THE INSTITUTE OF REFRIGERATION

REAL Zero – Reducing refrigerant emissions & leakage - feedback from the IOR Project

by

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Introduction

In October 2007, Jane Gartshore's Presidential Address highlighted the significant problems associated with leakage of HFC and HCFC type refrigerants. Refrigerant leakage has an adverse impact on climate change both directly because these refrigerants are very powerful greenhouse gases, and also indirectly because leaking systems are less energy efficient. There are also high financial penalties associated with the additional energy and service costs, downtime, and food wastage or lost production.

In recent years awareness of the issue has increased significantly both through the implementation of the European Ozone Depleting Substances and Fluorinated Gas (F-Gas) Regulation and the activities of the Institute of Refrigeration. The Regulations aim to improve containment of HFC refrigerants through leak testing, engineer qualification and record keeping. The Institute of Refrigeration has provided practical information to help industry comply with the F-Gas Regulation and make a real reduction in refrigerant leakage. This has been achieved mainly through the REAL Zero (Refrigerant Emissions And Leakage Zero) project. This paper summarises Real Zero, provides background literature on the global issue of refrigerant leakage, gives some up to date information from the analysis of current F-Gas use in installed systems and leakage record data, and provides a discussion on the way forward.

1. Background literature on refrigerant leakage

Preventing the leakage of refrigerants is a fundamental of good system design, service and maintenance, however, in recent years, the focus on leakage reduction has shifted towards evaluating the financial and environmental cost of leakage. These are described below:

1.1. The financial cost of leakage

Leakage has a financial impact on the refrigeration system and the equipment operator's business including:

- The loss of refrigerant and the cost of replacement.
- The cost of labour to locate and repair the leak and re-charge with refrigerant.
- The additional running cost of the system due to under charge of refrigerant. This is because system performance is dependent on the charge level in the system and an undercharged system can use significantly more energy than an optimally charged one. This is shown in Figure 1. However, the profile of energy consumption vs. charge amount varies with different systems and there is very little practical information available on this.
- The cost of downtime. This varies significantly with system and application, and can be very large. For instance it was estimated in 2000, that 1 hour downtime resulted in losses for brokerage operations and credit card authorizations of \$6,450,000 and \$2,600,000 respectively [Patterson 2002].

In reality the financial implications of leakage can be significant but will depend on many factors, including how quickly the leak is found and repaired. Typical costs of leakage as the leak develops over time are shown in Figure 2.

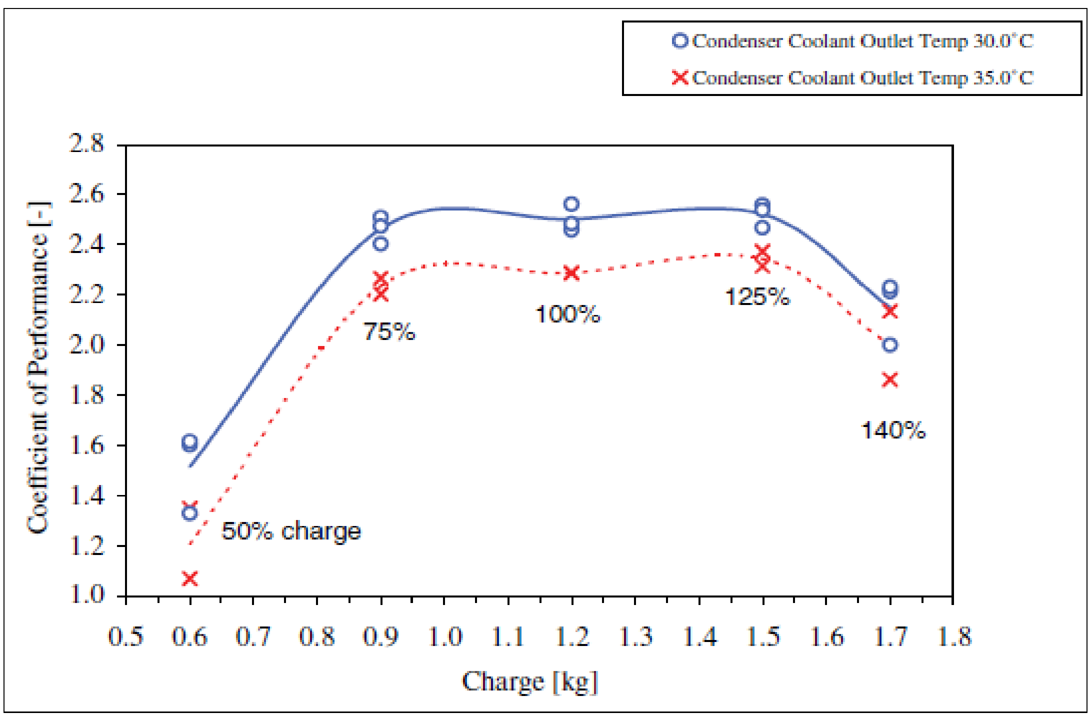

Figure 1: Variation of coefficient of performance with charge level [Grace *et al.,* 2005].

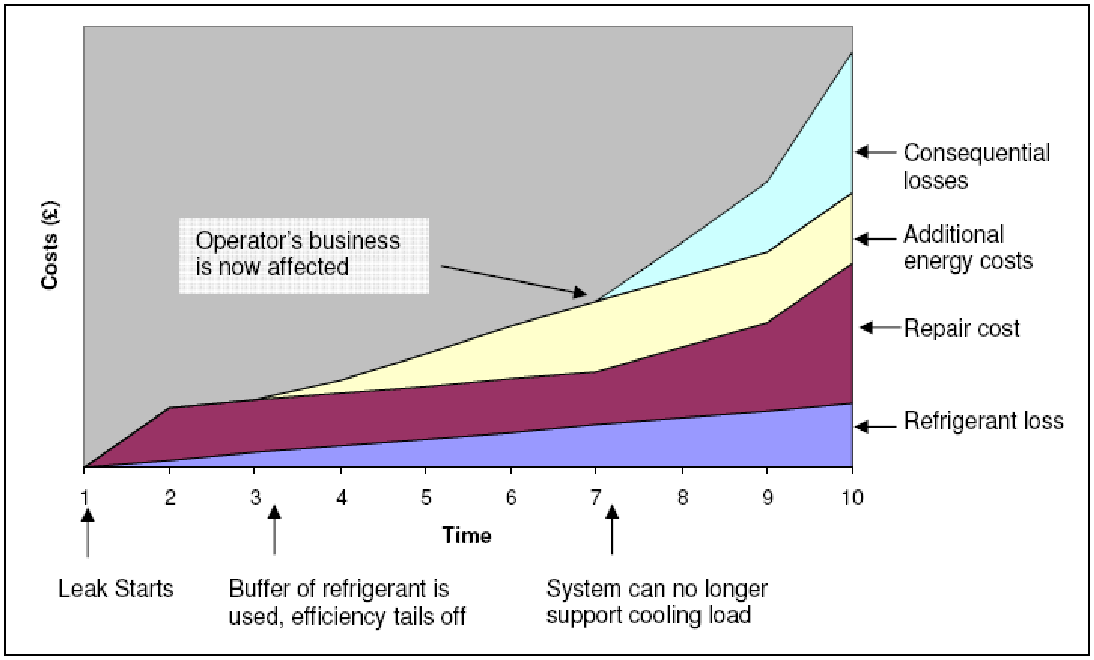

Figure 2: The financial impact of a refrigerant leak over time [IOR, 2009].

1.2. The environmental cost of leakage

Leakage also has a significant environmental impact. RAC is a large contributor of greenhouse gas emissions both directly though the emission of global warming refrigerants and indirectly through the emission of CO_2 in the production of electricity used to drive RAC systems. The main greenhouse gases used in RAC are HCFCs and HFCs, which generally have high global warming impact and according to DECC [2010] represent a significant proportion of greenhouse gas emissions in the UK. This is shown in Figure 3, which gives the breakdown of the UK GHGs emissions.

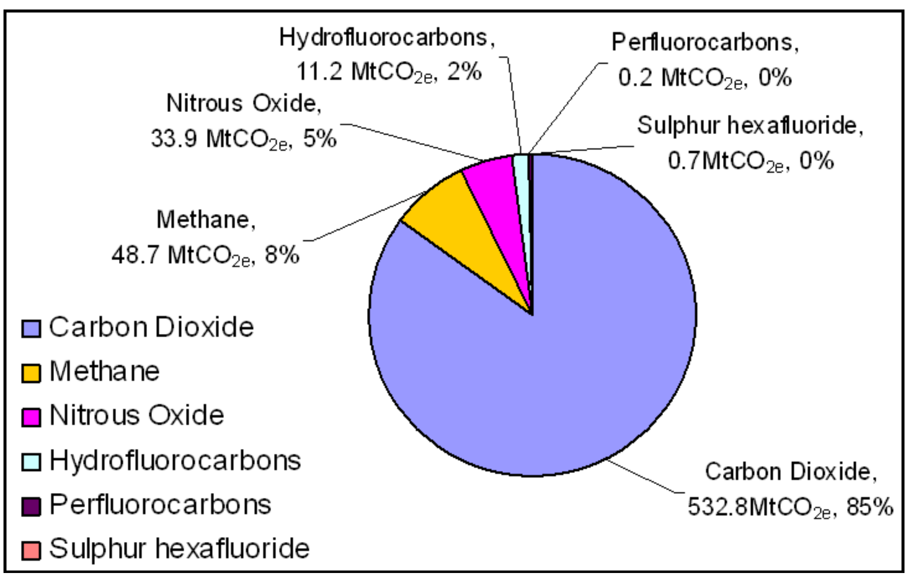

Figure 3: 2008 breakdowns of GHGs.

Figure 3 also shows that the emission of carbon dioxide represents 85% of the total GHG emissions and as a result much effort has been targeted towards tackling CO_2 directly, derived from the generation of electricity and the use of fossil fuels. As a large user of electricity (approximately 16% of all UK emissions), the indirect contribution of the RAC industry has been reported to be around 8% of all GHG emissions [IIR, 2006]. In addition refrigerant leakage however impacts on energy use since as previously stated an undercharged system can operate at lower efficiency.

The relative contribution to global warming of the direct and indirect effects varies depending on application. It also varies with the relative efficiency of the process, the type of refrigerant and any actual leakage. Table 1 gives the reported relative indirect and direct contributions for a range of applications for the EU. This shows that indirect emissions through energy use dominates the total global warming emissions for all applications. It should be noted that a similar study reported 10 years earlier that direct emissions in commercial and mobile air conditioning applications were more than 50% of the total equivalent carbon emissions. [AFAES/ DOE1991]. Kruse [2009] cites the main reason for change in the relative direct contribution is a reduction in leakage through better design and installation practice. This indicates the substantial environmental benefits that can be obtained by reducing leakage rates.

System type	Direct emissions $MTCO_2e$	Indirect emissions $MTCO_2e$	Total global warming impact $MTCO_2e$	Direct % related to total emissions
Retail	9.0	23.0	32.0	28%
Industrial	3.4	25.0	28.4	12%
DX AC	2.6	10.0	12.6	21%
Small commercial	1.8	12.0	13.8	13%
Chillers	0.7	12.0	12.7	6%
Other small hermetic	0.3	12.0	12.3	2.5%

Table 1: Annual EU Emission ($MTCO_2e$) for HFC Systems. Source HEAP, 2001.

1.3 Refrigerant leakage rates

Refrigerant contained inside the system circuit poses no threat to the environment, but it is difficult to make systems completely leak tight. Bostock [2007] defined a leak tight system as one that can operate within its normal operating parameters for its useful life without requiring additional refrigerant to be added (i.e. it does not leak enough refrigerant – typically <10% of its original charge - to affect system performance). Table 2 summarises the results of four separate studies for the UK, and suggests that the highest leakage rates tend to occur in the retail (supermarket) sector. This is partly due to the bespoke nature of these systems but also to long runs of sometimes difficult to access pipes that are necessary to connect the numerous fixtures (cabinets and cold stores) to the distributed system used in many retail applications.

Sector/ equipment	**Reported annual leakage rates (% of charge per annum)**			
	Johnson (1998)	*March (1999)*	*Haydock et al (2003)*	*ETSU (1997)*
Domestic refrigeration	1%	1%	0.3 – 0.7%	2.5%
Retail refrigeration	9 – 23%			
· Integral cabinets		1%	3 – 5%	2.5%
· Split/condensing units		10 – 20%	8 – 15%	15%
· Centralised supermarket		10 – 25%	10 – 20%	8%
Air conditioning	12 – 20%			
· Unitary/split		10 – 20%	8 – 12%	
· Chillers	15 – 22%	3 – 10%	3 – 5%	4%
· Heat pumps		3 – 10%	3 – 5%	4%

Table 2: Reported Annual Refrigerant Leakage Rates for the UK [MTPROG, 2007].

A number of authors have investigated leakage of the refrigerant charge from supermarkets from around the world over the last 20 years. This data has been reviewed and has been shown graphically against time as shown in Figure 4. Note some of this data is given as a range and this has been averaged. It can be seen from figure 4 that there is a large degree of scatter. However, fitting a straight line to the data shows a reduction in average leakage from 20% to 15% from 1990 to 2010. This chart is based on a range of data including that from specific store chains and national and international average figures. Care must be taken in interpreting these results because the type of store on which this information is based will be different. Some of the historical base data has been obtained from telephone interviews [IPCC, 2007] and indeed IPCC suggest that this reliance on anecdotal data may suggest underestimated emissions, since both the end-users and refrigeration contractors may have an interest in reporting low values.

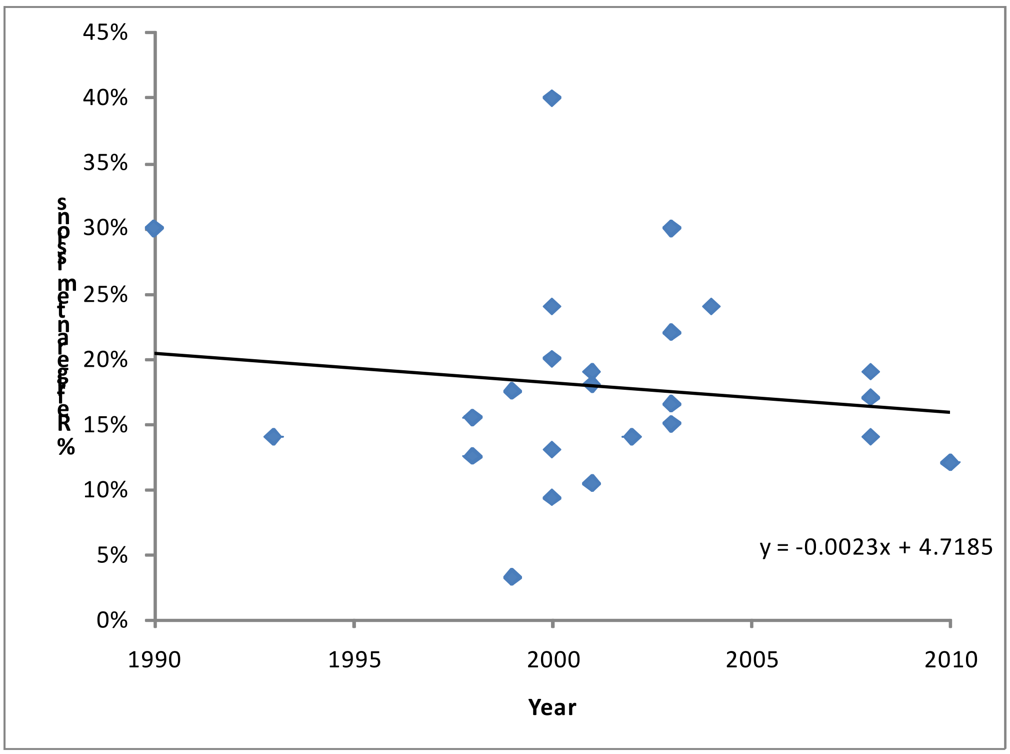

Figure 4: Reported refrigerant emissions against time for published data.

UK supermarkets are reported as estimating a 14%- 12% annualised charge loss in recent years. Rhiemeier *et al*. [2009] reported consistent leakage rates for multi-compressor refrigeration systems of between 5% and 10% in Germany, 8% for supermarkets in the US. Whereas Palm [2007] suggests that there is no clear indication that supermarket leakage levels below 10% should be reached in the near future. In the Netherlands, where they have had the STEK programme for a number of years, the average emission rates of only 3% are reported, although the reliability of this data is questioned by Anderson[2005].

1.5 The F-gas regulations and additional measures to reduce or control leakage

In the EU, as of the 4th of July 2007 all stationary refrigeration, ac and heat pump units containing HFCs came within the scope of the F-Gas regulation (Regulation (EC) No. 842/2006). Certain countries (e.g. Denmark, Netherlands, Norway, Austria, Germany, Switzerland, Sweden) have introduced additional regulations and measures aimed at reducing leakage.

1.5.1 Denmark

A ban on the use of HFC in systems with refrigerant charges of more than 10kg was introduced in 1st January 2007. In addition, a CO_2 tax is collected for the emission of greenhouse gases. The customer pays the CO_2 tax when purchasing electricity, fuel or heating oil, but also it applies to refrigerants with a high global warming potential. Currently, the CO_2 tax is 100 DKK per tonne CO_2 (13 €/ tonne CO_2). Table 3 shows the Danish greenhouse gas tax for refrigerants normally used in supermarkets.

According to Madson, [2009], the regulations have encouraged a movement towards the use of natural refrigerants in larger systems, but they have also resulted in a proliferation of small systems operating with HFC refrigerants and with a charge of below 10kg.

	Denmark		**Norway**	
	DKK/kg	**€/kg**	**NOK/kg**	**€/kg**
R134a	130	16.88	252	31.82
R404A (HFC-143a/HFC-125/134a)	378	49.09	632	79.80
R507A (HFC-125/HFC-143a)	385	50.00	640	80.81

Table 3: Danish and Norwegian greenhouse gas taxes for selected refrigerants, (2007) Rhiemeier et Al, 2009.

1.5.2 Netherlands

In 1992 the Netherlands introduced the STEK program which aims to increase the leak tightness of refrigeration systems. STEK is a certification system for refrigeration contractors supported by government legislation. Owners or users of equipment are obliged by law to have their equipment serviced regularly and repaired by a company certified by STEK. Refrigerant use is monitored and audited by STEK.

The success of the STEK approach has been widely quoted with annual leakage rates reported to fall from the European average of 15% to 3-4% in 1999 [Van Den Hoogen and Van Der Ree, 2002, Bostock, 2007] There is however, some dispute over the method used to measure leakage. Anderson [2005] reported that comparing end-user leakage data with sales figures from HFC distributors shows potential leak rates of anywhere from 6.9% to 12.7% annually.

1.5.3 Norway

Norway is not an EU member state and therefore is not required to comply with the F-Gas legislation. However, Norway does tax the use of greenhouse gases including refrigerants. In 2007, the tax rate was increased to 190 NOK/ tonne CO_2 equivalent (24€/ tonne CO_2). Table 2 shows the relative tax for different refrigerants. In Norway, the tax on greenhouse gas is redeemed against with the return of refrigerant for recycling or destruction.

1.5.4 Austria

In Austria a regulation has been in place since 2002 governing the use of fluorinated refrigerants, the HFC-PFC-SF6 regulation (Industriegas-V, BGBl. II Nr. 447/2002, with amendments from BGBl. II Nr. 86/2006 and Nr. 139/2007). Whilst it prohibits the use of HFCs, in practice, however, its restrictions are overcome by limiting refrigerant charges to 100 kg or 1.5 kg per kW cooling capacity related to "locally fixed systems with distributed piping", such as a supermarket refrigeration system [Kaltenbrunner, 2007].

1.5.5 Sweden

In Sweden, prior to the F-gas regulations, the maximum refrigerant charge allowed in a supermarket refrigeration system was restricted to 20 kg for medium temperature applications and 30 kg for low temperature [Colbourne,1999]. Also, the refrigerant charge for any RAC unit was not allowed to exceed 200 kg [Schenk, 2007]. As a result there are many indirect refrigeration systems installed and operated in supermarkets.

1.5.6 Switzerland

In Switzerland, legislation prescribes the use of indirect refrigeration systems for supermarket refrigeration systems with more than 80 kW refrigeration capacity and more than 3 cooling points [Schmutz, 2007]. Furthermore, the law requires the registration and tightness control of systems containing HFC refrigerants.

1.5.7 Germany

In Germany legislation was introduced in 2008 called ChemikalienKlimaschutzVerordnung [Anon, 2009,]. This has introduced a leakage limit for supermarket applications of less than 3%, depending on the age of the installation and the size of the refrigerant charge used. Non-compliance is listed as an offence with a minimum fine of €50,000. A number of major supermarkets are reported to be complying with this limit and the scheme is currently being audited by the German government office of statistics [Beermann, 2010]. Estonia have proposed a similar scheme which it plans to enact in 2010 [Truumaa, 2010]

2. The REAL Zero Project

The REAL Zero project (**R**efrigerant **E**missions **A**nd **L**eakage **Zero**) commenced in April 2008. Unlike the measures described above it is a voluntary, industry led initiative. Its aims included developing a greater understanding of how and why leakage occurs, providing tools and guidance on the financial and environmental impact of refrigerant leakage, and providing free information, tools and training to help the RAC industry to take practical steps to reduce refrigerant leakage.

The project outputs were based on research conducted at 81 systems across 30 sites during 2008/9. Site surveys were undertaken by RAC professionals and included:

- A detailed visual inspection of the system to check for general condition, operational status, cleanliness, corrosion, evidence of poor design, installation or maintenance practices and visual indications of refrigerant leakage (e.g. oil stains) and potential leakage points
- Using available F-Gas and service records to calculate the CO_2 equivalent emissions and the cost of the refrigerant added to each system during maintenance activities
- A consultation with site staff to obtain feedback on system reliability, historical problems and trends
- A leak check using a portable electronic leak detector, covering all accessible parts of the system, including components, pipe work, joints and auxiliary components such as pressure switches and pressure relief valve vent lines

The surveys covered several different types of RAC system including Large Retail (supermarket), Building Air Conditioning, Cold Storage, Industrial Processing and Small Retail. The refrigerant records, where available, covered periods of typically 12–18 months. The total CO_2 equivalent direct refrigerant emissions from the 56 systems for which records were available, were over 20,000 tonnes on an annualised basis and in a few instances the total system charge was lost on more than one occasion.

96 refrigerant leaks were detected during the site surveys. Many systems were found to be short of refrigerant at the time of the inspection and potential leakage points such as Schrader and service valves were not always capped. In many instances the approach to service and maintenance appeared to be reactive (responding to faults that had already occurred) rather than proactive and for some systems there was no evidence of regular leak testing being performed.

The information obtained from the system site surveys was used to develop a set of REAL Zero technical guides and monitoring tools, including:

- Guidance notes and advice for service and maintenance engineers, design engineers, service companies and equipment owners on topics such as common leak points, good practice in leak testing, new system design, maintenance contracts and legal responsibilities under the Regulations,

- Software tools to keep track of and value the carbon case for refrigerant management,
- A methodology for undertaking site surveys and developing leakage reduction strategies and
- A training and on-line assessment scheme to embed this knowledge within the industry

The project continues to monitor reductions in refrigerant use from the original survey sites and to gather information from additional surveys conducted by engineers who have undertaken training in using the site survey methodology. More recent data (up to April 2010) has been collected from 17 of the 81 systems. For these systems, a net reduction in refrigerant leakage of 4,851kg refrigerant was reported for 2009/2010 compared with 2008/2009. This represents a direct saving of 7,774 tonnes CO_2e.

The REAL Zero concept is now being implemented on a European basis via the REALSkillsEurope programme funded by the EU Leonardo scheme. More information can be found at www.realskillseurope.eu

3. The Importance of Refrigerant Management

The F-Gas Regulations require that equipment owners keep a record of leak checks and service and maintenance activity related to refrigerant use. The keeping of such records is essential to developing a clear understanding of the potential to reduce refrigerant use in individual systems or sites. In 2009, LSBU conducted a survey across a range of applications, analysing the records of over 1841 systems. In total 42 organisations were approached and 9 were able to provide access to their logs which totalled 1841 logs encompassing stationary refrigeration systems across the supermarket, industrial refrigeration, building air-conditioning and small commercial refrigeration sectors.

As a measure of determining whether the logs received meet the requirements stipulated by the F-Gas regulation, a compliance matrix relating to the required information was developed. Table 4, lists the compliance criteria and shows a typical example log that has been deemed partially-compliant. Full compliance required all the criteria to be met.

REQUIREMENT (UNDER REGULATION EC No 842/2006)	APPLICABLE (Y/N)	REQUIREMENT MET (Y/N)	EVIDENCE / COMMENTS
1. Type of F-Gas	Y	Y	From Log data received
2. Installed Quantity of F-Gas	Y	Y	From Log data received
3. Quantities oF-Gas added or removed	Y	Y	From Log data received
4. Identity of person/company performing checks/servicing	Y	Y	From Log data received
5. Information specifically identifying the equipment	Y	Y	From Log data received
6. Leak checks annually for systems 3-30kg (>6kg if hermetically sealed)	N	-	-
7. Leak checks biannually for systems 30-300kg	Y	N	Freq. of data does not meet requirement
8. Leak checks quarterly for systems >300kg and include auto leak detection*	N	-	-
9. Dates of leak checks performed*	Y	Y	From Log data received
10. Results of leak checks performed	Y	Y	From Log data received
		COMPLIANCE CHECK (X for yes)	
NON-COMPLIANT	PARTIALLY COMPLIANT		FULLY COMPLIANT
	X		

Table 4: F-Gas Log Book Compliance Matrix Example.

From the total number of logs received, a significant shortfall in the information required for compliance has been identified. Only 2.5% were found to be in full compliance of the Regulation. 88% were deemed to be partially compliant and 9% non-compliant. It is also worth noting that the small percentage of logs that were fully compliant were primarily from one company alone.

Partial compliance was mainly due to missing of test dates, missing information relating to the type and location of the leak. The significance of these findings is that, with no date or indication of the type or point of leakage, this data will not help the equipment operator to prevent the future occurrence of leaks or to improve their management of their refrigerant. It can be concluded that recording of data alone is not an effective tool for minimizing leakage - the necessary information must be recorded and data analysed by a responsible person on a regular basis.

Whilst regulators in England and Scotland (both local authorities and the Environment Agency) are responsible for carrying out F-Gas record audits, results or numbers of any such audit visits have not yet been made public. Specific case studies of actual audits would encourage compliance by sectors of the industry who are still finding it difficult to understand the requirement. The regulations allow for a system of fines and penalties for breach of regulations, including the serving of prohibition notices.

4. **Where do Systems Leak - Analysis of the Leakage Record Data**

A number of authors have reported on the reasons why refrigeration systems continue to leak. ETSU in 1997, identified the six most common leaks following an extensive survey of professionals, as shown in Figure 5. Whereas Bostock, [2007], cited a study on supermarket refrigeration systems carried out in Germany which showed that:

- 96% of the total refrigerant loss was through field assembled joints.
- 15% (by number) were responsible for 85% (by weight) of the refrigerant loss
- 22% of all measurable leaks were from flared joints, and these were responsible for 50% of the refrigerant losses.

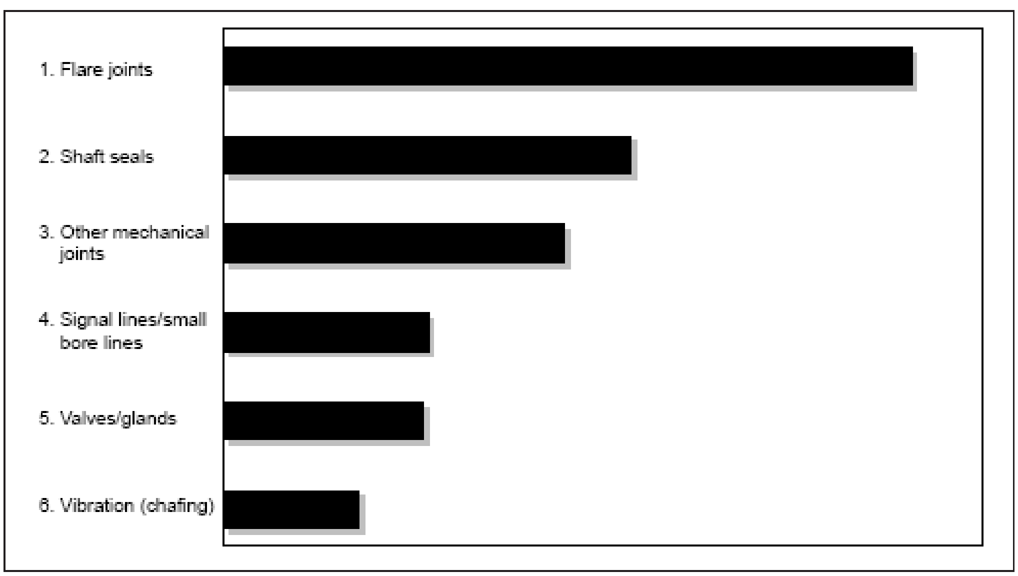

Figure 5: The six most common leaks identified by ETSU [1997].

However, these investigations provide limited information of where and why leakage occurs, which is essential knowledge if industry wants to be able to reduce it. The success of the REAL Zero project, has resulted in an increased willingness on the part of RAC system contractors and end users to share information relating to their system operation as part of the follow up to the REAL Zero project. This has increased the availability of refrigerant use data and a student from LSBU is undertaking detailed analysis for an MSc major project. This analysis is expected to provide further insight into the main causes and sources of refrigerant leak and how they can be addressed.

4.1 Leakage Data Collected

During the past 12 months some significant data has been obtained and analysed. Most of the data analysed was provided in the form of incident reports, taken either from the company's work order records or produced as a summary report of refrigerant use across multiple sites. This presented some difficulties in ensuring consistency of the data for analysis, especially between different companies, so a structured methodology was developed for categorising the incident types, fault locations and fault types, down to individual component level.

To date most of the data received relates to the retail sector and data from two sources have been analysed in detail, comprising over 200 incidents. The work is continuing with an extended data sample and information from additional sources.

4.2 Analysis of Leakage Data

The structured approach for the analysis used 26 data input fields capturing data such as previous (related) incidents, call out initiator, response time, leak detection method, number of leaks detected and repair actions and times, as well as more basic information about faults and refrigerant additions. It does not require all fields to be completed, simply whatever information is available, but it does allow data to be consolidated and compared from different sources. The following charts indicate some of the analysis that has been performed to date.

Figure 6 shows the reasons for the technician visit to site in relation to a leakage problem. Although the majority of visits (60%) resulted from the system failing to hold temperature, 24% were in response to an alarm from a refrigerant leak detector or liquid level detector. In practice, many of the over temperature incidents were also caused by a refrigerant leak, as indicated in Figure 7, which implicates a refrigerant leakage fault in approximately 50% of all call –outs.

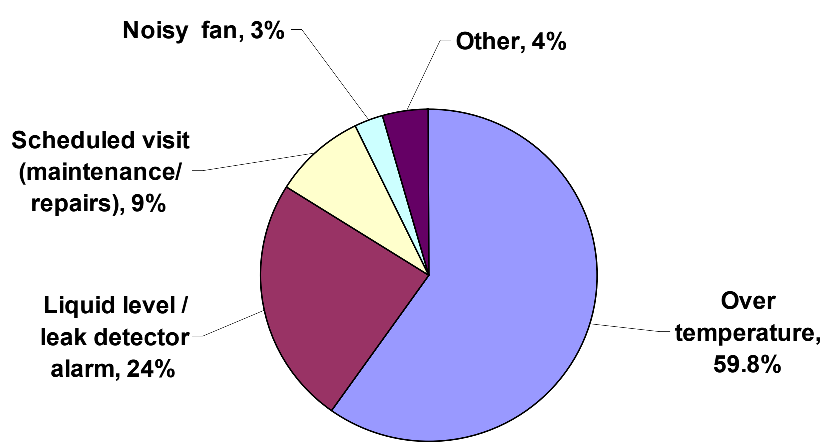

Figure 6: RAC system maintenance – reason for technician visit.

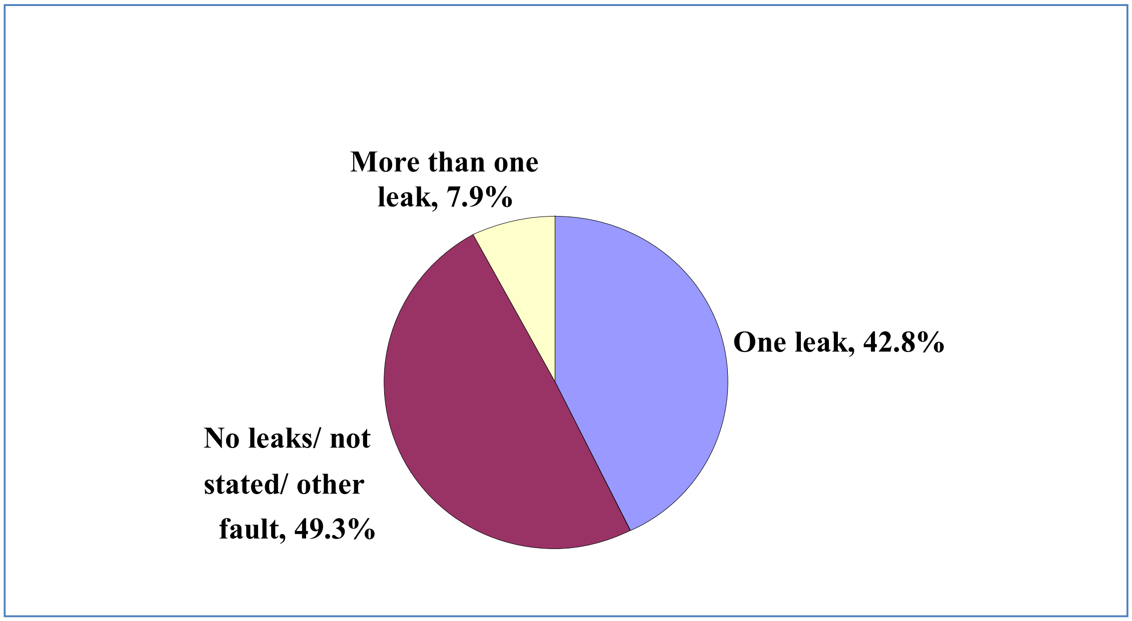

Figure 7: Refrigerant leaks identified per call-out.

Figure 8 compares two data sources and indicates a strong correlation between the data from both, despite significant differences in the format and type of the source data. It shows that the top six fault types were the same for both companies and that leaking seals and glands were the primary cause of leaks. A large proportion of leaks were reported as "refrigerant shortage" or "cause not known". However, for both companies over 20% of the faults were recorded as refrigerant leaks whose cause had not been identified (despite more refrigerant being added). The next two identified fault types were leaking flanges and joints and mechanical component failures.

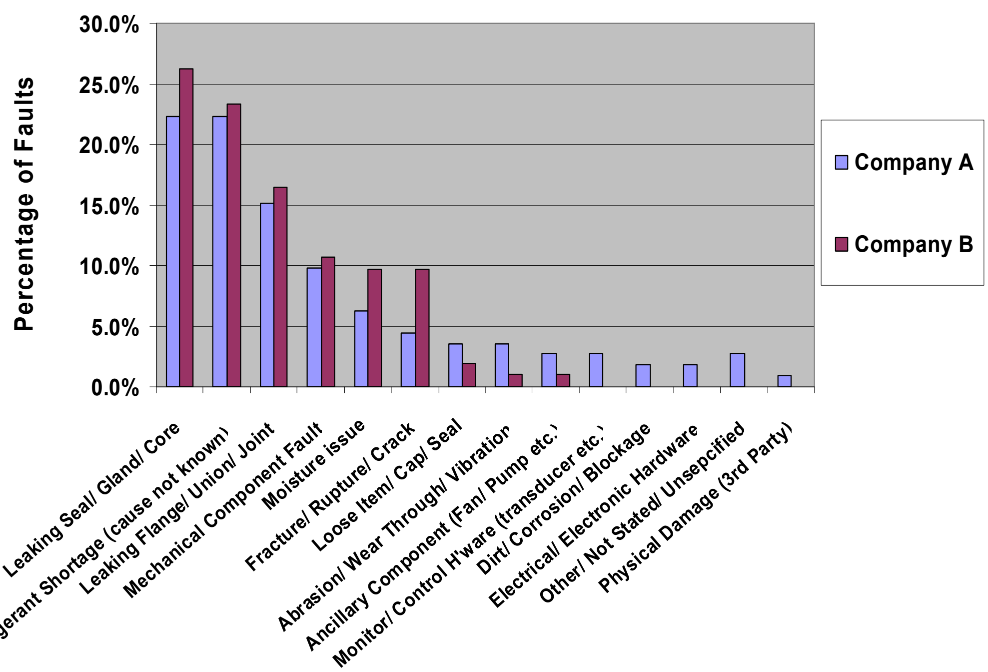

Figure 8: Comparison of RAC system fault types for two companies.

The analysis uses a simplified model for a typical distributed DX RAC system to categorise the location of faults. For a retail application this will typically comprise a roof mounted multi-compressor pack that may include an integral or remote condenser with evaporators remotely located, connected by long pipe runs. Figure 9 indicates that most faults occurred within the compressor pack or in the HP liquid line pipework (which includes the receiver, filter drier and sight glass).

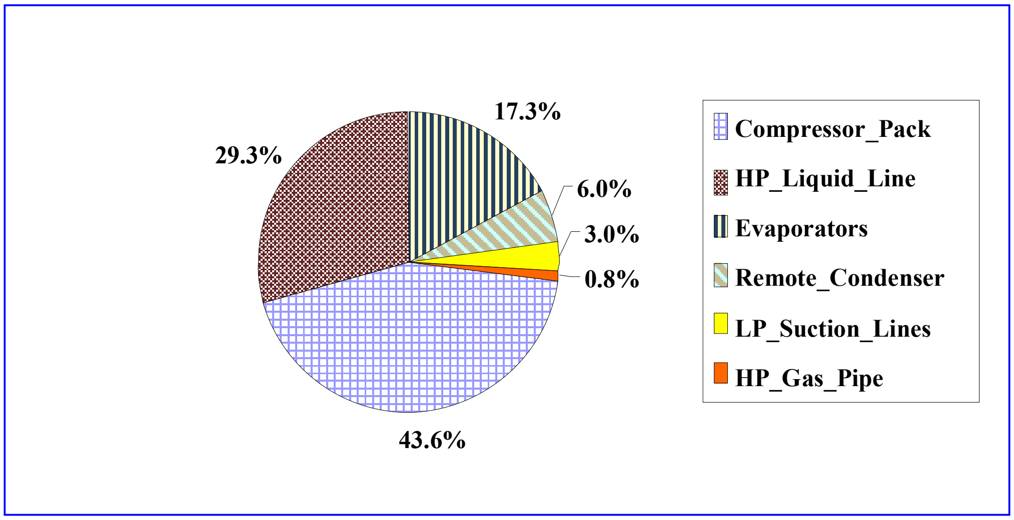

Figure 9: System level fault location.

Work is continuing to isolate and categorise faults at component level within each system location, but Figure 10 shows some preliminary results for component faults within compressor packs.

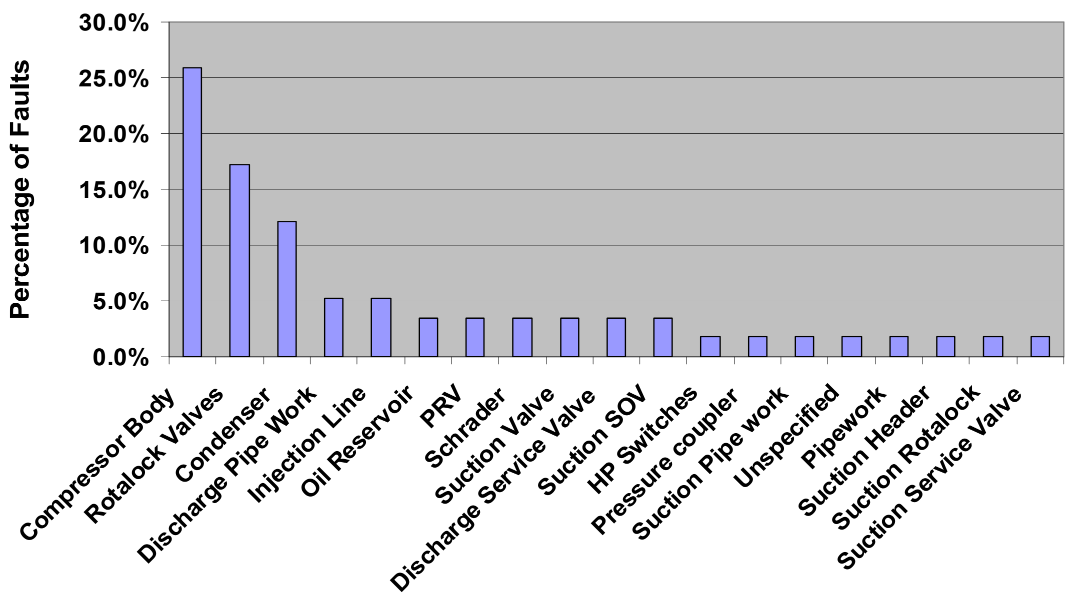

Figure 10: Compressor pack leak points.

The refrigerant used for over 85% of the incidents analysed was R404A. This refrigerant is used extensively in the retail sector, as well as R22 (5%) and R134a (6%). The average amount of refrigerant added per incident was about 21kg. Continued analysis of the key areas and causes of leakage over a greater range of data will enable the industry to influence and modify practices.

5. The Way Forward

Our ability to continue to use HFCs in the medium to long term will depend on our success in containing the refrigerant, legislation that could be forthcoming and the relative carbon emissions and costs of alternative solutions.

5.1 Projected Emissions and the Shift from R22

HFCs and HCFCs continue to be the most commonly used refrigerants for stationary RAC systems. The phase out of HCFCs and the EU ban on the use of virgin R22 refrigerant (from January 2010), have resulted in an increase in the total amount of HFCs used in the RAC sector. F-Gas emissions are still increasing, in certain countries where total greenhouse gas (GHG) emissions have either stabilized or fallen in recent years. One exception to this trend is in the UK where the data indicates a 5% reduction in F-Gas emissions between 2002 and 2007.

Projections for the potential future emissions from refrigerants vary considerably. The US Environmental Protection Agency forecasts that HFC emissions from the RAC sector will increase significantly between 2007 and 2020 [EPA, 2006]. Globally, F-Gas emissions were reported as being 1.1% of all GHG emissions in 2004 [IPCC, 2007] and reports by Velders *et al.* [2009], and Gschrey and Schwarz [2009] suggest that, without extensive mitigation measures, HFC emissions could eventually be responsible for as much as 6% of all GHG emissions. Data derived from the 2009 UNEP TEAP assessment [UNEP, 2009] suggests that with appropriate mitigation measures the increase in HFC emissions could be much smaller. Clearly there is much uncertainty in this area.

5.2 Future Policy on Refrigerant Emissions

There are a number of areas of legislation that may impact refrigerant leakage and the use of HFCs. Firstly, although not ratified in November the Copenhagen draft "**Towards a comprehensive climate change agreement in Copenhagen"** covered the future use of HFC refrigerants [Commission Of The European Communities, 2009]. It specifically stated that the EU objective is that developed countries should reduce their emissions to 30% below 1990 levels by 2020 and 50% below 1990 levels by 2050.

The Copenhagen draft specifically highlighted the need to address fluorinated gases. It also suggested an international emissions reduction arrangement for HFC emissions and the need for industry to intensify research into and the development of HFCs with low global warming potential and HFC-free alternatives.

Prior to Copenhagen, the UK Government view was reported in minutes of a Stakeholder Meeting published by DEFRA in October 2009: " the EU approach (supported by the UK), is to work for language in the Copenhagen climate agreement that 'enables' the Montreal Protocol Parties to negotiate an HFC phase-down. It is possible that an international HFC emissions reduction arrangement would be negotiated under the Montreal Protocol ("MP") in 2010". The term phase down rather than phase out is used in recognition of the need to maintain HFC use in certain essential applications and anticipating the availability of new low GWP HFC (HFO refrigerants) [DEFRA, 2009].

The next Montreal Protocol meeting in Bangkok in June 2010, the international Climate Change meeting in Mexico in 2010 and the F-Gas Review in 2011 will all have a bearing on the future UK Government position.

5.3 The Future Economic Impact of Emitting Carbon

Carbon released to atmosphere has a cost to the international community. This is consistent with the 2006 Stern Review of the Economics of Climate Change, which highlights the economic costs of failing to act to tackle climate change [HM Treasury,2006]. Amongst other items the Copenhagen agreement suggests climate adaptation costs could range between € 23-54 billion per year in 2030 and the setting up of a multilateral insurance funding to cover disaster losses in case of climate related natural disasters.

Currently, there are specific schemes in place designed to limit carbon emissions of specific sectors using fiscal incentives. These include the Carbon Reduction Commitment (CRC), the Climate Change Levy (CCL), the Climate Change Agreement (CCA) and the Emissions Trading Scheme. These generally apply to specific sectors and are aimed at reducing carbon emissions and energy consumption.

Currently, these mechanisms apply only to carbon emissions from energy, however, this may change with the Emissions Trading Scheme which will be modified in 2013 and run until 2020. The Scheme will be designed at a European level. The scheme will be expanded to include the production of all metals (including Aluminium) and potentially aviation. For some sectors, it will include the emission of other greenhouse gases in addition to carbon dioxide and this could well include refrigerants [The Carbon Trust, 2010].

5.4 Technological Solutions

With this backdrop it is important that the refrigeration industry is able to demonstrate significant reductions in refrigerant emissions to enable us as an industry to be free to choose the best (ie most efficient and safest) refrigerant for the application. The extent to which leakage can be limited depends upon the application but in the short term we should be working towards best practice levels that are being achieved elsewhere. In the longer term, we should be working towards leak free systems. As an industry, we have many years of experience of operating virtually leak free ammonia systems – for example there are on average just 70 losses of >100lbs of ammonia per year across the whole of the US (where there is a requirement to records ammonia leakage above 100lbs of charge [Rolfsman, 2010].)

For existing RAC systems the opportunities to reduce refrigerant emissions are most likely to be associated with improvements to service and maintenance regimes and procedures. System upgrades will also offer improvements that will achieve financial and environmental benefits relative to the capital cost. Two sources suggest that refrigerant emission abatement measures can be effected for as little as $20 per tonne CO_2e saved [IPCC, 2006] and €18.32/tonne CO_2e respectively [Anderson, 2005]. At these costs there is a strong financial argument for abatement bearing in mind the cost of refrigerant, servicing and the cost of carbon.

The requirements imposed by F-Gas Regulation EC/842/2006 for recording information about leak tests and refrigerant use rigorously and publicly enforced should ensure that system owners, operators and maintainers have ready access to the necessary information to achieve improved refrigerant management for their systems. However, we should also consider introducing measures to make the detection of leakage much easier. This could include the use of non destructive testing in assuring quality of brazing and the use of additives to give the refrigerant an odour. The use of an additive odour is under test by at least one supermarket in the UK.

It is essential that new systems are designed and installed in accordance with industry standards and best practice recommendations. Some recommendations a*re* covered in the REAL Zero guidance material but consideration should be given to low charge systems. Greater consideration should be given to the heat exchanger design, the receiver sizing, the technology of the expansion device and the diameter and lengths of pipework - the liquid line holds a large proportion of the charge and two applications are cited where the hp liquid line include 60% and 32% of the refrigerant charge respectively). The use of lower GWP refrigerants, including natural alternatives such as ammonia, CO_2 or hydrocarbons and alternative system configurations and technologies, including the use of secondary loop designs are also options provided that the system operating efficiency is not compromised. As a benchmark, Poggi states that the least amount of refrigerant is required for a direct expansion secondary refrigeration system with 0.5kg charge /kW cooling, whereas the greediest system (i.e. the greatest refrigerant requirement) is a flooded system with 5kg/kW.

Future developments in new refrigerants such as HFOs may provide a solution however this technology is as yet unproven in the field. There are also a number of derivatives proposed by the individual chemical companies which may or may not become available for future use [Low, 2010, Leck et al., 2010]

It should be remembered that improving the environmental sustainability of refrigeration systems is dependent on both reducing refrigerant leakage and maximising system efficiency. For existing systems it is likely to be easier to achieve short term improvements by reducing refrigerant leakage. Legislators should note that life cycle carbon and cost calculations provide a strong case for efficiency being at least if not more important than choice of refrigerant.

Conclusions

This paper provides a comprehensive review of the issue of refrigerant leakage carried out within the REAL Zero project. The paper highlights that leakage has an adverse impact on climate change both directly because these refrigerants are very powerful greenhouse gases, and also indirectly because leaking systems are less energy efficient. There are also high financial penalties associated with the additional energy and service costs, downtime, and food wastage or lost production.

The paper provides a review a small sample of F-Gas logs and leakage records. This work is ongoing but has identified a number of common areas of leakage, which are priorities for action. The ongoing analysis of such data is essential in order to develop greater understanding of the cause of leakage and how it can be reduced. .

The paper concludes with an overview of the impact of potential future legislation on the use of HFC refrigerants and the relative carbon emissions and costs of alternative solutions.

The REAL Zero project is an on-going area of work not just for the IOR but for the whole industry, and increasingly for a wide range of stakeholders in the UK and other countries, necessary to achieve a sustainable refrigeration industry for future generations.

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