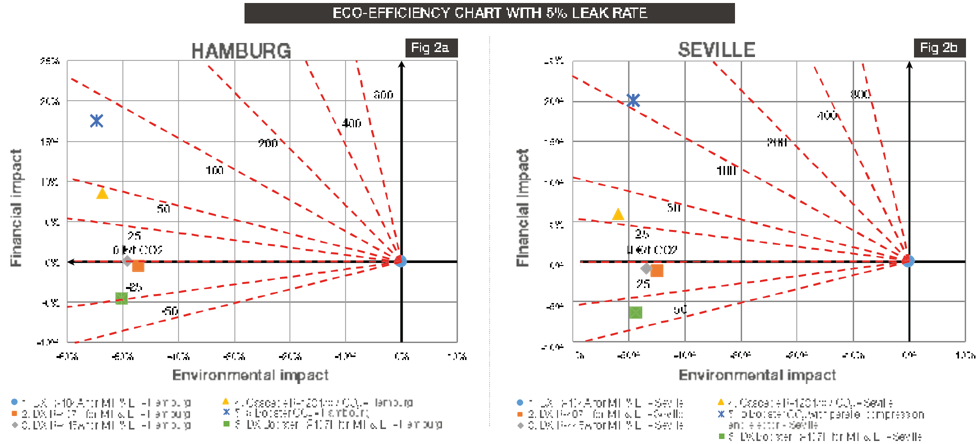
The cascade system with HFO and R-744 also result in considerable reduction in environmental impact, but at a reduced economic impact of 25 to 40€/tonCO_2 removed. The HFC solutions R-407F and R-448A exhibit environmental reduction between 30 and 40% with the added benefit that these reductions are obtained at a neutral or reduced financial impact. Opting for such a solution, a supermarket chain could actually meet its environmental targets with a economic benefit in the long term.

Architecture 4 relies on R-1234ze an A2L in a DX system. Current standards allow an important charge size with such refrigerant. Work is in progress to remove barriers to increasing further the charge size for A2L refrigerants in the near future. Solstice® ze is also non-flammable according the GHS (Global Harmonized Standard) and European flammability regulation. The results demonstrate that refrigerants like Solstice® ze should be allowed (in a safe way) to be used in much higher quantities in DX system in view of their environmental performance.

Standard systems based on R-407F and Solstice® N40 have not only the lowest CAPEX but also the best energetically performance in both cold and hot climates. The environmental impact can be further improved with simply reducing the leakage rate.

The benefits of leak reduction

A reduced leakage rate to 5% for both R-407F and Solstice® N40 (R-448A) systems was then studied. A 10% increase in the maintenance cost of these system was also added in order to reflect the associated cost to such a leak reduction. The results are shown in fig.(2a&2b). As expected the impact of leak reduction has reduced further the environmental impact of such systems with little or no impact on the financials.



Conclusions

Eco-efficiency is a bi-dimensional metric and covers close to 100% of both environmental and financial impacts, resulting in the best evaluation tool to compare different systems.

Comparison table versus R-404A baseline. The lower, the better.

	Systems	Environmental impact	Financial impact	Cost €/ton CO_2e removed
15% leaks	R-407F & R-448A systems	-30 to -37%	0 to -7%	0 to -50 €
	R-1234ze/R-744 cascade	-53%	5 to 7%	25 to 30 €
	R-744 system	-49 to -54%	17 to 20%	80 to 100 €
5% leaks	R-407F & R-448A systems	-45 to -51%	0 to -7%	0 to -35 €
	R-1234ze/R-744 cascade	-53%	5 to 7%	25 to 30 €
	R-744 system	-49 to -54%	17 to 20%	80 to 100 €

Although R-744 systems have a good environmental impact, this is mainly achieved because of the ultra-low GWP of the refrigerant, but at a considerable extra cost.

Standard HFC DX systems can equally have a considerable reduction in environmental impact but with financial benefits. Reducing leaks from 15% to 5% would make HFC/HFO blends based systems the most advantageous ones considering both environmental/financial benefits. These systems can be installed till 2022 and have no end date for service and maintenance.

Solstice® ze /R-744 cascade systems offer the most balanced alternative for new installations, and a wider use is expected after barriers to allow higher charges for A2L refrigerants are removed.

A practical example to our industry

According to the Gapometer from EPEE (European Partnership for the Energy and the Environment), there is a need to cut 51 million tons of CO_2eq to meet F-gas regulation phase-down objective of 60% emission reduction by 2021, and new installations need to contribute to 52% of this reduction (26 MT CO_2eq).

• Using only R-744 systems could **COST** the industry up to 2.1-2.6 Billion € (26 MT CO_2eq * 80 to 100 €/T CO_2eq = 2,123 to 2,654 M Euro).

• Using HFC/HFO systems (up to 2022) could **SAVE** the industry up to 910 Million Euros(26 MT CO_2eq * 0 to -35 €/T CO_2eq = 0 to -910 M Euro).

By leveraging the eco-efficiency tool, the industry could potentially avoid a cost of 2-1 - 2.6 Billions €.

This study is still being developed. Other architectures such as water-loop groups, R-455A boosters or cascade 1234ze/R-455A system will be studied. Sensitivity to key parameters (electricity cost, solution costs and tax) will also be measured.