ECO-EFFICIENCY COMPARISON OF SUPERMARKETS WITH DIFFERENT REFRIGERANTS

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ECO-EFFICIENCY COMPARISON OF SUPERMARKET ARCHITECTURES

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Abstract

Commercial refrigeration has been under scrutiny by politician and regulators around the world, because of the use of High GWP fluids like R404A and also because of the high leak rates. In Europe the F-Gas has a ban on high GWP refrigerants, and also a phase down on the use of HFCs based on their CO2 equivalent. It is clear that the use of refrigerant with low GWP will provide a 'future proof' solution in this segment. 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 R404A 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 R744 with newly developed HFOs and HFO blends offers added benefits of safety and performance.

Example of such applications and architectures will be presented and the concept of Eco-Efficiency will be introduced and used as a basis to compare the various architectures financial and environmental impacts.

Eco-efficiency concept

Many metrics have been developed to measure carbon footprint of refrigeration systems. GWP (Global Warming Potential), used by many legislator for its simplicity, is a measure of the direct impact on the environment. Depending of the system leak rate, it 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, with the indirect impact being the result of the 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) analyses.

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

Many refrigeration architectures have been developed over the years. The drive behind the development of new architectures is to reduce supermarkets carbon footprint and to ensure compliance to regulations. In this study 6 architectures will be evaluated. These architectures have been selected as they represent some of the main stream architectures used today and also new ones recently developed based on low GWP refrigerants.

1) Centralised DX system using R-404A for both low temperature (LT) and medium Temperature (MT) applications.

2) Centralised DX system, similar to system 1 but using refrigerant R-407F.

3) Centralised DX system, similar to system 1 but using refrigerant R-448A

4) Cascade system using a DX R1234ze system for MT loads and a sub-critical DX CO2 system for LT loads. Heat rejection from the LT CO2 system is cascaded into the MT HFO system.

5-a) CO2 booster system for colder region

5-b) CO2 booster system with parallel compression and ejector system for warmer region.

6) R-407F booster system

Assumptions

The study is based on a typical European supermarket having a surface area of 2000m^2, with refrigeration loads of 68kW for medium temp application and 18kW for low temperature application. Two distinct European regions are considered. A colder region represented by Hamburg (D), and a warmer region, represented by Seville (E). Temperature bin data of the two locations 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.

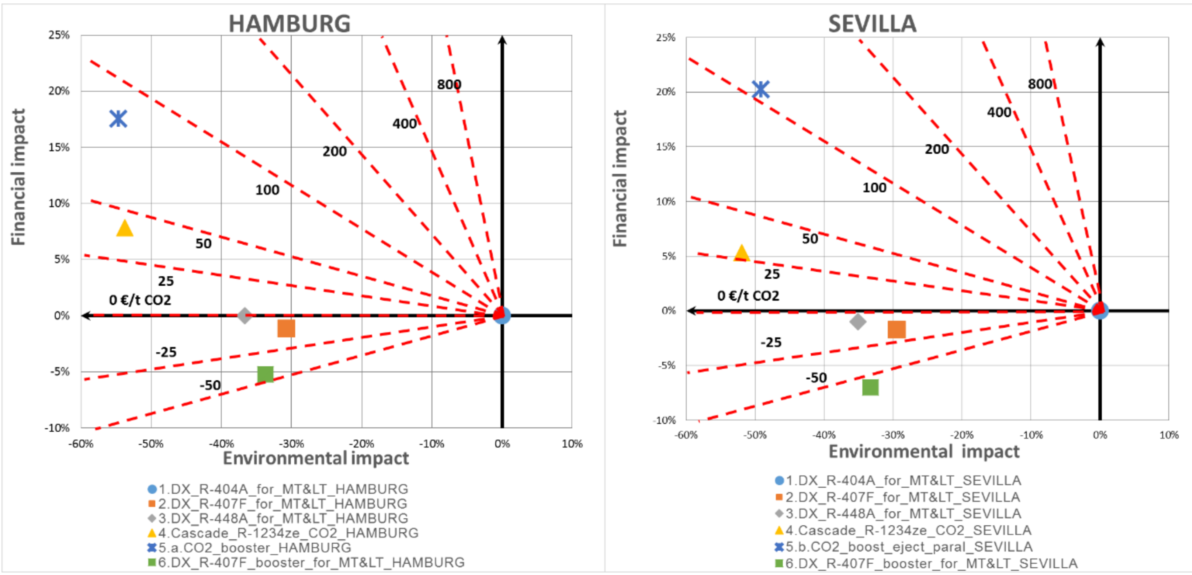
For electrical consumption the following components were considered: compressors, condensers fans, air cooler fans, display cabinets fans, display cabinets light, defrost heaters (only in LT units), defrost heaters assumed working 4 times per 24 hours, each defrost cycle 30 minutes. The electric power cost used 0.097€/kWh and the resulting CO2 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. This was derived through a development of a detailed Bill of Material 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). In this cost the service cost based on regular maintenance work (0il, filter change, minor repairs. The analysis is done over the 15 years lifetime of the unit, assuming also 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. Two R744 systems were simulated. A simple booster system for the cold location and an enhanced system with parallel compression and ejector for the warmer location. Derived results are shown on the eco-efficiency chart shown in fig.(1a&b) for both Hamburg and Seville respectively.

Fig. (1a & 1b): Eco-Efficiency chart for Hamburg and Seville



Conclusions

The results shown above, are with respect to the base line architecture R404A. As expected all alternatives show considerable reduction in environmental impact, 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. R407F and R448A have been adopted by many supermarkets already because of their lower GWP and also the energy savings demonstrated in many applications. Both in Medium temperature applications and also in low temperature application. The reduction in the environmental impact is therefor expected, with similar to lower total cost. The cascade HFO/CO2 and CO2 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 financial.

The dotted red lines represent constant €/ ton of CO2 removed. The R744 architecture 5a & 5b, although they show important reduction in environmental impact, this reduction is at the expense of an important financial impact. Both R744 systems reduce the CO2 at a cost of 80 to 110 €/ ton of CO2. The cascade system with HFO and R744 also result in considerable reduction in environmental impact, but at a reduced financial impact of 25 to 40 € / ton of CO2 removed. The HFC solutions R407F and R448A 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 financial benefit in the long term.

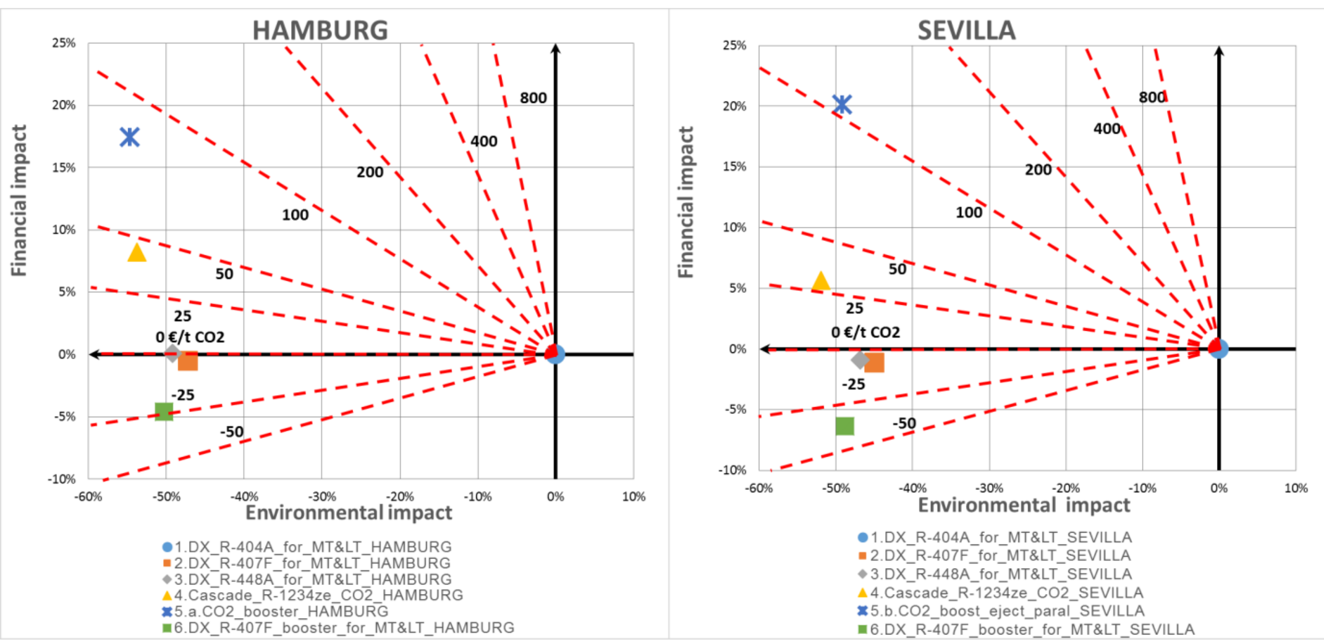
Although architecture 4 relies on R1234ze an A2L in a DX system. Current Standards allow an important charge size with such refrigerant. Work is in progress to remove barriers to increasing further the charge size for A2L refrigerants in the near future. R1234ze is also non-flammable according the GHS and European flammability regulation.

The results demonstrate that refrigerants like R1234ze should be allowed to be used in much higher quantities in DX system in view of their environmental performance.

Standards systems based on 407F and 448A 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 study was repeated with a reduced leakage rate to 5% for both R407F and R448A systems. 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.

Fig. (2a & 2b): Eco-Efficiency chart with 5% leak rate



The eco-efficiency is a powerful tool to compare commercial refrigeration architectures. The comparative exercise presented shows that although R744 systems have a good environmental impact, this is mainly achieved because of the ultra-low GWP of the refrigerant, and at a considerable financial impact. Standard HFC DX systems can equally have a considerable reduction in environmental impact but with financial benefits. Small investment to reduce leak rates of HFC systems would considerably reduce the environmental impact of these systems making them a much better solution for both the environment and the economics.