Institution: London South Bank University

Unit of Assessment: 12 – General Engineering

Title of case study: Reducing worldwide refrigerant leakage emissions

Period when the underpinning research was undertaken: 2008 – 2017

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title)**:	**Period(s) employed by submitting HEI**:
Professor Graeme Maidment	Professor of Heating and Cooling	1999 – present
Professor Judith Evans	Researcher - Air Conditioning & Refrigeration	2010 – Present
Dr Gareth Davies	Senior Research Fellow	2007 – Present

Period when the claimed impact occurred: August 2013 – June 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

The research into refrigerant leakage by Professor Maidment has had broad and far-reaching impact in greenhouse gas emissions reduction:

- led to a global training and awareness program on low Global Warming Potential (GWP) refrigerants;
- produced training materials on transitioning to low GWP refrigerants completed by 4,600 e-learners;
- produced awareness-raising activities of the benefits to transitioning to low GWP refrigerants that have reached 595,000 people through 430 events;
- resulted in 500 technicians taking practical training courses on how to reduce refrigerant leakage;
- contributed to switching to low GWP equivalents of F-gas refrigerants, with estimated annual savings of 4,200,000t CO_2e across 12 European countries in 2019;
- supported the net-zero emissions target in the UK;
- informed a United States Environmental Protection Agency program;
- helped reduce refrigerant loss across Asda stores from 50% to 10% per annum; and
- influenced an International Standard in refrigerated transport

2. Underpinning research (indicative maximum 500 words)

There are an estimated 5 billion refrigeration, air-conditioning and heat pump (RACHP) systems in use globally. Many of these use chemical refrigerants with huge Global Warming Potential (GWP): 1kg can cause as much atmospheric damage as 3,900kg of carbon dioxide (CO_2). Consequently, refrigerant leakage is a major environmental hazard: emissions from refrigerant leakage accounted for 7.8% of worldwide greenhouse gas emissions in 2019. Refrigerant loss also reduces the efficiency of refrigeration systems, leading to indirect emissions through increased fuel consumption and higher maintenance costs.

All refrigeration systems have the potential to leak because pressures in the system are usually many times higher than atmospheric pressure. Professor Maidment and London South Bank University (LSBU) team have been active in refrigeration leakage research for over 15 years, encompassing: 1) ascertaining the scale and critical sources of refrigerant leakage; and 2) reducing fluorinated gas (F-gas) leakage from stationary sources and refrigerated vehicles.

Mapping refrigerant leakage

The UK REAL (**R**efrigerant **E**missions **A**nd **L**eakage) Zero project, commenced in 2008, was undertaken by the Institute of Refrigeration and LSBU, and supported by the Carbon Trust. It researched the scale and causes of leakage of refrigerant leakage, investigating 81 systems

across 25 UK sites during 2008/9, including retail, building air conditioning, cold storage and industrial processing **[R1]**. Follow-up surveys in 2010 showed a net reduction in annual refrigerant use of 4,905 kg in 2009/2010 compared with 2008/2009. This represents a reduction of 43% in direct emissions, as a result of the interventions designed by LSBU. The LSBU Team led by Professor Maidment produced the following key findings:

- levels of refrigerant leakage were extremely high and previously not understood; and
- the key causes of leakage included poor maintenance, deficient training of technicians, large systems which offered a lot of scope for leakage due to their multiple joints, insufficient leak detection work and poor awareness of the scale of the impacts of leakage.

The work was extended into Europe as the REALSkillsEurope programme **[R2]**.

F-gas leakage from stationary systems

Many refrigerants used in RACHP systems are fluorinated gases (F-gases). The biggest contributor to CO_2-equivalent (CO_2e) emissions from the RACHP industry is the commercial refrigeration sub-sector, equating to 40% of total annual refrigerant emissions – despite accounting for only 22% of worldwide refrigerant consumption. Professor Maidment's research into commercial refrigeration systems established that **[R3]**:

- pipe/joint failure and leaking seals/valves account for over 53% of total average refrigerant mass loss; on average one leak from a commercial system was equivalent to the annual emissions of 16 households;
- continuous refrigerant leak control measures are effective immediately upon implementation and can be realised worldwide; and
- manufacturers, equipment installers and service technicians have a role to play in preventing leakage prevention

F-gas leakage from refrigerated vehicles

Primary food distribution by Refrigerated Road Transport (RRT) in the UK uses up to 37% more energy than comparable non-refrigerated vehicles. Moreover, RRT vehicle engines account for 2% of the total CO_2 emissions from the UK road sector. Efficiency improvements could achieve up to 50% energy savings for chilled goods transport. Professor Maidment's research **[R4]** into this area found that :

- RRT systems were more prone to leaks than stationary systems, particularly in the case of poorly maintained older vehicles;
- refrigerant leakage was a large component of the RRT environmental footprint;
- effective maintenance and operations could significantly reduce leakage; and
- the combined two-way filter dryer (which removes any impurities from the refrigerant) and sight glass (used to view the refrigerant and check its condition) were major sources of leaks across all manufacturers and models of refrigerated units.

The LSBU team subsequently worked with Hubbard, a UK based HVAC company active in the refrigerated vehicle sector, to analyse where energy and carbon savings could be made **[R5]**. Examination of 200 vehicle logs identified the areas most prone to leakage, and therefore opportunities to address this. One area alone, the 2-way filter drier, was responsible for over 10% of the greenhouse gas (GHG) leakage from the sample.

3. References to the research (indicative maximum of six references)

R3 is submitted as an output for REF2021 in UoA 12.

[R1] Cowan, D, Gartshore, J, Christina, F, Chaer, I and Maidment, GG (2011). REAL Zero – Reducing refrigerant emissions & leakage- feedback from the IOR Project. Proceedings of the Institute of Refrigeration, 2010 https://openresearch.lsbu.ac.uk/item/879xq

[R2]. Koronaki, I. P., Cowan, D., Maidment, G., Beerman, K., Schreurs, M., Kaar, K., Chaer, I., Cazauran, X., Refrigerant emissions and leakage prevention across Europe - Results from the REALSkillsEurope project, 2012, Energy 45 (1), pp. 71-80. https://doi.org/10.1016/j.energy.2012.05.040

[R3]. Francis, C., Maidment, G.G., and Davies, G.F. (2016). An investigation of refrigerant leakage in commercial refrigeration. International Journal of Refrigeration, 74(Feb), 10-19. doi: https://doi.org/10.1016/j.ijrefrig.2016.10.009

[R4]. Francis, C., Davies, G., Evans, J., Maughan, P., Sherwood, J., and Maidment, G.G. (2015). Modelling and development of sustainable Refrigerated road transport systems. Refrigeration Science and Technology 2883-2890.
doi: https://doi.org/10.18462/iir.icr.2015.0324
[R5]. Davies, G.F., Francis, C., Evans, J.A., and Maidment, G.G. (2017). Overview of Sustainable Refrigerated Road Transport Systems. In G. Smithers, L. Day, P. Ferranti, A. Fischer, M. Glibetic, K. Knoezer, A. Lee, P. McSweeney, G. Robertson, C. Schasteen, N. Smith, D. Tanner, and P. Varelis (Eds.), Reference Module in Food Science Elsevier.
doi: https://doi.org/10.1016/B978-0-08-100596-5.21245-6

This project is underpinned by funded research via: two EPSRC funded projects (industrial Case awards with the Institute of Refrigeration and Hubbard Refrigeration); three EU projects; and one KTP project with the Institute of Refrigeration, including two studentships and multiple master projects.

4. Details of the impact (indicative maximum 750 words)
The research has led to the following significant beneficial global environmental impacts:

***REALAlternatives*: an international programme to raise awareness of low GWP refrigerants**

Using the results of Maidment's research, the IoR developed a comprehensive set of training materials and monitoring tools to help equipment operators and technicians reduce leakage. The original REALZero work led on to international programmes: REALSkillsEurope to extend the leakage reduction training and awareness into Europe; and then REALAlternatives, which focuses on low GWP alternatives to F-gases. This project ran from June 2017 to June 2020 and had a budget of EUR703,461, of which the EU contributed EUR422,076 **[S1]**.

The transition to using low GWP refrigerants is critical to the environmental objective of reducing the projected 70,000,000t CO_2e emissions from the sector by 2030. REALAlternatives' aim is to enable the safe use of low GWP alternative refrigerants such as carbon dioxide, ammonia, hydrocarbon and new low flammables HFOs and R32. While these are preferable in terms of their global warming potential, they present a greater risk to health in case of leakage, due to flammability, toxicity or extreme pressure issues. REALAlternatives is designed to improve training capacity, the skills levels of installers, knowledge and awareness levels in the RACHP market. These areas are recognised by F-gas regulation as barriers to achieving emissions reductions through low GWP refrigerant use **[S2]**. The project set up European training centres and associations in partnership with the IIR to provide "*Train the Trainer*" sessions on low GWP refrigerants.

LSBU is one of six international project partners in the REALAlternatives Consortium, with responsibility for clarifying alternative refrigerant training needs and opportunities in Europe, developing a specification for the e-learning, and reviewing resources currently available in Europe to support learning. LSBU provides research capability for the consortium, ensuring the need and benefits of any activity have been clearly evidenced. The initiative has achieved global reach **[S2]**:

1. From an initial base of 6 European countries, the programme now has 20 participants including Canada, New Zealand and Russia **[S3];**
2. The website http://www.realalternatives.eu is available in 17 languages and has (at June 2020) 16,673 visitors and registration for e-news **[S2];**
3. It hosts nine e-learning modules and downloadable resources in 13 languages (i.e. the national languages of over 85% of Europe's 228,000 engineers and technicians). 4,600 e-learners have completed the training, against a target of 2,000: 84% agreed that their knowledge of low GWP refrigerants had increased **[S2];**
4. Feedback surveys from study visits (35 participants) and *train the trainers* sessions (105 participants) corroborated the impact of the training resources;
5. The project had a target of providing 75 training licenses and exceeded this by 30 (105 licences provided; 140% of target);
6. Awareness-raising activities reached 595,000 people through 430 events **[S4];** and

7. 500 technicians took part in practical training courses (NB Covid-19 curtailed practical courses; none took place after February 2020) **[S2]**.

A survey in January-February 2020 assessing change compared to the baseline position before the programme showed that the market is beginning to transition: the most significant change since 2017 has been greater acceptance of the value of training for alternative refrigerants and the need to adapt. The survey also found an increase in the take-up of equipment for alternative refrigerants. **[S2]**

The annual emissions in the 12 project partner and stakeholder countries was estimated at 84,400,000t CO_2e in 2017. Using Polish data as a benchmark (Poland collates this data; other countries do not, so it was agreed that the Polish figures could serve as a proxy) shows that switching from F-gas to low GWP alternatives resulted in estimated annual savings of 4,200,000t T CO_2e in 2019, and 12,600,000t CO_2e during the project (2017-2020) **[S2]** across these countries.

Implementation of new international policies

Maidment was credited as an expert by the UK Climate Change Committee (CCC) on reducing F-gas emissions, to which he provided evidence **[S5**]. The resulting report, 'Assessment of potential to reduce UK F-gas emissions', supports the CCC's Net Zero technical report, which in turn informs the final CCC Net Zero advice report. The recommendations of this final report were turned into legislation committing the UK to net zero emissions by 2050, passed on 27June 2019. The UK was the first country in the world to make this commitment.

The findings from the REALZero work prompted The International Institute of Refrigeration (IIR) to set up a Working Party on "Mitigation of Direct Emissions of Greenhouse Gases in Refrigeration". The IIR is the only independent neutral intergovernmental science and technology organisation present in the refrigeration sector. This working party developed a position paper (published January 2014) on minimising leakage of refrigerants recommending actions for reducing leakage, replacing the previous guidance from 1999. **[S6]**.

The REALZero work is also included in the United States Environmental Protection Agency's (EPA's) industry resources and reports related to its *GreenChill* program: an EPA partnership with food retailers to reduce refrigerant emissions and decrease their impact on the ozone layer and climate change **[S7]**.

Training developed under the REAL Alternatives programme has been recognised by the Spanish Environment Ministry and forms part of mandatory training in low GWP refrigerant alternatives **[S2]**

***REALZero* changed supermarket practices**

In 2007, Asda started examining ways to reduce energy and carbon usage. At the time, their gas and electricity expenditure was GBP120,000,000 (£120m). Refrigerant gas leakage cost GBP500,000 (£0.5m) and resulted in the same CO_2E as their total energy consumption. They quickly identified the REALZero programme as a way to address this: "*The work of Graeme, LSBU and the Institute of Refrigeration has been the guiding light for Asda…F-gas regulations were important and we had to go down this route. We bought into REAL Zero and certainly have no regrets.*" [Testimonial from Asda, **S8**]

In 2000 Asda had 250 stores with refrigerant loss of 50% per annum. In 2020 they have 620 stores, representing a 200% increase in shopfloor space, but refrigerant gas leakage is less than 10%: *"We work collectively across Asda and Walmart to ensure our continuous progress, which reduced leakages and associated costs. We are reminded that leakages mean that fridges work inefficiently, consume more energy and are likely to go wrong more often. We have associated costs – the fridge goes down and stock gets spoiled. Engineers also need to be called out and shelf space is lost."* [Testimonial from Asda, **S8**]

Reduction in leakages from refrigerated vehicles: development and commercialisation of a novel product to reduce leakage

Collaboration between Hubbard and LSBU resulted in the design of a new component as a simple way to reduce leakage, creating a multi-million pound market. The new component

replaced a flare connection with an O ring. With an estimated 5 million refrigerated road transport vehicles around the world, the reduction in leakage from this one, easily achieved change is significant: "*[LSBU] research had shown that a key leakage point was a seal between the high-pressure dryer filter and the sight gauge. We created a modified design to address this and marketed a new unit. This is replaced annually on over 100,000 trucks in the UK; its trade price is £31.*" **[S9]**

Reduction in leakages from refrigerated vehicles: a new international standard in place
Recent years have seen a growth in demand for temperature-controlled refrigerated delivery services in response to the increase in online shopping. Professor Maidment's research on the integrity of transport refrigeration systems informed the development of a British Standard for refrigerated vehicles in 2017 (PAS 1018:2017) and subsequently to an international equivalent, ISO 23412:2020 [**S10**].

This is the first international recognised standard for indirect, temperature-controlled refrigerated delivery services via land transport. It sets out requirements for refrigerated delivery service providers so that they can improve the quality and consistency of refrigerated parcel delivery services in a range of sectors (cold chain, parcel delivery, postal services, temperature-sensitive products e.g. food, plants, cosmetics). Based on the results of the research on refrigerated transport, LSBU recommended that the standard should include provision for: 1) driver training (for operating refrigerated vehicles); 2) regular temperature monitoring of the vehicle refrigerated compartment and products; and 3) regular maintenance of refrigerated vehicles and equipment. The first company to obtain ISO 23412 certification was Yamato in September 2020**.**

5. Sources to corroborate the impact (indicative maximum of 10 references)

[S1] Project details are available at https://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=search.dspPage&n_proj_id=6240
[S2] Evaluation, valorisation and impact final report
[S3] Expressions of interest from policy makers in adopting blended learning programme internationally
[S4] REALAlternatives Consolidated Dissemination Report, May 2020
[S5] Committee on Climate Change documents: A. Assessment of potential to reduce UK F-gas emissions ; B. Net Zero – Technical Report including a chapter on F-gas emissions; C. Net Zero – The UK's contribution to stopping global warming; UK becomes first major economy to pass net zero emissions law
[S6] Containment of Refrigerants within Refrigeration, Air Conditioning and Heat Pump Systems, 24th Informatory Note on refrigeration technologies, IIR January 2014.
[S7] US EPA website https://www.epa.gov/greenchill/greenchill-industry-resources-and-reports
[S8] Interview conducted by The Innovation Partnership
[S9] Interview conducted by The Innovation Partnership
[S10] British Standard: https://shop.bsigroup.com/ProductDetail/?pid=000000000030331566 ; ISO Standard https://www.iso.org/standard/75468.html; https://www.yamato-hd.co.jp/english/news/2020/pdf/2020_08_news.pdf?20101301