Developing a Product Range for Climate and Ozone Friendly Technologies

1. Introduction

With the growing attention on environmental concerns, and particularly the issues of ozone depleting and global warming substances associated with refrigeration and air conditioning equipment, the company Earthcare Products was set up to respond to the subsequent changes in the market. Founded in October1997, Earthcare provides advice, products and services that are progressive in terms of energy efficiency, sustainability and low environmental impact.. The services and products are aimed at end-users who are investing in systems that must anticipate evolving building regulations (such as the European Energy Performance of Buildings Directive, EPBD), companies whose properties need to score highly with green-building ratings (such as the BRE Environmental Assessment Method, BREEAM; http://www.breeam.org/), or for companies with prescriptive environmental CSR requirements. This article provides an insight into the types of systems and applications where Earthcare has successfully implemented the use of both natural refrigerants and improved energy efficiency.

2. Project Examples

2.1. Very Environmentally Friendly (VEF) heat pump air conditioning split systems

In 1998, using grant funding from the UK Government's Department of the Environment, Transport and the Regions (DETR) a new range of VEF heat pump air conditioning split systems was developed and launched.
The products resulted from research investigating improvements to the energy efficiency of small split air conditioning systems. The exercise formed part of a wider ranging project - part funded by the DETR's "Partners in Technology" scheme - to look at energy saving opportunities at the time of refrigerant replacement. The resulting VEF split systems were launched at the IKK Exhibition in Nuremberg in 1998. These systems minimise environmental impact by offering the combination of natural refrigerants and optimised efficiency. The result is an efficiency gain of 20% over the original HCFC22 systems. Hence both the direct and indirect aspects of global warming impact were addressed. The units have been re-engineered to optimise their performance with hydrocarbon refrigerants – thereby eliminating the powerfully global warming HFC and HCFC alternatives – whilst the use of motor voltage controllers has further brought indirect emissions down with reduced energy consumption.

Direct global warming impact was minimised in several ways:

- Minimised the amount of refrigerant held within the units;
- Traditional flared copper joints that are responsible for a high percentage of refrigerant leaks were eliminated from the systems. Copper capillary lines (small pipes for instrumentation and sensors that are particularly prone to cracking) were also eliminated;
- Charged the system with the hydrocarbon CARE 40 (R-290), a refrigerant with a Global Warming Potential (or GWP) of <3, a fraction of the GWP of the competing hydrofluorocarbons (HFCs)

Indirect global warming was also minimised by maximising energy efficiency:

- The thermodynamic properties of hydrocarbon refrigerants are well suited to this type of application, competing favourably on efficiency with all other alternatives;
- The refrigerant charge was optimised in laboratory trials and the installation process achieves precise repetition of optimum charge for each unit;
- The indoor unit (evaporator) was optimised using enhanced heat exchangers where necessary;
- Floating head pressure control was used, this allows the condensing temperature to float as low as 20°C if ambient conditions allow, instead of being held artificially at around 40°C. This can achieve up to a 30% increase in efficiency compared to fixed head pressure;
- The systems use fully flooded evaporators. This increases both the cooling capacity and efficiency.

These were all comparatively small changes which, when combined, make a big difference.
In re-designing the split system from bottom up, it was possible to maximise the advantage that could be gained by matching sensible heat ratio to local environmental conditions. Most split system manufacturers optimise for comfort conditions based on a worldwide average climate model. For most sites that were surveyed, the majority of the cooling requirement is for equipment or process cooling, predominantly with sensible heat loads. However, the cooling coils used are generally unsuitable for these conditions. By way of example, one can compare the sensible heat ratios for commonly used Mitsubishi models against the equivalent model developed within the project. A 4.9 kW PLH2 Mitsubishi Electric split system has a sensible heat ratio of 0.76, compared with 0.93 for a similar Earthcare model, based on Mitsubishi's "UK cooling" conditions of 23°C dry-bulb and 16°C wet-bulb indoor, and 30°C dry-bulb outdoor. Therefore, by simple optimisation of the indoor coil to suit the specific climate of operation, it is possible to achieve an average 6% improvement in sensible heat ratio, which in turn becomes a 6% improvement in energy efficiency. This kind of engineering is also needed to optimize equipment in hot climates although a slightly different approach would be needed according to local climatic conditions.

2.2 The UK's largest air conditioning thermal storage system, using ammonia and slurry-ice

At Middlesex University an air conditioning system has been installed, incorporating slurry ice thermal storage in a similar fashion to domestic storage heaters. It builds ice over night, which can then be pumped around the premises during the day. The installation has a capacity of 72 cubic metres, which makes it the largest slurry ice system in the UK. Additionally, it is Very Environmentally Friendly, using energy efficient ammonia natural refrigerant. The installation is used to provide cooling for the whole of the university site at Bounds Green, North London. This is providing them with annual running cost savings of almost 50% relative to conventional installations for the same application.

Middlesex University follows a strong environmental policy with other initiatives such as adiabatic cooling air handling units being implemented. However, this was their biggest investment in a single green application. The Environmental and Services Engineer explained that it made business sense. "The energy savings which we make as a result of installing this plant makes sense financially. The initial financial outlay was competitive with other installations, so contrary to popular belief, it actually pays to be green. I had been looking at how we could replace our old system which used CFCs and decided to install the Slurry Ice Thermal Storage System. When I looked at the capital outlay and the reduced running costs, it seemed to be perfect for us."

2.3 **Range of ground source heat pumps**

The company developed a range of ground-source heat pumps (GSHP) that employs the hydrocarbon refrigerant R-290 and optimal ground heat exchanger geometry.

One example is the GSHP project at Buntingsdale Infant School near Market Drayton, North Shropshire in the UK, installed with the help of a Carbon Trust Grant by the Shropshire County Council Energy Conservation and Sustainable Construction Unit. The heat pump system replaces electric night storage heaters, which were noisy, bulky and very difficult to control in terms of heat output, particularly during the spring and autumn. This innovative scheme used a GSHP, which draws heat from the soil in a nearby field to heat the school. The system removes heat from the soil and delivers it to the school in an upgraded form. A glycol solution is pumped around an underground loop of plastic pipe work to extract heat from the ground. This heat is then upgraded to a useful temperature by the heat pump unit before being distributed around the building to fan coil units.

Local geological conditions meant that installing the underground pipework in boreholes was not cost effective, so fifteen 50 m long trenches, 1.3 m deep by 1.5 m wide were dug in a farmer's field adjacent to the school. The pipework was arranged into 'slinky coils' 1.2 m in diameter and laid horizontally at the bottom of the trenches.
The project uses one Earthcare CWP21 to provide 36.4 kW heating output as water at 46°C, and with a power input of 8.46KW, it gives a COP of 4.3, when using a ground coupled heat exchanger supplying propylene glycol at 0°C as the heat source. 18 fan coil units of varying sizes are used to distribute heat around the building. These units are far smaller, less intrusive, more controllable and quieter in operation that the electric night storage heaters they replaced.

The insistence on the use of natural refrigerants together with the use of the latest ground source heat pump technologies has resulted in the most energy efficient and environmentally friendly heating system of its kind in the country. The combined effect of these energy efficiency measures result in energy savings in excess of 75% relative to direct electric heating. In addition the plant will run for only 5 days per week instead of 7 saving a further 28%, taking the total savings to a staggering 79%.

It was anticipated that the heat pump will save 18 tonnes of CO_2 per annum, based on data from the Edinburgh Centre for Carbon Management.

2.4 **A range of hydrocarbon air cooled chillers up to 1265 kW capacity**

The EHS range of air cooled chillers was designed within the constraints of the EU's BAT (Best Available Technology) protocol and uses the hydrocarbon (HC) refrigerant R-290, which is an ideal replacement for R22 with the lowest Global Warming Potential. Over the last three years, the company has been developing larger sizes to extend the application of HC environmentally benign refrigerants and these are the first air-cooled chillers operating on HC refrigerants to deliver very large cooling outputs – the largest model in the range offers 1,265 kW. HC chillers have been available on the UK market since 1995, but their capacities were previously limited to around 200kW.

Indirect global warming is reduced by maximising energy efficiency through a combination of factors including the favourable thermodynamic characteristics of HCs, the use of subcooling circuits, which improve the coefficient of performance (COP) and floating head pressure control that allows the condensing temperature to float as low as 20°C if ambient conditions allow, instead of the normal 40°C. This is said to be particularly beneficial for chillers that operate year round or at night when ambient temperatures are lower. The combined effect of these energy efficiency measures will result in a potential energy saving in excess of 50% relative to chillers that operate year round without these energy saving features. Further improvements will be achieved by the development of a new vapour injection economised screw. There is an increased demand for this type of solution because until now specifiers and users of screw compressor chillers have been restricted to choosing between expensive ammonia chillers or HFC chillers.

Britain's largest ever hydrocarbon refrigerant chiller for a building services application was installed at the historic Church House building in Westminster close to the Houses of Parliament in 2007. The 600kW air cooled water chiller is part of the new EHS range of hydrocarbon (HC) chillers developed by the company. The original Church House was built to commemorate Queen Victoria's golden jubilee and the current building was opened by King George VI in 1940. It is calculated that the long-term pay back, both financially to Church House and in reduced environmental impact, will more than offset all the capital, installation and disruption costs.

With both government departments and large corporations increasingly looking for cost effective alternatives to HFCs, this project is a practical demonstration that natural refrigerants can offer cost effective and practical solutions across the whole range of building services applications..

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2.5 Project to develop new refrigerants blends

An agreement with the Odessa State Academy of Refrigeration in the Ukraine gives the company the exclusive right to commercialise its research into low environmental impact refrigerants and funding by E-Synergy from its £30m Sustainable Technology Fund has allowed the company to develop and patent three new high pressure azeotropic refrigerants:

There are distinct advantages of fluids that possess low normal boiling point (NBP) – or high saturation pressure – such as more compact systems, possibilities for achieving higher system efficiency, and advantages associated with operating above atmospheric pressure. However, the currently available refrigerants, such as R410A and R744 suffer from negative characteristics such as high GWP and/or low critical temperature. There is no single-component refrigerant with low-GWP and high critical temperature using these fluids, and most mixtures that may achieve these criteria are zeotropes with high temperature glide.

It was therefore concluded that azeotropes with thermodynamic characteristics similar to R410A and R744 would be commercially attractive. A development project was subsequently undertaken with the objective of identifying such blends.

Three mixtures have arisen from this work:

ECP410A - Blend for domestic and commercial air conditioning and heat pumps

The saturated pressure-temperature characteristics and volumetric refrigerating capacity are close to that of R410A. The critical temperature is significantly higher (almost 20 K), indicating improved performance, particularly at higher ambient temperatures. Given these aspects, the blend is considered to be broadly applicable to systems used for domestic and commercial air conditioning, and heat pumping.

System performance evaluations conducted around European rating conditions revealed the following, when compared to R410A:

- Evaporating capacity was a little greater than the theoretical results, being about 85% of R410A, and condensing capacity being a little less.
- Cooling COP was between 6 – 10% higher than R410A, whilst heating COP was at least 15% higher.
- Evaporating temperature was up to 4 K higher than R410A, condensing temperature is about 1 K lower for the mixture and discharge temperature around 2 – 4 K lower than R410A.

ECP717 - Blend for industrial process, food and blast freezing applications

This mixture possesses advantages over the refrigerants normally used in industrial type applications. In the case of pure ammonia, which has a relatively high NBP and low specific heat, low evaporating temperatures lead to

sub-atmospheric operation which allows for the leakage of air into the system, and high compressor discharge temperatures. ECP717 overcomes these drawbacks by significantly reducing the NBP and also allowing much lower discharge temperatures. Consequently single-stage compression may be used instead of two-stage, which requires an additional compressor. In comparison to the use of R744, the problem of high triple point is overcome. Lastly, there are ongoing problems with refrigeration oils given the poor miscibility with R717, which ECP717 overcomes. Given these aspects, the blend is considered to be broadly applicable in systems used for industrial process, food and blast freezing applications.

The property data for this mixture was used to analyse the performance and the following findings were made:

- COP is similar to pure R717.
- Volumetric refrigerating effect (VRE) exhibits a synergetic behaviour and gives considerably higher values of VRE than the pure components.
- Discharge temperature is significantly lower than R717, which favours system reliability.
- Improved heat transfer, particularly in the evaporator, resulting in higher evaporating temperatures.
- The degradation in COP and refrigerating capacity with increasing temperature lifts in a single stage cycle is reduced relative to pure ammonia.

The azeotropic blend is optimised for below -33℃ applications. It has particular utility for industrial process, food and blast freezing applications and will displace liquid nitrogen as well as two stage ammonia systems.

ECP744 - Blend for commercial point-of-sale refrigeration and vehicle air conditioning equipment

ECP744 has advantages in terms of property changes, specifically, raising the critical temperature and lowering the triple point. For pure R744 these introduce hindrances in its application which result in super-critical operation at ambient temperatures above 25 C and solid formations when it undergoes rapid reduction of pressure towards atmospheric. Whereas R744 is being introduced into commercial refrigeration and point-of-sale applications, the characteristics of this mixture could help overcome several of the existing problems.

System performance evaluations were carried out and it was found that the refrigerating capacity and pressure was significantly greater than that of R410A, and less that pure R744. The cooling COP was found to be about 6% higher than pure R744. This was attributed to the higher critical temperature of the mixture. An additional consideration is the potential reduction in pressure rating of the system.

The higher critical temperature, lower triple point and more efficient refrigeration cycle are all significant benefits, but the commercial benefit arises from the reduction in condensing pressure, allowing the leak tight use of silver soldered joints. The real problem for UK refrigeration engineers using CO2 is the condensing pressure. Realistically all joints should be TIG welded stainless steel, but UK refrigeration engineers do not have the necessary skills and UK refrigeration customers are not prepared to pay for specialist labour. Consequently most CO2 installations in the UK have used compression fittings or silver soldered joints with seamed mild steel pipe. As a result most UK CO2 systems leak at more than 25% per annum. Arguably, the average HFC system is no better, but 25% leakage is unacceptable regardless of the working fluid, if only because under-charged systems use more energy.

Using a combination of novel property modelling, safety analyses and comprehensive system simulation, a number of previously unidentified azeotropic and near-azeotropic blends have been identified for use in certain applications where existing refrigerant options are subject to a variety of hindrances. A summary of the characteristics of these new blends is provided in Table 1 below.

Table 1: Characteristics of new blends

Name	**ECP410A**	**ECP717**	**ECP744**
Molar Mass	43.6	22.9	39.0
NBP (°C)	-49.2	-89.0	-84.5
Critical temp (°C)	94.9	41.9	37.9
LFL (% vol)	2.7 – 2.9	4.0 – 4.2	non-flammable
Likely safety class	A3	A2	A1
ODP	0	0	0
GWP (100)	7	2	46

These new blends offer notable advantages over existing refrigerants, in particular:

- Zero ODP and low GWP, below 150, and mainly "naturally" occurring
- Improved thermodynamic properties (such as critical temperature and minimal temperature glide) over similar existing refrigerants Good solubility with oils
- Low toxicity, and reduced flammability
- Known and understood chemical and material compatibility

Earthcare is currently negotiating global licenses for the new refrigerants.

3.) Influencing political decision-makers

Earthcare's work is not completed yet, as global CO2 emissions are spiralling out of control and there is an urgent need to start replacing fossil fuel boilers with heat pumps. However suitable equipment does not yet exist, and research in this area is still at an early stage. Moreover, anyone who thought that the F Gas Regulations have neutralised the HFC problem needs to think again. The formidable F Gas lobby continues to exert its malevolent influence and halocarbon emissions still account for some 13% of man made global warming. To counteract this Earthcare is campaigning for:

- The EU to provide funding for the research and promotion of F gas alternatives as committed by the EU environment directorate climate change program priority measures for F gas abatement, but never implemented.
- The EU to implement the F gas regulation commitment on the promotion of alternatives
- The EU to ensure that the F gas review considers natural refrigerants not just leakage reduction.
- The EU to recommend natural refrigerants within the eco-design directive.
- The EU to investigate how trade standards hinder the adoption of natural refrigerants.
- UNEP to stop subsidising the manufacture of ozone depleting refrigerants and to start providing carbon credits for the conversion of equipment manufacturing factories from ozone depleting refrigerants to natural refrigerants.

4.) Concluding remarks

To conclude, it would be fair to say that the changes in refrigeration technology – spurred on by legislation and environmental concern – give users an unrivalled opportunity to adopt energy efficient equipment utilising natural refrigerants. Current and proposed legislation will make it even more important to meet environmental best practice requirements. Earthcare is not yet a global player but will continue to tackle corporations head-on when they disagree with them. They believe that with vision, action and commitment the campaign for a sustainable future for our industry is winnable and that they will be on the winning side.