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refrigeration and air conditioning

2015 THE YEAR OF GREEN COOLING

THE ROAD FOR
NEW GENERATION
TECHNOLOGIES

ENVIRONMENT
ENERGY • TRAINING
CERTIFICATION • LEGISLATION

UNDER THE AUSPICES OF THE ITALIAN MINISTRY OF THE ENVIRONMENT

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Publishing manager:
Enrico Buoni
buoni@centrogalileo.it

Copy Editor:
M.C. Guaschino

Editor:
Centro Studi Galileo
via Alessandria, 26
15033 Casale Monferrato
Phone +39 0142 452403

Advertisement:
Phone +39 0142 453684

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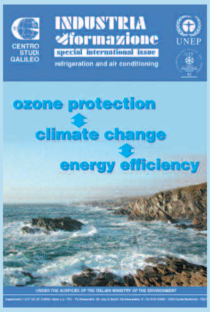

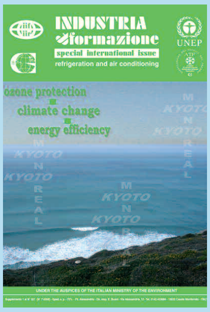

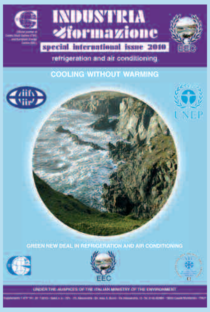

As issues 2006, 2008, 2010, 2012 (above)
About the pictures on the cover in the circle (clockwise)
– **The sun**, our source of energy, is also a major threat due to the Ozone hole and Climate Change
– **Aurora Borealis**, a demonstration of the radiation and energy of the sun
– The world's most magnificent mountain panorama, the image of **Monte Rosa mountain**
– **Achill Island**: the most north westerly point of Ireland
The pictures illustrate:
– **Ozone protection** the blue sky contains our Earth's ozone shield
– **Climate Change** the Global Glacier retreat due to global warming is a global threat
– **Energy Efficiency and Renewable Energy** glaciers and water are a primary source of energy for our hydroelectric plants.

2015: the year of Green Cooling (explanation in Editorial)

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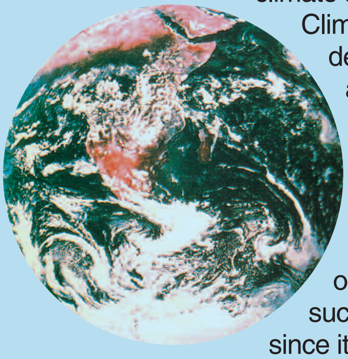
Contents

FOREWORDS

The refrigeration and air conditioning sector is a cornerstone of modern life and it continues to prove itself to be both innovative and responsive to environmental concerns. Global emissions of hydrofluorocarbons (HFCs) – some of the fastest growing and most potent greenhouse gases – are increasing at a rate of 8 per cent a year due to their use as a replacement for ozone depleting substances and the spread of refrigeration and air conditioning worldwide. Given the projected climate impact of HFCs, it is critical to begin the phase-down of high global warming potential (GWP) HFCs and accelerate the adoption of low-to-zero GWP alternatives, as endorsed by world leaders at the Rio+20 Summit. January 2015 marks an important milestone for the Montreal Protocol on Substances that Deplete the Ozone Layer. By this date, developing counties will have achieved a 10 per cent reduction in hydrochlorofluorocarbons (HCFCs), building on the great achievements made since 1987 in ridding the world of CFCs and a range of other ozone depleting substances. The challenge now is to ensure that HCFCs are replaced with climate and ozone-friendly, energy efficient technologies. Such alternatives are commercially available and already being used in many refrigeration and air conditioning applications, and industry continues to innovate for other applications where alternatives are not yet widely adopted.
The Montreal Protocol has already achieved a significant climate protection benefit, and has the potential to do even more through a smart HCFC phase out. UNEP, through its OzonAction Programme and as an implementing agency of the Montreal Protocol, is assisting developing countries through their National Ozone Units to make informed decisions about technologies and policies to replace HCFCs, with an added consideration on the climate benefits that can be achieved. Manufacturers, servicing technicians, industry associations and end users can make a real difference to continued ozone-climate success, under both the Montreal Protocol and the United Nations Framework Convention on Climate Change. I encourage you to consider the innovative technologies and approaches described in this Special International Issue and work in partnership to fully realise the vision of a low-GWP and energy efficient refrigeration and air conditioning sector.

Achim Steiner, UN Under-Secretary-General and UNEP Executive Director



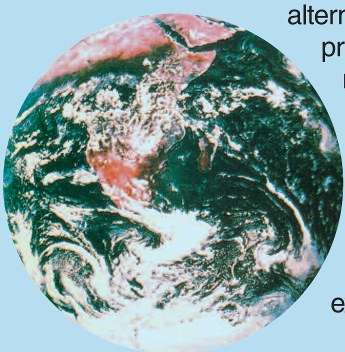
The Montreal Protocol on Substances that Deplete the Ozone Layer is one of the most effective multilateral environmental agreement, successfully phasing out the production of ozone-depleting substances since its adoption 27 years ago in 1987, placing the ozone layer on a path to full recovery. The positive results achieved to date surely depend from the combination of different aspects such as the global participation and cooperation among countries and the wide involvement of developing countries. Among those aspects, I believe that a crucial one has been the involvement of industries and civil sector and their acceptance of the challenges to improve and innovate. An excellent work has already been done, but some opportunities to synergize and maximize climate and ozone benefits still remain. In this regard, we are working hard to be prepared at the COP20 on Climate Change in Lima next December and present our national contribution to the Global Agreement of 2015. In Lima we will put the basis for the negotiating text of the conference in Paris next year, at the crucial moment for the achievement of the global agreement on climate. I am confident that on issues such as those related to the environment we can work closely with a constructive and generous spirit. The environment, perhaps more than many other issues, concerns life and our future and the heritage for the future generations.

Gian Luca Galletti, Italian Minister of the Environment

FOREWORDS (2)

The International Institute of Refrigeration (IIR) is an intergovernmental organization comprising developed and developing countries from all continents. Its aim is to disseminate scientific and technical information concerning all refrigeration technologies and applications, thanks to conferences, databases and publications. Presently, this takes on a particular importance, as 2015 is a key date for the development of the refrigeration and air-conditioning industry.
Refrigeration is necessary for life and its use will continue to expand worldwide: the need for larger amounts of food, for better health, for new energy sources, for new technologies (IT) is increasing, particularly in the developing countries where populations are often underequipped and growing. However, refrigeration accounts for 16% of global electricity use and most refrigerants (CFCs, HCFCs, HFCs) are potent greenhouse gases. Thanks to the endeavours of the refrigeration sector to phase out CFCs and then HCFCs, the ozone layer will recover. However, we must also mitigate our industry's indirect and direct impact on global warming.
The following articles we selected with UNEP and Centro Studi Galileo represent various aspects of this global issue:

- a few national experiences and projects are presented, showing that policies are currently being developed and that it is possible to face these challenges. The European Union is to phase down HFCs, starting in 2015. Japan is preparing a similar policy. The Middle East is trying to list all the solutions available under hot climates;
- There is no single solution, but rather a range of solutions for each application, taking into account all the technical and economic aspects in a holistic approach. We can first reduce refrigerant emissions thanks to better containment, proper reduction of refrigerant loads and the destruction of existing refrigerant banks. Secondly, we can use alternative refrigerants. An overview of the various possibilities and recent practical examples are presented. Important issues are presented, for instance: the implementation of new standards, the need to take into account both direct and indirect impacts when choosing solutions and the various kinds of energy that can be selected. It is possible to use renewable energy sources in the refrigeration sector and this of course has an immensely positive impact on global warming.



We hope that these articles will incite you to learn more about the current situation of a sector that is at the heart of your and other people's daily life and about the concerns and challenges your country, your company or university and yourself have to face. Be assured that solutions exist and that we are at your disposal to help you.

Didier Coulomb Director of the International Institute of Refrigeration (IIR)

Members of the IIR include Member Countries (there are now 60). They represent 80% of the global population. Members Countries take part in IIR activities via the commission members they select. Moreover, companies, laboratories, universities... can become corporate or benefactor members of the IIR.

Above:UNEP offices in Paris, from the left D. Coulomb-IIR, M. Buoni-ATF, J.Curlin-UNEP. Below: IIR offices, on the right E. Buoni-CSG

From left: P. Buoni EEC, E. Buoni CSG, L. Lucas CNF, A. Cavallini Università di Padova, D. Coulomb IIR, R. Patten EPEE, S.Yurek AHRI, W. Chakroun ASHRAE, H. Halozan University of Graz, R. Shende UNEP, F. Benassis Climespace, Y. Yifan CAR, M. Buoni ATF.

Editorial

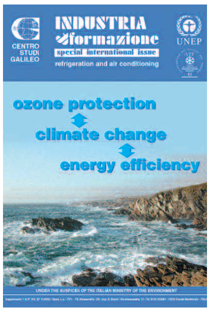
The year of "Green" Cooling

MARCO BUONI

Technical Director Centro Studi Galileo
General Secretary Italian Association of Refrigeration Technicians

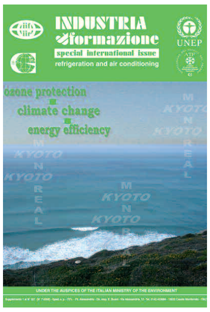
2015 will be an important year for the refrigeration, air conditioning and heat pumps sector for several reasons:

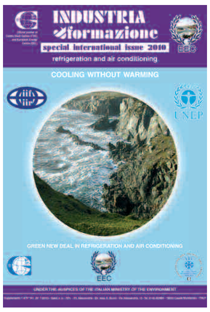
- The end of HCFC (as R22) in developed countries
- HCFC reduction in developing countries
- Higher use of alternative refrigerants both in developed and developing countries (both natural and LOW GWP refrigerants)
- A universal agreement on the reduction of greenhouse gases, as HFCs, at the UNEP Climate Change Conference (COP21) in Paris.



Left: International Special Issue 2006.
Presented at MOP18 (18th Meeting of the Parties to the Montreal Protocol in New Delhi), COP12 (Kyoto Protocol Conference in Nairobi, 2006) and COP13 (Kyoto Protocol Conference in Bali, 2007). Download at: http://bit.ly/caoo6m

Right: International Special Issue 2008
UNEP - IIR - Centro Studi Galileo
Presented at MOP20 (20th Meeting of the Parties to the Montreal Protocol Conference in Doha-) and COP14 (Kyoto Protocol Conference in Poznan, 2008) Download at: http://bit.ly/9W4L0a





Left: International Special Issue 2010
UNEP - IIR - Centro Studi Galileo
Presented at MOP22 (22nd Meeting of the Parties to the Montreal Protocol in Bangkok) and COP16 (Kyoto Protocol Conference in Cancun, 2010)
Download at: http://bit.ly/L5Md5C

Right: International Special Issue 2012
UNEP – IIR - Centro Studi Galileo – EEC
Presented at MOP24 (24th Meeting of the Parties to the Montreal Protocol in Geneva) and COP18 (Climate Change Conference in Doha, 2012)
Download at: http://bit.ly/1m89hhj

The International Special Issue 2014-2015 will be distributed at:
- Official UNEP meetings:
  - 26th Meeting of the Parties to the Montreal Protocol (MOP 26), Paris, France, 17-21 November 2014
  - 20th Conference of the Parties (COP 20) and Climate Change conference, Lima, Peru, 1 - 12 December 2014
  - 21st Conference of the Parties (COP 21) in Paris for a global agreement on reduction of GHGs in 2015
  - 27th Meeting of the Parties to the Montreal Protocol (MOP27) in 2015
- Meetings and conferences organised by IIR, UNEP and CSG
- The XVI European Conference, Milan, Italy, 12-13 June 2015
- Major global associations, institutions, GOs, NGOs involved in heating, ventilation, air conditioning and refrigeration (HVAC & R)
- To all operators connected with Centro Studi Galileo (AREA, ASHRAE, AHRI, ABRAVA, ISHRAE, IIAR, EPEE, REHVA, ECSLA, CA)

INTRODUCTION

We now arrive at the fifth edition of the International Special Issue (ISI) which follows the successful previous editions that have been launched at UN Summit Meetings of the Montreal Protocol and Climate Change Convention and delivered to Heads of State and Ministers with the purpose of demonstrating the environmental problems linked to refrigeration and air conditioning.
International Special Issue 2006 was launched at the MOP18 in New Delhi (India) by Mr Rajendra Shende - former UNEP director - together with the Italian Ministry for Foreign Affairs; ISI2008 at the MOP20 in Doha (Qatar) in the presence of the Environment Ministers of Qatar and Kuwait; ISI2010 at the MOP22 in Bangkok (Thailand) in the presence of IIR Director Didier Coulomb, Mr Shende, the Italian Environment Ministry Alessandro Peru and the Nepalese Minister of the Environment; and ISI2012 at the MOP24 in Geneva with Mario Molina, Nobel Prize winner for the discovery of the role of CFCs in ozone depletion.

XVI EUROPEAN CONFERENCE UNEP-IIR-CSG

Centro Studi Galileo, editor of ISI 2014-2015, organise a biennial European conference covering the latest technologies in refrigeration and air conditioning.
The upcoming 16th European Conference will be held at the Politecnico di Milano (University Polytechnic of Milan,

Italy). Participants will include the authors of the various editions of ISI, as well as all of the major international experts in the HVACR sector.
Included among the international associations that cooperate with Centro Studi Galileo and the Associazione dei Tecnici Italiani del Freddo (Association of Italian Technicians of Refrigeration) are:

- AREA (Air Conditioning and Refrigeration European Association),
- AFF (French Association of Refrigeration),
- ASHRAE (American Society of Heating, Refrigeration and Air conditioning Engineers)
- AHRI (Air conditioning, Heating and Refrigeration Institute), and many more which write on this issue.

These associations / institutes are the most important in the refrigeration and air conditioning field and the majority have contributed to this International Special Issue.

IMPORTANCE OF TRAINING

During the conference, knowledge about the latest technologies in Energy Saving and Environmental Safeguards will be disseminated both to experts, companies and operators involved in the production and design process. Of even more importance is the dissemination of this knowledge to the operators who manage the plants and install and repair equipment, as it is paramount that they do so with the required competence.
In order to achieve a positive effect on the Environment, adequate training and information about the latest technological innovations should be available for these operators as they are responsible for the efficient running of the plants and act as the handler and verifier of the correct use of the refrigerants.
Centro Studi Galileo - with the moral support of the United Nations Environment Programme - promote technical meetings for training and information-sharing dedicated to explaining the procedures, equipment and regulations required to reduce the environmental danger.
Each year, Centro Studi Galileo organises approximately 200 technical seminars, training more than 3000 Refrigeration and Air Conditioning Technicians at various training sites and major Universities around Italy (and Europe). The attendees are taught procedures of best practice for maintenance, installation and design, in order to optimize their work and consequently reduce energy efficiency and environmental dangers.
UNEP's OzonAction Programme, in cooperation with AREA / Centro Studi Galileo, have also invited several Presidents and Experts of the ECA network to a training session on strengthening National Refrigeration & Air Conditioning (RAC) Associations.
The objective of the meetings is to share experiences of all aspects of the management of a national RAC association including the recruitment of members, fund raising and providing services.
The meeting is also dedicated to the establishment of training & certification schemes, curriculum development, certification & assessment as well as regulations and networking with international stakeholders. The assessment session in Europe is part of the F-gas regulation and certification of the companies and the relevant personnel involved in installation, maintenance or servicing of the equipment containing fluorinated gases which are strong Greenhouse gases.

IMPORTANCE OF CERTIFICATION

Certification through an assessment is the only way to verify the competence of service technicians handling refrigerants in a proper, safe and reliable manner. In particular, there is a general concern about the safety aspects of non-specifically trained technicians when handling highly flammable hydrocarbons, high pressure CO_2 gases or toxic Ammonia.
RAC applications are also responsible for a sizeable part of the energy consumed globally. AREA is fully aware of the significant energy savings achievable by raising energy efficiency in the RAC sector. Some of these savings could be achieved without major investment in capital equipment and plant refurbishment but with education, good maintenance, implementation of good energy using practices and enforcement of relevant regulations.

●

WHO IS CENTRO STUDI GALILEO

For 40 years, Centro Studi Galileo (CSG) has been organising training courses, seminars and conferences in the field of refrigeration, air conditioning and renewable energy in support of Green Jobs, the Green Economy and the Green New Deal.
Centro Studi Galileo has received the support of the Italian Ministry of the Environment, Foreign Affairs, Economic Development and of the Presidency of the Council of Ministers for these activities.
Centro Studi Galileo, in cooperation with the United Nations Environment Programme, the International Institute of Refrigeration (Paris) and the leading International Association of Refrigeration and Air conditioning (AREA) periodically organises conferences on the latest technologies in the air conditioning and refrigeration industry. During these events, particular importance is given to F-Gas reduction, new alternative refrigerants and systems and new European and International regulations and standards. The International conferences have been organised biennially since 1983.
Centro Studi Galileo also publishes the International Special Issue (ISI) of Industria & Formazione namely ISI 2006, 2008, 2010 and 2012/13. The magazine is published with UNEP and IIR, with an introduction from the UN Under-Secretary General, Achim Steiner, and the Italian Minister of the Environment. ISI has been distributed at the Climate change summits in Bangkok, New Delhi, Cancun and Doha and the summits of the Montreal protocol in Durban, Copenhagen and Geneva. At the summits, ISI was disseminated to the Ministers and Heads of State of the countries participating.

- Centro Studi Galileo has an international presence and also operates in other countries. Centro Studi Galileo is currently working in Africa to provide training for local authorities and through its commitment with UNEP, in South-East Asia with a conference in Sri Lanka and in Iraq establishing a certification scheme through UNEP.
- Centro Studi Galileo collaborates with UNEP for conferences and for the special issue of Industria & Formazione review.
- Mr. Marco Buoni, technical director of Centro Studi Galileo, is the Vice President of the Air conditioning Refrigeration European Association (AREA) and the General Secretary of the Italian Association of Refrigeration (ATF)

The EU F-gas Regulation: making smart choices

BENTE TRANHOLM SCHWARZ, ARNO KASCHL, CORNELIUS RHEIN

Directorate-General for Climate Action – European Commission

The EU F-gas Regulation is expected to greatly influence the business decisions of, in particular, refrigeration and air conditioning equipment manufacturers and operators. The use of HFCs with high climate impacts will become much less common in the future. Smart investments will be required to bring a clear shift towards more climate-friendly refrigerants. Service companies have an important role to play in minimising emissions from installed equipment. They must also get ready to advise on and work with alternative refrigerants, which will open up new business opportunities. Reducing EU emissions is only the first step to a global solution to address this problem effectively. The EU is therefore reaching out to other countries in the world to work together towards a global phasing down of consumption and production of HFCs under the Montreal Protocol.

FIGHTING CLIMATE CHANGE THE SMART WAY

To limit climate change and avoid high costs in the future all major economies will need to make deep emission reductions in the short to medium term. The European Commission has set out a pathway for cutting greenhouse gas emissions in the European Union (EU) by 80-95% below 1990 levels by 2050 at the lowest costs. This will require reductions in all sectors. Reducing F-gas emissions is part of this comprehensive climate strategy.

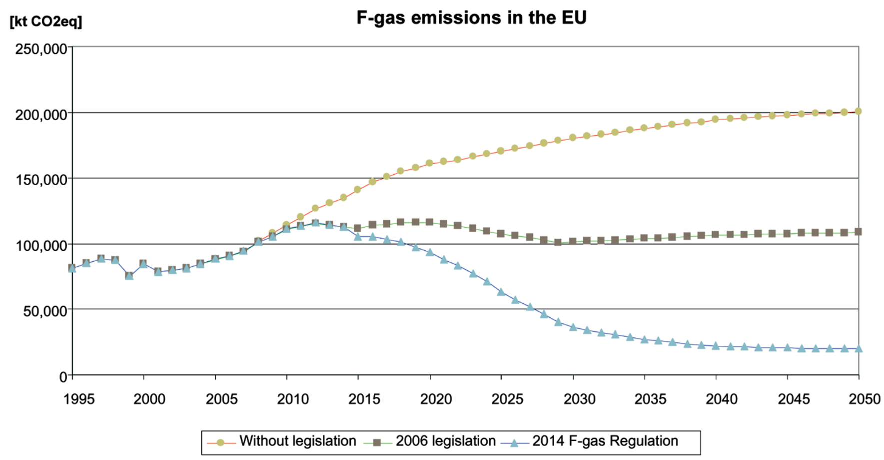
The European Union adopted a reinforced F-gas Regulation in 2014. It builds on legislation from 2006 that were already expected to halve F-gas emissions (HFCs, PFCs and SF6) in the EU compared to a business-as-usual scenario. The new Regulation will further cut emissions by two-thirds in 2030 from today's levels (see figure 1).

However, globally the climate impact of HFC emissions is still growing (UNEP, 2011). As illustrated in calculations by the Montreal Protocol`s Technical and Economic Assessment Panel (TEAP 2014), production and use of HFCs is expected to rise significantly in the coming decades if no measures are taken, mainly due to replacement of ozone depleting substances as well as higher living standards and the subsequent increase in the use of refrigeration and air conditioning.

Yet given that more climate-friendly and safe alternatives already exist for many types of appliances where HFCs with high global warming potential are used today, the expected growth in the climate impact of HFCs can still be avoided. Moreover, choosing more climate-friendly technologies is not necessarily more costly, particularly considering the important energy efficiency gains that can be made. In fact, reducing emissions from F-gases is one of the easiest and cheapest ways to fight climate change. However, this will not happen by itself; actions such as regulatory measures are needed to promote climate-friendly technologies.

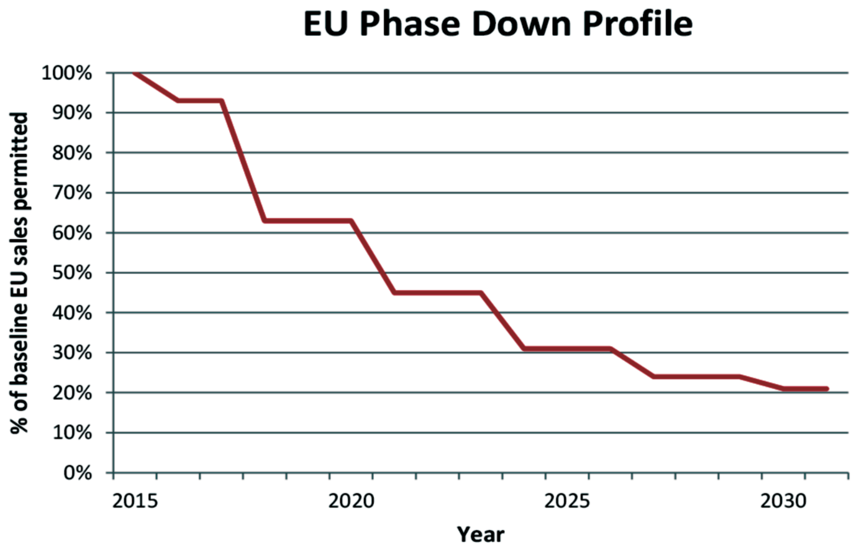
The European Union is encouraging other countries to take similar measures. It also encourages all Parties to the *Montreal Protocol on Ozone*

Figure 1.
Expected impact of legislation on F-gas emissions in the EU
Source: Schwarz et al. (2011)



Depleting Substances to support a global reduction of HFC production and consumption. Due to the similarities between the ozone depleting substances (CFCs and HCFCs) and HFCs, which were developed as their substitutes, the *Montreal Protocol* already has the mechanisms and institutions to take effective action also on HFCs. For the same reason, it presents the most cost-efficient way to effectively address the negative climate impacts of these gases by reducing their use and production. The Montreal Protocol and the *United Nations Framework Convention on Climate Change* (UNFCCC) should be mutually supportive in dealing with HFCs.
By acting now we can avoid that the large-scale replacement of HCFCs in developing countries in the coming years will result in an unnecessary growth in the use of highly warming climate gases. Avoiding this problem is clearly smarter and cheaper than having to solve it at a later point in time or having to require steeper emission reductions from other industrial sectors at higher costs.

Figure 2.
Phase-down profile for permitted EU sales of HFCs as percentage of average annual sales in the period 2009-2012 (in CO_2 equivalent).



PROMOTING CLIMATE-FRIENDLY REFRIGERANTS THROUGH THE EU HFC PHASE-DOWN

The main driver in achieving further emission reduction is the so-called “HFC phase-down”. The phase-down implies that the total amount of HFCs sold (placed on the market for the first time) in the EU must be reduced over time in terms of its global climate impact (measured in CO2 equivalents). The restriction of overall sales is not sector specific but applies to the whole HFC market, leaving flexibility to the market players to reduce the climate impact where least costly. By 2030, the climate impact of HFCs placed on the EU market must be reduced to almost one fifth of today’s level (see figure 2).
To safeguard the overall phase-down limit, the European Commission will set individual HFC quota limits for each producer and importer of HFCs each year. From 2015, producers and importers will only be able to sell HFCs in the EU if they have sufficient quota rights to do so. The quotas concern only the sales of the gas in bulk. For HFCs contained in refrigeration, air conditioning and heat pump equipment, manufacturers must from 2017 ensure that the respective gas quantities are covered by the phase-down. Importers can for instance obtain authorisations from importers and producers of bulk gases ensuring that the gas inside the equipment is within a quota.
It is important to understand the impact of using CO_2 equivalents as measurement unit for the quota limits. The global warming potential (GWP) expresses the impact of a substance on global warming over a 100 year period compared to that of the same quantity of CO_2. The various HFCs have different impacts and, consequently, different GWPs (see table 1 below). The overall climate impact of the HFCs sold in the EU is then calculated by multiplying the quantity by weight of each HFC sold with its particular GWP and subsequently summing up the results.
If in a given year a gas importer has a quota of 1 million tons CO_2 equivalent and assuming for simplicity that the importer choses to sell only one type of refrigerant, the importer may legally sell 1 million tons divided by the GWP of this HFC refrigerant. This would roughly equal a limit of 255 t of R404a, 700 t of R-134a or 1.480 t of R32. In other words, the higher the GWP of the chosen refrigerants, the lower the quantity a producer or importer is allowed to sell. Normally, when supply is getting scarce, prices can be expected to rise. The phase-down is therefore likely to affect prices of higher GWP-substances more strongly. On the other hand, if a refrigerant is not covered by the phase-down, their supply is not restricted at all. Consequently, HFCs with lower GWP and, notably, non-HFC refrigerants will become a smarter choice for manufacturers and operators of equipment.
All the gases covered by the phase-down and their respective GWPs are listed in Annex 1 (Section 1) of the F-gas Regulation. Mixtures containing any of those gases are also covered by the phase-down.
Furthermore, the F-gas Regulation includes a number of bans on selling new equipment with F-gases in the EU, such as certain refrigerators and freezers in private homes and supermarkets as well as small air conditioning units, foams and aerosols. By including a definite endpoint for the use of high GWP F-gases in the sectors where bans have been introduced, the use of F-gases in other sectors where replacement is more difficult is facilitated, since the available quantities under the phase-down regime can be re-directed to these sectors.
Care has been taken to avoid that existing equipment or products become redundant under the new Regulation. Nevertheless, there are still measures aiming to reduce emissions from such equipment. The use of high GWP sub-

Table 1.
GWPs of selected refrigerants and relation to the HFC phase-down.

Refrigerant	GWP	Phase down relevant?
R507	3985	Yes
R404a	3922	Yes
R410a	2088	Yes
R407a	2107	Yes
R134a	1430	Yes
R32	675	Yes
HFC1234yf	4	No
Hydrocarbons	3-5	No
CO_2	1	No
Ammonia	0	No

Table 2.
Translating CO_2 eq.-based limits for leak checking intervals into metric limits.

		Charge limits in tons of CO_2 eq.		
		5	50	500
Refrigerant	GWP	Charge limits in weight (kg)		
R507	3985	1.25	12.55	125.47
R404a	3922	1.27	12.75	127.5
R407a	2107	2.37	23.73	237.30
R410a	2088	2.39	23.95	239.46
R407f	1825	2.74	27.40	273.97
R134a	1430	3.50	34.96	349.65
R32	675	7.41	74.07	740.74

stances (GWP>2500) in the servicing of larger refrigeration equipment is prohibited from 2020 (while allowing the use of recycled or reclaimed gases). This measure was included after voluntary action by supermarkets, in particular in the UK, had shown that high GWP refrigerants such as R-404a and R-507a can be replaced relatively easily with refrigerants (such as R-407f) that have significantly lower GWP and bring significant energy efficiency gains. Experience shows that associated costs for typical supermarket equipment can be recovered in 2 years.

Building on the 2006 F-gas Regulation, F-gas emissions from existing equipment can be prevented by measures such as specific requirements to check for leaks, proper servicing, mandatory training and certification, as well as recovery of the gases at the end of the equipment's life. To a large extent the new Regulation consolidates and clarifies existing obligations in this area. The relevant certification and training schemes for service companies and personnel that have been established all over the EU should now bear fruit and lead to significant emission savings.

Requirements to contain emissions become more stringent depending on the equipment containing more than 5, 50 or 500 tons of CO_2 equivalent. A move away from the metric weight limits in the 2006 Regulation towards CO_2 equivalent based limits ensures that obligations are better targeted on equipment that risks having the highest impact on the climate. Also, it further rewards those operators who choose to invest in equipment using lower GWP refrigerants. By way of example, equipment using only 1.4 kg of R404a would exceed the 5t CO_2 equivalent limit and would therefore need to be leak checked yearly, while a piece of equipment using 7.3kg of R32 would still be under the 5t CO_2 equivalent limit and therefore would not need any mandatory leak checking.

Service personnel have a crucial role to play in helping operators comply with obligations related to existing equipment. They must be knowledgeable about the differences in the legal requirements depending on the type of refrigerant in order to provide sound advice to operators of equipment.

CHOOSING THE SMARTEST REFRIGERANT

The EU HFC phase-down was designed in a way that it could be achieved by state-of the art technologies already available on the market in 2010; technologies that are safe and are at least as energy efficient as conventional HFC equipment (Schwarz et al., 2011). Technological progress has continued and new additional alternatives are already becoming available (Clodic et al. 2013, SKM Enviros 2013). The phase-down will drive manufacturers of equipment to focus their innovation and production on solutions using refrigerants with the lowest GWP, or using refrigerants which are not restricted by the phase-down. Needless to say, an alternative is only suitable if it is energy efficient and safe. In the EU, legislation is in place to ensure both energy efficiency and safety of use.

With increased deployment of equipment using climate-friendly alternatives, service companies also need to be prepared to install and service such appliances. They should ensure their personnel are equipped and well trained to deal with systems based on CO_2, ammonia and hydrocarbons and can provide sound advice to operators about the advantages to shift to more climate-friendly alternatives.

Equipment users investing in new equipment should take into account both the effects of the increasing scarcity of higher GWP refrigerants, the service ban and the stricter service and maintenance obligations linked to such refrigerants. In general, the smart choice will be energy efficient and safe equipment with a refrigerant not covered by the HFC phase-down or an HFC with a relatively low GWP.

The new F-gas Regulation is expected to stimulate innovation by encouraging the use of green technologies. Higher demand will facilitate large-scale production of such equipment and result in better and cheaper climate-friendly solutions. This in turn is expected to make the transition towards climate-friendly alternatives to HCFCs easier and cheaper also in the rest of the world.

For more information see the European Commission website
http://ec.europa.eu/clima/policies/f-gas/index_en.htm

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Certification in the safe and efficient use of alternative refrigerants

Importance of Competence on Alternative Refrigerants - Importance of Certification in Servicing Refrigeration and Air Conditioning Equipment

PER JONASSON[1], MARCO BUONI[2]

[1]President of AREA (Air conditioning and Refrigeration European Association)
[2]VicePresident of AREA

ABSTRACT - INTRODUCTION

The global phasing out of CFCs-HCFs and future phase-down of HFCs (a 79% reduction by 2030 in Europe alone) will lead to a higher usage of alternative / low GWP refrigerants. Issues relating to low GWP refrigerants – which include safety, flammability, toxicity and high pressure – will need to be properly considered when handling such refrigerants. AREA has issued two guidance documents on the use of Low GWP refrigerants and recommends minimum requirements for the training and certification of contractors handling low GWP refrigerants to worldwide and European decision-makers.
Members of AREA (Air conditioning and Refrigeration European Association) are contractors who design, install, service, maintain, repair and decommission refrigeration, air conditioning and heat pump (RACHP) systems.
RACHP contractors operate with complete objectivity with regards to the use of equipment and refrigerants, using both synthetic and natural fluids. RACHP contractors operate with the sole aim of ensuring the highest level of reliability, energy efficiency and cost-effectiveness for their customers.
It is not AREA's intention to create a new certification scheme – but rather to add specific modules to the existing EU HFCs certification scheme based on Regulation (EC) N. 303/2008 which is successfully in place in EU Member States. While HFC certification will be the basis for every contractor who wants to handle any type of refrigerant, each additional module will focus on the specificities of the respective low GWP refrigerant (i.e. Hydrocarbons – Flammability).

CHAPTER 1. ANALYSIS OF THE NEED FOR SKILLS IN ALTERNATIVE REFRIGERANTS IN EUROPEAN COUNTRIES[1]

The proposed revisions to the EU's F Gas regulations – now due to be introduced on 1st January 2015 (see Appendix 1) – will phase down the availability of high Global Warming Potential (GWP) HFC refrigerants and ban their use in certain applications. This will lead to a rapid increase in the use of natural refrigerants such as ammonia, hydrocarbons, carbon dioxide and emerging HFOs and HFO blends. These refrigerants are different to HFC refrigerants, since they are either toxic, (slightly) flammable or operate at high pressures and temperatures.
The REAL Alternatives programme (which is part of the EU Leonardo lifelong learning programme for vocational education) has been set up with the aim of developing new blended learning material for European training providers to meet the need to address skills shortages and share resources in this area.

Potential use and status of alternative refrigerants

It is likely that the revised F Gas regulations will drive the use of alternative refrigerants – mainly hydrocarbons, ammonia, CO_2 and HFOs. However, each has limitations. For some current HFC applications, alternative solutions are not readily available and low flammable blends and HFOs are best proposed as a possible future development.

The Survey identifying the skills gap in using alternative refrigerants

A survey addressed the needs of the following target groups: Large companies, Contractors, Manufacturers, Educators and SME/Micro-Businesses. The questions focused on the needs for skills and training in each of the target areas.
The survey was distributed by each of the partner organisations to national stakeholders as well as through AREA, which has members operating throughout Europe. In total 104 stakeholders responded to the questionnaire.
The key conclusions are as follows:
- There is a general lack of preparedness for all refrigerants and particularly there is a large proportion of the industry with little knowledge on natural refrigerants i.e. Ammonia, HFOs and CO_2. There is a reasonable amount of training available in HC but poor take up and concerns about safety are high.
- The biggest technical issues that need to be addressed include the availability of skills, containment of the alternative refrigerants, system

[1]London South Bank University
Real Alternatives - Research and Needs Analysis Report – April 2014 www.realalternatives.eu

reliability and safety.
- There is demand for a mix of e-learning and external training provision i.e. blended learning.
- It is essential that individuals are tested on completion of their training.
- There is strong support from stakeholders and certified companies to share and contribute to a pan-European project.

CHAPTER 2. TRAINING & CERTIFICATION IN EUROPE[2]

Article 10 of the new F Gas Regulation (EU) No 517/2014 on fluorinated greenhouse gases.

The training and certification regarding equipment containing fluorinated greenhouse gases will mostly remain as they have been since the adoption of Regulation (EC) 842/2006 and the Commission Regulations (EC) No 303/2008 and 307/2008, which is working well in most EU Member States. However, some new requirements are introduced.

Who needs to be certified?

A - Natural persons (i.e. personnel) carrying out certain tasks on certain types of equipment must be certified or qualified.

Relevant equipment

- Stationary refrigeration, air conditioning and heat pump
- New! Refrigerated trucks (above 3.5 t) and trailers
- Air conditioning equipment in road vehicles within the scope of Directive 2006/40/EC on mobile air conditioning (recovery operations only)
- New! Air conditioning equipment in road vehicles outside the scope of Directive 2006/40/EC on mobile air conditioning (recovery operations only)

Member States can adopt further certification and training programmes on other types of equipment.

Tasks

a) Installation, servicing, maintenance
b) Repair
c) New! Decommissioning
d) Leakage checking
e) Recovery

[2]AREA F-Gas GUIDE – October 2014

For tasks a) to e) on stationary equipment and on refrigerated trucks and trailers, personnel must be certified.
For tasks e)
- *On air conditioning equipment in road vehicles within the scope of Directive 2006/40/EC* on mobile air conditioning, personnel must be appropriately qualified, i.e. hold at least a training attestation.
  Member States must ensure that training programmes are available.
- *On air conditioning equipment in road vehicles outside the scope of Directive 2006/40/EC* on mobile air conditioning, personnel must be appropriately qualified, but a training attestation is not required.

B - Undertakings (i.e. companies, but also self-employed contractors) carrying out certain tasks on certain types of equipment for other parties must be certified.

Relevant equipment

- Stationary refrigeration, air conditioning and heat pump

Member States can adopt further certification and training programmes on other types of equipment.

Tasks

- Installation, servicing, maintenance
- Repair
- *New!* Decommissioning

Equipment users must take reasonable steps to ascertain that the undertaking performing the abovementioned tasks holds the necessary certificate.

What happens to existing certificates and training attestations?

Certificates and training attestations issued before the new Regulation's application will remain valid in accordance with the conditions under which they were originally issued.

Alternative refrigerants & technologies

Although the new Regulation does not name the alternative refrigerants, Ammonia (NH_3), Carbone Dioxide (CO_2), Hydrocarbons (HCs) and Hydrofluoroolefine (HFOs) are the main fluids affected. It is expected that the combination of the phase-down and the planned bans will result in an increase in use of alternative refrigerants and technologies to HFCs. The new Regulation therefore provides for minimum information to be given to certified contractors. Such information is related to the technologies themselves, safety aspects and regulatory requirements. One must differentiate between information provided during the training or certification process and to certified operatives.

Certification and training programmes must now include information on relevant technologies to replace or reduce

Summary of certification requirements

	Installation, servicing, maintenance	Repair	Decommissioning	Leakage checking	Recovery
Stationary RACHP equipment					
Refrigerated trucks & trailers					
A/C in road vehicles Directive 2006/40					(1)
A/C in road vehicles (not included in Directive 2006/40)					(2)

Company Natural person
(1) Personnel must be appropriately qualified, i.e. hold at least a training attestation
(2) Personnel must be appropriately qualified, no formal training attestation required

the use of fluorinated greenhouse gases and their safe handling.
Certified operatives must have access to information on:

- Relevant technologies to replace or reduce the use of fluorinated greenhouse gases and their safe handling, and
- Existing regulatory requirements for working with equipment containing alternative refrigerants

CHAPTER 3. GUIDANCE ON MINIMUM REQUIREMENTS FOR CONTRACTORS' TRAINING & CERTIFICATION ON ALTERNATIVE REFRIGERANTS[3]

Minimum requirements for training and training facilities

Training is important and it is the only method to transfer to the contractor the knowledge to install, maintain and repair RACHP systems containing alternative refrigerants considering both the technical and safety issues.
Additional training may be required to achieve the mandatory certification. Training should be both theoretical and practical. For the training facilities AREA suggests that test rigs, equipment and components related to each alternative refrigerant are recommended to simulate best practices.
Access requirements: the candidate should have attended Basic Refrigeration Training (ex. F-Gas minimum requirements training).

Minimum requirements for certification and certification schemes

AREA suggests that certification should be made mandatory. Each candidate who wants to handle alternative refrigerants should hold a certificate which is assessed to the requirements of 303/08 and should take part in an assessment specifically for the alternative refrigerant they wish to handle. The brazing qualification required for low GWP refrigerants should be acceptable under the Pressure Equipment Directive and vice versa.
The table on the right lists the minimum competences which the candidate should have to obtain the certification specific to each alternative refrigerant.

[3]AREA Guideline: Low GWP Refrigerants October 2012

Minimum Requirements listed for the specific module HC – NH_3 – CO_2 – HFO*

	HC	NH_3	CO_2
BASIC THERMODYNAMICS AND PHYSICS			
Thermodynamic properties of low GWP refrigerant: temperature, pressure, density, thermal capacity, p/h diagram	T	T	T
Differences between low GWP refrigerants and HFCs	T	T	T
Toxicity characteristics, grades and limits for the human body	---------------	T	T
Characteristic of flammability of the substances, velocity of propagation, LFL, UFL, occupancy	T	T	---------------
Specific components for that refrigerant in the refrigeration cycle	T	T	T
Material compatibility	---------------	T	T[4]
Oil compatibility, requirements and oil return	T	T	T
REGULATIONS AND STANDARDS			
Knowledge of European and national regulations and standards	T	T	T
Storage of the refrigerant	T	T	T
Transportation of the refrigerant	T	T	T
Describe the process for handing over system to customer, completing and passing on appropriate commissioning documentation[6]	P	P	P
GOOD PRACTICE[5]			
Identify typical application of low GWP refrigerant RACHP systems[6] (refer to AREA: Low GWP Refrigerants Guidance)	P	P	P
State and identify the commonly used refrigerants' designation[6]	P	P	P
State the requirements for safely labelling low GWP refrigerant RACHP systems[6]	P	P	P
Select appropriate tools, equipment and PPE for work on low GWP RACHP systems[6]	P	P	P
Recovery of the refrigerant	P	P[7]	P[8]
Venting the refrigerant in a safe way (according to national legislation)	P	P	P
Calculate the safe fill weight for the recovery cylinder (density difference between HFCs and low GWP refrigerants) [6]	P	P	P
Leak check direct assessment with the correct equipment	P	P	P
Make vacuum of the refrigerant preventing moisture in the system and without refrigerant emissions	P	P	P
Make charge of the refrigerant with no emission relief	P	P	P
Make a connection without brazing with alternative connections	P	P	P
Check the correct functioning of the safety ventilation system		P	P
Check the correct functioning of the safety system controls	P	P	P
HEALTH AND SAFETY REQUIREMENTS			
Safe system shutdown and isolation [6]	P	P	P
Extinguish a fire, identify the appropriate fire extinguisher	P	P	---------------
First aid treatment for frostbite	P	P	P
First aid treatment for fire burn	P	P	---------------
First aid treatment for suffocation due to breathing problems	---------------	P	P
Safety issues related to high pressures	---------------	---------------	P
Calculate LFL (confined space)	T	T	---------------
Calculate confined space risk for asphyxiation (heavier than air)	T	---------------	T
Check that Health and Safety rules in the refrigeration system location are respected (emergency exits, fire alarms, leak detectors...)	T	T	T
Correct use of Personal Protective Equipment	P	P	P

I = theoretical / P = pratical

**HFO1234yf: same minimum requirements as Hydrocarbons*

**HFO1234ze: same minimum requirements as HFCs*

[4]For high pressures
[5]All practical trainings should include theoretical training
[6]City and Guilds, Level 2 and Level 3 Refrigeration and Air Conditioning CPD Pathways, March 2012 v1.0
[7]It is normally accepted to vent hydrocarbons with low charges (please refer to national legislation)
[8]It is normally accepted to vent CO_2 (please refer to national legislation)

F Gas Training and Assessment in the UK and Qualifications for Low GWP Refrigerants

KELVIN KELLY
Business Edge

F-gas certification session in Casale Monferrato: from the left Halvart Koppen (UNEP) and Kelvin Kelly.

With the new updated F Gas Regulations (EC Reg 517) coming into force on the 1st January 2015 and with it the quite rapid phase down of HFC Refrigerants, there will be in turn, a increase in the use of low GWP Refrigerants. The publication of the revised of the F Gas Regulations indicate that as of July 2011 (when all personnel were required to be assessed to the new qualifications) that the number of personnel subject to certification requirements were; 19,500 and out of that number 15,584 have become fully certified, this equates to 79.9%.

In real terms we feel that this is rather optimistic. We have been in contact with many organisations that have multiple members of staff that have yet to attend a certification course. Indeed many organisation have only completed 50-60% of their staff due many factors including, reluctance on the part of the individual and or company, Cost (both financial and time) and lack of policing. Certain sectors of the Industry have even less success with regard to the adoption of the scheme, particularly in the Domestic and Small Commercial Refrigeration, some of this is down to the fact that a large number of these systems utilise non Fluorinated Refrigerants.

Has the F Gas Training and Assessment Qualification been a success within the UK?

To a degree. On a positive note many Training Centres have seen a large number of candidates successfully complete the assessment process and gain their qualification to comply with the regulation. However, to a degree we have been "preaching to the converted", as the majority of the engineers attending the courses over the last 3.5 years have been "upgrading" from the previous UK voluntary Refrigerant Safe Handling qualification, therefore most of those who attended were familiar with the assessment process and prepared for what was required of them.

The feedback from the attendees of these courses has always been positive; many have stated that they felt that the Training and Assessment process was very worthwhile and that they now understand the obligations under the F Gas Regulations and what needs to be implemented on their part to ensure that their customers are compliant.

It would appear that the number of installations and equipment that have been worked on in accordance with the F Gas Regulations over the last four years are few and far between, leaving Operators open to prosecution. This will obviously improve as time goes on and more engineers are made aware of the legislation and their obligations.

What has been well publicised is the overall lack of uptake with regard to the opportunity to undertake the Assessment prior to the 4th of July deadline and this may be down to several reasons:

- The economic downturn within the UK.
- Leaving it to the last moment.
- Simply not wanting to undertake the training and assessment.
- Not believing that the regulations would be "Policed".
- Difficulty in booking a place on a course.
- Fear of failure.

Within the UK there are two Awarding Bodies that have been approved to issue Certificates to individuals (ConstructionSkills and City and Guilds) these awarding bodies have been asked by The Department for the Environment, Farming and Rural Affairs (the Governmental Department given responsibility for "Policing" the regulations with the UK) to try and ensure that there are sufficient numbers of Centres to facilitate the number of assessments required.

This has in turn led to an increase in organisations offering F Gas training and Assessment courses. It appears however that the multitude of these centres have had relatively few candidates attend and complete the process. I would imagine that this is due to the fact that although the centre may have the facilities, equipment and infrastructure to carry out F Gas courses, they are finding it difficult to find suitably qualified, experienced instructors and assessors to carry them out.

It is difficult to quantify how many engineers have been unable or unwilling to undertake the assessment process before the deadline as there appears to be some confusion on exactly how many people employed in the industry require certification; however what is not disputed is that a large number did not achieve the required standard in time and are therefore working illegally at this time.

What should be done regarding the enforcing of the Regulations?

By the 4th July 2011 Individuals and Companies carrying out activities covered under the F Gas Regulations MUST have obtained individual and company certification. Statutory Instrument Environmental Protection. Within the UK the Fluorinated Greenhouse Gases Regulations 2009 very clearly defines the enforcement, offences and penalties that should be implemented for failure to comply with the F Gas Regulations. This regulation states that failure to comply could result in penalties, court action, imprisonment etc. The "Authorised Persons" nominated to implement the Regulation have been given significant powers to "Police" it, including:

- Right of access to premises and materials
- Right to take possession of any relevant article or substance.
- Issuing of Information notices.
- Issuing of enforcement and prohibition notices.

Business Edge feels that if the F Gas Regulations are to be taken seriously they should be fully implemented. This has been ongoing as DEFRA are targeting organisations on a "risk basis" i.e. the major users of Fluorinated Greenhouse gases, to ensure compliance. With regard to the Individual and Company Certification requirement, DEFRA have contacted all approved Training and Assessment Centres in the UK to request details of Individuals and Companies that have successfully attended a suitable Assessment Course.

It is therefore important that companies and individuals are encouraged to undertake the Training and Assessment process, even though it is after the deadline date. The changes to the F gas Regulations show that they are not going to go away.

The Department of the Environment (UK Authorised Persons) have subsequently changed their approach to the policing of the F Gas Regulations. Previously their methods have been more about informing organisations of their responsibilities and not enforcing. This year things have changed and the Department for the Environment have many legal cases pending at the time of writing this article. Indeed they tell us that they will be adopting a "name and shame' approach, this means that any persons or organisations found to be in non compliance of the F Gas Regulations will be publicised to show everyone what the potential consequences could be. Indeed, we have had individuals sent to us for assessment by the Department for the Environment because they failed to do so voluntarily.

As previously mentioned some of the individuals and organisations that have not yet complied with the F Gas Regulations have not done so due to misconception and the fact that they predominantly work on "Natural" or low GWP Refrigerants such as Hydrocarbons and CO_2. The main confusion that has resulted in noncompliance is the "3kg rule". A great many people have either been misinformed or wrongly interpreted the F Gas Regulations and believe that if they work on systems with less than 3kg then they are exempt. This is obviously not correct as persons working on any size system containing Fluorinated Refrigerants need to be certified and service and maintain the systems in accordance with the F Gas Regulations and EN378. This situation could get further confused in 2015 with regard to adoption of CO_2 GWP equivalent in place of refrigerant mass.

The increased use in refrigerants that are better for the environment but potentially more hazardous to persons using them has led to the introduction of voluntary certification schemes for these refrigerants.

Training in Low GWP Refrigerants

The only disappointment to come out of the revised F Gas Regulations was that mandatory certification on alternative refrigerants was not included. With the growing use of low GWP Refrigerants, one of the main concerns is the increased risk with these predominantly flammable refrigerants and the lack of training and awareness within the industry. One of the F Gas Certification Bodies, City and Guilds has launched in the UK additional Training and Assessment Modules aimed at personnel that Install and Maintain Refrigeration, Air Conditioning and Heat Pump Systems with particular emphasis on Low GWP Refrigerants.

The Modules include:

- Brazing Techniques for Refrigeration, Air Conditioning and Heat Pump Systems.
- Understand and apply Hydrocarbon System, Installation, testing, Servicing and Maintenance Techniques.
- Understanding Hydrocarbon System, Installation, testing, Servicing and Maintenance Techniques.
- Understand Hydrocarbon System, Design, Installation, Com-missioning, Servicing and Maintenance Techniques.
- Understanding CO_2 System Installation and Commissioning Techniques.
- Understanding CO_2 System Service and Maintenance Techniques.
- Install and Commission CO_2 Air Conditioning and Refrigeration Systems.
- Service and Maintain CO_2 Air Conditioning and Refrigeration Systems.
- Understand Ammonia Refrigeration System Installation and Commissioning techniques.
- Understand Ammonia Refrigeration System Installation and Commissioning techniques.
- Install and Commission Ammonia Refrigeration Systems.
- Service and Maintain Ammonia Refrigeration Systems.

These qualifications are either QCF Level 2 or 3 (Brazing and Hydrocarbon modules are Level 2) and require between 4 and 100 guided learning hours. Some therefore only require the candidate to have an understanding (theoretical) of the subject through to a though Training and Assessment process.

The principle running through all modules is Health and Safety, ie ensuring that all operators of equipment using these aforementioned refrigerants can do so with minimum risk to all persons in the area as well as themselves. For example the Hydrocarbon element requires attendees to enable them to prove:

An understanding of the hazards of HC Refrigerants.

Standards and regulations covering HC usage and the impact they have for example on charge size.

How system varies when using flammable refrigerants.

How to safely service and maintain HC systems, including a calculation for the safe fill weight of recovery cylinders.

Practical elements covered within the module include:

Preparation of a Risk Assessment.

Selection and use of appropriate safety equipment.

Recovery of Hydrocarbon Refrigerants.

De-Brazing and component replacement.

Pressure Strength and Tightness Testing.

Evacuation. Charging HC Refrigerants.

Sealing of the systems. Leak testing.

Checking the systems performance and efficiency.

International E- Learning on Alternative Refrigerants

Another interesting source of information and training on Alternative Refrigerants will be the new European learning programme "REAL Alternatives" that will address skills shortages amongst technicians working in the refrigeration, air conditioning and heat pump sector. The focus will be on carbon dioxide, ammonia, hydrocarbon and HFO refrigerants. It will improve knowledge in the service and maintenance of these refrigerants in new systems from the point of view of safety, efficiency, reliability and containment.

Delivered through innovative blended learning - a mix of e-learning, face-to-face training materials, practical exercises, assessments and an e-library of learning resources - the programme will bring together industry knowledge and expertise from across Europe. REAL Alternatives will also build on the established REAL Skills Europe & REAL Zero containment approaches.

For further information please visit www.realalternatives.eu

real europe alternatives

New refrigerants and refrigerant management for refrigeration and air-conditioning

– Current situation in Japan and future aspect –

NOBORU KAGAWA

School of Systems Engineering, Department of Mechanical Systems Engineering, National Defense Academy
Executive Committee, Managing Committee, International Institute of Refrigeration

Refrigeration, air-conditioning and heat pump systems are very important for the civilized society. However, discharged fluorocarbon refrigerants from these systems and exhausted carbon dioxide during operating these systems are related to serious environmental problems. For alleviating this problem, new refrigerants with lower GWP and higher cycle performance must be used. In this article, Japanese current status and some of future aspects of the refrigerants for refrigeration, air-conditioning, and heat pump systems are introduced. To operate these systems and to use the refrigerants effectively, new systems with natural refrigerant, those with new refrigerant, and also total refrigerant managing system must be developed globally.

TREND OF JAPANESE GOVERNMENT AND ADMINISTRATION

To alleviate the ozone layer depletion problem (the objective of the Montreal Protocol)[1], the transition of CFC and HCFC to HFC in refrigeration and air-conditioning, (A/C) systems leads the rapid increase of the release of HFC into the atmosphere as shown in Fig. 1[2]. Japanese government introduced various measures, but the refrigerant recovery rate including CFC and HCFC keeps around 30%. There is a large amount of leakage from refrigeration and A/C systems during operation, maintenance service and recovery processes (Fig. 2[3]). In March 2013, the joint meeting of Ministry of Economy, Trade and Industry, METI and Ministry of the Environment, MoE completed and published "The Report of Policy to Reduce Fluorocarbon Emission". The new fluorocarbon bill was submitted to the ordinary session of Japanese Diet in April 2013. In June 2013, the bill passed the ordinary session, and published. The new law will be fully implemented in 2015. Considering the recent trend of Japan and European countries (e.g., Regulation No. 517/2014), actions to strengthen related regulations must be carried out globally. A comprehensive countermeasure to cover the entire life-cycle of fluorocarbon, urge the stakeholders to comply with the regulation at various stages. For example, fluorocarbon producers/importers must plan reduction of producing/importing the fluorocarbons by alternatives and recycle. Producers/importers that use these fluorocarbons in their products (refrigeration and A/C) including heat pumps should shift to zero ODP and low GWP refrigerants for each product (Fig. 3) before the targeted year.

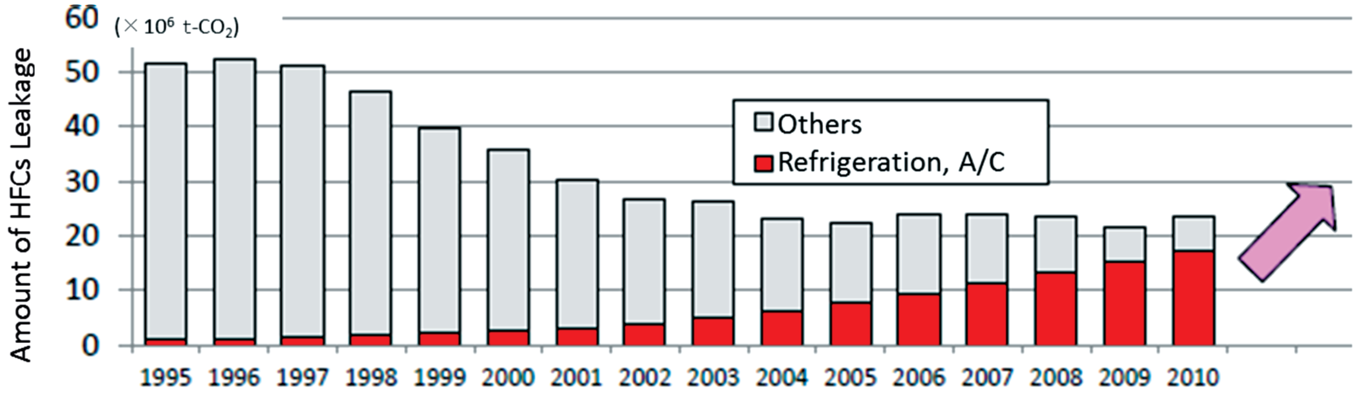
Refrigeration and A/C equipment users must periodically inspect their equipment to prevent the leakage, and report/disclose the annual leakage. Registered companies can only recycle the refrigerants, and also permitted companies can destroy the refrigerants. These companies should be issued the recycle/destroy certification registered company/organization. The stock and leakage amounts of refrigerants as arranged in Fig. 2 are also very important information to know situation more exactly and to make the countermeasure effectively

JSRAE REFRIGERANT MANAGEMENT WORKING

In May 2009, Momoki Katakura, the former president of Japan Society of Refrigerating and Air Conditioning Engineers (JSRAE). He has believed that it is important for the industry to tackle the refrigerant management, and initiated "JSRAE policy: Structure reform of countermeasures for the prevention of refrigerant leak"[4]. It was necessary to establish the proper countermeasure for the fluorocarbon industry, and responsible use of the fluorocarbons by establishing a refrigerant management system. A council was organized in order to achieve a win-win solution for the all stakeholders.

The main studied items as described in Fig.4, which were discussed under several working groups of the council until March 2012, were focused on : refrigerant distribution, management system, preparation for the regulations and proposal to the administrations, the increased cost due to strengthen management, an economical system, challenges and measures in each refrigerant distribution segment.

Figure 1.
Trend of HFCs leakage in Japan

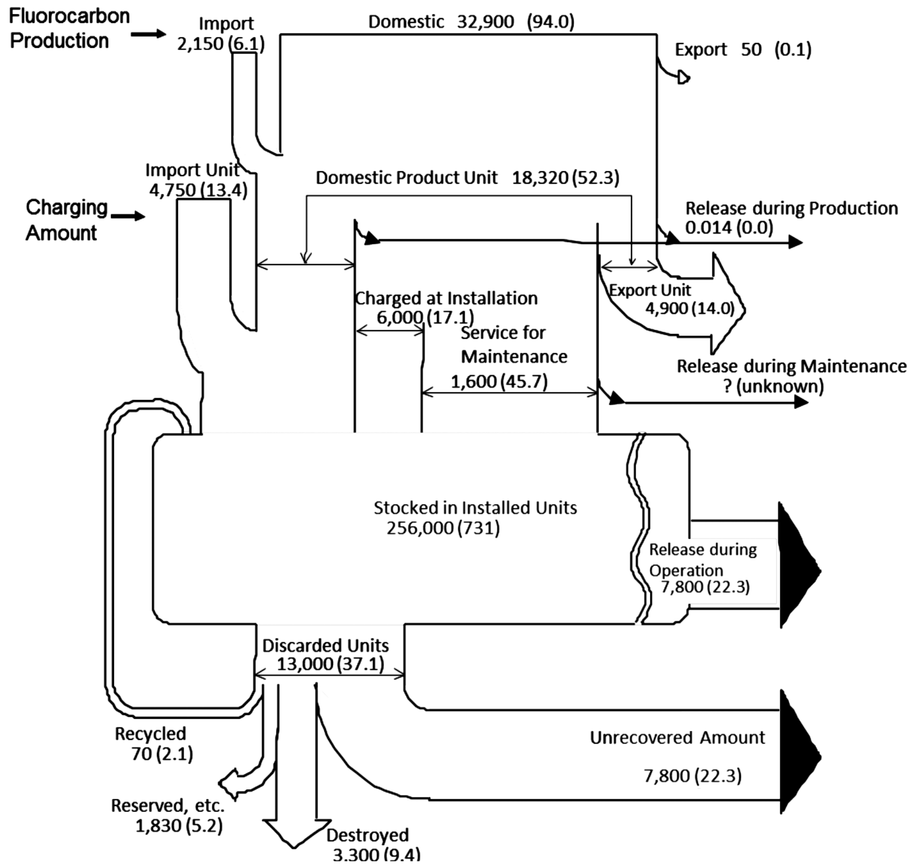


After the discussion, the proposed items were presented to Japanese government and to the public.
The proposal report by JSRAE can be downloaded from JSRAE Website (http://www.jsrae.or.jp/info/Proposal%20for%20refrigerants%20management_201304.pdf, in Japanese)

Discussed and proposed items:

1. Scheme of Refrigerant Management System
   (a) Introduce internet technology total management system into the entire refrigerant distribution channel
   (b) An unified body to manage the whole process
   (c) Details of organization and workflow of the management body
2. Financial scheme of the refrigerant management body
   (a) Financial source for the organization operation and refrigerant management.
   (b) Defrayer who bears the cost of refrigerant management.
3. Codes and Regulations
   (a) Propose the boundary of the code/regulation
   (b) Clarify the responsibility of management and emission reduction
   (c) Mandatory the system and organization by law
   (d) Inspection, direct, expose and reward
4. Import, produce, transportation of fluorocarbons
   (a) Prehension the refrigerant distribution amount (Fig. 2[3])
   (b) Prehension the imported refrigerant, prevent the smuggling, and ensure the quality.

Figure 2.
Flow of refrigerants for refrigeration and A/VC in 2008
Numbers mean refrigerant amounts (ton), Numbers in parentheses mean ratio to net refrigerant amounts (= domestic refrigerant production + import _ export)



   (c) Management system of refrigerant vessel
5. Equipment using refrigerant
   (a) Propose the technical guideline for equipment
   (b) Define and promote emission reduction and management technology
6. Operation and maintenance of equipment
   (a) Registration of equipment
   (b) Operation and maintenance management
   (c) Periodical leak inspection, inspection target, criteria, method, and report of result.

7. Promotion and management of refrigerant recovery and destruction
   (a) High performance refrigerant recovery equipment
   (b) Increase of refrigerant recovery
   (c) Commission of refrigerant recovery
   (d) Procedure control documentation
8. Promotion of refrigerant reuse/recycle
   (a) Refrigerant reuse/recycle system
   (b) Technical challenges of refrigerant reuse/recycle
   (c) Quality standard of recycled refrigerant
   (d) Promotion and rouse of demand for reuse/recycle
9. Refrigerant emission reduction target area
10. Insure the operator technical level, license/qualification

NEW REFRIGERANTS AND THEIR CYCLES

HFC refrigerants have higher potentials of global warming (GWP)[1]. GWP

Figure 3.
Stocked refrigerant amount and developed new refrigerants (in parentheses, NDY: Not developed yet) for application

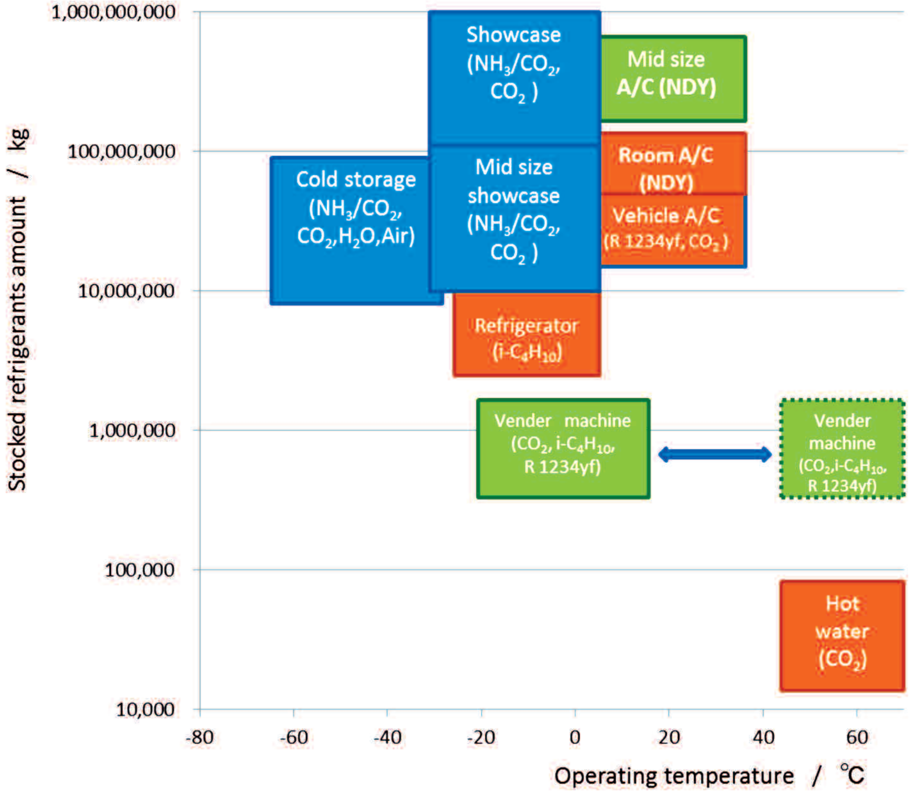
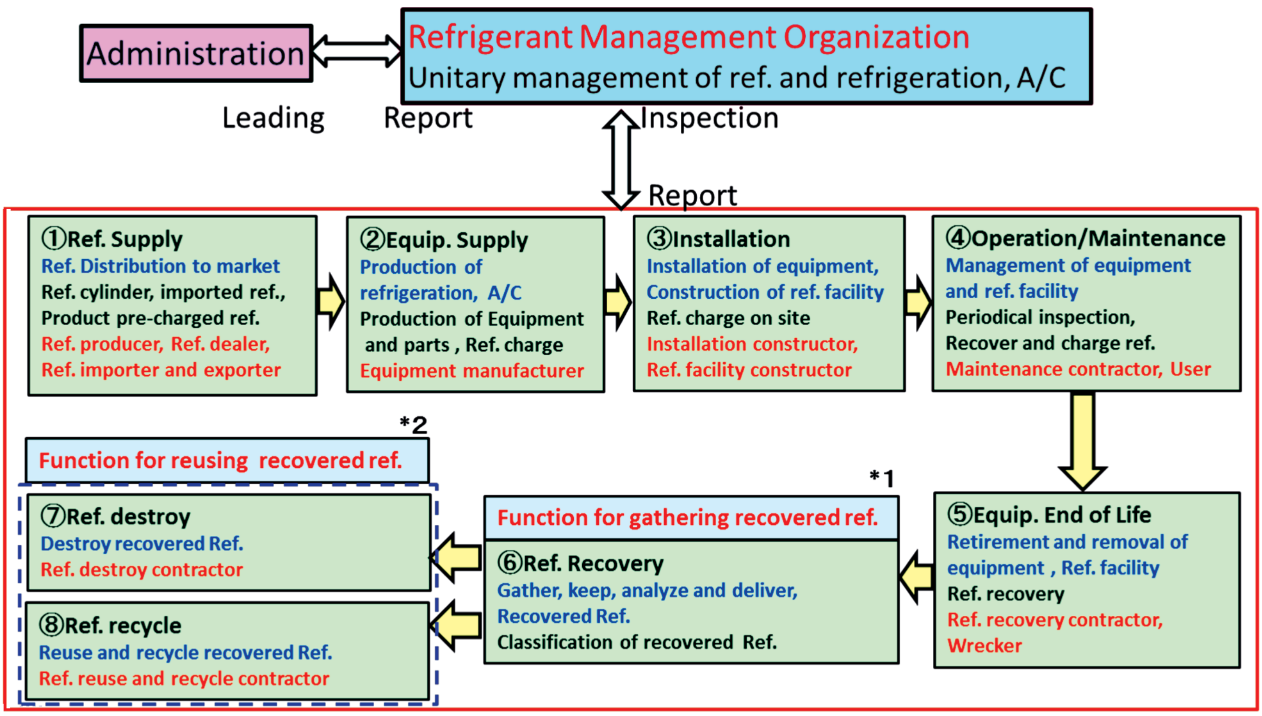


Figure 4.
Refrigerant distribution flow (yellow arrow) and proposed management system by JSRAE



*1 Regional center should weighing, analysis, store and transport to processing contractor the recovered ref.
*2 Detailed procedure, rules and cost for the management of ref. recovery, destroy, recycle should be established.

values of major refrigerants are arranged in Fig. 5. The global leakage amount from heat pumps is equivalent to 2 billion tons of CO_2 and account for 8% of total global CO_2 emissions[2]. For developing refrigeration and A/C technologies, there are two items to challenge: controlling HFC refrigerant use (refrigerant management as described in Chapter 2), and developing low-GWP refrigerants including new refrigerants and natural refrigerants[3,5].

To estimate the global warming contribution of a refrigeration or air-conditioning system, the total equivalent warning impact (TEWI) is used. TEWI is calculated with the total effect of direct emissions and the indirect effect of energy used over a specific period of time[6].

In Fig. 6 the calculated TEWI numbers are shown if the direct effect is able to be derived from the assumed amount of the charged refrigerant and the indirect one is to be that of CO_2 production throughout a service life. In this figure, to calculate TEWI for each refrigerant, a reference A/C system[3,5] with a cooling capacity of 3.5kW which charges 1 kg R 410A with small pressure loss and will produce 8t-CO_2 as the indirect effect, is applied. As an assumption, the refrigerant charging amount and the indirect effect will increase with the reciprocals of the refrigerating effect and the figure of merit, FOM (Fig. 7), which can be calculated from cycle performance values and their contribution factors[3,5].

From Figs. 6 and 7, it becomes clear that TEWI is higher if the system has a lower FOM even though a lower GWP refrigerant is used. In general, TEWI becomes more significant than the direct effect. R 32 and NH_3 (R 717) would be desirable refrigerants; however, they are flammable or toxic.

As already known, CO_2 (R 744) cycle is difficult to realize an actual higher COP even though the both theoretical COP and calculated cycle performance are very high. So there are many developments to improve the COP. In Japan, some of the modified cycles are already commercialized with reasonable high COP. Their theoretical COP arranged in Table 1[3].

In Fig. 7, NH_3, CO_2, and R 32 show higher FOM values. There is a possibility that they and new refrigerant mixtures, which are composed of them, will become new environment-friendly refrigerants. However, the cycle using nonazeotropic refrigerant mixtures requires special cycle elements and methods to obtain the high actual COP[5].

Figure 5.
GWP of major refrigerants

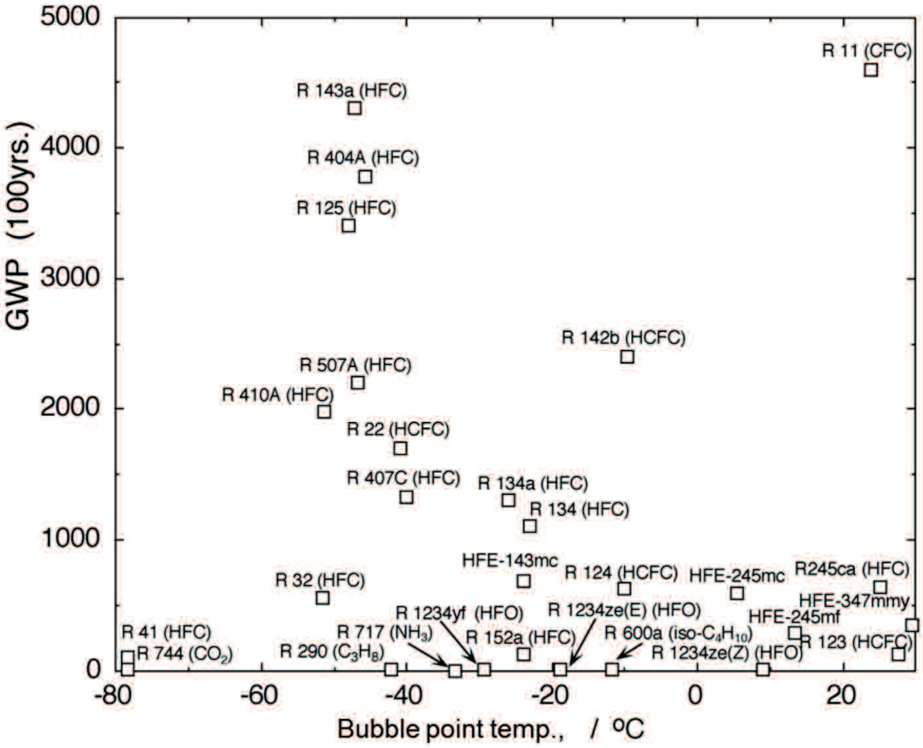


Figure 6.
Estimated TEWI of A/C
Cooling capacity of 3.5 kW, 13 years

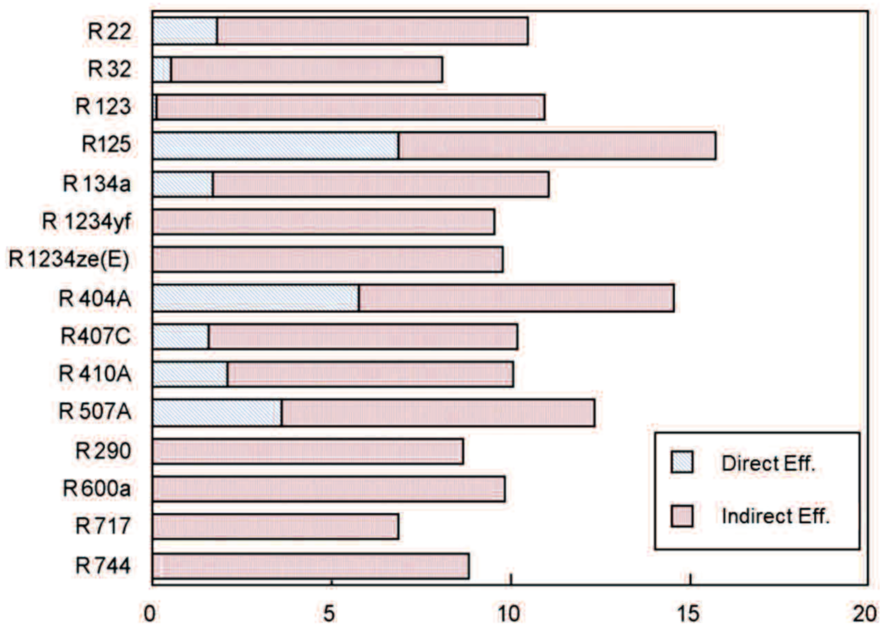
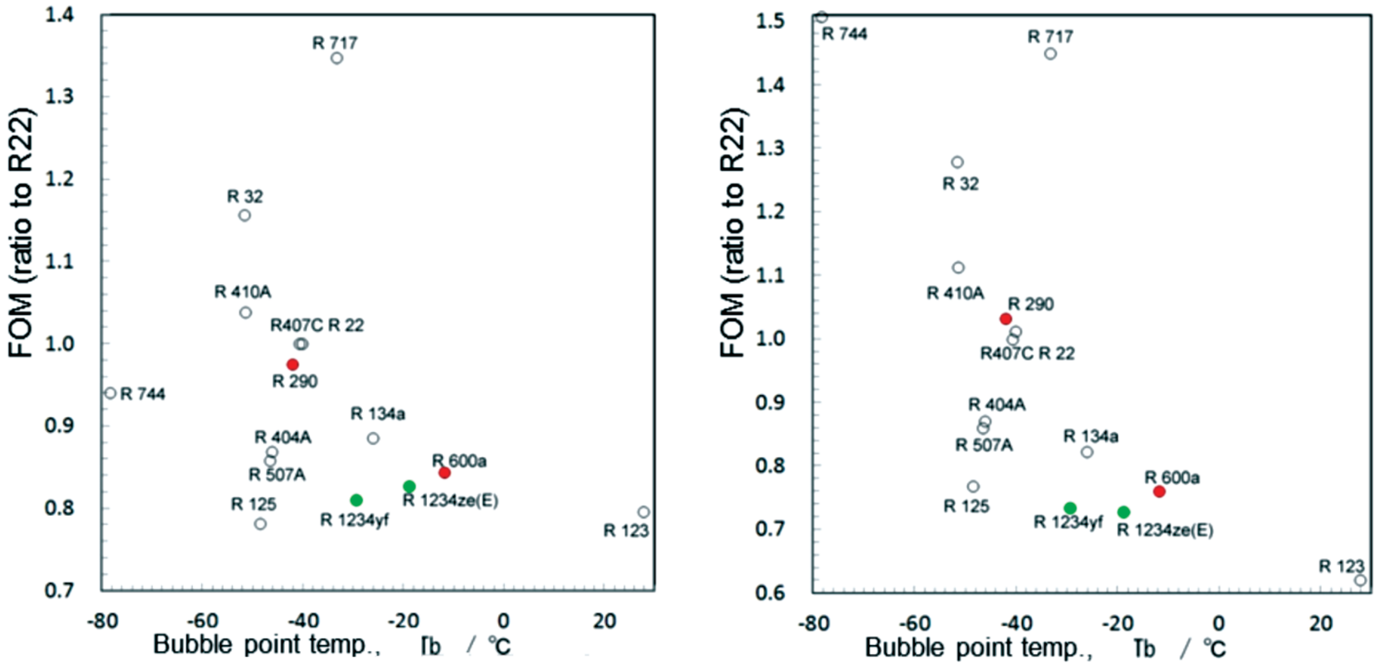


Figure 7.
Figure of merit
Green closed: hydrocarbons, Red closed: hydrofluoroolefins



(a) In case of small pressure losses in heat exchangers and connecting pipes

(a) In case of large pressure losses in heat exchangers and connecting pipes

Table 1.
Theoretical COP of Carbon dioxide

Cycle	Cooling COP	Heating COP	Cond. Max. Temp. (°C)	Exp. Valv. Inlet Temp.
(a) Single-stage cycle	4.3	5.3	70.6	37.0
(b) Two-stage cycle	5.2	6.2	49.3	37.0
(c) Single-stage cycle (evaporating Condenser: Cooling tower)	7.8	8.8	43.6	29.3
(d) Binary cycle (low temp. side: CO_2 high temp. side: R1234ze (E))	5.1	5.8	45.0	45.0

Cycle condition: Cond. Temp.: 43 °C, Evap. Temp.: 10 °C, Super Heat: 0 K, Sub Cool: 0 K, (a) (b) Cond. Press: 10 MPa, Exp. Valv Inlet Temp.: 37 °C

CONCLUSIONS

In this article, it was shown that TEWI is higher if the system has a lower FOM even though a lower GWP refrigerant is used. R32 and NH_3 (R717) would be desirable refrigerants; however, they are flammable or toxic. At present there is no another refrigerant, which has both environment friendly properties and high cycle performance of air conditioning. New safe materials including mixtures must be identified and heat pumps with low-GWP refrigerants must be developed as fast as possible. And also, it leads to that HFC refrigerants must be used taking care by refrigerant management until the new refrigerants with extremely low GWP will be available.

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Challenges in Identifying Low-GWP Refrigerants for High Ambient Temperature Climates

AYMAN ELTALOUNY[1], OLE REINHOLDT NIELSEN[2]
BASSAM ELASSAAD[3], WALID CHAKROUN[4]

[1]Programme Officer United Nations Environment Programme (UNEP)
[2]Unit Chief, Refrigeration and Aerosols Unit, United Nations Industrial Development Organization (UNIDO)
[3]P. Eng, RTOC member, Consultant to UNEP/UNIDO High-Ambient Project
[4]Ph.D., Fellow ASHRAE, Professor Kuwait University, Kuwait

THE MONTREAL PROTOCOL

Over the last two decades, the refrigeration and air-conditioning industry witnessed rapid changes and developments in response to the global environmental calls and conventions in particular those related to the preservation of the stratospheric ozone layer and combating climate change. In September of 2007, the Parties to the Montreal Protocol agreed to reduce Hydrochlorofluorocarbon (HCFC) consumption in developing countries through an accelerated scheme that included freezing consumption levels, based on 2009-2010 averages, in the year 2013 followed by cuts, to the same level, of 10%, 35%, 67.5% & 97.5% for the years 2015, 2020, 2025 & 2030 respectively allowing 2.5% to continue during the period 2030-2040 as service tail which will be further assessed and modified in the year 2025.

The Montreal Protocol proved to be one of the most successful global treaties in history: it has been ratified by every country and has delivered results ahead of the expected timeline. The ozone layer is mending and the risk that the ozone hole posed to humanity is receding. Montreal Protocol also delivered a major side benefit in reducing greenhouse gas (GHG) emissions to a larger extent than the Kyoto Protocol, which was designed for that purpose, did.

There are other benefits to the Protocol: creating awareness about the environment and climate change, reducing illegal trade in fake substances, training of technicians and other stakeholders, and the conversion of numerable old and leaky air conditioning and refrigeration plants. The billions of dollars spent on the various phases for the phase-out of ozone depleting substances had a high and well controlled cost effectiveness.

REGIONAL CONCERN

Energy is a fundamental ingredient for all nations but more so in hot ambient temperatures countries. The summer in the some of the Middle Eastern countries starts in April and ends in October with ambient temperatures exceeding 52°C in June, July, and August with the result that all buildings require cooling systems. The largest single consumer of electricity in the region is air conditioning accounting up to 75% of the countries' peak power demand and over 50% of the annual energy consumption.

The governments and respective industries in the Middle East region have expressed concern over the last few years about their ability to meet the environmental commitments of freezing or reducing the use of HCFCs when long-term low-GWP alternatives to HCFC-22, particularly for small/medium size air-conditioning applications, are not yet ready for their markets. Failing to meet phase-out commitments can have direct consequences on a global level for the country in question and lead to export restrictions and other penalties.

On the other hand Hydrofluorocarbons (HFCs), the primary commercially available alternative to CFCs and HCFCs since the early 90s, are currently doubtful to continue playing the same role given their contribution to global warming. Most of high/higher GWP HFC refrigerants have started to be less welcomed or accepted over the last few years in several places in the world.

Additionally, most of the governments in the region have started to apply new energy efficiency requirements for placing air-conditioning units into the markets. Known as MEPS (Minimum Energy Performance Standards), these standards will certainly have an impact on the choice of refrigerants as well as design and operating characteristics of air-conditioning units. The requirement of countries in the region to measure energy efficiency at 46 °C, and in some countries to 48 °C, while raising the minimum acceptable levels which could disqualify most of the commercially available HCFC-22 alternatives and add cost to both manufacturers and end-users. Meeting those conditions for high-ambient climates is a major challenge for these countries.

ADDRESSING THE PROBLEM

In early 2013, the Secretariat of the Montreal Protocol approved a project proposed by UNEP/UNIDO to test various low Global Warming Potential (GWP) refrigerant alternatives at high ambient temperature to compare the performance and efficiency ratings of these refrigerants with HCFC-22 for

Representatives of West Asia governments, A/C industry and global industry/association attending the annual UNEP prestigious symposium on high-ambient alternatives in its 3rd round organized in cooperation with the government of UAE, ASHRAE and AHRI and co-sponsored by UNIDO, IIR, GIZ and JRAIA. (Sept-2013)

various residential applications. The idea of testing refrigerants is not new and there are other projects such as the Air Conditioning, Heating, and Refrigeration Institute (AHRI) Alternative Refrigerant Evaluation Program (AREP) which is already in its second phase. The uniqueness of the UNEP/UNIDO project is that it tests prototypes specifically built for the assigned refrigerants and in that the builders of the prototypes are all located in Article 5 countries with particularly high ambient temperatures.

Countries with high-ambient temperature characteristics and high dependency on refrigeration and air-conditioning applications are mainly located in the Middle East and particularly in the Gulf region. Those countries have traditionally been recipients of globally proven refrigeration technologies. The trend has been witnessing a change lately with regional industries enhancing their research capabilities to design air conditioning machines that fit their market requirements. This newly expanding design capacity remains limited to what is commercially available worldwide in terms of components. The region however does not produce neither the refrigerants nor the compressors that are the basic element of an air conditioning or refrigeration system.

UNEP & UNIDO designed and launched the regional project for assessing the feasibility of Low-GWP Alternatives for the air-conditioning industry in high-ambient countries which is globally known today as PRAHA, an acronym for “Promoting Low-GWP Alternatives for the Air-Conditioning Industry in High Ambient countries”.

The project aims to practically assess next-generation low-GWP refrigerants taking into account energy efficiency, environmental impact, performance, safety, and cost.

The project involves partnerships of 13 international/regional technology providers and equipment manufacturers, who have all committed resources to the program.

PRAHA PROJECT DRIVERS

The challenges to the promotion of low-GWP alternatives in the region can be summarized as follows:

- Unclear global trend about refrigerant alternatives for each category of application particularly those suitable to operate in high-ambient conditions;
- Unavailability of components, mainly compressors, that work on low-GWP alternatives and designed for high-ambient conditions;
- Untested behavior of HVAC systems when operating at high ambient temperatures;
- Absence of national/regional codes /standards that can facilitate the introduction of low-GWP alternatives and deal with their flammability characteristics;
- Potential limitation to the introduction of applications with flammable characteristics in high-rise buildings which is a growing segment of the construction industry in many developing countries;
- Introduction of new energy efficiency rating schemes and regulations particularly for A/C systems.

West Asia A/C industry representatives and UNEP-UNIDO PRAHA activity leaders/consultants on a visit to a Japanese manufacturer as part of a study tour visit organized for the A/C industry in China and Japan (Nov-2013)

- Preferred adoption of low-cost alternatives particularly for price sensitive products.

This main objective of the project is to shed light into what can be considered as sustainable technologies for high ambient temperature countries. The proposed work will facilitate the technology transfer and experience exchange of low-GWP alternatives for air-conditioning applications operating in high-ambient temperature countries. Other indirect objectives that will be facilitated through the implementation of the project are:

- Supporting technical and policy decisions on long-term alternatives to HCFCs for the air-conditioning industry as part the overarching strategies for the phase-out of HCFCs;
- Encouraging the development of local/regional standards to ease the introduction of alternatives needing special safety or handling considerations;
- Ensuring that national and regional energy efficiency programs are linked to the adoption of long term alternative solutions in as far as low-GWP options.

This exceptional project is designed to answer challenges related to the availability of long-term low-GWP alternative refrigerants and their associated technologies including final products, components, and accessories in high-ambient temperature countries. The key elements of the project are:

1. Assessing available technologies:
   – Studying the availability of current and long-term commercially available refrigerants;
   – Involving research institutes, international panels, and industry experts
2. Assessing relevant Energy Efficiency (EE) standards and codes:
   – Development and upgrade of existing national/ regional standards;
   – Potential impact of selecting short-term alternatives
3. Economic comparison of alternative technologies:
   – Comparing initial and operating costs of low-GWP technologies;
   – Identifying technology and regulatory gaps
4. Promoting Technology transfer:
   – Identifying commercial opportunities and the fiscal implications of facilitating the technology transfer.

The main components of the project are shown as the figure below:

Project Components		
Building and testing prototypes	Study on Long-Term Feasible Technologies	Coordinating phase-out requirements with MEPS programs

APPLICATIONS TARGETED

The choice for the type and capacities of the air-conditioning prototypes was determined by the number of existing units installed in the region, the market growth trends, and the trends in local manufacturing and import. The data which helped in the decision making process was taken from surveys effected by the countries in the region to support their phase-out strategies.

Table 1: **Prototype categories and proposed refrigerants**

	60 Hz		50 Hz	
	Window A/C (18 MBH)	Decorative Split (24 MBH)	Ducted Split (36 MBH)	Packaged A/C (90 MBH)
	Prototypes			
R32				
HFO1				
HFO2				
HFO3				
HFO4				
HC				
	Base Units			
R22				
HFC base				

Those studies showed that 90% of the installed residential and commercial air conditioning units are below 17.5 kW (or 5 refrigeration tons as used in the region) representing 70% of the HCFC-22 refrigerant inventory.

The selection of alternatives was also a debatable topic at the early stages of implementation of the project in terms of defining what is meant of low-GWP and what are the cap value that can be used for determining such definition. Given the unclear global definition of such a term i.e. low-GWP, PRAHA participants agreed to consider the lowest and commercially available options that refrigerants and compressor manufactures can provide instantaneous support and supply sample materials.

Moreover, 70% of the newly built spaces are for residential / commercial use with 67% of the built area expected to use units below 50 KW (15 Ref tons). With GDP growth in the region hovering around 4%, the total air-conditioning capacity to be installed until 2030 is expected to be around 108 kW or 30 million tons of air conditioning.

The inventory of refrigerant in equipment under 50 kW capacity will be more than doubled, and so would the emissions. Table 1 shows the proposed categories to be tested as part of the PRAHA project. The project prototypes include window units of 5 kW, decorative splits of 7 kW, ducted splits of 10 kW, and rooftop packaged units of 35 kW.

The window and decorative splits will be 60 Hz which is the frequency of the biggest market, Saudi Arabia; and the other two applications will be 50 Hz which is used in the other GCC countries.

TESTING CONDITIONS AND REPORTING FORMAT

In assessing available technologies, an important element that is basic to the PRAHA project is to build prototypes taking into consideration the specific characteristics of the refrigerant and the outside operational temperature. The prototypes will need to be also tested in one independent lab to ensure uniformity of the results.

Each of the four categories will be built by two different manufacturers to

Table 2: **Number of tests per prototype**

Number of tests	Window	Decorative	Ducted	Packaged	Prototype per category*	**Total prototypes**	Number of tests conditions per prototype**	**Total Number of tests**
Base	R22	R22	R22	R22	1*	4	2	8
HFC base	R407	R410	R410	R407/R410	1	4	2	8
R32	No	Yes	Yes	No	2	4	3	12
HFO1	Yes	Yes	Yes	Yes	2	8	3	24
HFO2	Yes	Yes	Yes	Yes	2	8	3	24
HC	No	Yes	No	No	2	2	3	6
Total						**30**		**82**

ensure that the results will be compared with good accuracy and to eliminate the effect of the particular design. Seven regional manufacturers are building prototypes with dedicated compressors and other components to maximize performance for each specific refrigerant.
Applications will be tested for the four or five promising technologies and compared to the performance of base units with existing HCFC-22 and other available alternatives which are starting to be introduced in the market using HFC-410A or HFC-407C.
The tests will be performed at three outside ambient conditions; 35 °C, 46 °C and 50 °C for a proper comparison of the results. The indoor conditions will be kept the same for all tests. An endurance test will be performed at 52 °C to check that the compressor will not trip when run continuously for two hours. The testing will follow AHRI 210/240 and 340/360 standards. A total of 82 tests will be performed as shown in table 2 which is included for reference only, and the testing will be carried out at a certified independent lab.

CONFIDENTIALITY AND TERMS OF REFERENCE

The project is unique in the sense that it provides for the collective efforts of air-conditioning manufacturers and technology providers, who could be competitors. The project design should therefore facilitate both the evaluation of low-GWP alternatives as well as preserving the confidentiality of the results for the project participants.
After several stakeholder consultations, it was agreed to issue terms of reference for all the project participants outlining responsibilities while also ensuring the required and necessary confidentiality. In response to the terms of reference, memoranda of understandings (MoU) have been signed with all project participants.
Through the MoU, air-conditioning manufacturers will provide an agreed number of prototypes each optimized for a specific low-GWP refrigerant. The prototypes will be tested at a certified independent laboratory selected through competitive bidding.
The following conditions apply to the testing procedure:

- The manufacturer will not be allowed to attend the testing; and there will be no opportunity for iterative process in prototype development/lab testing;
- Test results will be available to the manufacturer only after issuance of the final project report;
- The final report will not provide any detailed test results for individual participants, but will provide a global result only.

In addition to the above mentioned MoU's; the PRAHA project has also entered into a MoU with the AHRI/AREP program; with the objective to share experiences and test results. Sharing of test results will naturally follow the same principles and conditions as outlined in the MoU's with the air conditioning manufacturer as well as technology providers.

TIMELINE

As mentioned earlier, the project was initiated during 2013. The current status is that all MoU's have been signed and the couplings between manufacturer and technology provider done. Prototypes are either ready or being built. The tests are expected to commence during 4th quarter 2014.
The goal is to have all tests are completed during 1st quarter 2015; which should allow for the final results to be available in 2nd quarter 2015.

CONCLUSION

The choice of alternative refrigerants should take into consideration many factors such as performance, energy efficiency, safety, and cost. This holistic approach in identifying future refrigerants ensures its sustainability and reduces the need for multiple conversion of production lines that is a load for manufacturing companies. Moreover, and since almost all low-GWP alternatives have some sort pf flammability, the air-conditioning industry should work with local regulators to ensure that safety standards for the production, installation, and operation of the machines are developed and adapted. PRAHA project has created an awareness on the need to develop solutions for high ambient countries in order to meet the phase-out milestones dictated by the Montreal Protocol. It constitutes a good start for more dedicated research related to high ambient temperature applications by scientists in the region. These research projects will have to be coordinated by regional research centers, and supported by local governments, for a sustainable implementation.

Containment of Refrigerants within Refrigeration, Air Conditioning and Heat Pump Systems

24th Informatory Note on Refrigeration Technologies

Graeme Maidment

DAVID COWAN, ISSA CHAER, PER LUNDQUIST
GRAEME MAIDMENT, DIDIER COULOMB

International Institute of Refrigeration – IIR

INSTITUT INTERNATIONAL DU FROID
177, Bd Malesherbes - 75017 Paris
Tel. 0033/1/42273235 - www.iifiir.org

This informatory note has been prepared by the IIR Working Party "Mitigation of Direct Emissions of Greenhouse Gases in Refrigeration" on behalf of the IIR Science and Technology Council. It provides information about the impact of leakage, why containment is beneficial from both environmental and economic perspectives, where and how leakage can be reduced, legislation and initiatives that have been developed to help containment and reference to sources of further information. This note is an update of a previous informatory note[1] and presents a series of measures to be taken. Although the main focus is often on the environmental impact of refrigerant leakage from refrigeration, air conditioning and heat pump (RACHP) systems, leakage also has a big impact on system reliability, efficiency and the economics of operation.

BACKGROUND

There has been good progress on reducing refrigerant emissions in many countries, as a result of various regulatory actions, fiscal and voluntary initiatives, as well as technological developments.

This reduction is exemplified in Figure 1, which shows the annual refrigerant leakage rates reported in several studies between 2000 and 2011[2] and Figure 2, which shows the annual leakage of refrigerant reported by two large end users in the UK retail (supermarket) sector[3]

Hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) continue to be the most commonly used refrigerant types for RACHP. Figure 3 shows projections of refrigerant banks and emissions reported by UNEP[4], based on an emissions mitigation scenario which includes reduced refrigerant losses and improved recovery rates.

The figure indicates that global HCFC refrigerant banks and emissions are predicted to change by only a small amount between 2002 and 2020, while at the same time HFC refrigerant banks and emissions are forecast to increase by 400% and 137% respectively.

The combined HCFC and HFC refrigerant emissions projections indicate an increase of nearly 50% in the global warming impact associated with refrigerant emissions between 2001 and 2020.

THE IMPACT OF REFRIGERANT LEAKAGE

A systems approach such as TEWI[5] or LCCP[6], expressed as a carbon dioxide equivalent mass, is frequently used to assess the total direct and indirect emissions over the lifetime of the equipment. The relative weighting between direct and indirect emissions from a RACHP system depends on several factors, including the global warming potential (GWP) of the refrigerant, refrigerant charge, the rate of refrigerant leakage, the cooling load, hours of operation and external temperature and efficiency of the cooling system.

Figure 4 demonstrates the potential impact of refrigerant leakage on TEWI for a high GWP refrigerant (R404A) in typical low temperature (LT) and high temperature (HT) direct expansion supermarket refrigeration systems. The worked examples[7] indicate that annual leakage rates in the range 10% - 20% can double the TEWI of a refrigeration system when using high GWP refrigerants.

However, although the direct emissions would be considerably lower from an equivalent system with a similar leakage rate but using a low GWP refrigerant, a less efficient refrigerant could result in increased energy use and higher indirect emissions.

Refrigerant leakage is, however, not just about emissions and global warming because it lso increases costs through:

- reduction in reliability

Figure 1.
Reported leakage rates from studies[2]

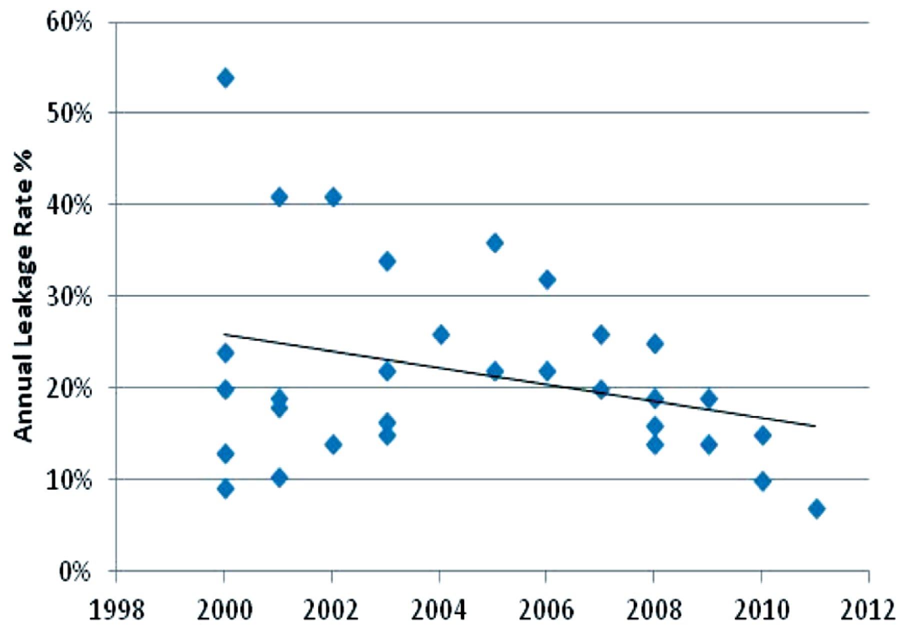
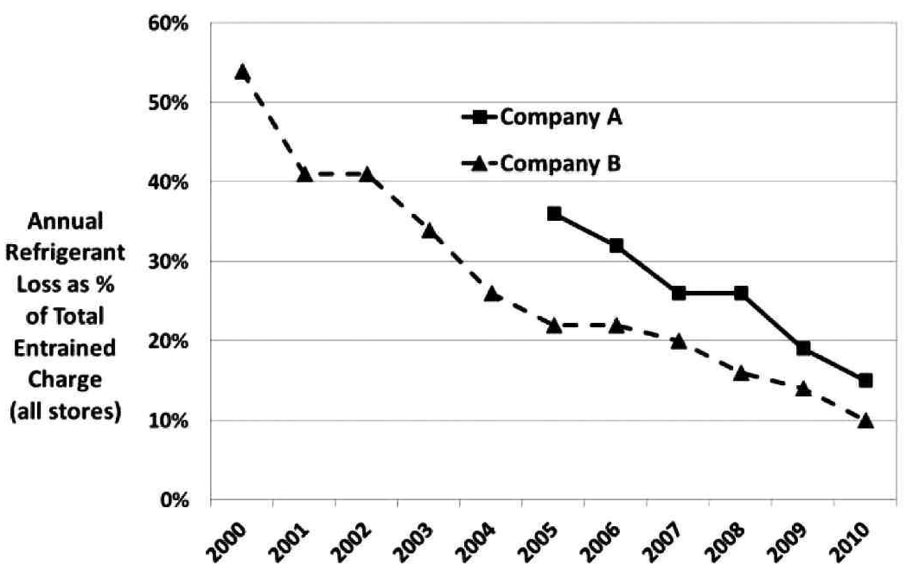


Figure 2.
Leakage rates reported by two end users (supermarkets)[3]



- increased down-time
- reduced efficiency
- reduced system capacity
- additional costs for replacement refrigerant, service and repairs.

The economic consequences of refrigerant leakage are indicated qualitatively in Figure 5[8]; the actual cost profile will depend on the application, the size of the leak and the time taken to identify and repair it. It should be recognized that even a relatively small leak may significantly increase the annual energy costs for the system. The economic impacts are not restricted to systems employing HFC and HCFC refrigerants, but will also apply to those containing natural refrigerants, such as CO_2, ammonia and hydrocarbons.

Reported refrigerant leakage rates vary considerably between different types of system and in different countries. Table 1 is based on the IPCC 2006 guidelines for reporting greenhouse gas inventories[9] and provides a range of emissions factors for installation and commissioning, operation of the system over its life and at disposal. The emissions factors are typically at the lower end of the range for developed countries and towards the higher end of the range in developing countries. The values for refrigerant remaining and recovered at end of life indicate that in many cases there is no recovery of refrigerant from RACHP equipment at disposal.

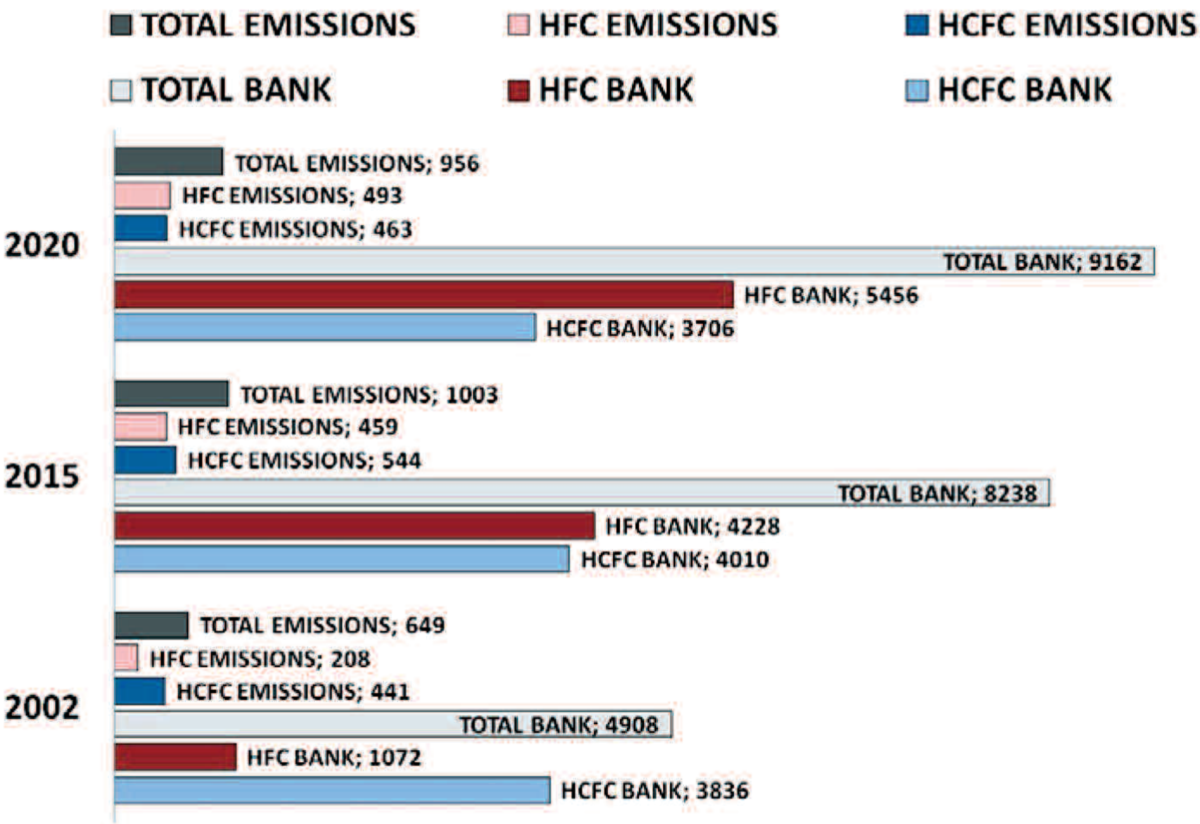
MINIMIZING LEAKAGE OVER THE SYSTEM LIFE CYCLE

Minimization of emissions must be achieved throughout the entire life cycle of refrigerants (production; storage; transport; operation; recovery; recycling; regeneration and destruction) and there are effective steps that can be taken to reduce leakage at all stages in the life cycle of RACHP plants (design; manufacture; operation; service and repair; decommissioning).

Actions required depend on the type of equipment concerned, and can be divided into broad categories including:

- integrated systems: small commercial and household appliances (refrigerators, freezers, small air conditioners, etc.). Most of these appliances are fully brazed and tightness depends on the quality of brazing: generally, less than 1 or 2 out of 10,000 appliances present defects
- chillers: all components of these systems are normally located in machine rooms, thus facilitating indication of leakage though detection of emissions
- direct-expansion systems with long refrigerant circuits: these systems are used in commercial and industrial refrigeration (particularly in the food industry) and residential space conditioning, and tend to be leak-prone
- vehicle air-conditioning systems: these systems have flexible elastomer hoses and open-type directly

Figure 3.
Global refrigerant banks and emissions projections 2002–2020 ($MTCO_2e$)[4]



driven compressors, so tend to be leak-prone

Emission levels vary according to the type of system and thus require containment policies that are appropriate to the system type and application. Several good initiatives have been taken internationally. One such example is a Code of Conduct[10] that was developed by the UK Carbon Trust, British Refrigeration Association (BRA) and UK Institute of Refrigeration (IoR) and describes a framework and best practice for refrigerant containment. A European initiative that provides information and training in refrigerant leakage reduction skills is REALSkills-Europe[11].

The endeavour to design systems with low charge per kW cooling capacity has been very successful. Application of new types of heat exchangers and designs without receivers has limited the amount of installed refrigerant considerably. However, these systems tend to be even more sensitive to system tightness and leakage has to be minimized to ensure long term proper functioning of the system. These issues have been thoroughly addressed by the IIR Working Party on Refrigerant Charge Reduction[12].

IIR RECOMMENDATIONS

The IIR advises users to take into account suggestions in this note. Above all, the IIR stresses the need:

- in national, international and corporate policy, to give top priority to reducing emissions, and in the case of global warming, to bear in mind the major impact of indirect emissions from energy conversion on global warming when implementing measures;
- to promote the setting up of coherent national plans covering recovery, recycling and destruction;
- to enforce regulations, particularly with respect to illegal refrigerant imports and sale;
- to utilize a life cycle approach in the design, selection installation and operation of RACHP systems;
- to implement financial and regulatory incentives in order to promote recovery, refrigerant emissions reduction and use of low-GWP replacement refrigerants;
- to promote staff and company training and certification in order to ensure compliance with good practice procedures;
- to provide assistance to developing countries in training and certification programmes on refrigerant uses in the framework of official development assistance by developed countries and United Nations agencies.

Such economic policies are enriched by discussions between the partners involved: national delegates of the IIR, organizations representing the various parties concerned, national associations and national refrigeration committees can be key partners.

The IIR is willing to continue to work in liaison with the various United Nations organizations implementing the Montreal Protocol, as well as with committees, professional organizations and governments of its member countries, in order to develop coherent policies.

This Informatory Note was prepared by David Cowan, Issa Chaer, Per Lundquist (Chairman of the IIR Working Party), Graeme Maidment and Didier Coulomb.

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Figure 4.
Impact of refrigerant leakage on TEWI for typical R404A refrigeration systems[7]

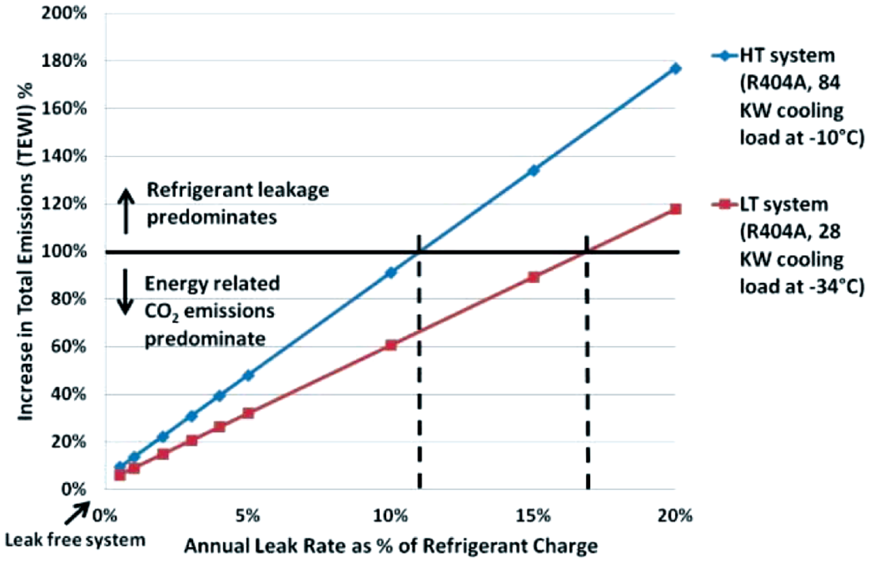


Figure 5.
Escalating cost of an unchecked refrigeration system leak[8]

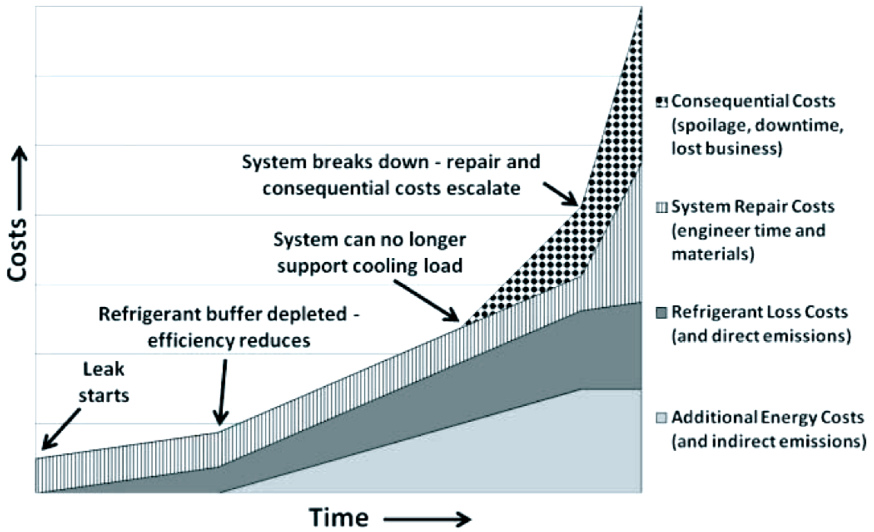


Table 1: **Range of values for charge and emission factors for RACHP systems**[9]

Type of Equipment	Typical Range in Charge Capacity (kg)	Installation Emission Factor (% of initial charge)	Operating Emissions (% of initial charge/ year))	Refrigerant remaining at disposal (% of initial charge)	Refrigerant recovered (% of remaining charge)
Domestic Refrigeration	0.05 - 0.5	0.2 - 1.0	0.1 - 0.5	0 - 80	0 - 70
Stand-alone Commercial Applications	0.2 - 6	0.5 - 3	1 - 15	0 - 80	0 - 70
Medium & Large Commercial Applications	50 - 2,000	0.5 - 3	10 - 35	50 - 100	0 - 70
Transport Refrigeration	3 - 8	0.2 - 1	15 - 50	0 - 50	0 - 70
Industrial Refrigeration (inc. food processing and cold storage)	10 - 10,000	0.5 - 3	7 - 25	50 - 100	0 - 90
Chillers	10 - 2,000	0.2 - 1	2 - 15	80 - 100	0 - 95
Residential and Commercial A/C including Heat Pumps	0.5 - 100	0.2 - 1	1 - 10	0 - 80	0 - 80
Mobile Air Conditioning	0.5 - 1.5	0.2 - 0.5	10 - 20	0 - 50	0 - 50

IIR offices: Didier Coulomb (left)

Refrigerant Charge Reduction in Refrigerating Systems

25th Informatory Note on Refrigeration Technologies

JOSÉ CORBERÁN

President of the IIR Working Party on refrigerant charge reduction in refrigerating systems

INSTITUT INTERNATIONAL DU FROID
177, Bd Malesherbes - 75017 Paris
Tel. 0033/1/42273235 - www.iifiir.org

The minimisation of charge in future refrigeration equipment is a very important target in refrigeration technology development. Charge minimisation allows for the reduction of direct emissions of refrigerant gases along the whole life of the unit, as well as the reduction of emissions generated along the whole chain of the refrigerant production, transport and service. Additionally, the reduction of the refrigerant charge implies a lowered unit cost, and fewer associated risks in the case of refrigerants with harmful properties, such as flammability or toxicity.
Nevertheless, minimisation of charge cannot be achieved at the expense of unit efficiency because this would imply higher electricity consumption and therefore higher indirect CO_2 emissions. An overall optimisation of the equipment design and charge is therefore necessary in order to achieve minimal CO_2 equivalent total emissions.
On the other hand, regulations impose maximum charge values depending on the refrigerant and on the application. Most HFC refrigerants are considered as greenhouse gases due to their high GWP value, while natural refrigerants as hydrocarbons or ammonia, must satisfy maximum charge-allowance and strict design requirements. Therefore, minimisation of charge becomes one of the most important requirements for future refrigeration equipment.

REFRIGERANT CHARGE AND CHARGE DISTRIBUTION

The minimum charge in a refrigeration system is the minimum charge required for stable operation of the unit over the full range of possible operating conditions. The minimum charge obviously depends on the design of the unit but also on the operating conditions. Therefore, the minimum refrigerant charge for a given unit is that required for stable operation under operating conditions requiring full refrigerant charge in all the components. The minimum charge will then be defined as that providing stable operation at conditions in which the minimum refrigerant charge provided via the upstream liquid column to the expansion device is sufficient to eliminate any bubbles going into it.
A typical figure of merit for charge comparison is the Specific Charge, i.e. the ratio between the charge (normally expressed in g) and the cooling capacity (normally expressed in kW). A review of this parameter for different applications and refrigerants can be found in Poggi et al.[1]. The value of the specific charge primarily depends on the application which will impose a certain design to the refrigerant circuit and heat exchangers but also strongly depends on the refrigerant employed, since density is an intrinsic property of the molecule. Refrigerants with lower densities, such as hydrocarbons, will lead to lower figures. Values of specific charges for refrigeration systems using HCFCs and HFCs are between 200 and 800 g/kW for small refrigeration systems and around 2000 g/kW for larger systems. Anyhow, the review shows a very high scattering of values which proves that minimal charges were not the design criteria for designs in the past.
Until now, research aiming at developing minimal charge equipment has mainly concentrated on natural fluids, trying to minimize the intrinsic risk associated with a potential sudden release of refrigerant (see for instance Cavallini[2], Primal[3], Corberan[4] and Hrnjak[5]). Achieved minimum values are around 30 g/kW for propane, and 20 g/kW for ammonia, proving that a substantial reduction of refrigerant charge is possible, if refrigerant charge minimization is part of the design requirements. Taking into account that the density of HFCs is around double that of propane, this means that designs with specific charges at around 60 g/kW are feasible for these synthetic refrigerants.
During operation, the refrigerant charge in the unit is distributed over all the different components, so that distribution depends on the density of the refrigerant at specific thermodynamic conditions of the component, and on its internal volume. The average density of the refrigerant in a component logically depends on the role of the component in the cycle, and on the actual operating conditions. Therefore, charge distribution among the different components varies according to operating conditions. Anyhow, these changes are moderate and ultimately

the charge distribution mainly depends on the unit design. From one component to another, common trends can be observed.

During normal operation of any basic refrigeration unit, the refrigerant is in vapor form between the evaporator outlet and the condenser inlet. The refrigerant charge contained in these parts is small, with the exception of the lubricant oil in the sump of the compressor which usually contains a non-negligible amount of refrigerant in dissolved form. The amount of refrigerant dissolved in the oil sump is only a small fraction of the total charge (10-15%) in normal units but this fraction can become considerable (30-40%). in units with a minimal charge.

Evaporators running under dry expansion mode contain a low amount of refrigerant. Typically the fraction of the charge in the evaporator would be at around 20%. Evaporators running under wet mode (flooded evaporators) contain a much higher charge.

The condenser contains (except at the inlet where de-superheating occurs) a high amount of refrigerant in the two-phase and subcooling regions. Taking into account that most of the refrigerant charge is in the region where the refrigerant is in liquid form, the importance of the charge in the condenser depends on the subcooling: the higher the subcooling the larger the charge. Typical charge fraction-values in the condenser could be at around 30 to 60% depending on the other unit components.

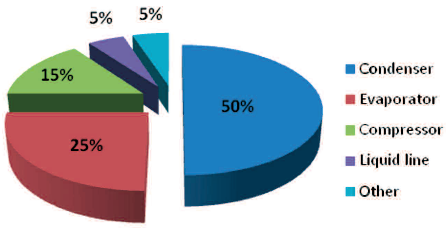
Charge in refrigerant lines is almost negligible with the possible exception of the liquid line, which in refrigeration systems or A/C split units can be very long and can therefore possibly contain a high proportion of the total charge.

Besides the basic components, a refrigeration unit can include other components which may also contain a non-negligible charge. This is especially the case of units with a liquid receiver, usually employed to compensate for large variations of the required refrigerant charge among different operation modes or big changes in the operating conditions. The use of a liquid receiver always implies a significant refrigerant charge as it must provide at least a minimum liquid level in order to ensure proper sealing and full liquid entrance to the liquid line, even at maximal system operating conditions. In principle, the lower the diameter (taller liquid receiver), the lower the extra charge required. The figure below shows the charge distribution that could apply to a small factory-sealed A/C unit without a liquid receiver, and with short refrigerant lines:

OPTIMAL CHARGE

What happens when a system is charged with more refrigerant than the minimum required? The answer is clear, the refrigerant mass must look for a place to stay, and a redistribution of the refrigerant will occur in all the different components of the system. Obviously the components with the highest capability to store the refrigerant are those which contain liquid refrigerant and have a large internal volume.

The first one to offer this feature is the liquid receiver when there is one in the circuit. This component is able to store refrigerant in liquid form until it is full. Therefore, in units with a liquid receiver all the extra charge is comfortably allocated to this component and this prevents any significant change from occurring during unit operation. The liquid receiver acts as a regulating device in the refrigeration cycle, storing all the extra charge and regulating the subcooling at a low value (typically around 1-2K); the concept of 'optimal charge' is not applicable to these systems.



Example of charge distribution in small A/C unit.

Units without a liquid receiver behave in a very different way when extra charge is added. In general, most of the extra charge is allocated in liquid form at the condenser end. This provides the opportunity to create subcooling that is beneficial for the coefficient of performance (COP). However, the increase in the liquid-flooded area reduces the area available for refrigerant condensation. This requires an increase in temperature difference, which implies the increase of the condensation temperature and pressure and tends to decrease the COP. The existence of these two counter-effects on the COP (increased subcooling and condensation pressure) leads to the existence of an 'optimal charge', maximizing the COP. The optimal subcooling mainly depends on the temperature variation of the secondary flow through the condenser, the flow arrangement, and the design of the condenser. Typical optimal-charge values correspond to subcooling levels situated between 5 and 10K.

Small systems without superheating control, such as domestic refrigerators and freezers, typically show a strong coupling between charge and performance. Refrigerant charge in these units simultaneously affects the subcooling and the superheating, and this influence strongly depends on the capillary-tube design. Therefore, optimization of the charge of these systems must be undertaken in conjunction with the optimization of the capillary tube and the overall optimization then becomes a complex procedure. Melo[6] has recently presented a full analysis of the combined optimization procedure for capillary design and refrigerant charge.

DESIGN OF REDUCED CHARGE SYSTEMS

The first requirement for reduced charge systems is high unit tightness providing that leakages become close to zero. Reduced charge systems should just contain the minimal charge and therefore, any substantial leakage rate will lead to a fast deterioration of performance, including COP and consequently to an increase in energy consumption, indirect emissions, maintenance requirements and cost.

Minimum refrigerant charge and refrigerant distribution has not attracted the interest of the scientific community until very recently. Fortunately, in recent years a number of experimental studies have targeted this important topic and are supplying very interesting information about it. See for instance: Primal[3], Palm[7], Poggi[1], Hrnjak[8], Peuker[9] and Cavallini[2].

The main design guideline for charge reduction is the minimization of the internal volume of the components. Moreover, taking into account that the highest refrigerant density corresponds to liquid conditions, it also becomes clear that the highest potential for charge reduction is achieved thanks to the minimization of the internal volume of the condenser end (where the refrigerant is liquid), of the liquid line, and of the minimum liquid level in the liquid receiver necessary for effective liquid sealing. The amount of charge and its distribution in a system therefore depends firstly on its size and secondly on the type of heat exchanger used (the more compact the heat exchanger on the refrigerant side, the lower the internal volume V_i). Circulation velocity also plays a role in the contained mass. (Nino et al.[10])

The first principle of charge minimization is having the refrigerant flowing through a small hydraulic diameter. As a matter of fact, the ratio between the internal volume V_i of N parallel channels of refrigerant and the corresponding heat transfer area is a function of the hydraulic diameter of each individual channel. Therefore, volume minimization is directly related to the use of tubes or channels with a small hydraulic diameter. This includes small-diameter tubes, new Al minichannel technology or parallel-plate channels such as those employed in brazed plate heat exchangers (BPHEs). Small hydraulic diameters tend to produce a high pressure drop along the channel so this must be compensated by reduced refrigerant circulation velocity which in practice is achieved by increasing the number of refrigerant circuits or the number of parallel channels.

Condenser/evaporator

In the case of refrigerant-to-water condensers or evaporators, the trend towards refrigerant-charge minimization is clearly towards the use of brazed plate heat exchangers, or if a shell-and tube construction is maintained, to having the water circulate through the shell and the refrigerant circulate inside small-diameter tubes, while focusing on volume reduction of the distributor and collector sections in order to keep the refrigerant charge in them at a minimum. Concerning high-pressure systems, a manufacturer has already developed a round-plate solution which makes it possible to keep a cylindrical shell. Special designs, employing multiport aluminium tubes with water in multi-pass cross flow, have led to very low specific-charge values of 20-30 g/kW for propane and ammonia.

In the case of refrigerant-to-air evaporators and especially condensers, minimization of charge requires the use of small-diameter tubes or multiport aluminium tubes. As a matter of fact, tube-diameter reduction has been a continuous trend over the past years, for instance in the AC industry, with an evolution from 12-mm for example to 9-mm and now 7-mm tube. Some manufacturers have already developed solutions with a 5-mm tube diameter. The use of minichannels and of multiport aluminium extruded flat tubes, presents a very good potential for charge minimization and additionally, a very good compromise between air-side heat transfer and pressure drop. Minichannel heat-exchanger technology also offers easy adaptation of the number of parallel channels in each pass to the required heat-transfer area and the density of the refrigerant, which ultimately also helps to reduce the refrigerant charge. However what is gained thanks to this technology at the level of the channels can be lost at the collector and distributor header level. Headers with two-phase flow can cause mal-distribution and an accumulation of liquid refrigerant. In any case, even if the header issue is considered, it has been proved that in practice the use of minichannel evaporators or condensers allows for important reduction of refrigerant charge in the heat exchangers, so this technology offers a high potential for refrigerant-charge minimization.

Flooded evaporators require a low-pressure receiver and contain a higher refrigerant charge so that for charge minimization, dry evaporation is generally preferred. Anyhow, flooded evaporators show greater efficiency that can compensate for the increase in direct emissions due to the higher refrigerant charge, so a detailed study in terms of TEWI is the way to know which option allows for the lowest total emissions.

Compressor

As commented above, the refrigerant charge contained in the compressor is not negligible and can become an important fraction when evaporator and condenser employ a minimum charge. Most of the refrigerant in the compressor is found in dissolved form in the lubricant oil in the sump of the compressor shell, so this amount depends firstly on the solubility of the refrigerant into the oil, secondly, on the amount of oil in the sump and thirdly on the operating pressure and on the oil temperature.

A certain degree of solubility of the refrigerant in the oil is of course required in order to achieve an effective return of the oil leaving the compressor. However; it is recommended that this solubility level should be the minimal required to reduce the amount of refrigerant dissolved in the oil. For the same reason the quantity of oil should be strictly the minimal amount required for the unit.

Liquid line

Regarding the other components of the unit, the most important for charge minimization are the liquid line and the liquid receiver. The liquid line in factory-sealed units is relatively small so its contribution to the total charge is small. However, in refrigeration systems or split AC units, it can be very long and thus contain a considerable fraction of the total charge. The refrigerant charge in liquid lines can easily be minimized by selecting a small but adequate diameter tube. Pressure drop along the liquid line is normally very low as liquid velocities are very low compared to the refrigerant velocity in lines with vapour. However, even a small pressure drop in a saturated liquid could induce the formation of bubbles likely to cause instabilities and a high increase in the pressure drop. Therefore, the diameter of the liquid line must be carefully selected depending on the available pressure head and over saturation level, given by the liquid pressure head and the subcooling. If the subcooling is high then pressure drop in the liquid line can be relatively high without any risk of flashing. In this case, the pressure drop in the liquid line does not bring any deterioration of performance.

Liquid Receiver

A Liquid Receiver (LR) considerably increases the refrigerant charge of the unit. Therefore, charge minimization first requires a critical review of the need for such an element, and if necessary, the subsequent optimization of its design in order to minimize the amount of refrigerant necessary for good operation.

The high-pressure LR is a receiver which is placed at the outlet of the condenser and its role can be either: a) to accommodate the variations of refrigerant mass due to changes in the operating conditions, compressor capacity regulation, or operation mode; b) to hold part of the charge in reserve to compensate for small leakages; c) to store the total refrigerant charge of the system during servicing or repair.

If the purpose of the LR is a), **to accommodate the variations of refrigerant mass**, a careful estimation of its dimensions must be performed in order for it to require the minimum possible refrigerant charge. From the design point of view, a tall aspect ratio is the best option for the LR since it provides the minimum level required for vapor sealing with the lowest refrigerant amount. If the purpose of the LR is b), **to hold part of the charge in reserve to compensate for small leakages**, small and compact factory sealed A/C units or heat pumps can be tight enough so as not to require a LR, in which case they should not use any. In large systems or in systems which must be manipulated on site, it is usual to make an estimate of the annual rate of leakage and install a LR with enough capacity to allow for a reasonable time span between recharging periods. However, refrigerant-charge minimization requires critical reviewing of this common methodology. Finally, if the purpose of the LR is c) **to store the total refrigerant charge of the system during servicing or repair**; since currently, technicians have efficient refrigerant recovery equipment, this practice should be abandoned.

Most of the attention on the LR has been paid in the sector of automobile air-conditioners where the need for compactness, high efficiency and long periods in between recharges has forced designers to continuously innovate and improve the LR design and carefully study the optimal charge. The integrated set: condenser + liquid receiver + subcooler, which is typically employed in automobile A/C systems is a very effective solution from the point of view of the unit performance as well as from that of refrigerant charge minimization. Abraham[11] gives a review of the evolution of the technology for the LR integration in the condenser as well as about the optimal charge of the system.

There is a second category of LRs, called low pressure LRs, which actuate as liquid vapour separators in systems with flooded evaporators. These low pressure LRs are also responsible for important refrigerant charges and there is also a tendency to try to optimize their size and design in order to minimize them. Brown and Pearson[12] presented a good review on the role and design of this important component.

Finally, it should be pointed out that large refrigeration systems are much more complex and therefore, a detailed total CO_2 emission analysis is the only way to assess the convenience of refrigerant-charge reduction measures. Anyhow, some trends have emerged clearly in recent experience, such as that of supermarkets with indirect systems employing a low GWP-distribution refrigerant, leading a very important decrease in emissions compared with existing direct systems.

IIR RECOMMENDATIONS

- Minimizing the refrigerant charge reduces the risk of important leakages and is thus beneficial both for the reduction of greenhouse gases emissions and for safety.
- Minimisation of charge cannot be achieved at the expense of unit efficiency because this would lead to higher indirect CO_2 emissions, therefore, an overall optimisation of the equipment design and of the charge is necessary.
- The first requirement for reduced charge systems is high unit tightness so that leakages come close to zero.
- The main design guideline for charge reduction is the minimization of the internal volume of the components containing liquid refrigerant as the condenser, the liquid line, and the liquid receiver.
- Minimization of charge in evaporators and especially condensers leads to the use of small hydraulic diameters, i.e. small diameter tubes, new AL minichannel technology or channels of parallel plates such as those used in BPHEs.
- Manufacturers of refrigeration equipment should work with compressor manufacturers in order to minimize the oil charge required for good and safe lubrication in order to save oil and reduce the refrigerant charge contained in the oil.
- The use of a liquid receiver should be avoided if its only purpose is to store part of the charge in reserve to compensate for leakages or to store the whole refrigerant charge of the system during servicing or repair, since this significantly increases the overall charge of the system. When required, LRs should be sized very carefully in order for them to require the minimum refrigerant charge possible.
- Research and technological development results on the minimization of the refrigerant charge in refrigerating systems should be publicized and disseminated to the greatest extent possible.

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Sulkhan Suladze

Disposal and destruction of contaminated artificial refrigerants in Georgia

NOE MEGRELISHVILI[1], SULKHAN SULADZE[2], SHALVA SHEKELADZE[2]

[1]**National Ozone Unit of Georgia**
[2]**Georgian Association of Refrigerating, Cryogenic and Air conditioning Engineers NGO**

BACKGROUND

Introduction of a sustainable system of recovery, disposal and destruction of contaminated artificial refrigerants is a direct contribution to the reduction of emissions of ODSs and F-Gases into the atmosphere especially for the countries operating under the Article 5 of the Montreal Protocol (developing countries).
The following assessment is made within the "Pilot demonstration Project on ODS-waste Management and Disposal in Georgia" of the Multilateral Fund of Montreal Protocol (MLF) and the objective of the Project is to propose a realistic and feasible option for the ODSs destruction in the country. The proposed activities include assistance in introduction of measures to support the sustainability looking at available ODSs waste that can be collected through two R/R centers operating in the country in cooperation with service companies, importers, car dismantling and metal scrapping companies in longer run with future waste disposal deploying in-country generated sources of finance.
This article gives theoretical evaluation of the possibility to establish a sustainable system for ODS waste permanent collection and destruction in Georgia, which in practical terms is based on the destruction of 1467 kg ODSs done prior to the beginning of the above mentioned project.
Unwanted ODSs wastes generally belong to industrial contaminants and their description, assessment and management fall under the general principles of industrial waste management and disposal strategy. Therefore, during the preparation of the feasibility assessment an experience of the Georgian Association of Refrigerating, Cryogenic and Air-conditioning Engineers (GARCAE) in development of the Pollutant Release and Transfer Register for Georgia was taken into account.

UNWANTED ODS BANK IN GEORGIA

Today there are four groups responsible for the existence of the bank of contaminated refrigerants, which are no longer subject to recovery. These are the Refrigerant Recovery and Recycling centers, service centers, refrigerant dealers and consumers. However, the reasons for ODS waste generation is various.
Refrigerant Recovery and Recycling centers are directly linked to the used refrigerants. According to existing national standards, if contamination of one refrigerant by other refrigerants exceeds 2% by volume, such refrigerant is considered as waste and it is not subject to further recycling and, therefore, should be stored for final disposal through destruction. Before the implementation of the Pilot Demonstration project of the MLF there had been recovered more than one metric ton of such wastes in the R&R centers. Most of them received from the service centers but there are cases when customs officers reveal imports of falsified refrigerants and ask the R&R centers for their appropriate storage and destruction.
Moreover end-users often ask the R&R centers for recovery of refrigerants from broken installations as well. In this case refrigerants are also identified and if they cannot be recycled are stored for disposal.
There are many service centers in Georgia which serve refrigeration and air conditioning equipment however only several large companies are able to recover refrigerants independently others perform this operation together with the R&R centers. At the same time large companies do not have sufficient technical means to store large amount of ODSs. That is why they avoid collecting refrigerants if it is clear in advance that they cannot be reused
The large importers of refrigerants are their distributors as well. They are not engaged in service of RAC installations and have no relation with used refrigerants however during the realization process gaseous refrigerant remains in a disposable cylinder from which it should be discharged because such cylinders must be removed then from consumption since it is forbidden to reuse. Thus, refrigerant remained in a container should be collected as well and if necessary be destroyed.
The source of contaminated refrigerant may be metal scraping centers also. From population together with other scraps they receive refrigerators and air conditioners which contain CFC and HFC. In such cases due to lack of adequate knowledge and technical equipment refrigerants are often

emitted to the atmosphere. It is necessary to promote cooperation between these companies and R&R centers. In this regard activities which intend to increase awareness of representatives of the field related companies in protection of the ozone layer have great significance.

Identification of refrigerants in the Georgian Refrigerant Recovery and Recycling Center.

PREPARATION OF EXISTING UNWANTED ODS FOR TRANS-BOUNDARY TRANSPORTATION AND DESTRUCTION

There are no technical facilities of destruction of refrigerants in Georgia at the moment. So the existing stock of unwanted ODSs has been prepared for trans-boundary transportation where they can be safely destroyed. First of all unwanted wastes stored in various storage facilities in Georgia were transported to Tbilisi in the Georgian Refrigerant Recovery and Recycling Center (GRRRC) and overall amount of contaminated ozone depleting substances reached 1467kg. Thus two transport tanks were filled with unwanted refrigerants with the amount of 750 kg and 717 kg respectively and were prepared practically for transportation from the country.

Samples were taken from both tanks for substance identification. VIPER 800600 and TA400 Identifiers as well as SRI 8610C gas chromatograph were used to identify composition. The analysis showed good repeatability which indicates accuracy of measurement. As a result it was detected that collected refrigerant represents ODS, which is contaminated with various blends and must be properly destroyed.

Taken Chromatograms are shown in figures below. It should be noted that the chromatogram in the second figure demonstrates that the blend along with ozone-depleting substances contained toxic and explosive chloromethane, R40. The identification was possible only by gas chromatograph, since identifiers that are used worldwide do not recognize R40. This substance had been used in refrigeration technology even before the CFC and was withdrawn from consumption as it was dangerous.

Unfortunately this substance re-emerged in circulation as an element of refrigerant falsification. Specialists ring the alarm at the international level in order to stop sales of this blend on the global market. It should be emphasized that in addition to abovementioned characteristics Chloromethane is incompatible with aluminum and damages it. This affects the impermeability of equipment and results in leak of refrigerants in the atmosphere. In this regard the contribution of Georgian Customs officers in preventing imports of such blends is greatly appreciable.

As it was planned in order to reduce costs of destruction the transportation of unwanted ODS wastes and POPs stocks abroad was carried out via joint actions. Thus the cost of the destruction of 1467kg of unwanted refrigerant was about US$6 per kilogram. That is less than world market prices (about US$10 per kilogram).

FINANCIAL MECHANISM FOR SUSTAINABLE SYSTEM OF ODS WASTES PERMANENT COLLECTION AND DESTRUCTION

Financial resources for future destruction of the stored refrigerants should be found inside the country. And it is important to design a scheme which will ensure ODSs collection across the country and their destruction. Several methods for accumulation of funds which will be enough for refrigerant destruction can be discussed for Georgia. One of them is setting certain taxes on realization/consumption of refrigerant. In this case refrigerant importers as well as consumers will have to pay a tax for handling refrigerants. Even a minimum tax (e.g. US$0.10 per 1kg) ensures the collection of sufficient sum for refrigerant destruction. Annually about 80000kg refrigerants enter Georgia thus if taxes were imposed the budget would increase by 80000kg X US$0.10 = US$8000.00. If we add a fee for refrigerant consumption the sum will be greater. However it must be mentioned that payment for consumption should depend on the quantity of used refrigerants.

The country can also adopt encouraging policy towards those companies, which contribute to environmental protection. In our case this means not to allow emission of refrigerant into the air and promote destruction of these substances. Encouragements from state may include issuance of the governmental testimonials (credentials), letter of appreciation and etc. However this will not be a sufficient incentive for private sector to promote environmental protection.

Encouragement should include certain advantages in terms of taxes for instance a company which will have a certificate (granted according to the certain criteria) confirming its involvement and contribution to environmental protection may enjoy some tax privileges. For instance have an obligation to pay the property tax 0.8% instead of 1% and the income tax 14% instead of 15%. These privileges will be important incentive for businesses.

The financial means can also be mobilized during the services provisioned by the R&R centers. At present, the regular activity of centers includes collection (recovering), recycling, reclamation and identification of refrigerants and their blends. Both centers during one year can on average collect about 1.5 metric tons of refrigerants for recycling:

- 800kg of this amount is recycled and returned to end-users;
- 200kg is re-used without recycling; and
- 500kg constitute waste which is

subject for storage before safe destruction.

Currently, the price of the refrigerant recovery is 5US$/kg, while recycling and reclamation operations cost 8US$/kg and 11US$/kg respectively. Taking into account strong demand for R&R operations in Georgia, the current income is regular and such operations can include waste accumulation and storage on a fee basis. Therefore a viable mechanism for resource generation would be to add to the current cost of refrigerant handling a small fee of 1.5US$/kg which will be devoted for future destruction of accumulated ODS waste. Annually, this fee fraction may reach US$3,450.00 as per the following costing formula: 1500kg of total annual recovered refrigerants x US$1.5 + 800kg recycled refrigerants x 1.5US$/kg= US$3,450.00.

In addition the R&R centers yearly perform about 200 to 300 hundred identifications of refrigerants and their blends. Cost of such process by VIPER identifier (for single gas refrigerants) is 5US$/sample and by TA400 identifier (for single and multi-gas compositions) is 8US$ per sample. As the testing is done to screen waste materials such identification cost will include up to US$2 to generate additional funds for future destruction of waste refrigerants. This will provide as minimum additional 250 samples x 2US$/sample = US$500 annually.

In total around US$3,950 annually can be generated to create a funding mechanism to accumulate missing resources for disposal of contaminated refrigerants in future on a sustainable basis.

Figure 1. **Chromatogram of 100% CFC 12**

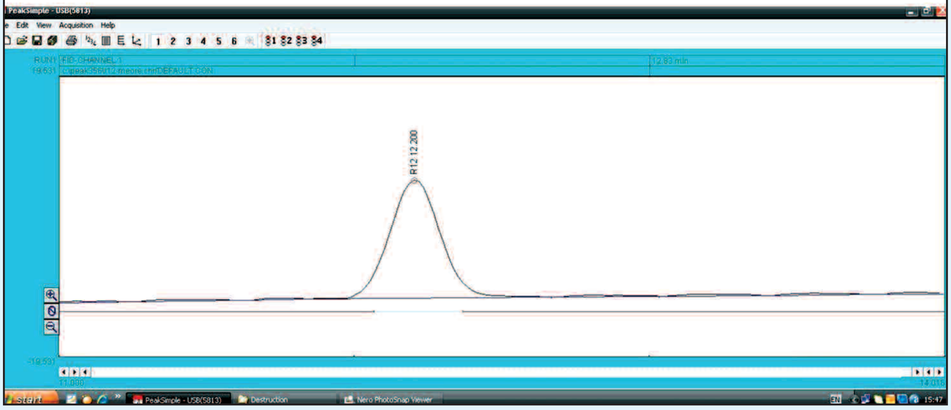
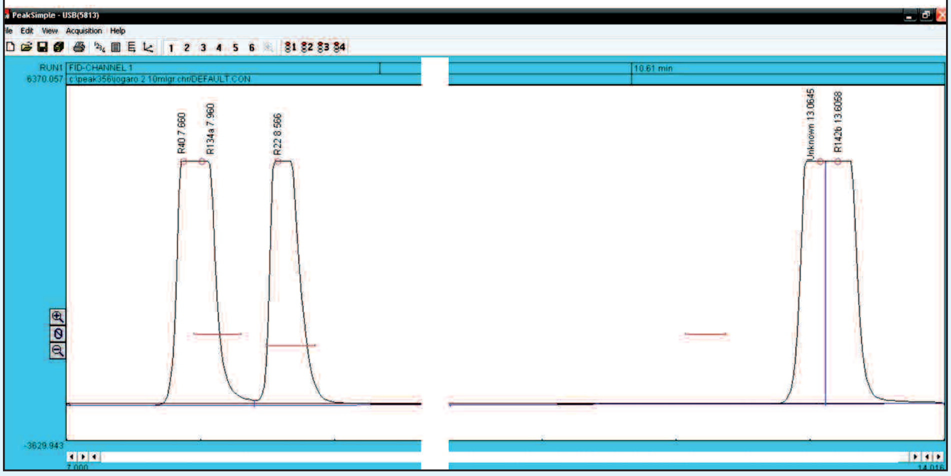


Figure 2. **Four-component blend among which there are ozone-depleting HCFCs: R22 and R142b**



CONCLUSION

The above-mentioned methods have their advantages and disadvantages. In the first case when Government imposes taxes on realization/consumption of refrigerants it is much easier to mobilize funds because companies will be obliged to pay by the law. Thus it will be much easier to collect money for unwanted refrigerant destruction. As for negative aspects additional taxes need new tax law changes this means many bureaucratic steps which could take a long time. Moreover the tax administration will require control over tax payment which is related to additional difficulties.

In the second case when Government propose benefits for companies positive aspect is that business will take care about reduction of environmental pollution and will be interested not to emit refrigerants into the air. Obviously, this benefits will not affect only refrigeration sector but spread to other companies as well, which will contribute to the reduction of the environmental pollution. The negative side of this method is that appropriate changes in tax law are required as well; moreover special attention should be paid to the reduction of taxes which at the same time reduces revenues of state. However the benefits that the country will have from the reduction of environmental pollution must be more than the loss that the state budget will experience due to tax reduction.

Finally, in the case of increasing of prices of the services provisioned by the R&R centers the positive aspect can be the fact that without the state measures the RAC private sector of Georgia will be able to mobilize financial resources for the further destruction of refrigerants. However it should be also taken into account that the Government of Georgia should maximally support activities of the R&R centers in the country.

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Industry Demonstrates Commitment to Environmental Stewardship with AHRI Low Global Warming Potential Alternative Refrigerants Evaluation Program

STEPHEN R. YUREK

Air-Conditioning, Heating, and Refrigeration Institute AHRI

The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) recently completed the first phase of its low global warming potential alternative refrigerants evaluation program (Low-GWP AREP). This industry-wide cooperative research program identified and evaluated promising alternative refrigerants' performance over the past two years. AHRI launched a second phase of testing at the beginning of 2014 that includes newly developed refrigerants and performance testing under high ambient conditions that were not covered in the first phase. This program and other efforts demonstrate the industry's commitment to environmental stewardship and proactive approach to improved performance and efficiency.

AHRI and its member companies are committed to environmental stewardship. This commitment is evidenced in the innovative, energy efficient products and equipment available all around the world, and in industry's proactive research and development of the next generation of environmentally responsible refrigerants.

The heating, air conditioning, commercial refrigeration, and water heating equipment manufactured by our member companies is more energy efficient and has less environmental impact than at any time in history. In fact, according to the U.S. Energy Information Administration, new homes are 30 percent larger but use only 2% more energy than in years past, thanks to innovative equipment developed by the industry. Not content to merely innovate until an individual product or component is as efficient as possible, AHRI is now looking at developing standards for, and certifying the performance of, whole systems of components and equipment that communicate and operate at peak efficiency throughout a home or an entire building or series of buildings.

HVACR equipment relies on refrigerant to deliver the comfort consumers have come to expect. Due to environmental concerns with high global warming potential (GWP) refrigerants, and with innovation in mind, AHRI member companies and refrigerant manufacturers around the world are currently undertaking a research program to identify and develop the next generation of refrigerants. There is no law or regulation in the U.S. that currently compels a major change in refrigerants, but AHRI is proactively working to identify those that have the right balance of efficiency and reduced environmental impact. We are confident that our industry will be very well prepared for any changes in refrigerant policy anywhere in the world.

This research immediately follows the completion of phase one of AHRI's Low-Global Warming Potential Alternative Refrigerants Evaluation Program (Low-GWP AREP). On January 16, 2014, AHRI hosted a conference where nineteen technical experts presented findings from the first phase of the program. More than 150 people attended the event to hear from industry, academia, and national laboratories.

The program was developed to identify promising low-GWP alternative refrigerants for major product categories, including air conditioners, heat pumps and heat pump water heaters, chillers, ice makers, and refrigeration equipment. All of the conference presentations and test reports are available on AHRI's website at www.ahrinet.org. In addition, at the conclusion of the first phase, 40 test reports were posted to the website.

The program identified and evaluated 38 low-GWP refrigerants either single components or blends. Their GWP values are significantly lower than their baseline refrigerants, namely, R-22, R-134a, R404A, and R-410A, which are commonly used in the field. The performance of some new alter-

Mr. Philip Johnson, chairman of the low-GWP ARAP Technical Committee.

natives was tested in compressors and/or in whole systems as pure drop-in refrigerants. To understand their potential performance improvement, some systems were modified for alternative refrigerants using standard production line components. Nine air conditioners and heat pumps, six chillers, four commercial refrigeration equipment, 10 compressors, one bus air conditioning system, and one transport refrigeration system were tested. All tests were performed at participating companies' laboratories, using their own resources, at their own expense.

The program began in 2011 as an industry-wide cooperative research initiative in response to environmental concerns raised by high-GWP refrigerants. The program, including the second phase, is strongly desired by the industry to assess the research needs, accelerate industry's response to environmental challenges raised by the use of high GWP refrigerants, and avoid duplicative work. The goal of the program is not to prioritize these alternatives; rather, it is to test potential replacements for high GWP refrigerants, and present their performance in a consistent and standard manner.

The second phase will continue research in areas that were not previously addressed. These include new refrigerants identified since testing for the program began three years ago; refrigerant performance testing under high ambient conditions for various equipment; and refrigerants in applications not tested in the first phase.

The research conducted in this second phase will expand the program to make it relevant to virtually all areas of the globe. Currently, AHRI is inviting applications from original equipment manufacturers, universities, and laboratories to perform tests on refrigerants for the second phase of the program, provided that applicants can complete tests and submit test reports for review by April 10, 2015. Interested companies should contact AHRI's Vice President of Regulatory and Research Karim Amrane at kamrane@ahrinet.org for more information. AHRI is proud to be at the leading edge of refrigerant research, and continue its legacy of guiding the industry in improved efficiency.

Centro Studi Galileo – Italy and European Energy Centre – UK provide International Certifications for the qualification of Service Technicians under the EU Certification Scheme for handling Fluorinated Gases. CSG supports UNEP in establishing Certification Schemes in developing countries, for example in Anglophone Countries of Africa (Rwanda, June 2014), Francophone Countries of Africa (Benin, October 2014), the East European and Central Asia Network (Montenegro, September 2014) and Iraq (Jordan, September 2014).

System configurations for supermarkets in warm climates applying R744 refrigeration technologies

Case studies of selected cities

A. HAFNER, P. NEKSÅ

SINTEF Energy Research, Norway

ABSTRACT

Energy efficiency, heat recovery and cost efficiency of commercial refrigeration systems still have a large development potential for systems applying R744 as the only refrigerant. The system architecture has to be in the focus with respect to increase the system efficiency when these units are operated at elevated ambient temperatures. The objective of this work is to investigate the energy required for different R744 commercial refrigeration systems at various locations in all the global continents. The most promising system configurations designed for high ambient temperatures as described by *Hafner (2014)* are taken into consideration, these are:

- Standard R744 booster cycle (R744 baseline)
- R744 booster cycle with a mechanical subcooler (MS) unit: working fluid MS: hydrocarbon
- R744 ejector supported parallel compression system

The energy consumption of these R744 system configurations are compared with measured values for HFC 404A supermarket refrigeration systems. It is shown that the efficiency level of R744 systems may be increased to exceed the baseline HFC system at all ambient temperatures up to 42'C either by utilizing mechanical sub-cooling or by ejector supported parallel compression. This means that the systems may be energy competitive at peak power even in the hottest climates of the world. At lower ambient temperatures, the efficiency of the R744 systems are always superior, resulting in seasonal efficiency of the R744 systems that clearly outperforms the HFC systems.

Keywords: R744 commercial refrigeration, high ambient temperature system, R744 ejector system

Figure 1.
Temperature bins for selected cities.
(Source Meteonorm)

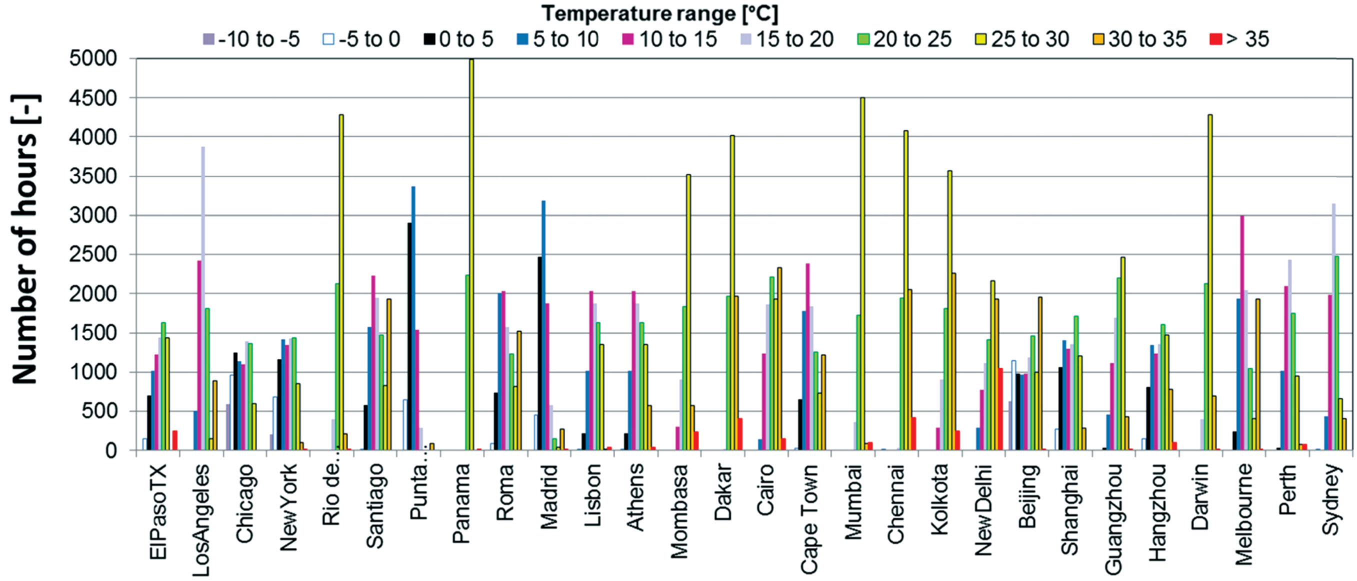


Figure 2.
Standard R744 booster cycle.

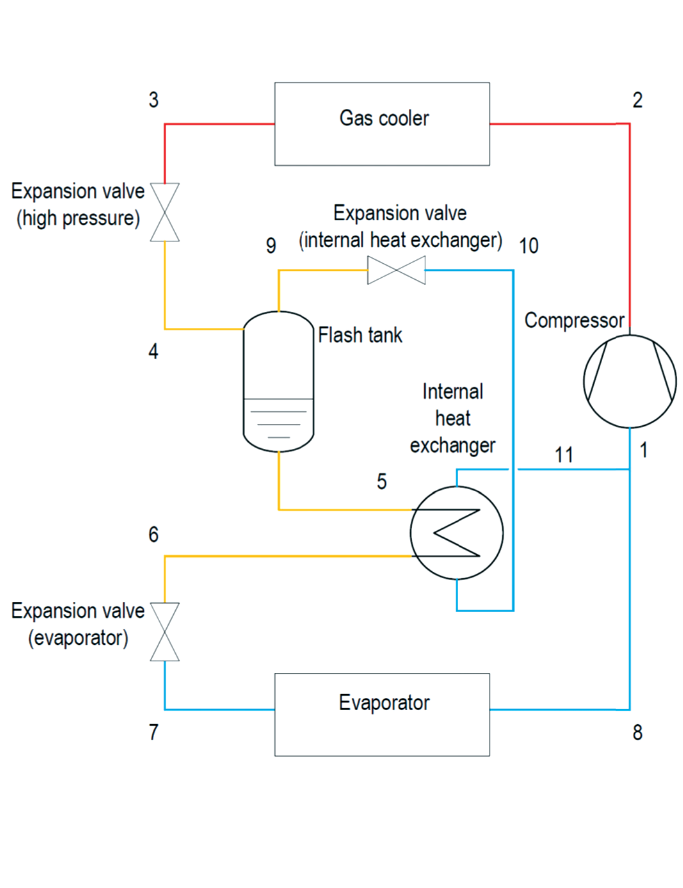
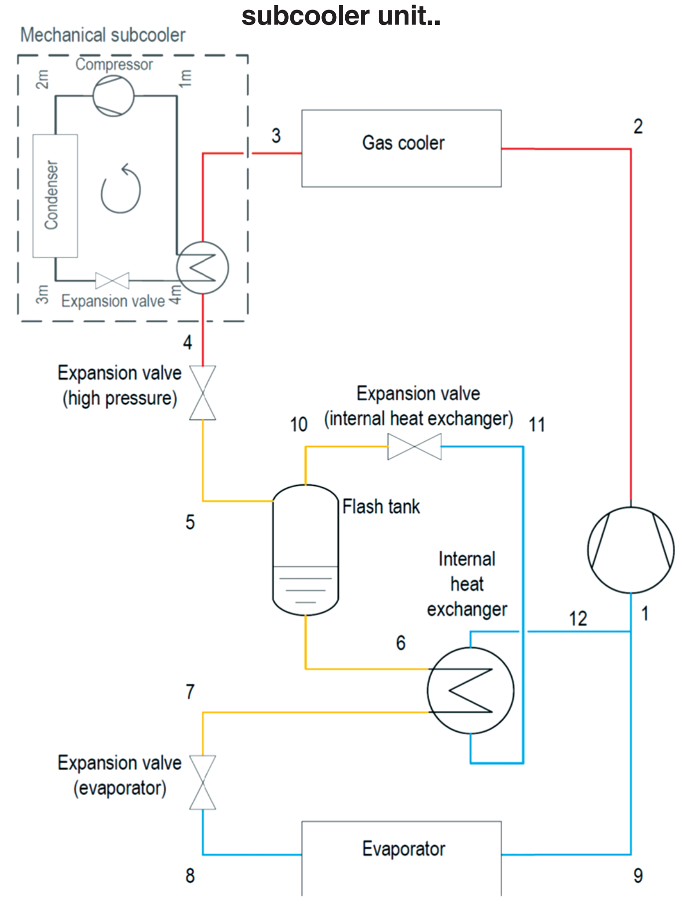


Figure 3.
Standard R744 booster cycle with mechanical subcooler unit..



1. INTRODUCTION

After the revival of carbon dioxide in the late 80's by *Gustav Lorentzen (1992/94/95)* several application areas have been identified where a transition from HFC's to the natural working fluid R744 should be feasible, both with reduced energy use and being beneficial regarding the environmental impact. Mobile AC-systems are one example, where the system efficiency has been improved by more than 100 %, due to the competition between HFC and R744 systems between 1995 and 2005. R744 heat pumps for tap water heating have become commonly in use in Japan *(Nekså 2010).*
A similar innovative development phase is ongoing within the commercial refrigeration industry, *Serwas (2012)*. The end-users of the equipment are more and more aware of the carbon footprint, energy consumption and general environmental impact of their business. As a consequence the number of transcritical commercial refrigeration units is fast increasing in Europe. The industry tries to develop standard solutions to achieve cost advantages by producing more similar units. As current R744 commercial systems are energy efficient in most European regions, *Serwas (2013)*, there is a need to identify the system configurations which will open up the market for R744 commercial refrigeration technology in Southern Europe and other parts of the world with hot climates.
The COP cross over temperature region for baseline, non-enhanced R744 booster systems has been described by *Finckh (2011).* When operated at ambient temperature above 22-26 °C the systems do have a slightly lower COP compared with state of the art HFC 404A commercial units, meaning that the peak power demand may be higher. However, an annual energy consumption analysis has to take into consideration every hour of operation during a year, since commercial refrigeration units in Supermarkets are always in operation 24 h a day / 7 days a week / 52 weeks per year.
This work utilise the findings described by *Hafner (& Hemmingsen et al. 2014)*, combining and applying them for an energy requirement analysis for Supermarket installations under various global climatic conditions.

2. MODELS AND METHODS

Efficiency figures for installed booster R744 commercial refrigeration systems have been published, e.g. by *Finck et al. 2011*. In order to increase efficiency ambient temperatures above 26 °C two alternative system constellations have been proposed, one utilising a standard refrigeration system for mechanical subcooling, another utilising an ejector assisted parallel compression concept. Based on experimentally based ejector efficiencies and real compressor effi-

Figure 4.
Ejector supported parallel compression system.

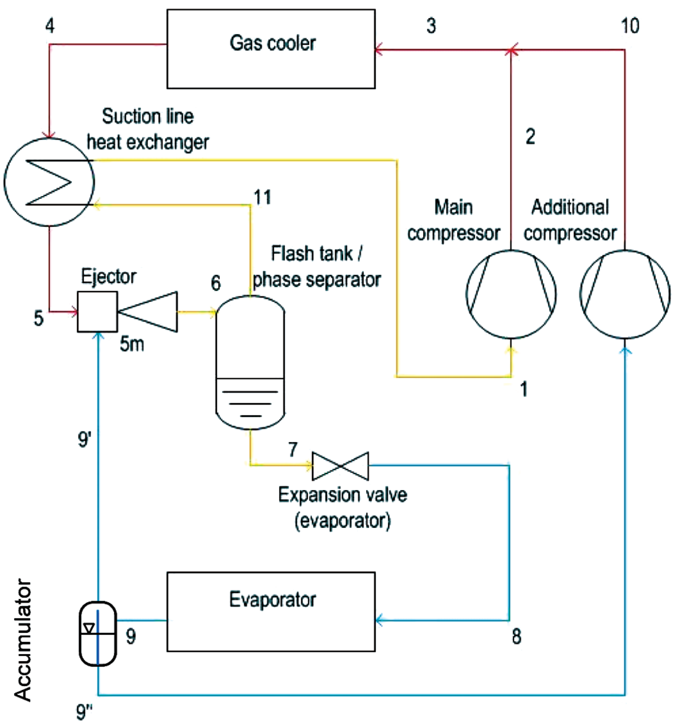
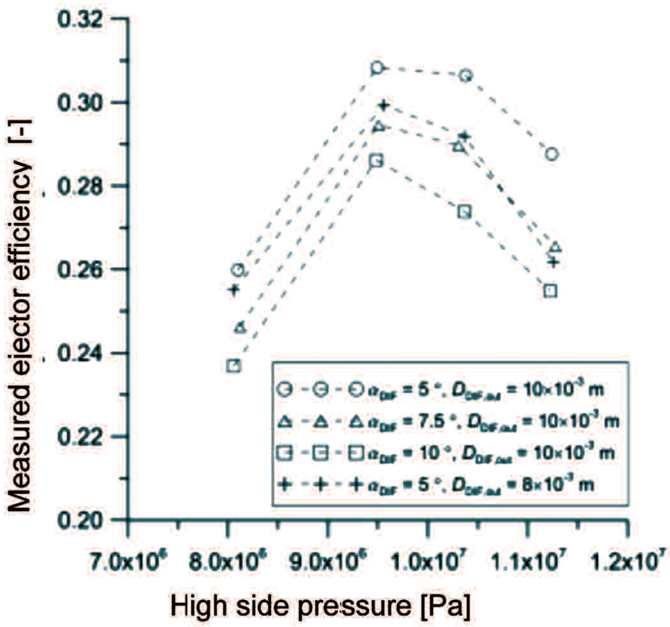


Figure 5.
Measured ejector efficiencies of different ejector geometries.
Banasiak 2012.



ciencies, a simplified model has been used to predict system efficiency figures at different ambient temperatures. These efficiencies has been used to estimate energy use for different Chinese cities based on recorded temperature readings.

2.1 Climate conditions

The meteonorm 7 database was applied to structure the ambient temperature conditions for the

- Four North-American Cities: Chicago, Los Angeles, El Paso and New York.
- Four South-American Cities: Panama, Rio de Janeiro, Santiago de Chile and Punta Arenas.
- Four South-European Cities: Lisbon, Rome, Madrid and Athens.
- Four African Cities: Cairo, Mombasa, Dakar and Cape Town.
- Four Indian Cities: Kolkota, Mumbai, Chennai and New Delhi.
- Four Chinese Cities: Beijing, Shanghai, Guangzhou and Hangzhou.
- Four Australian Cities: Perth, Darwin, Melbourne and Sydney.

Figure 1 shows the temperature bins (5K intervals) indicating the different global climate zones.

2.2 Commercial refrigeration units

The energy efficiency of the different alternative R744 system architectures are compared at high ambient temperature conditions. Only the medium temperature part is shown in the figures, since the low temperature part, i.e. the freezing application will be similar for all configurations.

Boundary conditions and assumptions

The source for the compressor performance characteristics (isentropic efficiency versus pressure ratio) for both the R744 and R290 applications obtained from tables published by BITZER (2010)

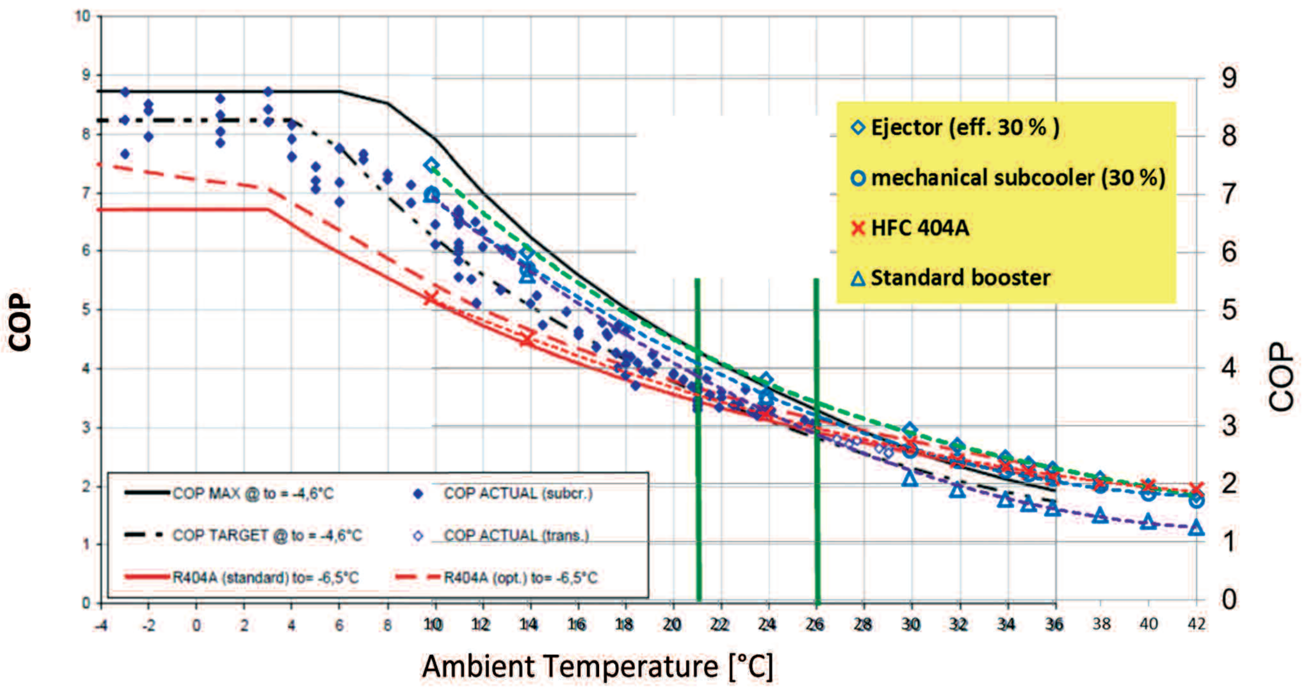
The flash tank (separator) set point is 40 bar, except for the ejector system, due to floating evaporation pressures since no superheat in the evaporators is required.

Figure 2 shows the baseline system, the classic R744 booster system, with a flash gas bypass (9-11) from the separator to the suction line of the compressor via an internal heat exchanger. There are three pressure levels, indicated by the different colours, in a baseline booster system. Most of the currently installed R744 booster systems, mainly in the northern part of Europe, are designed as shown in Figure 2. With this configuration the high side pressure is not present inside the public shop area, i.e. at the inlet of the evaporators inside the display cabinets. The pressure rating of the equipment could be kept below 40-45 bar when this technology was introduced. However, the pressure rating is expected to rise to 60 bar in the near future; one advantage is the additional time between system shut down (power cut) and blow out due to raising stand still pressures. In addition 60 bar systems able to restart themselves after a longer power cut event since the charge is still present, which is essential in rural locations. The COP of the baseline booster cycle is determined by the evaporator cooling capacity divided by the power input to the compressor.

Standard 45 bar R744 booster systems, as described in Figure 2, do have a small capacity subcooling device, cold finger, in case of a system shut down. This unit, connected to the separator, has to maintain a certain system pressure to avoid a pressure rise above the blow out limit of the safety valve.

Figure 6.

COP of various commercial refrigeration systems. Left hand part as presented by Finckh 2011, right hand part as presented by Hafner 2014 for high ambient conditions of R744 units. HFC performance extrapolated towards 42 °C.



The enhanced system as shown in Figure 3, with a higher capacity mechanical subcooling device, is able to significantly reduce the refrigerant temperature downstream of the main gascooler. The mechanical subcooling system represents a practical alternative, lately applied by Carrier in pilot plants in Spain, *Serwas, 2013*. The natural working fluid propane (R290) is applied as the refrigerant in the *"Spanish"* subcooling devices of the R744 booster systems. The condenser of the subcooling device has to reject the heat to the ambient air. 10 K is the assumed required temperature difference in the heat exchangers. In order to calculate the cycle efficiency, two approaches can be assumed:

a) The subcooling device is able to reduce the R744 refrigerant temperature to a given set-point, i.e. 20 °C. (not applied in this study)

b) The capacity of the subcooling device is limited to a certain cooling capacity, i.e. up to 30 % of the total cooling capacity.

The COP of the R744 booster system with mechanical subcooling is defined as the evaporator cooling capacity divided by the sum of power input to the R744 compressor and the R290 compressor.

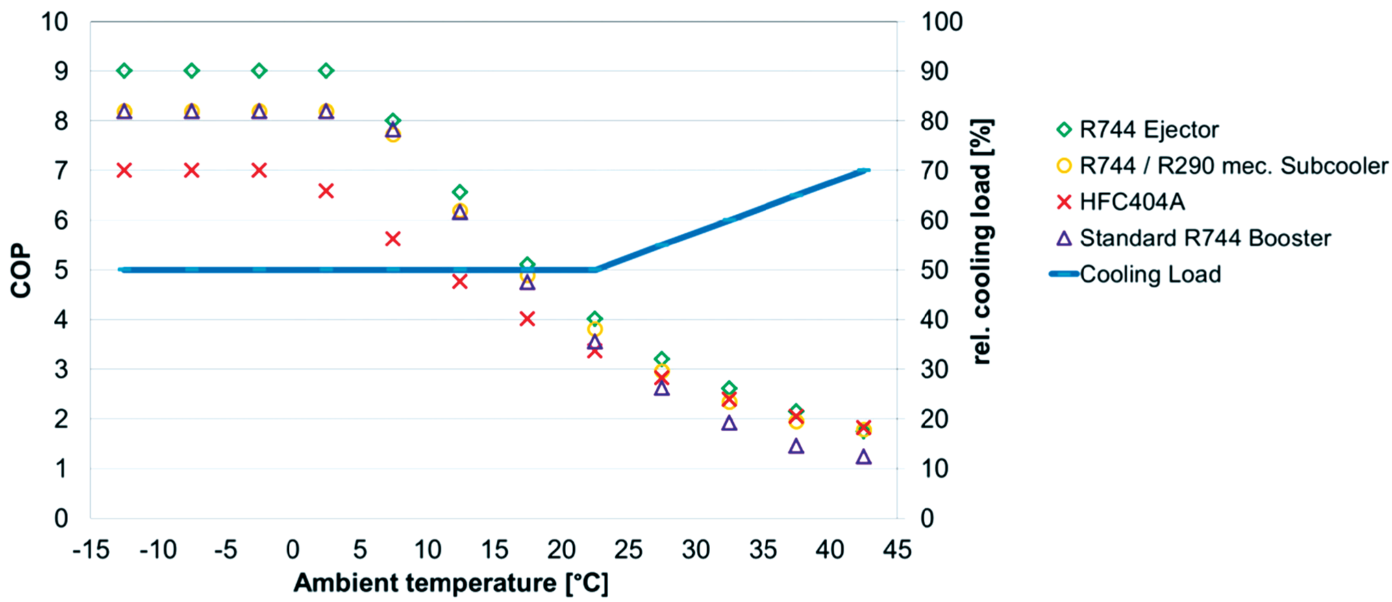
Figure 4 shows the ejector supported parallel compression system as described by *Hafner et al. 2012*. The ejector, utilising the pressure difference usually dissipated in the throttling valve for energy recovery, actively controls the high pressure according to ambient temperature or load requirements, i.e. to operate the refrigeration system at optimum COP. The main compressor is connected to the flash tank (separator) downstream of the ejector. Its suction pressure is therefore between 3 to 10 bar higher compared to an ordinary R744 booster system, *Girotto (2013)*. The ejector is applied to maintain a certain pressure difference between the separator and the accumulator downstream of the evaporators, so that the liquid refrigerant can be distributed to the evaporators in the display cabinets and back to the accumulator.

At low and moderate ambient temperatures the optimum high side pressure is low, i.e. subcritical operation of the R744 refrigeration systems. In this case the pressure lift capability of the ejector is limited, since the available expansion work is reduced. Therefore the additional parallel compressor is connected to the vapour outlet of the accumulator to compress some of the vapour directly to the high pressure side. This reduces the entrainment ratio of the ejectors, which supports the ejectors in operation to maintain the required pressure lift of the refrigerant flow via the ejector into the separator. Priority is given to return liquid refrigerant, so the system is always able to rise the evaporation temperature in the medium temperature evaporators towards -2 °C due to flooded evaporators *(Hafner, Schönenberger et al. 2014)*, this value was applied in this study.

The COP of the ejector supported system is defined as the evaporator cooling capacity divided by the sum of power input to the main compressor and the additional parallel compressor. The ejector efficiency, as shown in Figure 5, is defined as the ratio of the expansion work rate recovered by the ejector to the maximum possible expansion work rate, or the recovery potential. The recovered work is applied to pre-compress the fluid leaving the evaporators back to the phase separator. The upper limit for the ejector efficiency in this study was fixed not to exceed 30%.

Figure 7.

COP of various system configurations and relative cooling load as a function of the ambient temperature.



2.3 Efficiency of commercial refrigeration systems

Figure 6 shows a combination of the field analysis work presented by *Finckh 2011* and the latest simulation result related to commercial refrigeration systems for high ambient temperature locations, by Hafner 2014. The temperature range of the R744 system simulations has been enlarged, i.e. also the system COPs at moderate ambient temperatures have been calculated with the model. Boundary conditions for the R744 system architectures have been adapted, so the simulation results of the baseline R744 booster system matches the performance measured in the field. The same conditions applied for the ejector supported parallel compression system as well as the booster system with a mechanical subcooling unit.

Figure 7 shows the COP values of the different system architectures at the ambient temperatures which represent the mean temperature of the temperature bins shown in Figure 1.

The relative cooling capacity is indicated to be 50 % of the installed capacity when the ambient temperature is lower than 25 °C. At elevated ambient temperatures, the cooling loads of the display cabinets and cold room's increases as assumed and indicated by the blue line.

As shown in the next chapter, the temperature related COP values are multiplied with the number of hours of each temperature bin. The results, the required power consumptions are then summarized to an annual power consumption value.

3. RESULTS AND DISCUSSION

Two different ways to analyse the findings are chosen. Subchapter 3.1 shows a local approach, i.e. one system in each location represents the baseline (100 %) while the annual energy consumption of the alternative system solutions was compared. In subchapter 3.2 the HFC 404A system located in city with the star (*) was chosen to be the reference for the continent. This allows an estimation of climate influence on energy consumption in the commercial refrigeration installations across the globe.

3.1 Local comparison

The annual energy consumption of the HFC-404A system was chosen to be the reference for the comparison of commercial refrigeration units Figure 8 shows that the relative differences in energy consumption are similar when comparing the different locations. However, the Standard R744 Booster system has challenges in El Paso, Rio, Central America (Panama), Africa, India and the Southern part of China as well in Northern Australia, due to the many operating hours of high ambient temperature conditions as also indicate in Figure 1.

At the investigated load conditions and the 12 months operation time, hour by hour, the R744 ejector supported refrigeration systems requires between 72% and 89% of the energy compared to the HFC404A system in the respective locations. The R744 / R290 mechanical subcooled unit requires between 77-97% of the baseline, while a standard R744 booster unit requires between 77-113%.

3.2 Regional differences

Figure 9 shows that the relative differences in energy consumption between the different regions in one continent. The HFC404A systems located in cities marked with'*' are the baseline units for this comparison. Due to the higher number of operating hours at high ambient temperatures, as also indicate in Figure 1, the commercial refrigeration units in the hot climates require more energy, compared to units installed in colder parts of the continents.

The R744 units located in Chicago require only 58% to 65% of the

Figure 8.
Relative annual energy consumption of alternative commercial refrigeration systems. Local HFC systems are set to 100%.

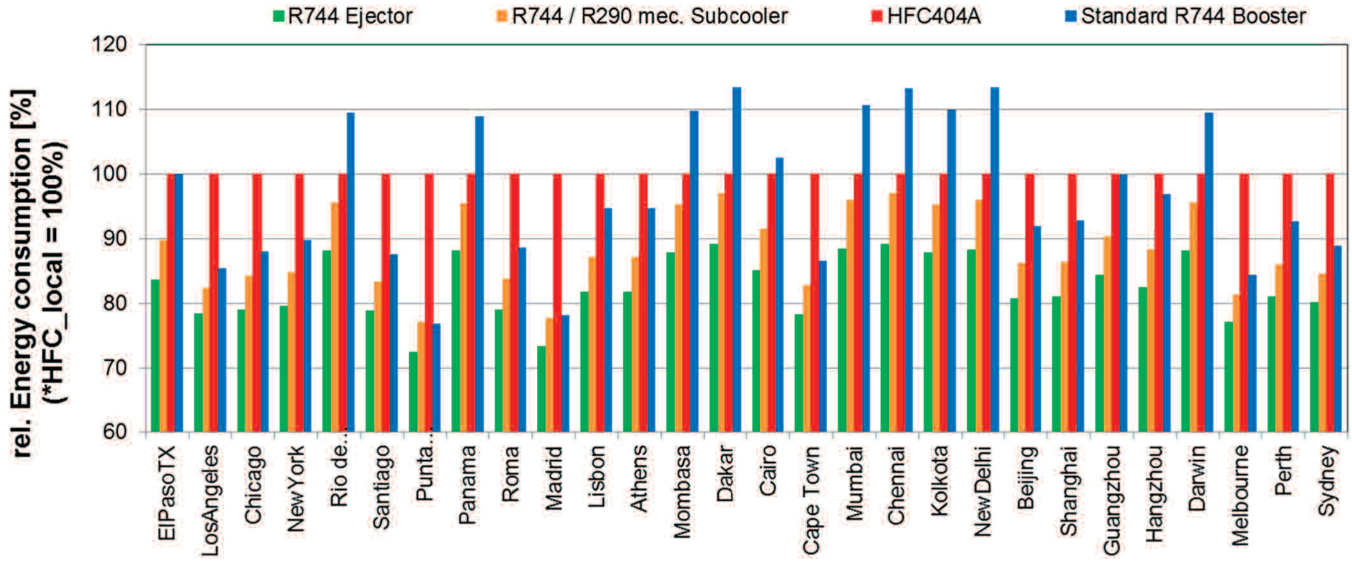
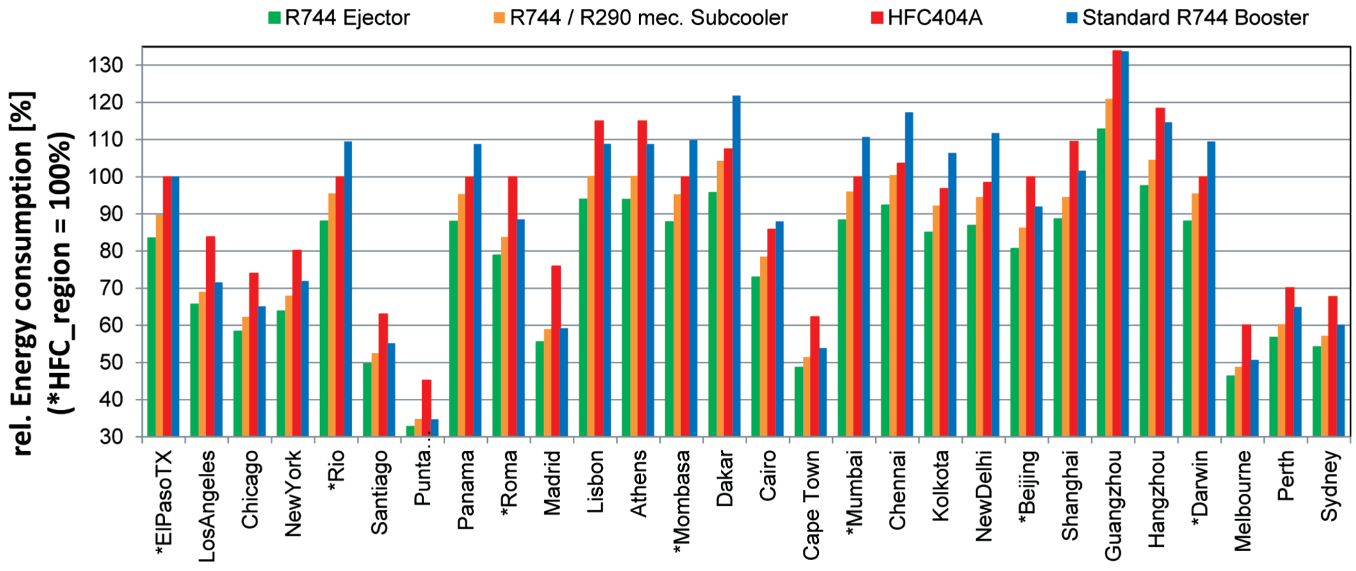


Figure 9.
Relative annual energy consumption of alternative commercial refrigeration systems for four different locations.HFC system located in city (*) are set to 100% for the continent.



HFC404A system in ElPaso, while the local HFC404A unit still would require 74%. The commercial refrigeration units in the northern parts of South America require more energy, compared to units installed in the southern part like Santiago and Punta Arenas.
The commercial refrigeration units located in Roma, Lisbon and Athens require more energy, compared to units installed in central Spain (Madrid).
Compared to the HFC404A unit in Mombasa, the ejector supported R744 unit located in Cape Town requires only 49% of the energy, while the standard HFC404A still requires 62 % in the most southern location of Africa.
In India, the commercial refrigeration units do have almost the same energy consumption, a slightly higher consumption will occur in the southern part of India (Chennai), compared to units installed in the more northern part like Kolkata.
A R744 ejector supported commercial refrigeration unit installed in Guangzhou requires 13% more energy as a HFC404A unit in Beijing. However, the HFC404A unit in Guangzhou requires 34 % more compared to the HFC unit in Beijing.
Compared to the HFC404A unit in Darwin, the ejector supported R744 unit located in Melbourne requires

only 46% of the energy, while the standard HFC404A still requires 60% in the most southern location of Australia. In Sydney the consumption of an ejector supported R744 unit would be 54% and 57% for Perth.

4. CONCLUSIONS AND FURTHER WORK

For Central Europe and the Northern parts the figures would look even more in favour of the R744 units, which are gaining more market shares every year and are the preferred choice of supermarket chains, at least in Scandinavia. The rest of central Europe will follow when the cost of HFC systems will be higher compared to R744 units, as it is the case in Scandinavia.

The relative energy consumption of alternative R744 commercial refrigeration units has been investigated for various global locations. A comparison has been done with state of the art HFC404A units and their performance in the field on an annual approach taking into consideration the local ambient temperatures hour by hour.

Only the energy consumption is investigated. The direct environmental impact related to refrigerant production and leakage was not considered, however, this would add a significant additional negative impact to the HFC units. Compared to a HFC404A unit, R744 ejector supported units with parallel compression do have the highest energy efficiency values, followed by a standard booster system equipped with an external mechanical subcooling system. Energy savings can be obtained in many regions when replacing HFC404A units even with standard R744 booster systems, except areas with a high number of extreme high ambient temperature operating hours.

The first pilot installations of the various alternative R744 system solutions described in this work are under construction or already in operation in Europe. Important practical knowledge will be available within a short time period, so that the decision makers within the leading equipment manufactures can decide which will be the preferred and saleable solution for Southern Europe, Asia, Africa, America and Australia, i.e. regions with high ambient temperature conditions currently mainly not applying R744 technology.

Innovation related to R744 units will support to outperform commercial refrigeration units applying HFC not limited to the GWP issue due to system leakage. More important is the energy efficiency and the life cycle cost of these units, which have to run 24/7 for decades.

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The application of NH_3/CO_2 refrigeration technology of Yantaimoon in China

CHENGCHENG JU

Yantai Moon Co., Ltd. - China

This paper mainly talks about the application of CO_2 in the refrigeration industry in China. NH_3/CO_2 refrigeration system contains of NH_3/CO_2 cascade refrigeration system and CO_2 secondary refrigeration system, it can meet the demand of -52~0 °C.The article show three application cases and how we made good on our promises to meet the requirements of our customers and achieve good energy efficiency.

Keywords: CO_2, NH_3/CO_2 Cascade system, Refrigeration, Cold Storage

1. INTRODUCTION

Yantai Moon is China's leading enterprise in the refrigeration industry, our business scope covers commercial refrigeration, industry refrigeration, central air conditioning, engineering service package and system integration of refrigeration and air conditioning. Due to the security problem of NH_3 and CO_2, in 2006, We began to research and develop the NH_3/CO_2 cascade refrigeration system. We have been concentrating on expanding the scope of application and strengthening the security defense. Also we have shared our experience on NH_3/CO_2 refrigeration system through the national road show in domestic.

The NH_3/CO_2 cascade refrigeration system and CO_2 secondary refrigeration system could be used both alone or through collocation according to the characteristics of each project. In addition, Some project can be configured with intermediate load and hot gas defrosting system. What's more? we also have a variety of cooling methods to choose, such as overhead coil, shelves and cooling fan. Detailed examples are as follows.

2. EXAMPLES

2.1. Refrigeration project in Fengrun

Overview of the project:

Yantai Fengrun Food Co., Ltd. is a corporation with the industry of frozen processing of food such as apples, taros and so on. It has the total GFA of 8,742 square meters, including a 4-floor office building, a one-floor factory building with 3 floors in some parts and a cold Storage with the load of 1000t. The project construction began in February, 2009 and ended in October, 2009.

The main equipment of Yantai Fengrun Food Co., Ltd. is a fluidization IQF device with the temperature inside of lower than -30 °C.

Figure 1. *CO_2 auxiliary unit*

Figure 2. *CO_2 compressor unit*

Figure 3. CO_2 *Auxiliary unit*

Figure 4. CO_2 *barrel pump unit*

The freezing ability is 1500t/h (calculated from green beans) and the heat capacity is 220kW. The cold source is an NH_3/CO_2 cascade refrigeration system. A CO_2 screw compressor with brand LG12R is applied under the designed condition of -40 °C / 35 °C and heat capacity of 240kW. Liquid refrigerant is supplied by pump forced multi-factor system. Cooling is depended on direct cooling method.

When the system steps into commissioning, only buttons of start and stop on the freezer are needed for automation operation with 10% of energy saved, which is highly praised by customers.

Figure 5. CO_2 *compressors*

2.2. CO_2 refrigeration project in Weihai Jiuye

Overview of the project:

Construction enterprise: Weihai Jiuye Warehouse Logistics Ltd.

The project includes two set of NH_3/CO_2 cascade refrigeration systems with the evaporation of -45 °C and -35 °C respectively. The system with the evaporation of -45 °C is composed of two impact IQFs with a plate whose mass flow is 0.5 t/h and a belt IQF as the cold source whose mass flow is 1 t/h. The total cooling capacity demand is 405 kW. The system with the evaporation of -35 °C is composed of a secondary freeze device and a low-temperature buffering room as the cold source whose mass flow is 20 t/h. The total cooling capacity demand is 133 kW. The liquid refrigerant is supplied by a multi-factor liquid supply system circulated by a pump with the direct cooling.

Two CO_2 screw compressors, LG12R, are used in the refrigeration system with the evaporation of -45 °C. It has the designing condition of -45/35 °C and the nominal cooling capacity is 414kW. One CO_2 screw compressors, LG12R, is used in the refrigeration system with the evaporation of -35 °C. It has the designing condition of -35/35 °C and the nominal cooling capacity is 275kW. The two systems benefit from a single CO_2 high-pressure system. The condensate evaporator, LZH140 has the nominal heat transfer area of 140m^2. The reservoir, ZY 2.0, has the nominal volume of 2.0 m^3. A horizontal barrel pump unit, WQFB1200, is utilized in the low-pressure end of -45 °C system while a horizontal barrel pump unit, WQFB900, is utilized in the low-pressure end of -35 °C system.

After the commissioning of the system, it is highly praised by Ministry of Environmental Protection, Chinese Refrigeration and Air Conditioning Industry Association, China Association of Refrigeration, Domestic Trade Engineering Design and Research Institute and honored with 'Demonstration project of substitution technology of NH_3/CO_2 environmental friendly refrigerants'.

2.3. Refrigeration project of Zhangzi Island in Dalian

Frozen shellfish and sea cucumber processing center of Zhangzi Island Group Co., Ltd. constructed by Yantai

Figure 6. *CO_2 refrigeration system with CO_2 as a secondary refrigerant*

Figure 7. *CO_2 Auxiliary unit*

Figure 8. *Corner of CO_2 engine room*

Figure 9. *CO_2 IQF machine*

Moon Co.,LTD is the largest refrigeration system using natural refrigerant thoroughly around China. It is composed of NH_3/CO_2 cascade refrigeration system, NH_3/CO_2 refrigeration system with secondary refrigerants, refrigeration system of R410A with piston compressors paralleled, Chillers of R404A with double late heat exchangers, a heat recycling system of R404A, chillers hanging ice and so on. The system has passed the commission and been transported to clients.

The project is composed of an NH_3/CO_2 cascade refrigeration system with the evaporation temperature of -45 °C as a cooling source for three IQFs, an NH_3/CO_2 cascade refrigeration system with the evaporation temperature of -42 °C as a cooling source for two freezers and an NH_3/CO_2 cascade refrigeration system with the evaporation temperature of -30 °C as a cooling source for three cryogenic freezers.

The whole system is highly praised by Ministry of Environmental Protection and peers. The design agrees with the concept 'Security refrigeration, green refrigeration and low carbon refrigeration' advocated by the nation. It is the first system that is honored with 'Demonstration project of substitution technology of NH_3/CO_2 environmental friendly refrigerant'. As the largest and most advanced CO_2 refrigeration system used in aquatic products processing industry around the country, the delivering of the system is the symbol of the mature and completion and large-scale applications of CO_2 refrigeration equipment of China.

3. CONCLUSION

In this paper three successful application examples about NH_3/CO_2 refrigeration system are shared. NH_3/CO_2 cascade system is a safe, environmentally friendly and energy-saving system. We sincerely share our experience in friendly refrigeration technology and looking forward to cooperation.

International Standards in RAC: Their importance adopting HCFC alternatives

EZRA CLARK

United Nations Environment Programme UNEP

To many in the refrigeration and air-conditioning sector, particularly in the developed world, the whole issue of standards will be so well established that their existence goes without saying. In most developed counties national standards, whether created independently or adopted from regional or global standards, are so well integrated into legislation and practice that they are simply one part of the process of selecting, developing, installing and servicing RAC equipment. This however is not a universal status quo.

By January 1st 2015 under the *Montreal Protocol on Substances that Deplete the Ozone Layer* developing counties will have made the first reduction step in their consumption and production of hydrochlorofluorocarbons (HCFCs). The introduction of alternatives with not only zero ozone depleting potential (ODP) but also low global warming potential (GWP) and improved energy efficiency is becoming an issue of increasing importance, especially in developing countries. UNEP, through its OzonAction Programme (as well as the other Implementing Agencies of the Montreal Protocol's funding body - the Multilateral Fund) is assisting National Ozone Units, the government bodies in developing countries responsible for implementing the national commitments under the Montreal Protocol to make informed decisions about technologies and policies to replace HCFCs, with a particular emphasis on the climate benefits that can be achieved.

HFCs (hydrofluorocarbons), which have a zero ODP but many of which have high GWPs, are still the most commonly used replacement for HCFCs. There are a number of other available replacements. These include 'ozone and climate-friendly alternatives' such as natural refrigerants - hydrocarbons (HCs), ammonia (NH_3) and carbon dioxide (CO_2); and lower GWP HFCs, both saturated HFCs (e.g., HFC-161 and HFC-152a) and unsaturated HFCs (sometimes referred to as hydrofluoroolefins, HFOs, e.g., HFC-1234yf, HFC-1234ze).

It is the responsibility of each country to set up appropriate national legal measures to comply with their commitments under the Montreal Protocol to phase out HCFCs and other ozone depleting substances (ODS). However, in many sectors and individual situations adoption of low GWP alternatives is not completely straightforward as these alternatives can exhibit a range of specific properties which may prevent them from being unconditionally adopted: flammability, toxicity and high working pressures can limit their applicability and require special practices or approaches for safe handling.

Since these characteristics represent a deviation from normal practices, 'standards' can assist with process of application of these alternative refrigerants particularly in developing countries for enterprises that are not necessarily familiar with them and can be very useful tools to assist countries with the introduction of alternatives to ozone depleting substances and related technologies, especially from the point of view of their safe handling and preventing hazards. A 'standard' (sometimes called a 'norm'), is a formal document developed by experts to ensure a certain uniform level of products and services. International standards adapted by countries to suit the national situation, or directly adopted into national legislation, bring with them the great advantage of a tool which is agreed by the consensus of participants of national committees, with the aim of achieving high quality and safety.

International, regional and national standards can provide an easily accessible mechanism and examples for nationally-applicable requirements which could be adapted/adopted in countries for alternatives to HCFCs. Such standards can be useful tools for the introduction of alternatives and technologies for ODS especially through specifying safe handling practices and provision of measures for minimising risks.

Standards can provide the framework and 'insight' as to how alternatives can be adopted with minimal disruption. A national consultation process may be required prior to adoption of a standard to ensure the national context is carefully evaluated in reference to existing standards and that the requirements of all relevant stakeholders are taken into consideration.

For the developing countries which OzonAction works with it is clear that, at present, the issue of adoption and utilisation of appropriate standards in the refrigeration and air conditioning sector is a relatively new or unknown

topic for many of the National Ozone Units.
In the process of the HCFC phase-out, developing countries can take advantage of experiences and lessons learned by the developed countries that have already significantly progressed along the path of HCFC phase-out and in the development and application of such standards. Since the middle of the last century, especially in developed countries, several standardisation organisations were established to produce standards - documents based on consensus of group of participants, to ensure a certain uniform level of goods, products and services quality. Development of new standards and their regular revisions reflect general technological progress, the changing needs and requirements of international trade. Through the voluntary use of standards, producers, users and other stakeholders can assure and be assured of comparable levels of quality around the world.
As alternatives are considered and adopted better engagement with these processes is becoming increasing important and OzonAction is providing assistance to developing countries to increase their understanding of the standardisation process in general and current standards in their particular national context. Guidance is being provided in OzonAction network meetings and information materials as to how to establish a dialogue with the relevant national standardisation bodies to ensure that the relevant standards are adopted and that these will be appropriate to the national context and support their efforts to phase-out HCFCs while adopting non-ozone depleting, low-GWP, energy-efficient alternatives

This short article is based on a recently produced UNEP DTIE concise guide which is intended to provide an introduction to standards and how they can be useful in supporting the adoption of alternatives in the context of the HCFC phase-out in developing countries.
The guide can be downloaded from: http://www.unep.fr/ozonaction/information/mmcfiles/7679-e-International_Standards_in_RAC.pdf

Upgrading skills of refrigeration & air-conditioning (RAC) technicians through training & certification schemes

Becici / Montenegro: The Environmental Protection Agency of Montenegro, the Italian Centro Studi Galileo, the European Association of Refrigeration, Air-conditioning and Heat Pump Contractors (AREA), UN Industrial Development Organization (UNIDO) and the UN Environment Programme (UNEP) concluded the thematic meeting on HCFC phase-out management plans with Montreal Protocol and RAC experts from Albania, Bosnia and Herzegovina, Croatia, Macedonia FYR, Montenegro, Romania, Serbia and Turkey.
Representatives of national RAC associations and RAC experts participate since 2009 in the meetings of the Regional Ozone Network for Europe & Central Asia (ECA network) and they play a crucial role in implementing the national HCFC phase-out management plan. So far, the ECA network supported the creation of national RAC associations in Bosnia & Herzegovina, Croatia, and Macedonia FYR and promoted the strengthening of existing associations.
Mr. Marco Buoni, Vice President of AREA and Technical Director of Centro Studi Galileo, conducted the theoretical and practical assessment under the European Union F-gas regulations for the representatives of the RAC sector. The theoretical assessment consisted of 30 questions about the minimum requirements and competence for personnel to handle F-gases and successful candidates had to achieve a score of 60% of correct answers. The practical part covered 3 different operations:
1) Indirect leak checking through measuring system parameters (temperature, pressure, fluid velocity)
2) Refrigerant recovery including evacuation and re-charging with minimum emissions
3) Building a leak tight piping system.
Mr. Buoni congratulates the 7 RAC experts who successfully passed the test. There were well prepared especially for the theoretical part where they all scored above 83%. The certified experts are now expected to share the acquired skills and information with their colleagues and to promote the adoption of minimum skills & competence of refrigeration servicing technicians in Europe including candidate countries such as Macedonia FYR, Montenegro, Serbia and Turkey. AREA offers assistance to interested countries to establish their certification schemes and to share its experience from implementing similar certification schemes in Europe. Training needs and approaches for the refrigeration servicing sector and the status of implementing of the HCFC phase-out projects where discussed and future priorities identified including the establishment of training & certification schemes for servicing companies and technicians, codes of good practices and equipment log-books, standards for the safe handling of flammable, toxic or high-pressure refrigerants and the destruction of waste refrigerants.
E-learning courses for service technicians are not yet widely accepted but might become cost-efficient tools for up-grading the skills of servicing technicians in future. A commercial e-learning course on the F-gas regulation is now available in English, Russian and Serbian and the real alternatives e-learning course is currently being developed under an EU-funded project (www.realalternatives.eu). Once finalized, the e-learning course will be available free-of-charge. It is structured in seven modules:
1. Introduction to alternative refrigerants
2. System design for alternative refrigerant
3. Containment and leak detection for alternative refrigerants
4. Maintenance and repair of alternative refrigerant systems
5. Checklist of legal obligations for alternative refrigerants
6. Tools for measuring the financial and environmental impact of leakage
7. Templates for conducting site surveys and investigations of existing equipment

Attila Zoltán on the left

Selection of environmentally friendly refrigerants

Tool to Optimise the Choice of the Best Available Refrigerant to Dedicated Application

ATTILA ZOLTÁN[1], **ZOLTÁN MAGYAR**[2]

[1]**Hungarian Coordinating Association of Building Engineering, Budapest, Hungary**
[2]**Technical University of Budapest, Department of HVAC, Budapest, Hungary**

PREFACE

There are always higher importance to choose the most environmental friendly refrigeration, airconditioning and heat pump solution (the optimized refrigeration circuit with the optimized refrigerant, primary and secondary loops, terminals) to a dedicated application. After having optimized the heat loads, the temperature levels, the heat exchange parameters of the evaporator and condenser side, the loops, then one of the most importatnt task of the engineer/designer to choose the optimal refrigeration circuit and finally the optimal refrigerant, which results the lowest total environmental impact in the lifecycle of the application. The normal procedure, when we apply the **Total Environmental Warming Impact**, is he **TEWI**[1] calculation method. Using this method we should calculate (estimate, define) the carbon dioxide equivalent emissions of the application in the whole lifecycle. The TEWI value involves both of the direct and indirect impact of the dedicated solution. To get a proper tool, a better comparision method in relation of environmental impact we should define and calculate the following, different **TEWI** figures for different refrigerants and operating conditions, circumstances:

1. the **theoretical TEWI**, where we sholud calculate with the best available technology, best available refrigerant based on the ideal efficiency (EER/COP) of the comparable refrigeration circuit,

2. the **manufacturers TEWI**, where the “promised or prophetable” impact of the application/equipment should be defined using the EuroVent criteria at different refrigerants, and

3. the **operating TEWI**, where the operating conditions and circumtances define and influenc the real environmental impact of the application.

By comparing the different **TEWI** values to the theoretical (best available theoretical) one, the method results a kind of ranking between evaluated refrigeration circuits using different refrigerants for the same application. These dimensionless factors describe and define the relative environmental impacts of different application.
To get a better picture about the environmental impact of the dedicated application, we can use also so called **Total Environmental Energy Impact** factor (**TEEI** - a kind of reversed **TEWI**, expressed in total equivalent kWh-energy will be used, consumed in the lifecycle of the application) in the same (theoretical, manufacturer, operating) categories. This way we should evaluate the total (virtual and real) environmental energy impact in one step taking into consideration the applyed refrigerants with different Global Warming Potential (GWP) and the different EER values of choosed refrigeration solution (cooling energy generation) for the application.

Keywords – refrigeration; total environmental warming impact; TEWI-comparison; carbondioxide-equivalent;

INTRODUCTION

1. The TEWI calculations

The TEWI method is well-known from the related EN 378 standard. The equation is as follows:

$$TEWI = \underbrace{(GWP \times Q \times L \times N)}_{\substack{DIL \\ \text{Direct Impact/leaked}}} + \underbrace{(GWP \times Q \times (1 - R))}_{\substack{DIR \\ \text{Direct Impact/recovery}}} + \underbrace{(N \times E \times Co)}_{\substack{IDI \\ \text{Indirect Impact/operation}}}$$

Where:

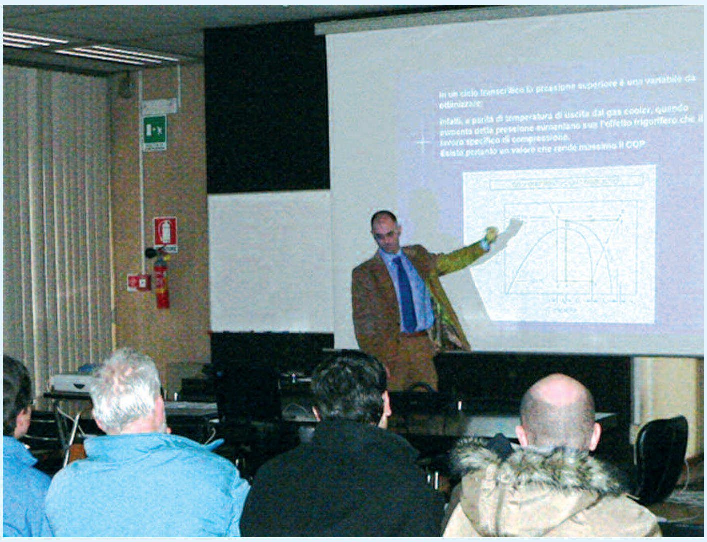
TEWI	Total Environmental Warming Impact, expressed in	$kgCO_2$
GWP	Global Warming Potential of the refrigerant substance expressed in equivalent kg of CO_2 (100 years integrated time)	$kgCO_2$

Q	Charge of refrigerant in the system in kg	kg
L	Leakage rate of refrigerant per annum expressed in % of the charge	%/100
N	Life time of the equipment in year, annum	a
R	% of refrigerant recovered at the end of lifetime	%/100
E	Annual energy consumption of the equipment in kWh/year	kWh/a
	E = C x EER x t, where:	–
	C is the nominal capacity of a refrigeration circuit in kW	kWh
	EER is the Energy Efficiency Ratio (in case of HP is COP= EER+1)	–
	t is the application's average running time h/year	h/a
Co	Specific emission of CO_2 per electrical power generation / kWh in power plants/average in the electrical network, electrical energy production factor	$kgCO_2$/kWh

2. The specific TEWI calculations

Definition of a formula, a characteristic value in relation of the environmental impact of refrigeration, air conditioning and heat pump (RACHP) units/refrigeration circuits taking into consideration the TEWI calculation method should be a dimensionless number, a specific value, a relative proportion based on TEWI calculation method, where we should define, use and compare:

1. The theoretical TEWI, the **$TEWI_{th}$**, the lowest ever environmental impact, based on optimum, theoretical, best vailable criteria, as:
   - ideal efficiency (EER) of the comparable refrigeration cycle, with theoretically best refrigerant,



CSG training on Carbon Dioxide as refrigerant.

   - criteria defined by application fields, similar to "EU Lot-packages" and taking into consideration their criteria,
   - nominal capacities criteria of the circuit at EuroVent conditions/criteria, as theoretical, nominal running hours, operating temperatures, etc.

2. The manufacturers' TEWI, the **$TEWI_{man}$**, the nominal environmental impact, based on pre-agreed conditions, as:
   - EuroVent/Lot/EuP based operating (running hours per year, nominal working temperatures, EER calculation method,..) and
   - European average ($kgCO_2$/kWh, BATs', EER,..., eventually differentiated by geographical zones) values,
   - Or valid for European average conditions.

3. The operation TEWI, the **$TEWI_{op}$**, the real environmental impact, based on Member States' meteorological and any different, dedicated conditions:
   - Member States' operating circumstances (running hours per year, geographical zone temperatures, ..)
   - Member State's average ($kgCO_2$/kWh, operating or seasonal EER, running time,..), or
   - dedicated customer conditions, operation habits.

3. The TEWI factors

Both of the manufacturers' and operation TEWI values can / has to be compared to the only theoretical one, that is the TEWI-factor, the ZOLTANs'-factor!!
There are the opportunities to create different ZOLTANs'-factors (Zf) and the relations between these should be:

$$Zf_{man} = TEWI_{man} / TEWI_{th} \quad (2)$$

$$Zf_{op} = TEWI_{op} / TEWI_{th} = Zf_{man} * TEWI_{op} / TEWI_{man} \quad (3)$$

where:
- the best value should be 1.00 (if we should ever reach the comparable refrigeration circle efficiency in each application field,
- the greater the value, the higher the environmental impact ("wronger", "non-proposed" the application) of the dedicated RACHP application, the refrigeraton cycle,
- having taken into consideration parallel both of the GWP and EER issues and impacts!

Same ZOLTANs'-factors in same applications but for different refrigerants (therefore the relative impacts of applications) should be compared to define the best choice/less environmental impacts:

$$Zf_{R,man} = Zf_{man,\ refr1} / Zf_{man,\ refr2} \quad (4)$$

$$Zf_{R,op} = Zf_{op,\ refr1} / Zf_{op,\ refr2} \quad (5)$$

For a real calculation example see Tablet #1 enclosed. In this case we have make a theoretical comparison between with R410a, R32 and CO_2 charged units. For the calculation of the theoretical TEWI value of the best available system ever we applyed buthane as refrigerant. The manufacturer and operational TEWI calculation relates with R32 filled application under EuroVent criteria. Same calculations have been made for R410a and CO_2 for the comparision of the different applications. The result of the comparison, the relative ZOLTAN-factors show, that in this case and at these circumstances the use of R32 is the most environmental friendly solution in the lifecycle of the dedicated application.

4. The TEEI calculations

One thing is, to reduce the total warming impact of the application, to evaluate the TEWI values by using methods mentioned above. But there are other aspects, too, not only the carbon dioxide equivalent. Not only if we use/take into consideration natural refrigerants (with no direct emission) and no or low fossil-based electricity generation, but in all other cases we should/have to consider and evaluate the energy consumption of the application. To get a better picture we can use a so called Total Environmental Energy Impact (TEEI) factor, a kind of reversed TEWI, expressed in equivalent total kWh-energy used in the lifecycle of the dedicated application in the same (theoretical, manufacturer, operating) categories. This way we should calculate the total (virtual and real) environmental energy impact (consumed energy) in one step taking into consideration the used refrigerant with different Global Warming Potential (GWP) and the worse-good-better EER of the application.

$$\mathrm{TEEI} = \underbrace{\frac{(GWP \times Q \times L \times N) + (GWP \times Q \times (1-R))}{Co_{worst}}}_{Pf_R} + \underbrace{\frac{(N \times E \times Co)}{Co}}_{E_{LC}}$$

Impact (penalty) factor of REFRIGERANTs' **Total lifecycle energy consumption**

The similar investigation for theoretical, manufacturer and operation TEEI should be examine like for TEWI has been made and mentioned above to get an easy tool for energetic evaluation of RACHP solutions to be able to use always the optimal system, the optimal refrigerant.

ACKNOWLEDGMENT

All these ideas and methods derive from the existing F-gas regulation and it's review. There were and probably will be huge debates about the real environmental impact of refrigerants on different trade and committee meetings. Which is more (or absolutely) important? The Global Warming Potential values, the carbon dioxide equivalent, the direct and indirect impacts, energy efficiency, in which cases and which applications, in which countries in which way worth taking into consideration? We tried to create a tool to answer a bit easier the questions have been arisen from the opposite interests of the refrigerant and the equipment manufacturers, the installers and the operators, the politicians and the stakeholders.

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How to optimise the choice of the best available refrigerant to dedicated application??	Version	(4.1)	Budapest, 10092014
*Comparison of the Manufacturers' and/or Operating TEWI values with unified BAT-TEWI, and between!! By using the **ZOLTAN-factor** !*			
Only both of the direct and indirect climate/environmental impacts of stationary and mobile refrigeration, airconditioning and heatpump solutions -charged with fluorinated greenhouse gases- were taken under investigation. Any other health and safety, toxicity and flammability impacts and /or aspects has to be/must be handled separately. See more in the enclosed description!!	Mr.Attila, ZOLTÁN Mr Zoltan, Dr. MAGYAR		HCABE TU, Budapest

TEWI =	(GWP x Q x L x N) +	(GWP x Q x (1 – R)) +	(N x E x Co	R32
*	DIL	DIR	IDI	
	Direct Impact/leaked	**Direct Impact/recovery**	**Indirect Impact/operation**	

			measures	aspects, methods, basic data	OVERALL data		TEWI$_{th}$ theoretical/comparative/BAT?			TEWI$_{man}$ manufacturer			TEWI$_{op}$ operation		
TEWI	*expressed in*		*kg $_{CO2}$*												
GWP	*Global Warming Potential of the refrigerant substance expressed in equivalent **kg of CO2** (100 years integrated time)*		*kg $_{CO2}$*	*rolldown, ICCP figure by type of refrigerant*	R32	670	R...		670			670			670
Q	*Charge of refrigerant in the system in **kg***		*kg*	*manufacturers' data*			Q_{th}		10	Q_0		10	Q_0+Q_{op}	upfill	12
L	*Leakage rate of refrigerant per annum expressed in **%** of the charge*		*%/100*	*rolldown, f(ICCP) by application*			L_{th}		0,04	L_{man}		0,04	L_{op}	by designer	0,06
N	*Life time of the equipment in year, **annum***		*a*	*to be agreed by application*	N	10	N_{th}		10			10			10
R	***%** of refrigerant recovered at the end of lifetime*		*%/100*	*rolldown, f(ICCP) by application*					0,98			0,98			0,9
E	*Annual energy consumption of the equipment in **kWh/year***		*kWh/a*	*to be calculated, as follows*			Ea_{th}		7968,127	Ea_{man}		11428,5714	Ea_{op}		13103,448
	E = C x EER x t, where		_												
	C	*is the nominal capacity of a refrigeration circuit in **kW***	*kWh*	*Eurovent certified*			C_{comp}		40	C_{cert}	Eurovent-certified value	40	C_{op}		38
	EER	*is the Energy Efficiency Ratio (in case of HP is COP= EER+1)*	_	*Carnot?/ comparable? / best available technology?*	butane	5,02	EER_{comp}	best available technology	5,02	EER_{cert}	Eurovent-certified value	3,5	SEER	Eurovent-certified value	2,90
	t	*is the application's average running time **h/year***	*h/a*	*European avarage*	t	1000			1000			1000	t_{op}		1000
Co	*specific emission of CO2 in power plants/average in the electrical network to produce / electrical energy production factor*		*kg $_{CO2}$/kWh*	*European avarage/ MSs/onsite*			Co		0,62	Co		0,62	Co_{op}	on site	0,56

Calculations of the ZOLTAN-factor		TEWI	*	R32										
Manufacturers'			DIL	(GWP x Q x L x N)					2680			2680		4824
Zf_{MAN} =	$TEWI_{man}$ / $TEWI_{th}$		DIR	(GWP x Q x (1 – R))					134			134		804
Operational			IDI	(N x E x Co)					49402,39			70857,1429		73379,31
Zf_{OP} =	$TEWI_{op}$ / $TEWI_{th}$ = Zf_{MAN} * $TEWI_{op}$ / $TEWI_{man}$	Sum							**52216,39**			**73671,14**		**79007,31**
Compared, Relative		**ZOLTAN-factors**		**Zf...**	EER_{BAT}	5,02		Zf_{BAT}	**1,0000**		Zf_{MAN}	**1,4109**	Zf_{OP}	**1,5131**
Zf_R =	Zf_{refr1} / Zf_{refr2}	**relative ZOLTAN-factor ZfR**		**CO_2**	EER_{CO2}	2,69								
				R32 compared to CO2	EER_{410a}	4,41			**na**			**0,90459551**		**0,66628**
				R32 compared to R410a	EER_{32}	4,5			**na**			**0,81026099**		**0,86895**

Renewable Energy and Energy efficiency A game-changer

Solar Powered Future of Energy efficient, Low-and-Zero GWP refrigeration and air conditioning technologies

RAJENDRA SHENDE

Chairman TERRE Policy Centre and former Director UNEP

BREAKING THE RECORDS AND MISSING THE GOALS

9 May 2013 was a different day for the two teams of scientists at the Mauna Loa Observatory in Hawaii. One was from U.S. National Oceanic and Atmospheric Administration (NOAA), the other from the Scripps Institution of Oceanography working independently. They have been measuring carbon dioxide concentration there for decades, and have watched the level inch toward a new milestone. On that day they **recorded a long-awaited climate milestone: the amount of carbon dioxide in the atmosphere there has exceeded 400 parts per million (ppm) for the first time in 55 years of measurement—and probably more than 3 million years of Earth history**. The camels lived in the Arctic when the last time the concentration of Earth's main greenhouse gas reached this mark. At the sea levels 30 feet higher at that time of period of Pliocene, today it would inundate major cities around the world. The planet was about 2 to 3 degrees Celsius warmer, the temperature at which the world is trying to contain the temperature-rise, not as determined goal but as helplessly marked self-pronounced goal.

Only difference is that the CO_2 concentrations were on their way down at that time. This time, 400 ppm is a milepost on a far more rapid uphill climb toward an uncertain climate future. Both teams converged on the reading on famous Keeling Curve: it showed a concentration of 400.3 PPM.

The milepost was regretted but the climb is continuing like never before. Since then even monthly average has crossed 400 ppm in May 2014. And we may as well have annual global average crossing 400 PPM in 2014 if WMO's announcement of unprecedented annual rate of rise in Green House Gases is to be believed.

World has not only noted these records with regret but have also observed that the 12 hottest years on record since the measurements of GHG started, all occurred in the last decade and a half.

The unfolding story of missed targets of reducing emissions GHGs by 5 percent by 2012 is frustrating. The target is not only missed but the world increased GHG emissions almost by 40 percent as compared to 1990 level. The warming continues. As per IPCC's fifth assessment report called AR5, the world is ill prepared for catastrophic risks from a changing climate. What next?

REFRIGERATION AND AIR CONDITIONING SECTOR IS A LIFEGUARD

IPCC's AR 5 also states that there are opportunities to respond to such risks. RAC sector stands as lifeguard tower to save the world, if the appropriate actions are implemented globally. Such actions do not exclude the actions to reduce CO_2 and other non-CO_2 GHGs. Like lifeguard, though, it can prevent the dreadful consequences.

Montreal Protocol on substances that deplete the ozone layer has succeeded in phase out of Chlorofluorocarbons (CFCs) and other more than 90 chemicals. It is now implementing phase out of Hydrochloroflurocarbons (HCFCs) used mainly, like CFCs, in refrigeration and Air-Conditioning (RAC) sector. These gases are also powerful Green House gases with their Global Warming Potential (GWP) far higher than CO_2. Their phase out has already contributed to reducing GHGs in the atmosphere and pushed back the adverse impacts-like seal level rise and earth surface temperature rise- by nearly 10-12 years.

What more, RAC sector also holds promise to further push back the adverse impacts arising out of rise in emissions of GHGs if the low or Zero GWP alternatives to present high GWP refrigerant are deployed. If the technologies that could improve the energy efficiency of the appliances and equipment using such alternatives are commercialized the adverse impacts could be delayed further by a decade. And, to top it all if the renewable energy like solar energy can be used to power the RAC, not only we would be able to get further –not yet measured but-immense advantage of GHG reductions but also save money, reduce the air pollution, improve the health and help reducing poverty and meeting the Millennium Development Goals (MDGs) and the subsequent yet to be formalized Sustainable Development Goals (SDGs).

HFCs: OPPORTUNITY TO RETRACT AND TAKE THE RIGHT PATH

HFCs are the fastest growing greenhouse gases in much of the world. As per 2014 UNEP/WMO Science Assessment Panel the global emissions of HFCs are increasing at the rate of 7 percent. The industry estimates that globally the production of HFCs is increasing at a rate of 10-15% per year. HFCs are manufactured in chemical industry and used mainly in in air conditioning, refrigeration and foam insulation.

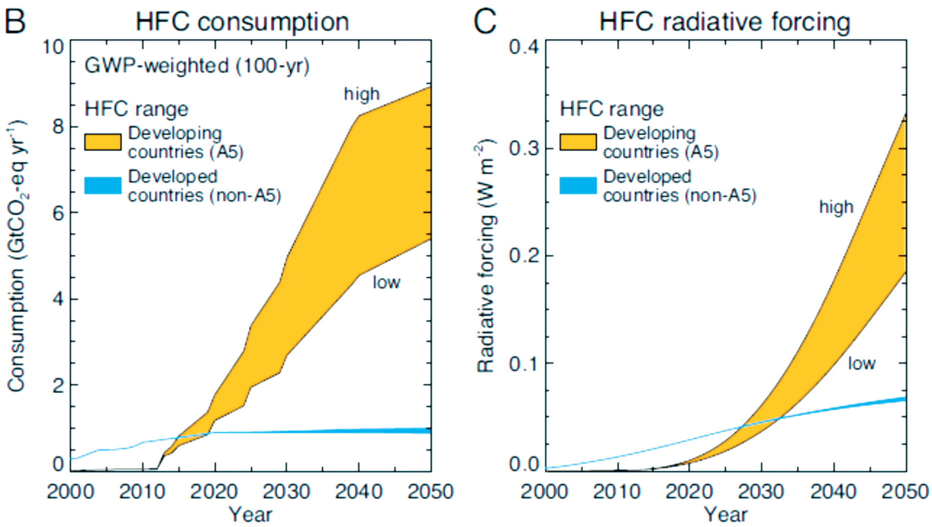
HFCs are invented and commercialized in 1990s as ozone-friendly alternatives to CFCs and HCFCs. Their high Global Warming Potential was known right from its invention and was first officially recorded by IPCC in 1990s. However the world community decided to adapt to HFCs because it was good alternative to solve the Ozone depletion issue. Indeed, the world at that time did not spend time and money resources to develop the alternative that are ozone and climate friendly except deploying natural refrigerants like hydrocarbons, ammonia each of which had health and safety issues. Hence they were used in in limited way.

Recognizing that continued growth in HFCs will add up to 0.1 °C of global average temperature rise by mid-century, which will increase five-fold to 0.5 °C by 2100, World leaders recognized the threat posed by the growth of HFCs in the outcome document of the Rio +20 Summit in 2012 and called for the gradual phase-down of their production and consumption. Without fast action, by 2050, uncontrolled growth in HFCs would cancel much of the climate benefit achievable under an aggressive CO2450 ppm mitigation scenario.

Phasing down HFCs will be indeed the start of correcting the delay in developing non-HFC alternatives. It would also set the world on the path of avoiding up to 0.5°C of warming by 2100. Avoiding this warming is essential for staying within the long-term international goal of stabilizing global temperature rise at or below 2 °C over pre-industrial temperatures by the end-of-century.

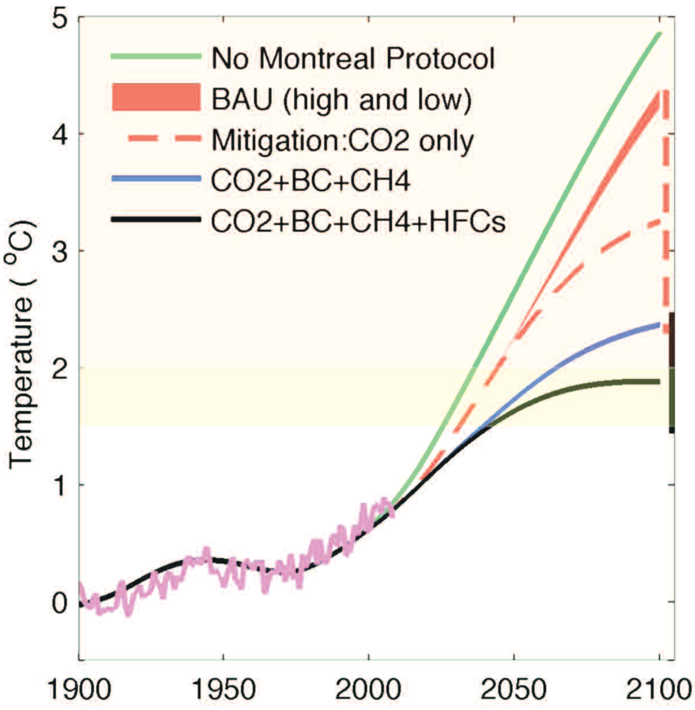
Phasing down HFCs will also prevent the equivalent of up to 8.8 billion tonnes of CO_2 per year in emissions by 2050. The cumulative total by 2050 will be equivalent to 100 billion tons of $CO_{2\text{-eq}}$ in avoided emissions (with a range of 76-134 billion). The lifeguard, however, has potential to go far in to save the situation. That potential is due to proven prowess of RAC i.e. enhancing the Energy Efficiency.

Projected growth in HFCs and climate forcing from emissions



Velders G. J. M. et al. (2009), The large contribution of projected HFC emissions to future climate forcing, Proc. Nat'l. Acad. Sci. USA 106:10949.

21st Century warming prevented by SLCP and CO_2 mitigation



Xu Y., Zaelke D., Velders G. J. M., & Ramanathan, V. (June 2013) The role of HFCs in mitigating 21st century climate change, Atmos. Chem. Phys, 13:6083-6089.

ENERGY EFFICIENCY: PROWESS OF RAC SECTOR

The phase-out of CFCs under the Montreal Protocol, which began in the mid-1980s, catalyzed substantial improvements in air conditioning and refrigerant energy efficiency—up to 60% in some subsectors. These efficiency improvements were the result of replacing old products and equipment with a new generation of higher efficiency machines. When refrigeration and air conditioning manufacturers redesigned their systems to be CFC-free, many took the opportunity to improve the efficiency of their designs. For example, the U.S. Environmental Protection Agency estimated that CFC-free chillers were up to 50% more energy efficient in the U.S. and over 30% more efficient in India than the CFC-based machines they replaced. In the case of Domestic Refrigerators, it was indeed a silent revolution. It went unnoticed that The energy efficiency gains were more than 50 % and individual consumers and families benefitted by the saving of money.

These energy efficiency advantages in RAC sector were not intended under the Montreal Protocol, which had a focused objective of phasing out of Ozone Depleting substances. However industry, when challenged to change the technology, it also upgrades it by summoning the inherent potential it has to innovate.

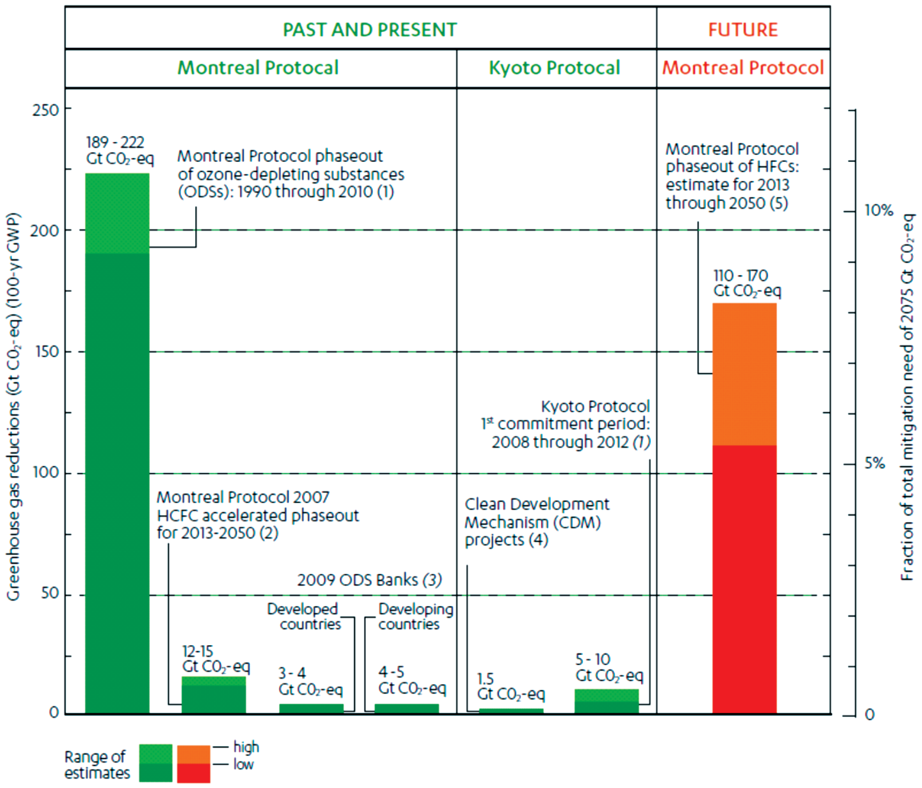
Similar energy efficiency improvements are expected with an HFC phase-down. A number of global companies that are already transitioning away from HFCs, report significant gains in energy efficiency. For example, the companies were inspired to innovate under UNEP supported Refrigerants Naturally coalition, the Coca-Cola Company and PepsiCo have both reported energy efficiency gains of up to 47% in their new CO_2 and hydrocarbon-based refrigeration equipment over baseline HFC-based models.

Global supermarket chains Tesco and Unilever both report a 10% gain from new hydrocarbon based commercial refrigeration equipment and freezer cabinets over HFC-models.

Although there have already been improvements in the efficiency of air-conditioning and refrigeration equipment over the last several decades, substantial potential still remains. For example, a 2013 assessment by the Super-efficient Equipment and Appliance Deployment Initiative (SEAD) found that deploying superefficient air-conditioners can significantly reduce energy use and CO_2 emissions by 2020 and avoid the need for additional power plants, with the largest potential savings in emerging countries like India, China, and even in the EU.

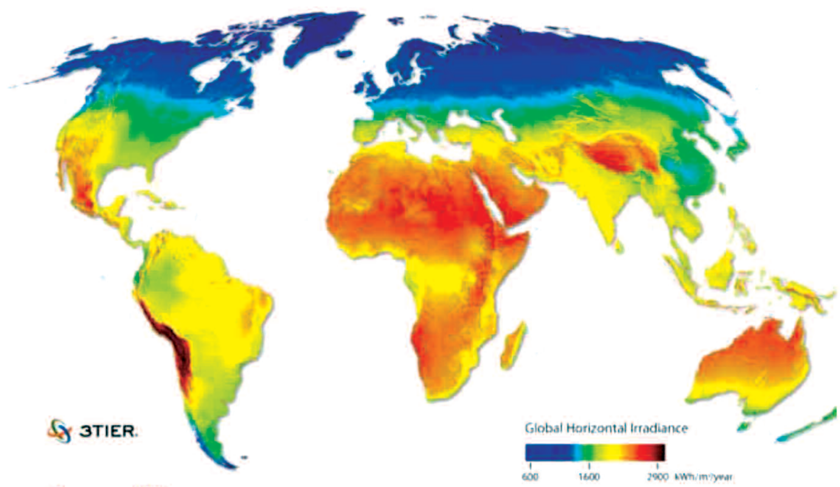
A recent study by the U.S. Department of Energy's Lawrence Berkeley National Laboratory calculates that, in India alone, the potential energy savings from improving the energy efficiency of room air conditioning could avoid the equivalent of 120 new medium-sized coal power plants of 500 MW each by 2030. The energy efficiency gains catalyzed by the HFC amendment will have the added benefit of easing pressure on aging electricity grids, especially in developing countries where air conditioning use is growing rapidly.

Climate protection of the Montreal Protocol and the Kyoto Protocol

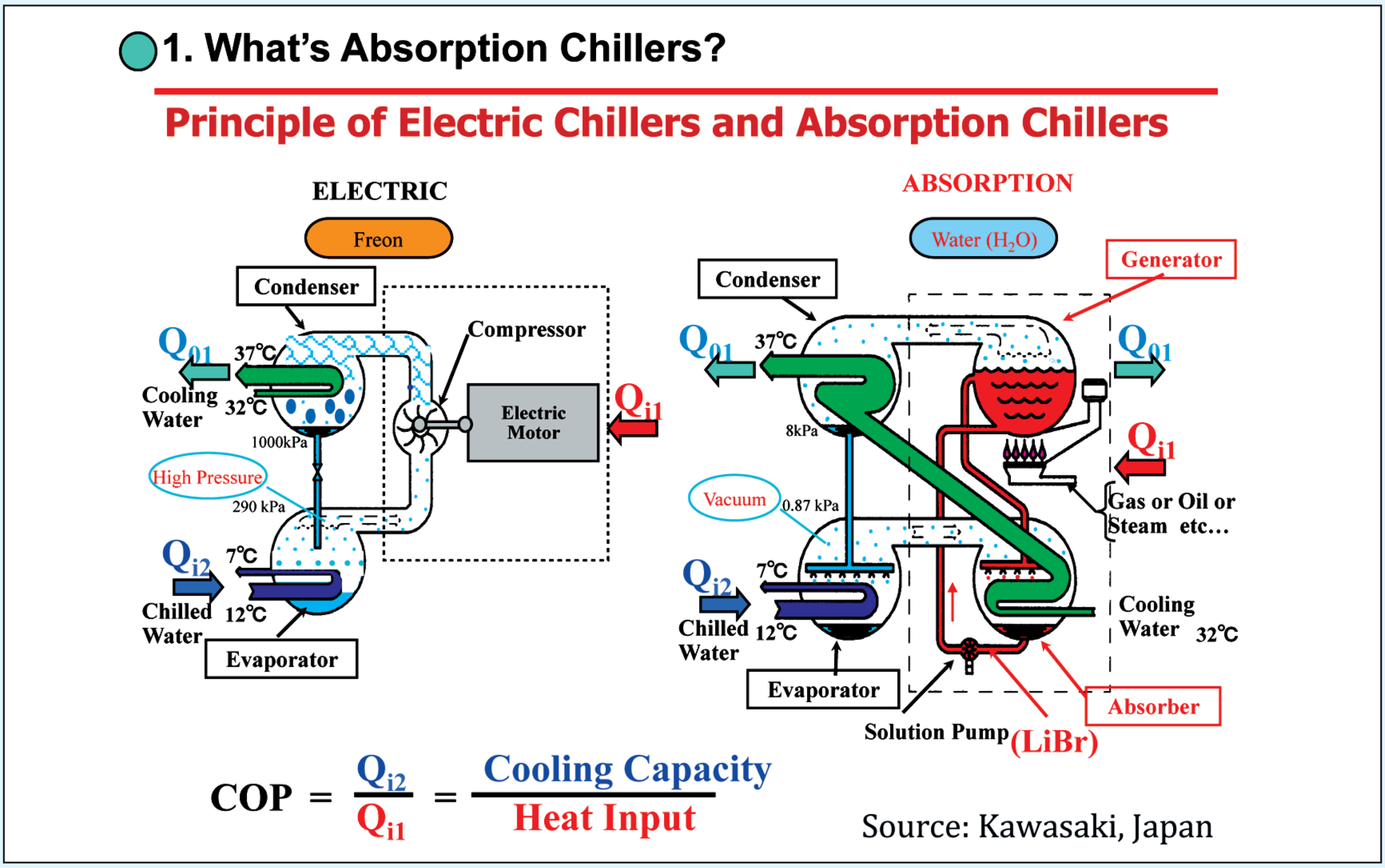


UNEP (2012) The Montreal Protocol and the Green Economy: Assessing the contributions and co-benefits of a Multilateral Environmental Agreement.

Satellite-derived solar resource map



Source: 3Tier.



In many cities in India, for example, air conditioning accounts for 40 to 60% of peak electricity demand during the summer months. While the efficiency gains also would lower the cost of operating the equipment and save consumers money, the efficiency gains have one more advantage for the emerging country like India who is struggling to meet the demand and supply of the electricity to its 1.25 billion people. The peak demands, particularly in summer, far exceed the supply from India's power plants.

This is mainly due to millions of the room and commercial air conditioning machines that need to cool the houses and buildings. As India emerges as nation of 'middle-class' families, the room ACs is common white goods desired by the Indians. And more and more Indians buy the ACs that strains India's grids during the peak demand. In year 2013 summer, more than 300 million people in the north India were deprived of electricity due to grid failure, a largest grid failure in the history of the world. Enhanced energy efficiencies in RAC would certainly avoid such failures which also lead to loss to India's GDP.

RENEWABLE ENERGY IN RAC: CROWN OF THE LIFEGUARD TOWER

Phasing down high GWP refrigerants like HFCs, enhancing the energy efficiency in RAC are the strategic mapping elements in ' climate war room'. It would win the battles. But not the wars. But what will take us closer to winning war would be the use of renewable energy globally. RAC sector, which contributes most to the energy consumption in the buildings that by themselves consume 40 percent of all the energy that world needs, have the potential to deploy the renewable energy in big way. International Institute of Refrigeration has estimated that nearly 15% of all the global electricity use goes into RAC sector. Replacing it by renewable energy step by step would put the world into the carbon neutral path.

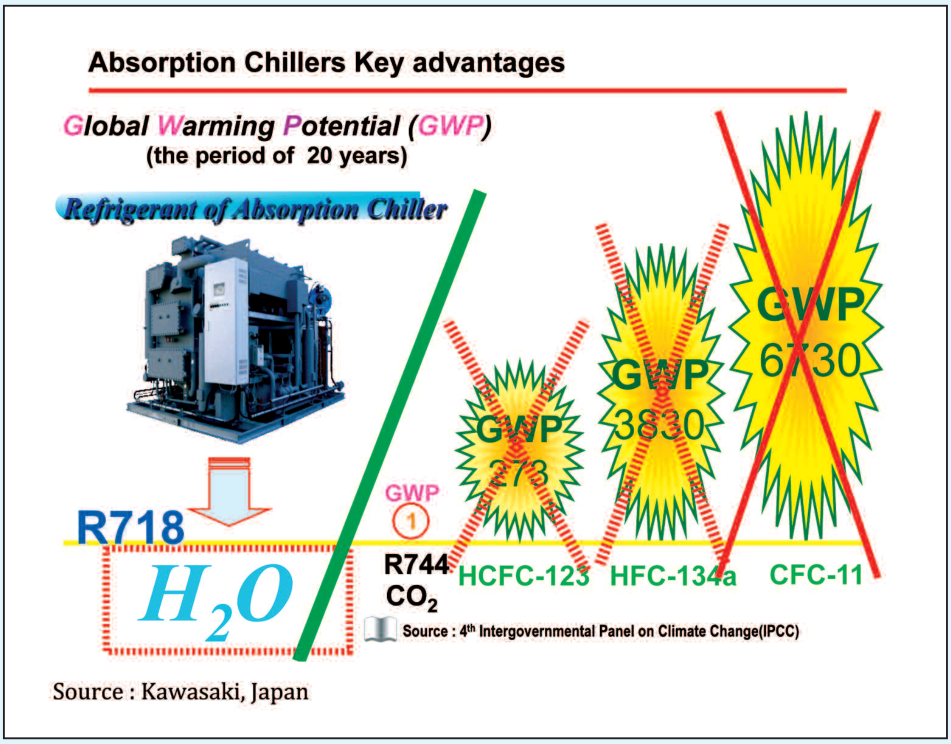
It is interesting that the geographical area where Sun shines most of the time are obviously have warm or hot climate requiring more refrigeration and Air-conditioning. Why not then use that solar energy for needed cooling?

In the past, solar water collectors were installed for the main purpose of pre-heating domestic hot water or to cover a fraction of the space heating demand. However, solar cooling systems were first constructed just for demonstration purposes, by using solar energy for heating the fluid that is then used in absorption-cooler using ammonia water or LiBr-water systems. Such arrangement avoids use of vapor compression cycle and also the refrigerants.

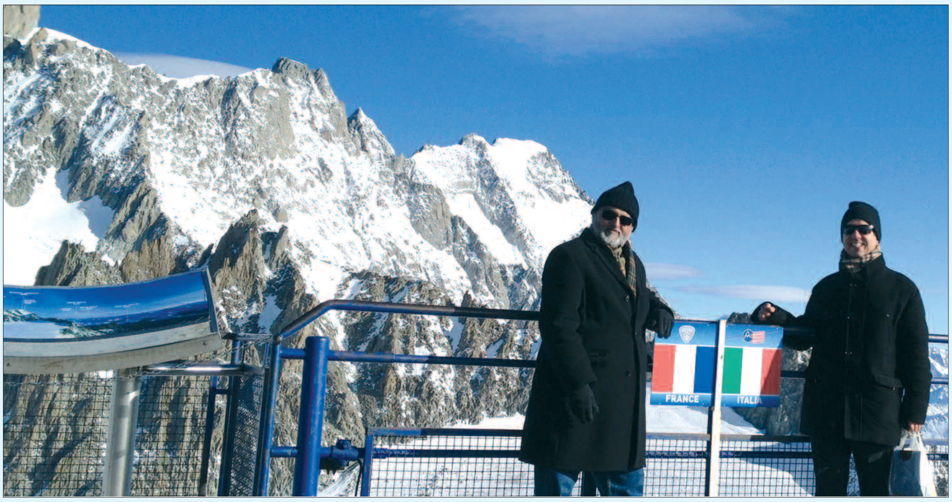
Currently, absorption chillers are the most common thermally-driven cooling process in solar cooling installations. Common absorption cooling pairs include ammonia-water and water-lithium bromide, with many sorption chillers available commercially over a range of capacities, but few at capacities of 100 kWh or less. The so-called "single effect" absorption chillers typically need heat with temperatures in the range of 70 to 100 °C, and achieve a Coefficient of performance (COP) of about 0.7. Adsorption chillers are able to work at lower temperature ranges (down to 55 °C), however this leads to an inferior COP (nearly 0.6).

"Double effect" absorption chillers achieve higher efficiencies by using

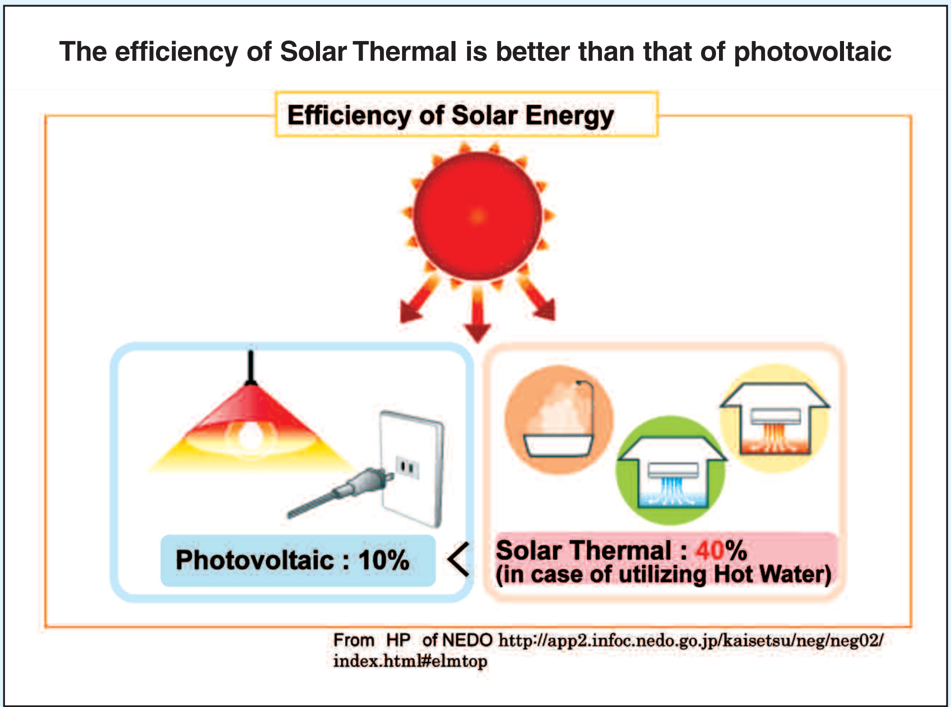
two thermal generators operated in series, which work at different temperatures. This arrangement allows a higher COP, in the range of 1.1 to 1.2, however higher driving temperatures in the range of 150 to 180°C are required. The higher driving temperatures necessitate a more complex collector technology.
These systems are only available for large capacities, of 100 kW and above. Recently triple effect cycles have entered the market, achieving COP values in the range of 1.6 to 1.9 and requiring driving temperatures of 200 °C to 250 °C.
Beyond thermal efficiency of the chillers, another important figure for solar thermal cooling efficiency is the COP, presenting the overall solar cooling system electrical efficiency: the ratio of “produced” cold per unit of electricity that is needed to run the full system (mainly pumps and fans).



Kawasaki in Japan, Robur in Italy, Thermax in India and Broad in China are the leading developers and manufacturers of Solar based cooling systems. Many others are developing the systems in these countries.
Even in China, since the building of the first solar-powered absorption cooling system in Shenzhen in 1987, there have been over 10 additional solar cooling demonstration projects constructed. Solar absorption cooling systems have been shown to be more suitable for large building air-conditioning systems. Comparatively, solar adsorption cooling systems are more promising for small size air-conditioning systems. Highly efficient heat pumps are considered as the most appropriate auxiliary heat sources for solar cooling systems, for the purpose of all-weather operation. Both China and India are developing and commercializing large solar cooling systems supported by gas based heating to provide heat when there is no sun.
As per the latest statistics of the International Energy Agency, Solar Heating and Cooling Programme (IEA SHC) released in 2014, worldwide solar heating and cooling commands a growth off 9.4% in 2012, the installed capacity of solar collectors reached 269 GW. Share of BASIC (Brazil, Argentina, South Africa, India and China) countries is more than 90 percent. The collectors provided 228 TWh of solar thermal energy, thus saving 79 million tons of CO_2 emissions.
Most (87%) of the solar systems provide domestic hot water only. However, in some countries, combisystems, which provide hot water and space heating, have become a major part of the market. Industrial applications, district heating and air conditioning, too, are all growing solar thermal applications. Taken together, combisystems and other applications beyond domestic hot water reached 13% of installed systems in 2012. It can be guessed that solar heating systems used for cooling purposes would be less than 10 percent of the 269 GW of solar heating capacity.
Investment costs for solar cooling are difficult to assess due to the emerging status of the technology – limited experience and a high proportion of demonstration projects, which may include a large amount of R&D funding. Despite This there are a number of available examples of solar cooling installations that have been realized without subsidies, e.g. in tropical regions with high electricity costs.



About the top picture on the back cover the image of Monte Rosa mountains. The picture with Rajendra Shende and Marco Buoni above shows Mont Blanc montains and illustrates:
*– **Ozone protection** the blue sky our Earth’s ozone shield*
*– **Climate Change** the Global Glacier retreat is a global threat due to global warming*
*– **Renewable Energy** the water is a primary font of energy for our hydroelectric plants*



Estimates of solar cooling investment costs for medium to large systems range from USD 1 600/kW cooling to USD 3 200/kW cooling

China, who is rapidly becoming the world's leader in renewable energy development has just unveiled the world's first air conditioned unit powered by solar

Energy. The Shandong Vicot Air Conditioning unit also allows for 24-hour continuous cooling, heating, and supply of hot water, while natural gas can be used as a supplemental energy supply, so during periods of poor sunshine, heating and cooling can still be provided. Sunlight hits two thirds of the China's surface area and annual solar irradiance exceeds 2,200 hours – optimal conditions for any national solar endeavor. Use of solar electricity to run RAC systems like absorption coolers has been proposed. However, following figure shows the advantage of solar thermal vs solar PV.

WHAT NEXT

By 2050, solar energy could annually produce 16.5 EJ (1 EJ = 1018 Joule) of solar heating, more than 16% of total final energy use for low temperature heat, and 1.5 EJ solar cooling, nearly 17% of total energy use for cooling. For solar heating and cooling to play its full role in the coming energy revolution concerted action is required by scientists, industry, governments, financing institutions and the public. This roadmap is intended to help drive these necessary developments. International Agencies including United Nations agencies, International Energy Agencies International Solar Energy Society (ISES), the International Association of Plumbing and Mechanical Officials (IAPMO), ISO TC 180, the European Solar Thermal Industry Federation (ESTIF) and the European Technology Platform on Renewable Heating and Cooling will have to collectively come together to make the change happen.

SOLAR ENERGY COULD MEET ONE-SIXTH OF GLOBAL DEMAND FOR HEATING AND COOLING IN UNDER 40 YEARS

The International Energy Agency Solar Heating and Cooling Programme (IEA SHC) is one of over 40 multilateral technology initiatives of the International Energy Agency. Its current mission is to *advance international collaborative efforts for solar energy to reach the goal set in the vision of contributing 50% of the low temperature heating and cooling demand by 2030.*

Investing in a broad range of solar heating and cooling technologies could save another 800 megatonnes of CO_2 emissions per year by 2050 as per IEA apart from gains from HFC phase down and enhanced efficiency of the RAC sector.

While cooling today makes a modest contribution to world energy demand, the roadmap envisages that if governments and industry took concerted action, solar energy could annually produce more than 16% of total final energy use for low-temperature heat and nearly 17% for cooling. This would correspond to a 25-fold increase in absolute terms of SHC technology deployment in the next four decades.

Key actions include creating a stable, long-term policy framework for solar heating and cooling; creating global network of research and development institutes and industries, developing collaborative programmes between developed and emerging economies on research and development, pilot and demonstration projects, introducing economic incentives; and addressing barriers such as a lack of quality-control standards.

Rajendra Shende, graduate of IIT-Bombay, India is Chairman of TERRE Policy Centre and former Director of UNEP. He was coordinating lead author of IPCC's 2007 AR4 and Expert Reviewer of 2014 Scientific Assessment Panel. He was also a member of Steering Committee of UNEP on "HFCs: A Critical Link in Protecting Climate and the Ozone Layer".

He has installed the first ever room AC and domestic refrigerator in the Rural Demo Unit of TERRE Policy Centre in India that works on solar energy and uses Hydrocarbons with low ODP and near zero GWP.

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Peter W. Egolf

Breathing building: A decentralized façade-integrated solar air-conditioning system

PETER W. EGOLF[1], ARSENE N. NOUME[2], DIDIER VUARNOZ[1], GREGORY GOTTSCHALK[3]

[1]University of Applied Sciences of Western Switzerland
Thermal Science and Engineering Institute, Yverdon-les-Bains, Switzerland
[2]Institut National des Sciences Appliquées, INSA
Ecole publique d'ingénieurs et d'architectes, Strasbourg, France
[3]IQAir AG, Goldach, Switzerland

A decentralized adaptive solar air-conditioning system is presented, which contains usual air-conditioning equipment and a new module, designed with a honeycomb structure, containing phase change material for latent thermal cold and hot energy storage. Heat recovery devices are responsible for higher system efficiency. A low-cost configuration and a multi-function deluxe version are presented, where in the second case a (magnetic) heat pump, a (magnetic) cooling device and an evaporative apparatus are added. Whereas the simple configuration is of medium cost and shows a good energy saving potential, the deluxe version is more expensive, but, on the other hand, is designed to show a higher energy saving potential. It is also expected to yield exquisite indoor hygienic and climatic conditions.

1. INTRODUCTION

In previous times in its housings a building façade usually had a high thermal capacity and by this showed a large cold and heat storage capacity and could improve the indoor climate positively by large phase shifts of the temperature of one to several days and by substantial temperature amplitude reductions.
With the development of large and high buildings, centralized air-conditioning systems were developed, which, by a centralization of the air handling processes in a central unit, can be more economic, if the buildings are compact and the rooms that require air conditioning are laying not too far apart. Most content in standard air-conditioning handbooks focuses on this main type of system (ASHRAE, 2013, Schramek et al., 2008).
Already before, but especially from the 1960's – with the occurrence of cheaper construction of domestic houses and office buildings with a fast response on internal sources and outdoor weather changes – a tremendously high number of (cheap) air-conditioners were installed, containing each an entire small air-conditioning system mounted to or integrated into the building façade (see Figure 1).
Energy consumption was not much considered, and these units were/are very energy consuming. Then in the last decade, big efforts were undertaken, especially in Germany, to develop high-quality and energy-saving decentralized air-conditioning systems. An example is the 535-feet-tall Post Tower, the tallest office building in the German Federal State of North Rhine-Westphalia. It contains floor units, taking fresh air from the space between the building and a covering glass façade. The air is then individually conditioned and blown into the back laying office rooms (see Figure 2).
The parallel researches and developments of passive and active solar energy devices and systems, as e.g. photovoltaics, thermal opaque, semi-transparent or translucent façade systems, double skin façades, mechanically ventilated solar façades, etc., and those of modern decentralized air-conditioning today are merging together. Examples of utilizing passive solar thermal energy, for example by applying the technology of phase change materials, has been studied and reviewed (see e.g. Mehling and Cabeza, 2008).
The authors of the present article have also strongly contributed to this development with some new ideas as a solar heating and storage façade (Manz et al., 1992), a translucent heating and day-lighting façade (Manz et al., 1997) and another application, which is a system lowering and phase shifting the temperature profiles in Minergie® houses by the application of phase change material storages (see Muriset et al., 2009, 2010). A direct continuation of these system ideas and the work of the Swiss research group is the modern decentralized façade-integrated solar air-conditioning system presented in this article (for more scientific and technical information consult Noume, 2010).
Depending on the geometry and other parameters of the building, architects, building and air-conditioning engineers, etc. must take at the very beginning of a building design process the decision, based on criteria of economy, energy consumption, esthetics of the façade, etc., between the two basic alternatives, which are the centralized and the decentralized air-conditioning system. Important help in such a decision process, for example, may come from comprehensive studies with comparisons

Figure 1. *Split systems are façade air-conditioning systems with a condenser each mounted externally to the room for which they are active. Reference: Split System, 2014.*

Figure 2. *The 163 m tall German Post Tower is equipped with a very modern decentralized air conditioning system. Reference: Post Tower, 2014.*

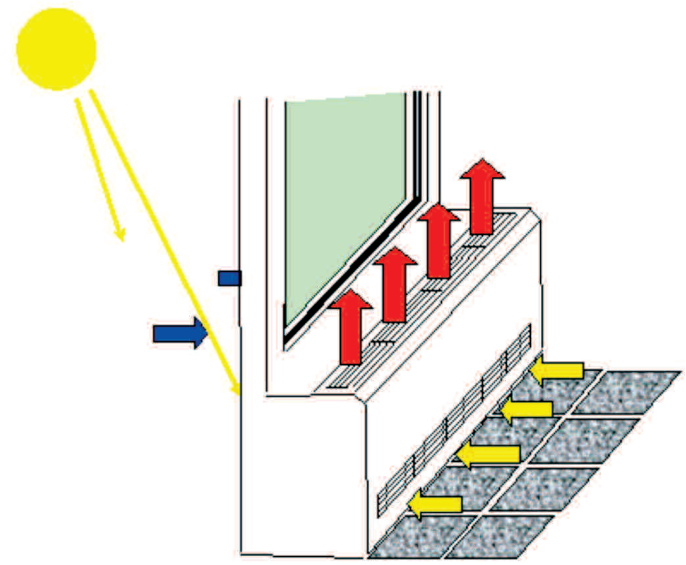

Figure 3. *The solar assisted façade system is mounted into convector-type housing underneath a window with a shading device.*

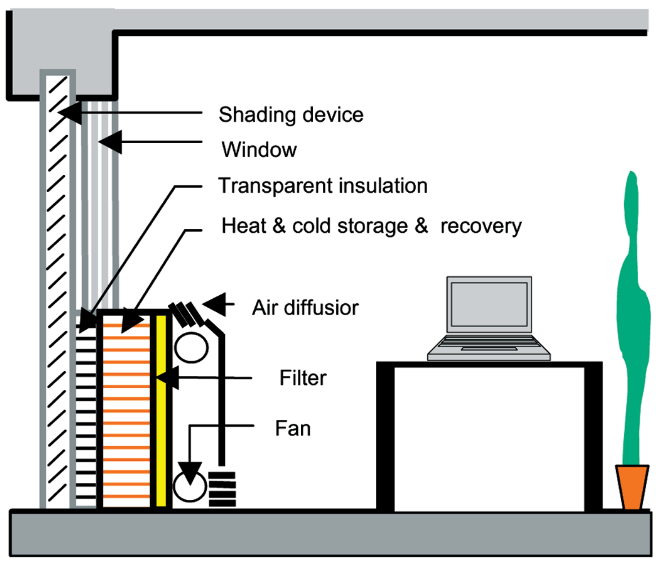

Figure 4. *In this figure a cross section of the decentralized air-conditioning system is presented.*

between the two alternatives and some listings of advantages and disadvantages of the two variants. Such have been published by Franzke et al., 2003 and Bhatia, 2012.

2. THE DECENTRALIZED SYSTEM

2.1 The basic system

The new designed decentralized façade system is an automatically controlled adaptive ("intelligent") façade system (see e.g. Figures 3 and 4), which is capable of monitoring the internal and external climatic conditions and reacting in an appropriate energy saving manner also by utilizing solar energy. A comfortable indoor environment is provided which follows a high hygienic standard and shows a low-energy demand. This is obtained by a controlled acceptance or refusal of outdoor free energy, respectively by storing it from night to day time or vice versa. With these functions the system shows a low impact on the environment.

The system was designed in the context of a Master diploma work (see Noume, 2010) in two different versions, namely a (simple) low-cost configuration (see Chapt. 2.2) and a (deluxe) multi-function configuration (see Chapt. 2.3).

2.2 The low-cost configuration

The low-cost system contains standard energy-collecting and saving materials and devices as high-quality glazing, transparent insulation and a new type of honeycomb packaging of phase change material for thermal energy storage purposes. Furthermore, (mechanical) ventilation equipment is present, as fans, filters, heat recovery devices and air distribution grids for the inlet and outlet of the air (all these components are shown in Figure 5). The operation characteristics are described in Chapt. 3 for a winter and summer period.

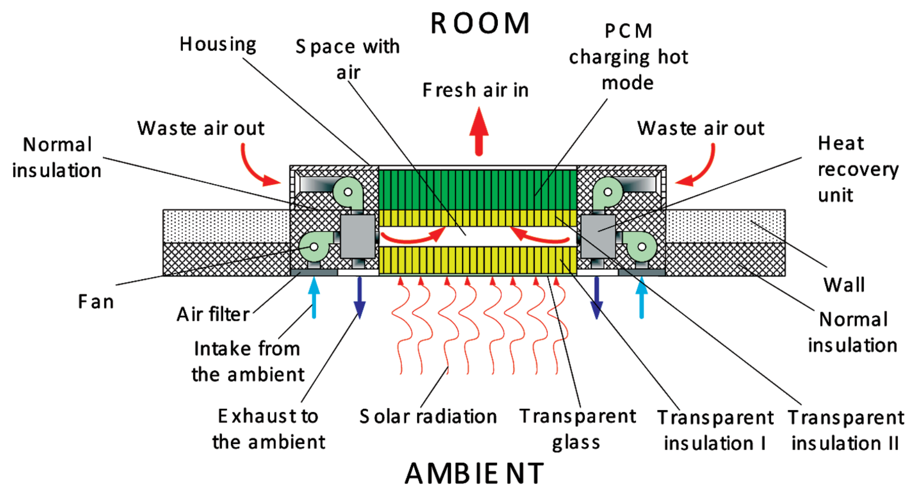

Figure 5. *The low-cost configuration system is shown in a cross section. It contains only basic ventilation equipment with the exception of a specially developed honeycomb phase change material storage device which is translucent for visible radiation (from Ref. Noume, 2010).*

2.3 The multi-function configuration

The multi-function configuration system is a full façade-integrated air-conditioning system (see Figure 6). It also has all the solar collecting features. Furthermore, it contains hot and cold recovery devices. The additional equipment contains an air/liquid heat exchanger for additional heating (HHEX) and for cooling purposes (CHEX), which is combined with a water condensation unit. In a very future-oriented window module heating and cooling may be realized by the application of the magnetic heating and cooling technology (see e.g. Tishin and Spichkin, 2003, Yu et al., 2010, Egolf et al., 2014). But one has to be aware that this technology is just at the entrance to heating and refrigeration markets, but has not yet been established.

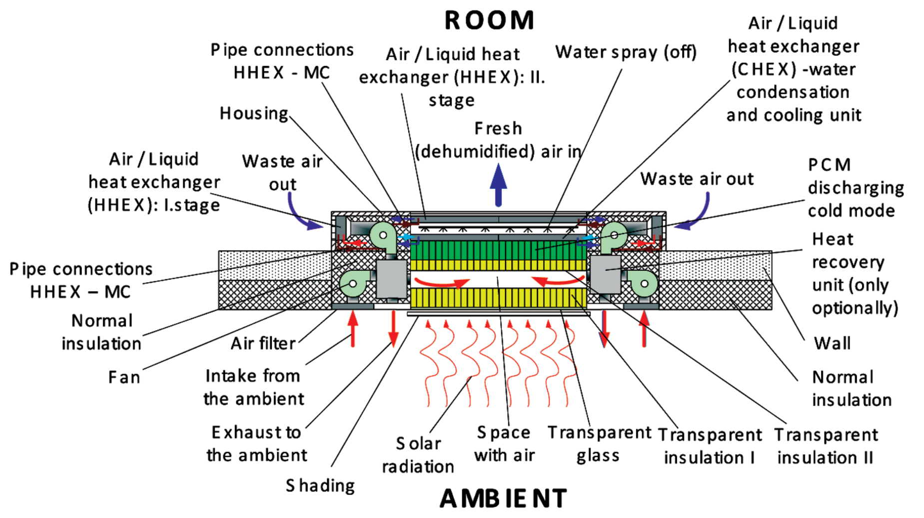

Figure 6. *The multi-function decentralized air-conditioning system is a module with a larger number of built-in apparatuses than contained in the simple low-cost configuration. It additionally contains heating, cooling and water spraying or water vaporization equipment (Ref. Noume, 2010).*

3. OPERATION CONDITIONS

Nine different operation conditions have been chosen for a system operation evaluation (see Table 1). This article is too short for a deep and detailed discussion of all of them. But they can be found in the final report of (Noume, 2010). Important is to state that it is taken advantage of many newest developments of building physics (e.g. passive or active night cooling), solar energy technology (e.g. new glazings, transparent insulation, translucent elements, chess–board pattern packaging of PCM in honeycomb structures, photovoltaics), refrigeration (e.g. magnetic heating and cooling, desiccative cooling) and air conditioning (e.g. by forced convection, by displacement ventilation, etc.). Instead of a lengthy and detailed description of all operation conditions, in the following two sections only two illustrative examples are given.

Figure 7, for example, presents a heating mode during a sunny winter day. The shading device is open if no occupants are in the office; otherwise it covers the window to avoid dazzling by bright sun light. But the decentralized air-conditioning device under-

Table 1. *The table shows nine different operation modes, which have been evaluated corresponding to different times of the season and day time.*

Operation	Season		
	Winter	Spring & Autumn	Summer
Sunny-day	X	X	X
Cloudy-day	X	X	X
Night-time	X	X	X

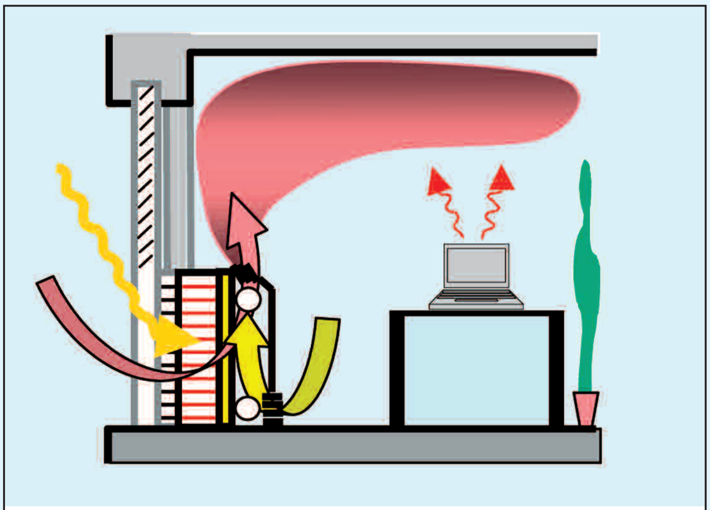

Figure 7. *On a sunny winter day mixed convection is the adequate ventilation method.*

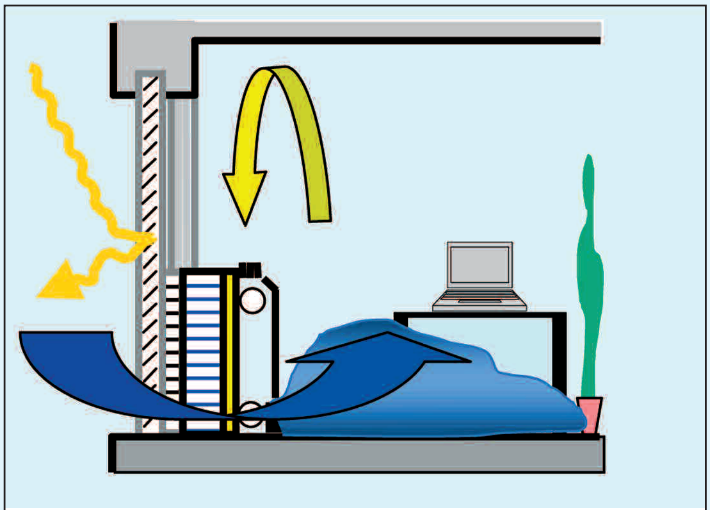

Figure 8. *On a sunny summer day displacement ventilation is applied.*

neath the window is fully opened and solar radiation enters through a transparent insulation, that avoids too high heat transfer losses, directly into the honeycomb storage module, where direct transmission and absorption of solar energy and transport of heat by air flow leads to a solid-liquid phase transition of phase change material in the filled cells and a thermal energy storage for the inlet air during daytime. In the empty cells air crosses and makes the necessary heat transfer to the cells, which are filled with PCM. If there is a net heat storage capacity in the evening available for a heating at night time, the system takes advantage of this. The air conditioning in this operation mode is mixed convection (see e.g. Awbi, 1995), where air is taken from outside and mixed with indoor air and then blown through the upper diffusor grid into the room by turbulent convection flow. If heat exchangers are also present, the described mechanisms are only responsible for a preheating of the air. Good insulation and glazing properties together with high internal sources as given by persons, computers, etc., (in Southern countries) may make it avoidable to install additional heat exchangers for heating purposes.

Figure 8, for example, presents a cooling mode during a sunny summer day. Active night cooling is applied, that means by forced convection colder air is blown into the storage device where by phase change "cold thermal energy" is stored. Furthermore, all the thermal masses in the back-lying room are cooled down at night as much as possible. At day time the shades are fully closed, but as they are no barriers to an air flow, a reduced amount of air is entering the room from outside. The incoming air is cooled by the thermal honeycomb storage device and by this is cooler than the air in the building's room. This condition allows operating the system in the displacement ventilation mode (see e.g. Skistad, 1994). Then air is creeping along the floor and fills a lowest layer in the room by cool air. A person in this "lake" of cool air initiates by its elevated temperature a natural convection flow, which brings fresh air into its respiration zone. It is clear that in this operation mode clean floor conditions are required, as it is usually the case in well-maintained office rooms.

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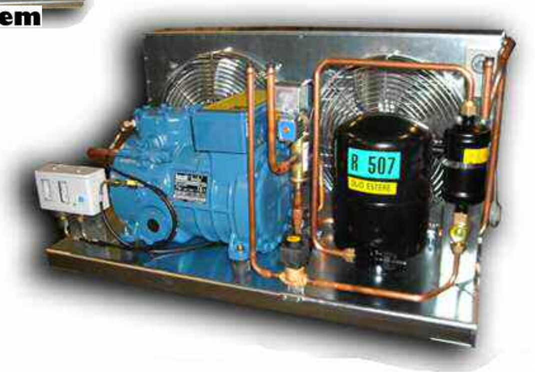

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