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SUSTAINABLE COOLING FOR A HEALTHY FUTURE

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SPECIAL SECTION ON FOOD COLD CHAIN AND THE MONTREAL PROTOCOL

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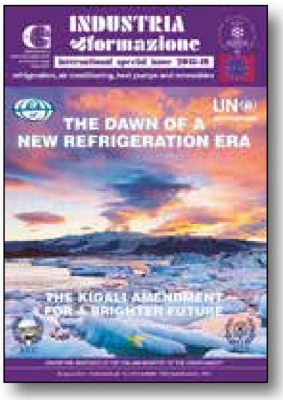

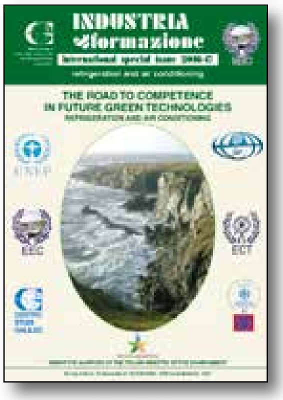

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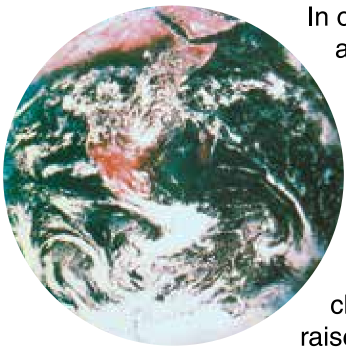
FOREWORDS

Italy is profoundly honoured to host this year in Rome the 31st Meeting of the Parties to the Montreal Protocol (MOP31), the first historic meeting after the entry into force of the Kigali Amendment as a legally binding instrument.
In fact, since 1st January 2019, three years after its adoption in the capital city of Rwanda, the Kigali Amendment on the phase down of hydrofluorocarbons (HFCs) under the framework of the Montreal Protocol entered into force at the global level, laying down one of the key pillars towards an enhanced, synergic implementation of the international climate and ozone protection regimes hence complementing the 2015 Paris Agreement.
At EU level, we are working hard to translate our ambitious commitments for 2030 into concrete action and in parallel we have begun to develop our EU vision for the full transition to a climate neutral future by 2050. This shows clearly our firm determination to lead global climate action by doing our fair part to achieve the Paris Agreement temperature goals.
But this effort cannot be limited to States and Governments: regions, cities, organisations, people, all have a role to play and transformative action must therefore extend beyond state level, with an essential role for non-state actors and local communities in tackling climate change and implementing ambitious solutions on the ground.
The Special Report on Global Warming of 1.5 degree Celsius which was published in October, 2018 by the Intergovernmental Panel on Climate Change (IPCC) provides an important and timely scientific assessment on the negative impacts of climate change on human societies and natural systems, including impacts on health, livelihood, food, water as well as human security.

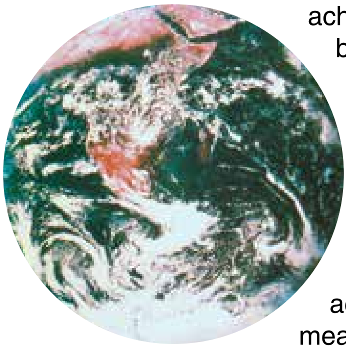


In other words, all countries can and must contribute to accelerated short-term action and enhanced longer-term national ambition considering that practical and cost-effective options are widely available to make this possible.
Italy - together with the European Union and its Member States - continue with full determination to be committed to the Paris Agreement as the essential multilateral framework governing global action to deal with climate change.
In Katowice at COP 24, we were able to maintain the promise made in 2015 by agreeing on a full package of implementing rules which fully equips the Paris Agreement to serve as anoperational platform for tackling the most urgent of global challenges while providing a strong momentum for all countries to move forward and to raise their level of climate ambition.
On the other hand, the control measures on the global production and consumption of HFCs devised by the Kigali Amendment - which will integrate the ongoing phase out schedule of ozone-depleting substances already established by the Montreal Protocol to continue protecting the ozone layer for the years to come - are in fact expected to reduce the emissions of these powerful greenhouse gases in a manner that could prevent up to 0.5 degrees Celsius of global warming by the end of this century.
The Kigali Amendment is therefore often referred to as potentially being the single largest contribution to the target of the Paris Agreement to keep global warming “well below” 2 degrees Celsius.
As the national ratification process of the Kigali Amendment moves forward, the Italian Government is hence strongly committed to deliver a systematic implementation of the Montreal Protocol and the Paris Agreement long-term climate mitigation goals.
Our committment does not only unfold by means of an accelerated domestic action, but also through an integrated approach aimed to align the multilateral and bilateral instruments of international cooperation as vehicles to scale-up action and partnerships with developing countries for the implementation of the Nationally Determined Contributions as well as for supporting capacity building and transfer of “greener” technologies to support industrial re-conversions in specific sectors which are often key to multiple dimensions of sustainable development.
In this respect, the refrigeration and air conditioning sectors are remarkable examples of this “multi-dimensionality” and their sustainability in a green economy requires a coordinated efforts at multiple layers, such as Governments, international organizations, but also the civil society and the world business community. For this reason, we believe that the MOP31 in Rome can represent a milestone event to showcase how a tight dialogue between successful multilateral regimes such as the Montreal Protocol can be beneficial to a series of new global climate change framework of committments, including the Paris Agreement and the 2019 United Nations Climate Summit summoned by the UN Secretary General.

The Montreal Protocol Parties have in fact recognized that, while the Kigali Amendment will deliver its expected mitigation of direct HFC emissions in the atmosphere by moving from refrigerants with a high global warming potential to low or zero global warming potential alternatives in the air conditioning, refrigeration and heat pump sectors, there is a need to achieve synergies whenever and wherever possible to tackle also indirect emissions from these sectors by enhancing the equipments' energy efficiency.
Recent estimates from the Technological and Economic Assessment Panel (TEAP) of the Montreal Protocol suggest that over 80% of the global warming impact for the refrigeration, air-conditioning and heat pump systems is associated with the indirect emissions generated during the production of the electricity used to operate the equipment, and that the largest potential for energy efficiency improvement comes from improvements in total system design and components, which can yield efficiency improvements that can range from 10% to 70%.
We should, in this perspective, seek cooperation between the Montreal Protocol and all relevant organisations and institutions that can contribute to enhancing energy efficiency and increase the impact of our work in phasing down HFCs.
Furthermore, additional co-benefits can be yield by addressing the refrigeration and air-conditioning sectors in the broader perspective of the Sustainable Development Goals.
As highlighted by the FAO, food losses due to lack of efficient refrigeration can reach up to 23% in developing countries, harming the efforts to reach the eradication of hunger and a balanced, sustainable production and consumption patterns agreed among the SDGs, beside causing aditional GHG emissions.
We consider that the MOP31 in Rome, that is organized by the Italian Government and the Ozone Secretariat also with the support of the Food and Agriculture Organization (FAO), represent a good opportunity to highlight these synergies and explore new connections and networks, considering for example the partnership that the Italian Ministry for the Environment has launched with UNDP and the FAO with the establishment in Rome of the Africa Center for Climate and Sustainable Development (ACSD) at the presence of the Italian Prime Minister, Prof. Giuseppe Conte.
Italy has a huge experience and technological know how, also through its industry and training and research institutions, that was also historically beneficial to support the Montreal Protocol's industrial conversions that helped phasing out ozone-depleting substances in many sectors. As of today, many bilateral projects are underway under the framework of the Multilateral Fund for the Implementation of the Montreal Protocol to support partner countries in leapfrogging from HCFCs to HFC-free, low-GWP alternatives, such as in Argentina, Brasil, China, Iran, Ghana, Mexico and Nigeria.
With UNIDO and UN Environment/OzonAction, we are also supporting enabling activities to fast start the implementation of the Kigali Amendment in Lesotho, the Maldives, Rwanda and Tunisia.
If sometimes challenges can still be hard to overcome, we as international community shall be cognizant that alternatives towards an energy-efficient, climate friendly refrigeration and air-conditioning exist, and that the global framework of the Kigali Amendment and the Paris Agreement provide us with the long-term objectives and instruments to succeed.

Sergio Costa, Italian Minister for the Environment, Land and Sea Protection

In January this year, the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer entered into force. This historic amendment bought hydrofluorocarbons (HFCs) under the purview of the Protocol, committing countries to phase-down the production and consumption of these chemicals according to agreed schedules. While not ozone depleting, HFCs have high global warming potentials, of up to almost 15,000 times more powerful at warming the atmosphere than carbon dioxide. So, the Montreal Protocol is set to achieve a significant contribution to combatting climate change, avoiding up to 0.4 °C of global temperature rise by the end of the century, thus contributing to the climate protection aspirations of the Paris Agreement.
This co-benefit of the Montreal Protocol is in addition to its widely recognised success in addressing global ozone depletion by phasing out 99 per cent of ozone-depleting substances (ODS) which were commonly used in refrigerators, air-conditioners, and other applications.
The most recent Scientific Assessment of Ozone Depletion indicates that as a result of the Montreal Protocol the ozone layer is forecast to recover by around 2060. This success is reflected in the theme of this year's World Ozone Day: "32 Years and Healing".
The theme reinforces two very important aspects of the Montreal Protocol, one, that the treaty has demonstrated unprecedented international cooperation over three decades and two, that it has produced significant and measurable results.

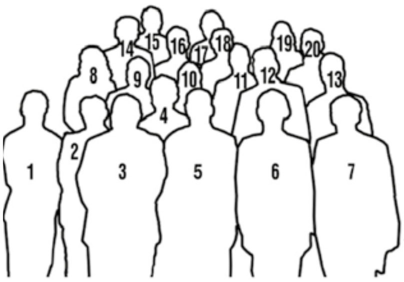


While this success should justifiably be celebrated, the cooperation and commitment achieved needs to continue to be strengthened so as to grow, especially as the Protocol broadens its scope.
Along with the continuing commitments to phase out ODS and forthcoming commitments to phase down HFCs, there are huge associated opportunities for countries to consider in terms of adopting alternative technologies and refrigerants which can achieve considerable climate and energy efficiency benefits.
One very important sector with regards to refrigeration is the Food Cold Chain, which is critical to ensure food security and reduce food loss. The world produces enough food to feed the entire population, yet the poor availability, preservation and access to this food – often due to an imperfect or non-existent food cold chain – means that the current food systems are failing to fulfil societal, nutritional and environmental needs.
There are acute imbalances in availability, consumption and diets over the world. The Food and Agriculture Organisation estimates that to satisfy the demand of the world's growing and richer population – who seek more meat in their diet – by 2050, food production will have to increase by at least 60 per cent. However, this figure can be reduced by improving production efficiency, changing dietary trends and decreasing food losses and waste. Efficient and systematic food cold chains including refrigerated storehouses, refrigerated transport, cold rooms, and domestic refrigerator-freezers can play a significant role in preventing food loss and waste.
It is therefore very apt that this edition of the International Special Issue focuses on the importance of Food Cold Chain for food production and food security. United Nations Environment Programme (UNEP) recognises that our work can only be effectively delivered through partnerships with countries and with other like-minded organisations and expert institutions. UNEP OzonAction is very pleased to once again partner with Centro Studi Galileo, the International Institute of Refrigeration, the Italian Refrigeration Association and the European Energy Centre to share key developments in refrigeration and air conditioning technology through this edition.
Information in this publication concerning technological advances and latest research which contributes to protecting the Earth's climate and stratospheric ozone layer, specifically technologies that avoid high global warming options and that are energy efficient will assist developing countries to better understand and make informed choices that will benefit their country and the global environment.
By continuing to work together, we can positively contribute to climate and ozone protection for generations to come.

Elizabeth Maruma Mrema, Director, Law Division, United Nations Environment Programme

WORKING TOGETHER FOR THE FUTURE OF REFRIGERATION

THE PRESIDENTS OF THE XVIII EUROPEAN CONFERENCE:



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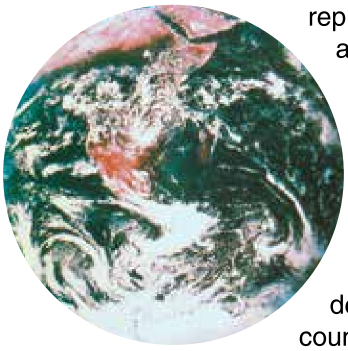
2 Fabio Polonara, Co-chair – TEAP-RTOC, Director – Industrial Engineering Dept., University of Marche
3 Ayman Eltalouny, Coordinator International Partnerships, United Nations Environment – UNEP
4 Niccolò Costantini, Policy Officer, European Commission DG Clima
5 Carlo Fidanza, Member of European Parliament
6 Noboru Kagawa, President, Japan Society of Refrigerating and Air Conditioning Engineers – JSRAE
7 Enrico Buoni, President, Centro Studi Galileo – CSG
8 Andrea Voigt, Director General, European Partnership for Energy and the Environment – EPEE
9 Gerald Cavalier, President, Association Française du Froid – AFF
10 Franziska Menten, Project Coordinator, United Nations Industrial Development Organization – UNIDO
11 Stephen Yurek, President and CEO, Air Conditioning Heating and Refrigeration Institute – AHR
12 Wolfgang Zaremski, President, Assoc. Component Manufacturers – ASERCOM
13 Federico Riboldi, Mayor of Casale Monferrato
14 Didier Coulomb, Director General, International Institute of Refrigeration – IIR
15 Luca Tagliafico, Professor, University of Genoa
16 Marco Buoni, President – AREA, Director General – CSG, Secretary General – ATF
17 Alberto Cavallini, Honorary President, International Institute of Refrigeration – IIR
18 Roberto Saccone, President, Associazione Costruttori Sistemi Climatizzazione – Assoclima
19 Stefania Bracco, Former Economist, Food and Agriculture Organization of the United Nations – FAO
20 Paolo Buoni, Director, European Energy Centre

UNEP - IIR - AREA - CSG in one of the latest meetings in Paris in view of MOP31.

The Panel of the conference. From left to right: (4), (17), (16), (7), (3), (14), (11), (8), (12).

2019 is unmistakably quickly becoming the year of Refrigeration. On June 26, 2019, we inaugurated the first "World Refrigeration Day" to be promoted in all countries each year to celebrate Lord Kelvin's birth date ("founder" of the international temperature unit). In this regard, you will have the opportunity to read, at the end of this special international issue, a report on the dedicated events which took place in Africa. Moreover, several declarations concerning refrigeration were made at the top level: at the G7 at the end of August and at the UN Conference in September. Allow me to quote Mr. António Guterres, United Nations Secretary-General:
"Implementation of the Kigali Amendment will be front and centre for climate action. We need all countries to develop national cooling action plans to deliver efficient and sustainable cooling and bring essential life-preserving services like vaccines and safe food to all people. We are calling for concrete and enhanced actions from industry. The leadership of global leading companies is essential to realize the vision into reality."
This is a welcome declaration for us. It recognises the importance of refrigeration and its role in a sustainable world. The IIR published an Informatory Note on June 26, 2019, "The role of refrigeration in the global economy", which provides figures on the various uses of refrigeration and their impact on daily life and on the environment. A reprint is provided in this International Special Issue. For instance, according to IIR calculations, refrigeration represents 20 % of the overall electricity used worldwide and its demand could more than double by 2050, particularly because of air conditioning.



Having a clear view on what refrigeration and its various sectors represent today, and will represent in the future, is necessary to drive sustainable development. In addition, the article provided by the RTOC explains the technological developments in these sectors and the possible solutions to reduce the carbon footprint and adhere to the commitments of the Montreal Protocol.
You will also find some examples in different applications and in different countries which, with our help, could inspire you to propose the national plans that Mr. Guterres urges you to implement. A special focus on the cold chain for food is included, considering its importance for food security in the future thanks to the reduction of food losses. Articles on training were also added: technological developments are necessary but not enough. Individuals must be trained, in all countries, in order to efficiently run the equipment in safe conditions.
There are many challenges but we are committed to succeeding. I am convinced that the sector will properly phase down HFCs as it already successfully phases out HCFCs, thanks to the Kigali Amendment. However, the energy challenge is still facing us, as is building a sustainable cold chain for food and health products since this is a vital need. The International Institute of Refrigeration (IIR) is at the disposal of all its member countries to help them develop national cooling actions, with our partners within the various United Nations bodies, including of course UN Environment, FAO, UNIDO and with industry, such as the Global Food Cold Chain Council.
We already collaborate with them and will continue to do so, more than ever, in order to reach the UN Sustainable Development Goals.

Didier Coulomb, Director General, International Institute of Refrigeration (IIR)

The Role of Refrigeration in the Global Economy in 2019

38th IIR Informatory Note on Refrigeration Technologies

This Informatory Note was prepared by Jean-Luc Dupont (Head of the Scientific and Technical Information Department) and reviewed by Piotr Domanski (President of the Science and Technology Council), Philippe Lebrun (President of the General Conference), Felix Ziegler (President of the Executive Committee) and Didier Coulomb, Director General of the IIR

Refrigeration has become a part of 21st-century life. This "invisible" industry plays a major role in countless sectors ranging from food and air conditioning to healthcare, industry and energy.

Refrigeration is vital for reducing post-harvest losses and in the preservation of food products.

Air conditioning plays a key role in the economic and social development of warmer countries and its use is expanding dramatically – especially in the world's emerging economies – with rising global temperatures.

In the healthcare sector, refrigeration preserves pharmaceuticals and medicines, especially vaccines. New treatments, such as cryosurgery or cryotherapy, were developed thanks to ultra-low temperature technologies.

Refrigeration is employed in numerous industrial processes such as chemicals and plastics. Deprived of refrigeration, data centres – and the internet – would collapse in minutes.

Regarding energy, natural gas can be liquefied through cryocooling, making it easier and cheaper for transportation and storage.

Economically speaking, the importance of refrigeration is paramount, as illustrated by the constant increase in the sales of refrigerating equipment and in the number of refrigeration-related jobs.

However, over 1.1 billion people – mainly in the least developed countries – globally face immediate risks from lack of access to refrigeration that could help address hunger and malnutrition and alleviate the worst of deadly heat waves.

This Informatory Note* summarises basic data illustrating size and reach of the refrigeration sector and its importance for mankind.

* This Informatory Note is an update of a first version published by the IIR in November 2015.

It aims to raise policy makers' awareness on the growing importance of refrigeration in order to further encourage its development in a sustainable manner, particularly in the least developed countries.

1. THE IMPORTANCE OF REFRIGERATION

1.1 Refrigeration economics

In order to illustrate the importance of the refrigeration sector, the IIR estimated the number of refrigeration systems in operation worldwide (based on published sources and own estimations as summarised in Table 1.

Based on the above-mentioned figures, the IIR estimates that the total number of refrigeration, air-conditioning and heat pump systems in operation worldwide is roughly 5 billion, including 2.6 billion air-conditioning units (stationary and mobile) and 2 billion domestic refrigerators and freezers.

Global annual sales of refrigeration, air-conditioning and heat-pump equipment amount to roughly 500 billion USD, which, by way of comparison, represents roughly three quarters of global supermarket sales.

1.2 Refrigeration and employment

The socio-economic importance of refrigeration in today's world can be illustrated by means of employment data. The IIR estimates that over 15 million people are employed worldwide in the refrigeration industry, which means that almost 5 workers out of 1000 have a job linked to the manufacturing, installation, maintenance and servicing of all type of refrigeration equipment.

This ratio is even higher in countries such as Australia, where around 300,000 people (2.5 % of total employment) are employed in over

Table 1.
Number of refrigeration systems in operation worldwide per application

Applications	Sectors	Equipment	Number of units in operation
Refrigeration and food (see § 2.1.)	Domestic refrigeration	Refrigerators and freezers	2 billion
	Commercial refrigeration	Commercial refrigeration equipment (including condensing units, stand-alone equipment and supermarket systems)	120 million
	Refrigerated transport	Refrigerated vehicles (vans, trucks, semi-trailers or trailers)	5 million
		Refrigerated containers (« reefers »)	1.2 million
	Refrigerated storage	Cold stores	50,000
Air conditioning (see § 2.2.)	Stationary air conditioning	Residential air-conditioning units Commercial air-conditioning units Water chillers	1.1 billion 0.5 billion 40 million
	Mobile air-conditioning systems	Air-conditioned vehicles (passenger cars, commercial vehicles and buses)	1 billion
Refrigeration and health (see § 2.3.)	Medicine	Magnetic Resonance Imaging (MRI) machines	50,000
Refrigeration in industry (see § 2.4.)	Liquefied Natural Gas (LNG)	Magnetic Resonance Imaging (MRI) machines	126 525
Heat pumps (see § 2.5.)		Heat pumps (residential, commercial and industrial equipment, including reversible air-to-air air conditioners)	220 million
Leisure and sports (see § 2.7.)		Ice rinks	17,000

20,000 businesses operating in the refrigeration sector.
In this field, the need for engineering and technical staff (e.g. installers and mechanics) increases due to the growing demand for refrigerating capacities, along with the unique skills required of refrigeration-related professions.
In the US, employment of mechanics and installers in heating, refrigeration and air conditioning is projected to grow by 15% from 2016 to 2026, much faster than the average for all occupations (7%).

1.3 Refrigeration and energy consumption

Electricity consumption for refrigeration and air conditioning has been increasing for many years in both developed and developing countries.
The refrigeration sector – including air conditioning – consumes about 20% of the overall electricity used worldwide. This IIR estimation is based on an analysis of fragmentary data about the sectorial electricity consumptions by various areas of the world.
This 20% share highlights the importance of the refrigeration sector, which is expected to grow further in the coming years because of (i) increasing refrigeration demand in numerous sectors, and (ii) global warming.
The IIR estimates that global electricity demand for refrigeration – including air conditioning – could more than double by 2050. This assessment is based on IEA "Baseline Scenario" – taking into account the likely effect of current policies and targets – which predicts that electricity needs for space air-conditioning will triple by 2050.
However, continued efforts to improve the energy efficiency of refrigerating equipment may allow to significantly limit this increase in energy consumption, especially in the air-conditioning domain (see §2.2. *Air conditioning*).

1.4 Refrigeration and environment

The contribution of refrigeration to the environmental aspect of sustainable development might be illustrated through the indispensable role of refrigeration technologies for maintaining biodiversity by cryopreservation of genetic resources.
Refrigeration technologies are now being considered as a means to capture CO_2 from large power stations and industrial plants thanks to cryogenics; they also enable the liquefaction of CO_2 for underground storage.
However, the adverse environmental effects of refrigeration – and first and foremost its global-warming impact – must also be addressed.
Around 37% of this global-warming impact is due to direct emissions (leakage) of fluorinated refrigerants (CFCs, HCFCs and HFCs), while the remaining 63% are due to indirect emissions originating from the electricity production required to power the systems.
Overall, according to IIR estimations, the refrigeration sector-related emissions account for 4.14 $GtCO_2eq$, representing 7.8% of global GHG emissions.
Hence, actions implemented by refrigeration stakeholders to fight global arming focus on two objectives:

- reduction in the direct emissions of fluorinated refrigerants to the atmosphere through better containment, refrigerant charge reduction and end-of-life recovery, development of alternative refrigerants with negligible or no climate impact and

training/certification of technicians.
- reduction in primary energy use by increasing energy efficiency of refrigerating plants.

It is important to underline the positive environmental contribution of the recent implementation of the Kigali Amendment to the Montreal Protocol – supported by the refrigeration industry –, which plans a gradual reduction of HFC production and consumption worldwide.

Without the Kigali Amendment, the HFC emissions from the refrigeration sector would rise to between 3 and 4 $GtCO_2eq$ in 2050. However, according to IIR estimates, thanks to the implementation of the Kigali Amendment, the HFC emissions will only amount to approximately 0.7 $GtCO_2eq$ in 2050, after a peak around 1.5 $GtCO_2eq$ at the end of the 2020s. Based on these estimates, the Kigali Amendment is expected to prevent a substantial increase in average temperatures up to 0.3 °C by 2100. This result must be put into perspective with the Paris Agreement, whose objective is to limit the rise in global average temperature to well below 2 °C above pre-industrial levels.

2. ROLE AND APPLICATIONS OF REFRIGERATION

2.1 Refrigeration and food

Refrigeration is crucial for the food sector because it ensures optimal preservation of perishable foodstuffs and provides consumers with safe and wholesome products.

However, the food cold chain is still insufficiently developed, especially in developing countries. Global food production comprises roughly one third of perishable products requiring refrigeration..

A striking example is India, whose percentage of cold chain logistics in perishable food logistics is less than 22% for fruits and vegetables and 34% for meat, well below the approximately 95% in Europe and the US.

This results in huge food losses. According to the IIR, the lack of a cold chain causes significant global food losses: up to almost 20% of the global food supply.

The FAO estimates that global gross agricultural output will have to increase globally by 50% from 2012 to 2050 under BAU scenario(19) and refrigeration has a vital role to play in this context. Refrigeration can also make a significant contribution to addressing the issue of undernourishment considering 821 million people, approximately one in nine people in the world, were undernourished in 2017, especially in the least developed countries.

Continuous and ubiquitous refrigeration is necessary throughout the perishable food chain, from production to consumers.

In supermarkets, between 30% and 60% of the electric energy consumed is used by refrigeration equipment supplying cold to the display cabinets and the cold rooms for chilled and frozen food storage. It is inconceivable that small shops, restaurants, bars, and hotels could function without refrigeration equipment.

About 2 billion domestic refrigerators and freezers are in service worldwide[(2)]. Based on the number of refrigerated appliances installed and their electricity consumption, the IIR estimates that domestic refrigerators and freezers consume almost 4% of global electricity.

However, energy efficiency in refrigerators has been increasing constantly, as highlighted by the constant qualitative evolution of the energy labels. For example, in the USA, the annual average electricity consumption was divided by 4 between 1974 and 2015, while the equivalent volume increased by 20%. Refrigerated food processing, cold storage, refrigerated transport and distribution are less visible for the customer, but are key elements of the cold chain.

Currently, there are around 5 million refrigerated vehicles in service worldwide, including vans, trucks, semi-trailers or trailers. Moreover, the global refrigerated transport market is expected to grow strongly in the coming years (+30% between 2018 and 2022).

Furthermore, the volume dedicated to cold storage in the world accounts for 616 million m^3 in 2018 – representing around 50,000 cold stores – with an increase of 34% over 2012.

The continuous advancement in freezing technologies permitted the fast development of new food markets such as frozen foods and ice creams. Convenient and ready meals, currently the dominant segment of the global frozen food market, responds to the changing and busy lifestyles of many people, especially in urban areas. In addition, numerous studies show that frozen fruits and vegetables have nutritional qualities that are globally equivalent to those of fresh products, and often contain more vitamins than fresh products kept for several days.

Annual consumption per capita of frozen food is about 50 kg in countries such as the USA, Ireland, UK, Sweden and Germany.

Valued at USD 219.9 billion in 2018, the global frozen food market is expected to grow by almost 30% by 2023 and reach USD 282.5 billion.

2.2 Air conditioning

Air conditioning is an essential part of the refrigeration sector. Its use is increasing for both human comfort and health (see §2.3. *Refrigeration and health*), and industrial processes (Information Technology, biotechnologies, etc.; see §2.4. *Refrigeration in industry, transportation and energy sectors*).

Hot areas and zones with high air humidity underwent remarkable economic development due to the introduction and expansion of air-conditioning technologies over the past 60 to 70 years.

Several independent studies reported that high ambient temperature and poor quality of indoor air have a significant influence on students' cognitive learning and the productivity of office workers. A study carried out on over 10 million US high school students shows that without air conditioning, each 0.5 °C increase in school year temperature reduces the amount learned that year by one percent.

Inappropriate ambient temperatures impair work efficiency and may cause economic losses.

Globally, the International Labour Organization points out that even in a scenario of effective climate change mitigation, temperature increases resulting from climate change will lead to the loss of the equivalent of 72 million full-time jobs by 2030 due to heat stress. Developing countries and the most vulnerable population groups –

particularly migrants, people in poverty, and indigenous and tribal peoples – are most exposed to these impacts. Air-conditioning is responsible for over 8% of global electricity consumption, according to IIR estimations.
This ratio varies widely from one country to another, depending on the local climate and the development level. Household ownership of ACs varies enormously across countries, from around 4% in India and less than 10% in Europe, 60% in China to over 90% in the United States and Japan, and close to 100% in a few Middle Eastern countries.
Air-conditioning is expanding dramatically, especially in the world's emerging economies and this trend is expected to increase since of the 2.8 billion people living in the hottest parts of the world, only 8% currently possess air conditioners.
Furthermore, air conditioning is expected to play an increasing role in the context of climate change and the associated increase of ambient temperatures. According to IEA « Baseline Scenario », which takes into account the likely effect of current policies and targets, global energy needs for space cooling will triple by 2050. Most of this projected growth in energy use comes from the emerging economies, with India, China and Indonesia alone contributing half.
Associated CO_2 emissions are expected to almost double by 2050. However, potential exists to curb this strong increase in energy demand and CO_2 emissions. IEA states that the average energy efficiency of air conditioners sold today is one third of best available technology.
It presents an «Efficient Cooling Scenario» based on much stronger policy action resulting in much tighter minimum energy performance standards (MEPS) for air-conditioning equipment, in all countries. The implementation of these policies would allow to cut down by three the energy needs increase of the "Baseline Scenario".
These figures highlight the critical need for determined policy action regarding energy efficiency in order to ensure sustainability of air conditioning.
Mobile air conditioning is expanding at a comparable pace since almost all new vehicles currently sold are air-conditioned. There are currently about 1 billion mobile air-conditioning units in vehicles and buses worldwide.

2.3 Refrigeration and health

Refrigeration has a direct impact on human health through preservation of foods and pharmaceuticals, as well as through new low-temperature therapeutic techniques.
Refrigeration inhibits the development of bacteria and toxic pathogens therefore preventing foodborne diseases. Refrigeration dramatically reduces the need for chemical preservatives in food. Since 1930, thanks to cold-chain enabled food preservation, a 90% decrease in the number of stomach cancer cases was noticed, according to a study by the WHO.
Heat-sensitive health products, kept at a controlled temperature (particularly between 2 °C and 8 °C), experienced a tremendous market extension all over the world. From 2011 to 2017, the number of heat-sensitive healthcare products increased by 45%: 1 out of 2 medicines on the market is heat-sensitive.
Concerning vaccines, a particularly striking example is the role of refrigeration in the eradication of poliomyelitis. In 2018, the number of cases of poliomyelitis occurring worldwide was 33, i.e. over ten thousand times fewer than the 350,000 cases registered in 1988.
Cryosurgery is an easy-to-use and relatively inexpensive technique which requires only fairly basic equipment. Cryoablation is used as a clinical treatment. Its ability to cure skin cancer, for example, is proven to have a success rate for 99% of patients. It also showed a 99.4% success rate in the treatment of women with low-risk breast cancers.
Whole-body cryotherapy consists in exposing a patient to extreme cold (-80 to -160 °C) for a short time (2 to 4 minutes) in a specialised cold chamber. Preliminary studies suggest that this technique induces significant physiological and psychological benefits. Little known a few years ago, this therapy is currently attracting keen interest.
Superconductivity – a phenomenon enabled by cryogenic technologies – is at the heart of Magnetic Resonance Imaging (MRI) scanners, helping to give doctors an unprecedented view of structures deeply within the human body. Most MRI machines use superconducting magnets to maintain strong, stable magnetic fields. MRI has a wide range of applications in medical diagnostics, with over 50,000 MRI scanners in use worldwide.
Finally, the health benefits of air conditioning should be emphasised. A study suggests that the mortality impact of days with a mean temperature exceeding 27 °C has declined by about 75% over the course of the 20th century in the United States, with almost the entire decline occurring after 1960; the diffusion of residential air conditioning explains essentially this decline.

Launch of previous International Special Issue 2018-2019 in MOP31 in Ecuador: from the left, Andrea Voigt EPEE, Didier Coulomb IIR, Cristiano Piacente Italian Ministry of Environment, Shamila Nair-Bedouelle Former UNEP.

2.4 Refrigeration in industry, transportation and energy sectors

Refrigeration is vital for the food (see §2.1 *Refrigeration and food*), chemical, plastic, steel and building industries, etc. Other advanced industries, such as electronic-data processing or biotechnologies could not operate without refrigeration.

Air separation by cryogenic distillation is a mature technology and the only feasible means currently available for mass production of air products such as oxygen and nitrogen. The consumption of high-purity oxygen by steel, medical, and chemical industries amounts to 1.2 million tons per day.

Refrigeration has a major influence in the high-tech sectors, including Information Technology (IT). While data centres are responsible for about 2% of global electricity consumption, between 30% and 55% of this consumption is used for cooling IT equipment. Since the average power density of data centres is expected to be multiplied by 8 by 2025, implementation of advanced efficient cooling technologies is essential.

New energy-related sectors such as gas liquefaction are rapidly growing. World trade in liquefied natural gas (LNG) more than tripled since 2000, growing to 316.5 million tonnes of LNG in 2018, which constitutes 10.7% of global gas consumption. LNG accounts for almost 90% of the projected growth in long-distance gas trade to 2040. LNG starts to be used as clean fuel for ship propulsion, particularly in closed seas (Baltic ferries).

Although liquid hydrogen remains a fuel of choice for rocket propulsion, it will certainly appear in the more conventional transport distribution chain, namely electric vehicles powered by fuel cells.

The International Thermonuclear Experimental Reactor (ITER), currently under construction, is a large magnetic device for plasma confinement aimed at demonstrating the feasibility of controlled thermonuclear fusion for electricity production. The machine uses very large superconducting magnets cooled at liquid helium temperature and cryopumps cooled by liquid nitrogen.

2.5 Heat pumps

Heat pumps are devices that use the refrigeration cycle for both heating and cooling. They have a unique role in the energy system of the future. No other technology can simultaneously provide for net primary energy savings, economic benefits to the users and reduced climate impact.

In heating mode, heat pumps are very energy-efficient since for each kW of electricity consumed, about 3 to 4kW of thermal energy is generated.

In Europe, operating heat pumps save about 1% of the total CO_2 emissions today. According to IEA, nearly 8% of global emissions could be saved by heat pumps, especially in the building's sector.

2.6 Refrigeration in science

Refrigeration is at the heart of major scientific projects of strategic nature essentially as an ancillary technique to superconductivity.

Nuclear magnetic resonance (NMR) is a powerful analytical technique requiring high magnetic fields. Such magnetic fields are produced by superconducting magnets cooled by liquid and sometimes superfluid helium. NMR has found a variety of applications in many disciplines of scientific research, medicine, and various industries.

The CERN's Large Hadron Collider (LHC) – the world's largest and most powerful particle accelerator – uses a 27-kilometre ring of superconducting magnets maintained at -271.3 °C through superfluid helium to reach the high energies needed to test fundamental theories of particle physics. The discovery of the Higgs boson in July 2012 is the first major result of LHC research.

The Future Circular Collider (FCC), the next-generation facility currently under consideration, is intended to produce magnetic fields nearly twice as strong as the LHC, and accelerate particles to unprecedented energies of 100 tera-electron volts, about 7 times higher than the LHC.

2.7 Leisure and sports

Ice rinks (about 17,000 worldwide, artificial ski runs, bobsleigh, luge and skeleton tracks become more and more popular. Snowmaking machines, employing state-of-the-art refrigeration technologies, are increasingly used as, with rising temperatures, the snowfall season has become shorter, especially in the northern hemisphere.

IIR RECOMMENDATIONS

The issues of food safety, health, energy and the environment make it quite clear that refrigeration is of paramount importance for mankind and must become a priority for governments in the sectors of industry, education and research.

It is necessary to advance training and qualification of staff in the refrigeration sector, but also to incite more young people to turn to promising refrigeration-related careers offering long-term perspectives. No effort should be spared to help developing countries reach refrigeration capacities necessary to preserve food safety and human health. Investments in infrastructures should also be made in order to implement the adequate equipment.

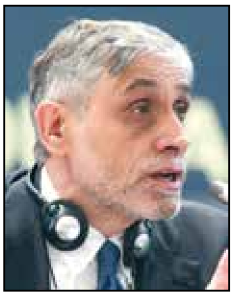
Improving the energy efficiency of refrigeration plants is a key issue and must remain a constant concern for the refrigeration industry. This involves further research and development in innovative efficient refrigeration technologies and in different renewable energy sources (solar, wind, geothermal, biogas, etc.), offering smart alternatives to the electrical grid when powering refrigeration plants. This also involves the generalisation of policy measures to encourage consumers to purchase increasingly efficient refrigeration equipment.

The amount of high-Global Warming Potential (GWP) refrigerant emissions from refrigerating plants must be reduced through leakage control, charge reduction, end-of-life recovery and use of alternative natural or synthetic low-GWP refrigerants.

Refrigeration-related research and development must be further stimulated and actively supported by national and international authorities, funding agencies, public and private industries in order to improve health, well-being, energy and environmental sustainability around the world.

For the list of references visit: bit.ly/IIRInformatoryNotes

The 2018 RTOC Assessment Report under Montreal Protocol



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1. INTRODUCTION

The Refrigeration Technical Options Committee (RTOC) under United Nations Environment (UNEP) Montreal Protocol (https://ozone.unep.org/) has released its 2018 Assessment Report in March 2019 (UNEP, 2018).
The RTOC is one of the five Technical Options Committees of the TEAP (Technology and Economic Assessment Panel), which assist parties to the Montreal Protocol in implementing the Protocol and its subsequent amendments, such as the Kigali Amendment that mandates a phase-down of HFCs (https://ozone.unep.org/science/overview).
The 2018 RTOC Assessment reports on the state of the art of Refrigeration, Air Conditioning and Heat Pump (RACHP) technologies in relation to the Montreal Protocol framework on phasing out ODS (Ozone Depleting Substances) and implementing non-ODS replacements.

2. THE REPORT

This 2018 Refrigeration, A/C and Heat Pumps Technical Options Committee Assessment Report (hereafter called “2018 RTOC Assessment Report”) forms part of the UNEP review pursuant to Article 6 of the Montreal Protocol. It is part of the 2018 assessment work of the Technology and Economic Assessment Panel.
The information collected (particularly in the form of the Key Messages and Executive Summaries) is also part of the 2018 Technology and Economic Assessment Report, as well as the overall 2018 Synthesis Report as composed by the three Assessment Panels[5] by April 2019.
All the reports can be downloaded from the UNEP Montreal Protocol website (https://ozone.unep.org/science/assessment/teap).
The RTOC assessment report was developed by all full RTOC (reporting) members; as resource persons, the RTOC also had a small number of reviewing members. Each of the chapters was developed by 2-8 experts in the specific sector, and the chapter was chaired by a Chapter Lead Author (CLA) - who did the larger part of the drafting and the co-ordination.
Several drafts of the report were made, reviewed by the separate chapters and discussed in five RTOC meetings (2015-2018). Drafting and reviewing meetings were held in Paris, France (2015), Kingston, Jamaica (2016), Amman, Jordan (2017) and Bruges, Belgium (2017), as well as in Delhi, India (2018).
A last meeting to discuss peer review comments and to decide on the final 2018 RTOC Assessment Report contents was held in Rome, Italy (December 2018).
The 2018 RTOC Assessment Report has been drafted in the form of a number of chapters. There are chapters on refrigerants and their properties, on the different RACHP application areas and there is one chapter on sustainable refrigeration. The structure of the report was decided to be more or less similar to the structure of the 2014 RTOC Assessment Report:
The following Table reports, for each single Chapter of the report, the list of Chapter Lead Authors and Co-Authors.
All chapters drafted key messages as well as executive summaries. These key messages, derived from the summaries, as well as the summaries have been put together and form the first part of the 2018 RTOC Assessment Report. They are elaborated upon in the following.

[5] See: https://ozone.unep.org/science/overview

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Chapter 9, Chillers	D. Dorman (US)	J.M. Calm (US), M. Dieryckx (BE), S. Hamed (JO), A. Pachai (DK), G. Rusignuolo (US)
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Chapter 12, Not-In-Kind Technologies	M. Alaa Olama (EG)	Guangming Chen (CN), S. Devotta (IN), S. Hamed (JO), P. Vodianitskaia† (BR)
Chapter 13, High-Ambient-Temperatures Applications	B. Elassaad (LB)	D. Colbourne (UK), M. Dieryckx (BE), S. Hamed (JO), L. Kuijpers (NL), T. Li (CN), M. Mousa (SA), M. Alaa Olama (EG), A. Pachai (DK), R. Peixoto (BR)
Chapter 14, Modelling of RACHP Systems	L. Kuijpers (NL)	D. Godwin (US), M. Janssen (NL), M. Mousa (SA), R. Peixoto (BR), A. Vonsild (DK)

3. KEY MESSAGES

Refrigerants

- Since the publication of the RTOC 2014 Assessment Report (UNEP, 2014), 35 new refrigerants have received a standard designation and safety classification and five are single-compound refrigerants.
- There is not a single "ideal" refrigerant. Refrigerant selection is a balanced result of several factors which include: suitability for the targeted use, availability, cost of the refrigerant and associated equipment and service, energy efficiency, safety, ease of use, and environmental issues.
- The HFC phase-down under the Kigali Amendment, as well as regional and national regulations, are driving the industry towards the use of low GWP refrigerants. Alternatives to high GWP refrigerants exist and new lower GWP refrigerants have been proposed, which creates a challenge to finding the best refrigerant for each application. Many of these newly introduced refrigerants are expected to play only an interim role in the phase-down process, as their GWP may still be high for the average future application.
- Refrigerants with low direct impact on climate change are often flammable and may have higher toxicity. In order to maintain the current safety levels new technologies are being developed and an increased level of training will be needed.

Domestic appliances

- HC-600a (predominantly) or HFC-134a continue to be the refrigerant options for new production and currently, more than 1 billion domestic refrigerators use HC-600a. None of the other new refrigerants has matured to become an energy-efficient and cost competitive alternative.

Commercial refrigeration

- Lower GWP HFC/HFO blends and non-halocarbon options like R-744, HC-290, HC-600a and R-717 are growing in use, especially as research and development continues into improving system performance; this trend will increase once new safety standards and codes go into effect in the next few years.

Industrial refrigeration and heat pump systems

- In larger industrial refrigeration plants, R-717 has been extensively used for more than 150 years. Current technological advances enable the use of low charge R-717 systems, as well as cascade systems using R-717 together with R-744, opening up new opportunities.

Transport refrigeration

- In some regions, a significant migration from R-404A to lower GWP has occurred since the last assessment. Today, R-404A has been completely replaced by R-452A in new truck and trailer equipment in Europe. This trend might extend across the rest of the world.
- R-744 and R-513A have been introduced in intermodal container appli-

cations. R-744 is being field tested on trucks and trailers.

Air-to-air air conditioners and heat pumps

- The phase out of HCFC-22 in non-Article 5[6] parties is essentially complete and is progressing in Article 5[7] parties.
- There is an almost continuous introduction of new refrigerants for use in air-to-air air conditioners and heat pumps, but few match or exceed the performance of HCFC-22 regardless of the GWP. Component and system optimization can be a design challenge.
- Despite the reported low risk for certain applications, safety standards remain restrictive to several low GWP flammable refrigerants in certain product types, but are under revision for all refrigerants. There remains no large-scale shift to low GWP refrigerants as yet.

Water and space heating heat pumps

- Water and space heating heat pumps are a dynamic market with a number of options. Low GWP refrigerant HC-290 and the medium GWP refrigerant HFC-32 are commercially available, and other medium and low-GWP HFC blends may become commercially available. R-744 based water heating heat pumps have been mainly developed and commercialized in Japan, where around 6 million units have been installed since 2001. In Europe, commercial sized units are being installed for multi-family houses and hotels.

Chillers

- The phase-out of ozone depleting refrigerants in new chillers is nearly complete. HCFC-22 in new, small chillers has been phased out in non-Article 5 parties, but limited production continues in Article 5 parties.
- Since the HFCs in use today are considered to have a high GWP, there is global pressure to change to lower GWP refrigerants. Research for alternative refrigerants with lower GWP are nearly over and have yielded several acceptable alternatives.

Vehicle air conditioning

- At present, more than one refrigerant is used for new car and light truck air conditioning: HFC-134a will remain widely accepted world-wide while, due to regulations, the use of HFO-1234yf will continue expanding mainly in the US, Europe and Japan. R-744, currently available for very few car models, is expected to be considered as an option for electrified vehicles, when used at the same time for a heat pump function.

Energy efficiency and sustainability applied to refrigeration systems

- Industry and policymakers may consider the methods, tools and incentives described in this RTOC assessment report chapter to stimulate and support improvements on energy efficiency and sustainability. A wider range of relevant environmental and social aspects is briefly described in this chapter while keeping focus on possible environmental impacts of refrigeration systems.
- Comprehensive sustainable selection criteria for refrigerants have been introduced. They address energy efficiency, impact on climate and hydrosphere, usage of renewable energy, and other options to reduce GHG emissions and consumption of natural resources, adaptability for thermal energy storage, costs, technological development level, safety, flammability and liability.

Not-in-Kind technologies

- Not-In-Kind (NIK) technologies do not primarily use mechanical vapour compression (MVC) technology to produce air conditioning or refrigeration.
- These technologies can be classified as “widely commercially available”, “commercially available” or “emerging and R&D”. They are divided into three groups: (1) thermal, (2) solid-state, and (3) electro-mechanical technologies.
- Thermal technologies are predominantly available commercially; solid-state technologies are mostly available commercially with one technology in the R&D stage; electro-mechanical technologies are mostly in the R&D stage. The last ones are assumed to become the NIK technologies of the near future, with expected higher EERs compared to other NIK technologies.
- NIK technologies are expected to provide savings in operating costs. Their unique ability to use waste and renewable energy sources makes their application potentially highly energy efficient.

High Ambient Temperatures (HAT) Applications

- Research done at HAT conditions reveals viable low-GWP refrigerant alternatives that can be effectively used.
- There is more awareness of the challenges faced at HAT conditions in the design, implementation, and even servicing of equipment using low-GWP refrigerants that are capable of delivering a high level of energy efficiency.

Modelling

- Determination of current and future refrigerant demand has been a task for RTOC experts when involved in recent Task Force reports. The demand follows from “bottom-up” calculations of banks and emissions that give good insight into future developments, albeit that these imply assumption of a large amount of parameters. This includes economic growth, equipment base and composition, leakage, end-of-life characteristics, recovery and recycling.
- The methodology used by the RTOC to model banks and emissions from the global sector transitions is described in significant detail for the first time in this assessment report.

4. REVIEW

After the meeting in India (March 2018) a peer review draft was developed and was ready for review by the end of August 2018. This draft was subsequently peer reviewed by a number of institutions and associations (twenty in total); each of them reviewed (via their experts) the different chapters in a co-ordinated effort.

[6] “non-Article 5” are those countries not included in Article 5 of Montreal Protocol (see https://ozone.unep.org/classification-of-parties)

[7] “Article 5” parties are those developing countries included in Article 5 of Montreal Protocol (see: https://ozone.unep.org/montreal-protocol-substances-deplete-ozone-layer/79722/22 and https://ozone.unep.org/classification-of-parties)

This took place between late August 2018 and early October 2018 (see the Table below for the organisations involved). As a result, a total of 2000 comments were received.
During the December Rome meeting, RTOC members decided in separate chapter meetings (and thereafter in plenary) on whether and how to amend the draft chapter texts on the basis of all the peer review comments received.
This resulted in semi-final drafts of the chapters which were put together and formatted into one complete, consistent report, after which the report was once more reviewed by the RTOC CLAs and co-authors.
After that all final comments had been inserted the report was submitted to UNEP in the course of February 2019. The Key Messages of the RTOC Assessment Report are part (as in the case for the Key Messages from all TOC reports) od the TEAP 2018 Assessment Report which was reviewed during the TEAP meeting in April 2019.

1 AICARR	IT	Ass. Italiana Condizionamento dell'Aria Riscaldamento e Refrigerazione
2 AIRAH	AU	Australian Institute of Refrigeration, Air Conditioning and Heating
3 ASHRAE	US	American Society of Heating, Refrigeration and AC Engineers
4 CAR	CN	Chinese Association of Refrigeration
5 CARB	US	California Air Resources Board
6 CHEAA	CN	China Household Electric Appliances Association
7 CRAA	CN	Chinese Refrigeration and Air Conditioning Association
8 CSE	IN	Center for Science and Environment, CSE India
9 DKV	DE	German Refrigeration Association
10 EHPA	EU	European Heat Pump Association
11 EIA	US	Environmental Investigation Agency
12 EPEE	EU	European Partnership for Environment and Energy
13 Eurammon	EU	European Industry - Association for Ammonia etc
14 IIR		International Institute of Refrigeration
15 IOR	UK	Institute of Refrigeration, UK
16 ISHRAE	IN	Indian Society Heating Refrigeration Air Conditioning Engineers
17 JRAIA	JP	Japanese Refrigeration and Air-conditioning Industry Association
18 NIST	US	National Institute of Standards and Technology
19 SAE	US	SAE Interior Climate Control Steering Committee
20 shecco		R/AC Market Development Expert Organization Brussels

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Mobile Air Conditioning (Chapter 10)

1. INTRODUCTION

The Refrigeration Technical Options Committee (RTOC) under United Nations Environment (UNEP) Montreal Protocol (https://ozone.unep.org/) has released its 2018 Assessment Report in March 2019.
The Chapter 10 of the Report is devoted to the Mobile Air Conditioning system used for road transport vehicles covering the new developments since the RTOC 2014 Report including the evolution related to the vehicle electrification. Even though railway (train) air conditioning falls within mobile mass transit, because of similarity of technology it is covered in Chapter 6 (Transport Refrigeration).

2. SCENARIO

The majority of new AC equipped passenger cars worldwide uses HFC-134a while HFO-1234yf is rapidly increasing its market share in US and Europe due to the enforcement of regulations. The transition from CFC-12 is complete for new systems, but there are still cars in use especially in Article 5 countries where average age of vehicles is higher than in the other regions of the world.
More than one refrigerant will be used in the coming years for car and light truck air conditioning. HFC-134a will remain largely used worldwide, HFO-1234yf will continue its growth in new models, R-744 is used in a couple of car models and is expected to be reconsidered as an option for electrified vehicles when used also with in heat pump function.
The de-carbonization of road transport and its progressive electrification is leading to a very relevant technology change that includes the Mobile Air Conditioning. The vapour compression cycle will remain by far the most used technology but implemented with different configuration where the direct expansion will be in part replaced by liquid cooled systems to allow the electric and battery thermal management. HFO-1234yf will increase its take rate but the global vehicle air conditioning market will be significantly governed by additional considerations such as safety, costs, regulatory approval, system reliability, heat pump capability (especially for electric driven vehicles) and servicing. The transition to new and more expensive refrigerants is driven by regulations, so where there are or will be specific regulations, HFO-1234yf will be further diffused, otherwise the old refrigerant HFC-134a) will be kept as main option unless (or until) less expensive solutions will become available. In this framework, it should be mentioned that there are studies to evaluate the use of less expensive but flammable low GWP refrigerants in Article 5 countries. Finally, it is unclear whether the bus and heavy duty truck MAC will follow the passenger vehicle evolution or another path, utilizing for example HFO-1234yf or other options (HFO blends, R-744, …)

3. TYPES OF EQUIPMENT AND FUTURE TRENDS

Light duty vehicles use from 0.3 kg to 1.4 kg refrigerant charge, while for buses the charge could be from 8 kg up to 16 kg as a function of the vehicle category (e.g. simple bus, articulated bus). Currently there are approximately 1,000 ktonnes of refrigerant in vehicles considering that there are about 1.3 billion road vehicles circulating (see (https://www.statista.com/statistics/281134/number-of-vehicles-in-use-worldwide/). Estimating that 75% of circulating vehicles are equipped with MAC, and assuming a yearly renewal rate of 8% (e.g. 100 million units approx.), the refrigerant demand (excluding service) is about 75 ktonnes/year.

HFC-134a is widely used for new equipment as well for retrofits worldwide as replacement of CFCs. In the mid-1990's the evaluation of lower GWP refrigerant started, as an alternative to HFC-134a where several synthetic and natural working fluids (e.g. R-744, R-290) have been evaluated, the HFO-1234yf has been then selected to replace R-134a and reducing the GWP in spite of its (low) flammability and higher cost.

In 2013 OEMs started the transition to lower GWP refrigerants driven mainly by regulations (US light-duty vehicle regulations, European MAC Directive, Japanese regulatory prohibitions). and supported by non-regulatory initiatives (e.g. the Improved Mobile Air Conditioning (I-MAC) SAE Cooperative Research Program CRP) as well as four SAE 1234yf CRPs and the SAE Interior Climate Control Committee).

4. LIGHT DUTY VEHICLES AND ELECTRIFICATION ASPECTS

Usually a vapor compression cycle in combination with a ventilation system is used to provide the passenger compartment cooling. The system also includes a coolant circuit and heat exchanger to use the engine waste heat to heat the cabin. The combination of cooling and heating function ensures the air dehumidification that enhance the fogging prevention function. The worldwide regulation to reducing the GHG emission are driving toward an increasing of vehicle electrification (e.g. the European Union is on its way to fully de-carbonize the light duty vehicles) that will reflect on MAC design and requirements.

The Hybrid Electric Vehicle combines a combustion engine and an electric motor to recuperate the vehicle kinetic energy that is stored in a battery. The electric motor is used to support the conventional engine and to enable the vehicle to travel in pure electric mode. To ensuring the thermal comfort in electric driving mode an electric semi-hermetic compressor is usually implemented. In case of Plug-in Hybrid Electric Vehicle have usually larger batteries that can be charged also connecting the vehicle to the electric power network (plug-in) enabling the vehicle to drive longer distances (e.g. 50 km) in pure electric mode.

These vehicle together with pure BEV (Battery Electric Vehicles) the MAC system is used also to thermally control the battery especially during charge phases, although in some instances two separate systems may be employed. The system loop integrates a chiller (refrigerant to coolant) or a direct expansion evaporator, either conventional for air-cooling or plate coupled to the battery array for battery thermal management. The refrigerant charge of such a system is usually about 30% to 50% higher than that of a conventional system. The cabin heating is ensured by the engine waste heat or, when in pure electric mode, by an electric heater or a heat pump. The heating and air conditioning function may affect in a relevant way the pure electric range reducing it up to 50% (Denso, 2017, Koehler, 2018; Westerloh, 2019).

5. HEAVY-DUTY TRUCKS

The heavy-duty trucks use a main system based on the same concept which is used in light duty vehicles but with a slightly higher refrigerant charge due to the longer distance from compressor to cabin. Quite often, to ensure comfort while parked, an auxiliary air conditioning system is used. This system is usually quite similar to domestic systems with an external condenser, an internal cooling and ventilation unit and an auxiliary electric compressor. Currently heavy-duty truck MAC systems rely on HFC-134a, although HFO-1234yf is allowed on some classes (e.g., USEPA, 2016a).

6. BUSES AND COACHES

Buses and Coaches are mass transit vehicles that have air-conditioning systems that are larger in size with higher cooling capacity, and larger refrigerant charges than passenger cars. They also operate at ambient temperatures ranging from -30 ºC to 50 ºC. These systems are typically packaged type roof or rear mounted units with compressors belt driven by the vehicle engine. The predominant refrigerant is HFC-134a with R-407C for high ambient temperature applications in some instances, while R-744 has also been introduced in small volumes in Europe. Typical refrigerant charge sizes have been around 10 kg, which was reduced in recent years by 50% and more, due to the implementation of microchannel condensers.

7. ENERGY EFFICIENCY IN MAC APPLICATIONS

Base on average annual values, HFO-1234yf as well as R-774 systems exhibit efficiencies comparable to HFC-134a for cooling and heating.

To achieve these performance levels, in case of HFO-1234yf, manufacturers use either an IHX or larger degree of sub-cooling while for R-744 appropriate system design (e.g. IHX) and control are required.

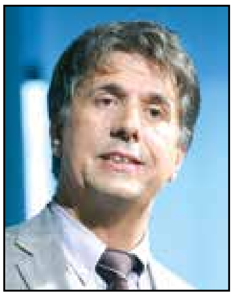
8. CONCLUSIONS

Currently, more than one refrigerant is used for car and light truck air conditioning: HFC-134a will remain largely used worldwide, while HFO-1234yf is currently the main option in Europe and North America and the R-744 is currently available on a couple of models The progressive diffusion of highly electrified vehicles (PHEV and BEV) in Europe, China and North America will lead to the implementation of heat pump function where R-744 will be also reconsidered thank to its properties.

Other low GWP synthetic refrigerants and refrigerant blends (e.g. R-444A, R-445A) have been investigated but do not seem likely to be used in the near future while interest has been shown for R-152a for application in non-article 5 countries thanks ot is lower GWP and cost.

Currently, it cannot be foreseen whether or not all these refrigerants will remain for a long period of time parallel in the market. It is also unclear where bus sector (where currently HCFC-22, HFC-134a, R-407C and R-410A are used) and the heavy-duty truck sector will follow these trends.

AREA Vision 2025 To Face the Global Challenges of Our Time



Marco **BUONI**

President of AREA
Air Conditioning and Refrigeration European Association

Director of Centro Studi Galileo

Secretary General ATF

Cooling is essential to modern life and it makes people's lives better: refrigeration preserves foodstuff and vaccines whilst air conditioning provides thermal comfort and keeps data centres running. Versatile and omnipresent, cooling has become absolutely critical to people's well-being and will be even more so in the face of climate change and digital transformation. Contractors fulfil an essential mission: they ensure the proper design, installation and functioning of the refrigeration, air conditioning and heat pump systems that satisfy these various societal needs.
The refrigeration, air conditioning and heat pump contracting sector is undergoing profound changes driven by 4 main factors: increased demand for cooling, sustainable cooling, technological developments, and attracting, retaining and upskilling personnel.

Increased demand for cooling
Changes in people's lifestyle, digital transformation and climate change result in a surge of the demand for cooling. Such a trend will accelerate in the coming years.

Sustainable cooling
Whilst the need for cooling increases, its impact on the environment conversely decreases under the combined effect of several factors: transition towards alternative refrigerants with low global warming potential (GWP), decarbonisation and circular economy measures, technological developments and increased competence of personnel.

Technological developments
Plug-and-play equipment, essentially unserviceable, is growing in numbers. However, the biggest change our sector faces certainly lies in the industry's transition from product-based towards a system approach: versatile systems working with different energy sources and adapting to weather and climate conditions, and more technologically advanced systems integrating artificial intelligence abilities.

Attracting, retaining and upskilling personnel
As demand for cooling increases, so does the need for personnel. Yet, attracting and retaining talents is challenging. At the same time, regular upskilling is necessary to adapt to fast technological developments.
In this context and with a new EU political cycle starting, AREA would like to present its strategic vision for the European refrigeration, air conditioning and heat pump contracting industry for the next 5 years. This also follows on from the Vision 2020 presented in 2014.

The AREA Vision 2025 consists of 4 pillars:

- Refrigerants: succeeding in the transition towards alternative refrigerants
- Sustainable innovation: supporting energy and resource efficiency principles in a lifecycle approach
- Human capital: supporting members in attracting and retaining skilled personnel
- Framework conditions: promoting a coherent and supportive regulatory and standardisation framework.

Refrigerants

'succeeding in the transition towards alternative refrigerants'

The Kigali Amendment to the Montreal Protocol has set ambitious global targets on HFC consumption reduction. In Europe, the transition towards low GWP alternative refrigerants has already started under the F-Gas Regulation. The European refrigeration, air conditioning and heat pump contracting industry is committed to help reduce greenhouse gases emissions thanks to highly efficient alternatives handled safely by competent personnel.

To support the transition towards alternative refrigerants, we will:

- ▶ Support initiatives aimed at tackling refrigerants' availability and illegal trade
- ▶ Promote mandatory certification for alternative refrigerants
- ▶ Support a balanced approach between environmental effectiveness and safety imperatives

Sustainable Innovation

'supporting energy and resource efficiency principles in a lifecycle approach'

Installers can play a key role in the decarbonisation efforts by designing refrigeration systems that are both energy efficient and that use refrigerants with a low GWP. AREA will support the different interlinkages between the decarbonisation of the sector (more energy efficient systems, using renewable energy resources) and the introduction of Circular Economy criteria (durability, reparability, recyclability of materials).

We will work to support decarbonisation in our industry by:

- ▶ Promoting energy e?ciency gains that can be achieved through proper design, installation and maintenance of refrigeration systems
- ▶ Encouraging life-cycle assessments of refrigeration systems to measure the sustainability of systems throughout their lifetime
- ▶ Ensuring that sustainability of the refrigeration and air conditioning sector remains high on the political agenda

Human Capital

'supporting members in attracting and retaining skilled personnel'

Human capital certainly is contractor's most valuable asset. Yet, it is also the mostfragileone.Asdemandforcoolingincreases,sodoestheneedforqualified personnel. Like many other industries, refrigeration and air conditioning contractors find it challenging to attract and retain new talents.

Reasons are numerous, ranging from misperceptions toa lack of visibility of the sector and of understanding of its technological edge and societal purpose.

To attract and retain new talents, we will:

- ▶ Highlight the industry's societal purpose and positive contribution to citizens' daily life
- ▶ Put forward the technological dimension of the industry, where digitalisation is an integral aspect of many working tasks
- ▶ Promote a more inclusive workforce, notably attracting more women in the profession
- ▶ Emphasise the numerous career advancement opportunities that the sector has to o?er

The industry is also experiencing profound changes under the combined effect of digital transformation and the transition towards alternative refrigerants. More than ever, regular upskilling is necessary to maintain the high level of expertise that the industry takes pride for.

To continuously enhance personnel's competence, we will:

- ▶ Promote lifelong learning and strong vocational training curricula to address digital transformation and the transition towards alternative refrigerants
- ▶ Work to ensure that education systems match industry's evolving needs as the sector is moving from mechanical (products) to digital/automation (smart and innovative systems)
- ▶ Facilitate the exchange of information and best practices among members

Framework Conditions

'promoting a coherent and supportive regulatory and standardisation framework'

Because of its technological feature and environmental dimension, the refrigeration and air conditioning sector falls under a large amount of legislation and standards. Consequently, industry's success with refrigerants, sustainable innovation and human capital depends to a large extent on a coherent and supportive framework.

We will work for competence, safety and product standards that are:

- ▶ Consistent with the regulatory framework
- ▶ Supporting contractors' trading landscape

We will work for a supportive legal framework:

- ▶ At national level, by supporting our members towards their national authorities
- ▶ At EU level, through advocacy, networking and cooperation
- ▶ At international level, by collaborating with both institutional and industry stakeholders

Looking Towards 2030

In a continuously evolving working environment, the cooling sector is already looking further ahead. Whereas this Vision & Strategy paper is focused on the medium term, we are already identifying longer term trends and opportunities for the industry.

A future where:

- ▶ We will have moved from owning equipment to renting thermal conditions (e.g. comfort temperature levels at home, in a refrigeration plant).
- ▶ We will have achieved a more uniform education framework.
- ▶ Refrigeration and air conditioning equipment will be smarter and more connected to achieve optimal efficiency from an energy, environmental and comfort point of view.

► AREA will have increased its representativeness at European level and international outreach.

These pillars will serve as overarching strategic imperatives that will guide AREA's activities in the next 5 years and beyond.

Competence and Training

AREA is involved actively in 3 Projects on Competence and Training
- REAL Alternatives for LIFE
- Refrigerant Driving License[1]
- Universal Training Kit for Alternative Refrigerants UT-KAR

real alternatives europe

With contribution of the LIFE programme of the European Union

Financed by the EU's funding instrument for the environment and climate action, "the LIFE programme", the REAL Alternatives for LIFE project is an extension of the previous REAL Alternatives project.

As part of this funding programme, the European Commission is co-financing a consortium of European training centres and associations in partnership with the IIR to provide "Train the Trainer" sessions on low GWP refrigerants (Hydrocarbons, CO_2, Ammonia, HFOs, R32) in order to ensure safe, efficient, reliable and cost-effective implementation.

The objective of the project is to develop new and update existing training material, as well as to introduce a range of practical exercises and assessments with an aim to standardising skills sets and requirements for handling low GWP refrigerants across the globe.

The project will promote the best practice in training in this field whilst equally increasing awareness, experience and knowledge at all levels by ensuring a presence at key national, EU and international meetings, conferences and events.

Confirming its international scope, initially it has been defined that it would be conducted in 13 languages and 15 countries which are involved in the project.

Due to the large success now it has already been translated in 15 languages for 18 countries. More countries asked to join.

Why do technicians need to do alternative refrigerant training?

- The F-Gas Regulation in Europe is phasing down availability of HFC refrigerants
- Use is increasing in alternative refrigerants both natural and synthetic
- HFC refrigerant prices are unpredictable
- Industry needs to move away from high GWP HFCs for environmental reasons

- Kigali Amendment will bring a worldwide phase down

Training is KEY to quickly move to low GWP refrigerants.

Our research has shown that the market for Alternative Refrigerants is growing and demand for training is growing alongside this.

REAL Alternatives offers a ready-made training and assessment programme for use by trainers.

It is possible to apply now to become an official training provider to access teaching and assessment tools.

Why REAL Alternatives is good news for training providers

- Offer your students a training Certificate in alternative refrigerants recognized throughout Europe
- Use course materials designed for you by a team of international training experts - saving you time and money
- Be recognized as an Official Qualified REAL Alternatives Training Provider

REAL Alternatives offers everything to set up a two-day course in the safe use of flammable refrigerants HCs (propane, isobutane) and A2L (R32, HFOs including R1234ze, R1234yf and HFO blends), and a three-day course for carbon dioxide.

Course content
Background to the use of natural refrigerants
Refrigerant properties – an introduction
Managing Safety hazards
Cylinders and cylinder handling
Working safely
Service & repair procedures
Installation & commissioning
Reducing leak potential
Applications
System design differences

The training provider course guide includes teaching programme, pre-learning materials, training and test equipment specifications, practical and theory assessments and certification. A specification for minimum skills of trainers is also included. Ammonia Course materials as theoretical knowledge and awareness only is also available.

Optional support can be included to teach trainers how to deliver alternative refrigerant courses.

[1] More information in a following article, page 72

How to become a REAL Alternatives Official Training Provider

To start offering training courses in flammables (including HFO lower flammable refrigerants), carbon dioxide and ammonia, REAL Alternatives Provides:

- Guidance on what training equipment you need
- Training materials available in 15 different languages
- Programme designed by a team of independent European training experts
- Practical and theory assessments and marking schemes
- European Certificate in REAL Alternatives for successful technicians

real alternatives europe — With contribution of the LIFE programme of the European Union — Official Training Provider

Additional benefits

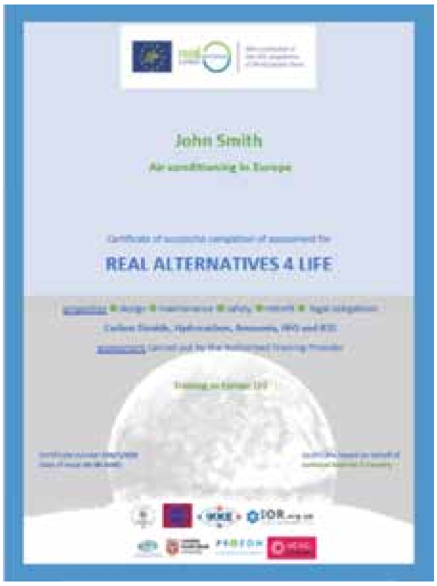
- Become part of a worldwide network of training providers
- Marketing support from the international team
- Optional training available for your trainers

In Europe, levels of training received and required[2]

In this section we investigate the current share of low GWP against traditional refrigerants in use through a public survey.

Type(s) of Business of Responses to the Survey	Number of Responses
Equipment Manufacturers and Wholesalers	**39**
Large scale (more than 250 employees) ○ **Designers** ○ **Consultants** ○ **Suppliers** ○ **Installers &** ○ **Maintenance Companies**	**14**
Small to medium scale Suppliers / Installers both Individuals & Companies (1 - 249 employees)	**109**
Owners / Operators of systems	**4**
Training providers and Educators	**44**
COUNTRIES: UK, Poland, Belgium, Italy, Germany, Czech, Croatia, Turkey, Spain, Slovakia, France, Denmark, Portugal, Romania	TOTAL **210**

[2] Real Alternatives for LIFE 16 GIC/UK/000007 Needs Report 2018, Alex Paurine, Graeme Maidment.



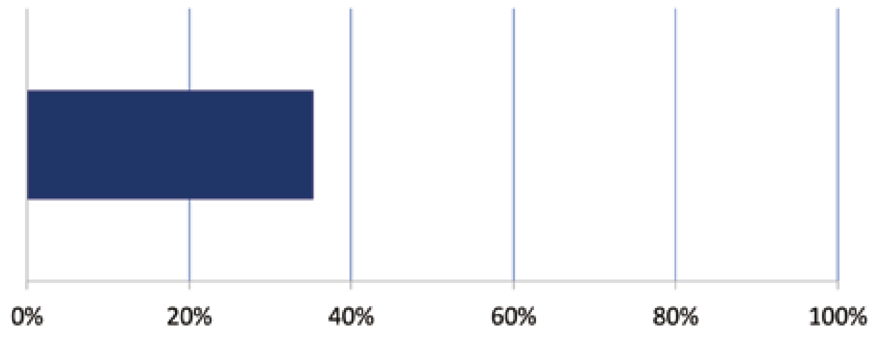


Figure 1: *Estimated Market Share of Low GWP refrigerants versus traditional HFCs*

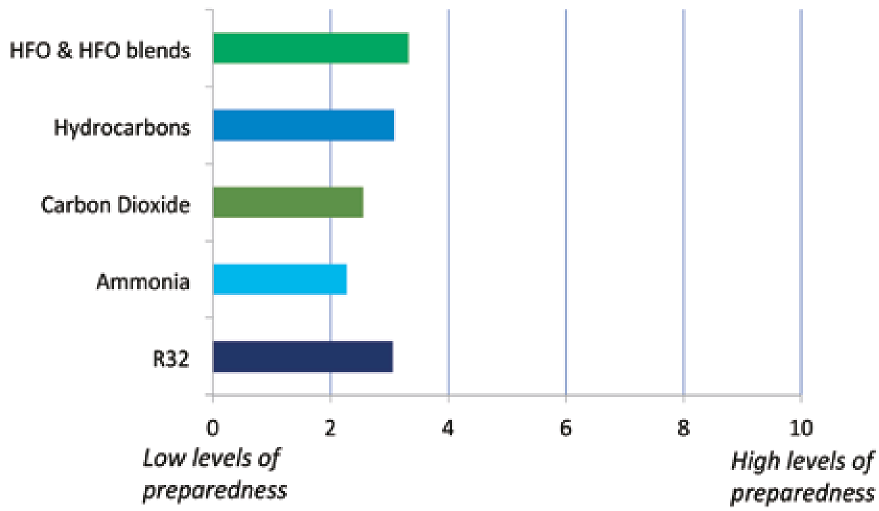


Figure 2: *Average level of preparedness for manufacturing and/or selling of Low GWP refrigerants equipment or components*

Current % share of Low GWP refrigerants versus traditional HFCs in use

Figure 1 shows that only 35% of users consider the market to be currently using this type of refrigerant. If the market share of these refrigerants is to grow, then all businesses need to have increased experience and confidence in the market.

Extent of training offered on Low GWP refrigerants-based systems

Of the 35% of businesses that were using low GWP refrigerants, we asked about the extent of training available. 50% of the companies provide training themselves, 10% provide training via external the trainers and 40% have no training ability for these refrigerants.

Taking into account all businesses including those not using low GWP refrigerants currently, it appears that only 21% of businesses have training provision for low GWP refrigerants. This represents a major barrier to the development of low GWP capability and market change.

The nature of the training provided in low GWP refrigerants

Most of the respondents indicated that they do not provide training on Low GWP refrigerants and of those few who confirmed they did, only do so informally e.g. during handover to service engineers who will service the newly installed systems after completion of the project.

Of the respondents that do offer training in the use low GWP refrigerant systems 56% insist on both practical and theoretical training.

Preparedness in manufacturing and/or selling equipment or components that use Low GWP refrigerants

We asked respondents about their preparedness for selling equipment and components that use low GWP refrigerants, with a self-evaluation scoring scale of 0 for “Not prepared” to 10 for “Fully Prepared”.

Figure 2 shows the average score results from the respondents to this question. This indicates very low average levels of preparedness for these refrigerants.

The survey results point towards low levels of capability for low GWP refrigerant systems as well as low capacity.

Launching Event of #AREAvision2025: with the President of AREA, Bente Tranholm-Schwarz EU Commission and Carlo Fidanza Member of the European Parliament.

On the way to carbon neutrality, cooling is truly at the forefront of global & EU solutions: #Count on Cooling

Andrea **VOIGT**

Director General of the European Partnership for Energy and the Environment (EPEE)

Recent developments on European and international level showcase that cooling is no longer a "forgotten" sector on the way towards carbon neutrality. With demand set to grow in the coming decades, and being essential for health, fresh and safe food, through to comfort and well-being, cooling contributes to many Sustainable Development Goals. EPEE, the voice of the heating and cooling industry in Europe, is committed to provide and promote sustainable solutions that are fit for the future, demonstrating the industry's value to contribute to carbon neutrality.

Cooling is an intrinsic part of our lives: it makes our cities liveable, keeps our food safe and fresh, contributes to best-in-class health care and helps us to keep pace with digitalisation. The demand for cooling is set to grow significantly in the coming decades as the climate is warming – and even more so in the light of major trends which will directly impact the need for cooling including increasing urbanisation, a growing population and middle class and an increasing need for comfort, health and well-being.

In Europe alone, the number of air-conditioners and refrigerators is expected to double by 2030. And already today, 50% of the EU's final energy is used for heating & cooling, of which up to 6% are used for cooling. In datacentres and supermarkets, the share for cooling can reach half of their total energy consumption.

On a global level, cooling is predicted to become the single largest user of electricity in buildings, accounting for 16% of global electricity consumption by 2050.

If not properly addressed, the growing demand for cooling will impact energy consumption and emissions – as typically today at least three quarters of the total emissions of cooling systems are related to energy use. In the EU, where over 70% of the primary energy use is still based on fossil fuels, the impact of energy on total greenhouse gas emissions is significant. Furthermore, peaks in electricity demand, for example during heat waves in summer, can threaten the stability of electricity networks, unless appropriate adaptation measures are taken.

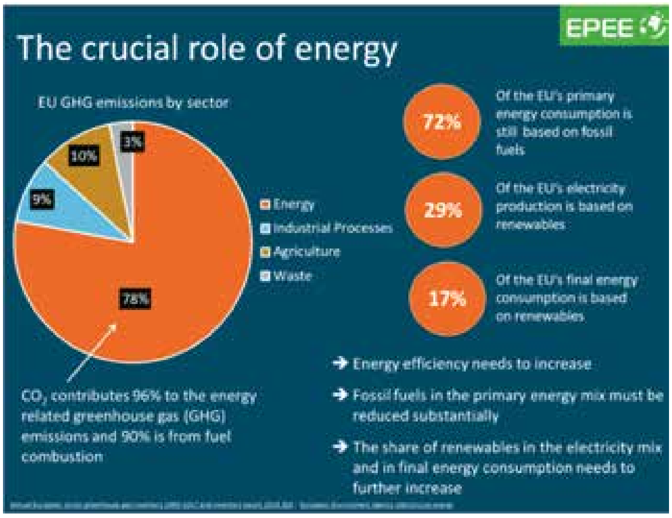
At a time when global energy and climate goals build on a total transformation of the energy system, while access to cooling and affordability of technologies remain a key priority to ensure quality of life for all citizens, it is crucial to address these factors. Energy efficiency must increase, fossil fuels in the primary energy mix must be reduced substantially and the share of renewables in the electricity mix and in final energy consumption needs to grow. Sustainable cooling must adapt to this renewable energy nexus and become mainstream on the way to carbon neutrality.

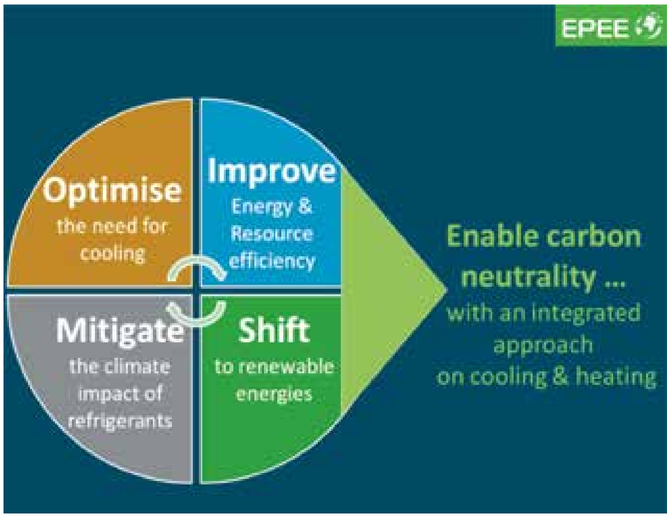
The cooling industry is ready to address the challenge

The cooling industry has already shown that it is ready to address the sustainability challenge. The Montreal Protocol to eliminate ozone depleting substances and the recently agreed Kigali Amendment for a global phase-down of HFCs are tangible examples of the instrumental role the private sector plays in driving change.

The Kigali Amendment alone could avoid up to 0.4 °C of global warming by 2100. These benefits could be further enhanced by high energy efficiency, and a shift towards adaption to renewable energies. Cooling has a massive potential to deliver on these priorities and, by doing so, to be an important enabler for carbon neutrality. Many technologies are readily available but have not been broadly deployed yet (e.g. heat pumps, heat recovery, Building Automation and Control Systems, smart appliances, thermal storage, etc.).

The European Union has undertaken concrete and ambitious climate action, notably through the revision of the EU F-Gas Regulation in 2015 and through the recently adopted Clean Energy Package, which aims to facilitate the transition away from fossil fuels towards cleaner energy and to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas emissions. EPEE supports the EU's measures and welcomes the introduction of integrated 10-year national energy and climate plans





(NECPs) for 2021 to 2030, as they will help Member States draw up concrete roadmaps to reach the 2030 climate and energy targets and beyond and provide more regulatory certainty to industry. EPEE also believes in global action such as the implementation of the Kigali Amendment, enhanced National Determined Contributions (NDCs) and dedicated national heating and cooling plans to address emissions in a way that is economically viable, affordable and accessible to people, compatible with high safety standards and promotes energy efficiency as a fundamental pillar of the energy transition.

EPEE's pledge: #CountOnCooling

In this sense and enshrined in EPEE's pledge #CountOnCooling, published at the occasion of the UN Climate Summit in New York in September, the association commits to be an active and supportive industry player to provide and promote sustainable cooling solutions on the way to a carbon neutral Europe.

EPEE members will continue to undertake concrete, proactive actions to raise awareness about sustainable cooling solutions in order to help the EU and its Member States reach their targets and remain a leader in the reduction of greenhouse gas emissions. Specifically:

→ EPEE will continue to support a full and harmonised understanding of the EU F-Gas Regulation and its implementation across Europe, as well as global action in the context of the Kigali Amendment via dedicated tools and partnerships;

- Further development of 'HFC Outlook' in cooperation with Gluckman consulting and UN Environment, a dedicated tool to model different scenarios and assess progress towards the phase-down of HFCs according to the EU F-Gas Regulation and the Kigali Amendment.

→ EPEE will continue to support EU Member States to develop and implement their national energy and climate plans (NECPs), raising awareness on the potential of sustainable cooling to improve energy efficiency, shift to renewable energies and enable carbon neutrality;

- Development of new tools for a better understanding of energy efficiency and the importance of reducing energy consumption in the context of sustainable cooling

→ EPEE will reach out to authorities and other stakeholders to highlight and address barriers preventing the uptake of sustainable cooling solutions and their integration with heating.

- Dedicated #CountOnCooling communication campaign on sustainable cooling and creation and support of new and existing partnerships to promote sustainable cooling.

An important pillar of EPEE's planned activities and #CountOnCooling campaign is a dedicated White Paper, setting out 5 key steps to ensure sustainable cooling which is fit for the future.

If these steps are fully implemented, cooling systems will have minimum cooling demand, be highly efficient and be well integrated with the power generation system.

Step 1: Optimise the need for cooling

Optimising the cooling demand should always be the first step – in many cases it will lead to a smaller system being required and a significant reduction in energy use. There are numerous ways in which this can be achieved, for example:

- Building design measures to reduce the thermal load, such as shading, high performance glazing, and improved insulation.
- Improved control systems to avoid poor consumer habits such as "overcooling". For example, using a higher temperature set point for an air-conditioned building has the dual benefit of reducing the number of hours when cooling is needed and improving the equipment efficiency at times when cooling is required. Just a 1 degree C increase in set point can save 5% of energy use. Control systems also help to avoid cooling when no people are present in the room.
- Doors on chilled retail displays can reduce the cooling demand significantly.
- Designing data centres to operate at a higher temperature to reduce the energy needed for cooling.

Step 2: Improve the energy and resource efficiency of cooling equipment

There can be massive differences between the energy consumption of different cooling systems used for the same application. There are many potential reasons for poor performance, falling into 5 main areas:

- Design: A state of the art design

might use half the energy of an older design. Technologies such as variable speed compressors and optimised heat exchanger designs can deliver significant efficiency improvements. Savings of 30% to 50% are often possible.

- Sizing: Cooling equipment is often found to be oversized due to inadequate cooling load calculations, leading to inefficient operation of the equipment and increased energy use.
- Control and operation: Modern control systems can ensure that the use of a cooling system is minimised and that the correct control settings are always used. Many inefficient systems have poor controls or the controls are not well optimised. Good controls are relatively inexpensive and might save 20% to 50% of energy use.
- Maintenance: Over a period of time the performance of a cooling system can deteriorate due to a range of maintenance issues, such as fouled heat exchangers or refrigerant leakage. A good maintenance regime is essential to minimise energy consumption. Savings of up to 30% are typically achievable.
- Monitoring performance: It is common to find that end users are unaware their cooling systems are operating inefficiently. Good instrumentation helps generate the savings possible through improved control, operation and regular maintenance.

A sustainable cooling approach also requires responsible use of the natural resources used to produce the cooling equipment (for example copper, aluminium, steel, refrigerants, etc...). This includes the need to reduce, recover and reuse these materials, contributing to a Circular Economy approach. Heating and cooling products are subject to different Regulations (e.g. in the EU: Ecodesign, RoHS, WEEE), and therefore contribute to Circular Economy across their whole lifecycle, for example:

- End of life: Heating and cooling products are not allowed to be disposed of by consumers directly, but only by professionals and installers that ensure proper handling of all materials.
- Extended Producer Responsibility (EPR): Significantly improved end-of-life recycling techniques that enhance material recovery.

Step 3: Mitigate the climate impact of refrigerants

The direct impact of refrigerants can be minimised by a combination of various factors, such as:

- The GWP of refrigerants: When new equipment is being purchased the "traditional" high GWP HFC refrigerants should be avoided. In the EU, the F-Gas Regulation has already led to the availability of lower GWP alternatives in almost all parts of the refrigeration, air-conditioning and heat pumps market. The Kigali Amendment of the Montreal Protocol will lead to rapid uptake of lower GWP alternatives throughout the world.
- Proper installation, maintenance and servicing, by working with qualified installers.
- Set up of refrigerant recovery and recycling schemes to avoid that refrigerants are emitted into the atmosphere during servicing or at end-of-life.

Panel discussion at the Energy Action Forum in the context of the New York Climate Summit in September this year. From left to right: María Fernanda Suárez Londoño, Minister of Mines and Energy, Colombia; Brian Motherway, Head, Energy Efficiency, International Energy Agency; Andrea Voigt, Director General, European Partnership for Energy and the Environment;Sergio Costa, Minister of the Environment, Italy. I spoke about our five steps towards sustainable cooling at that panel.

Step 4: Address the investment cost for higher efficiency solutions

In most countries there is little or no interaction between decisions made to purchase cooling equipment and decisions affecting the supply of electricity. If end users continue to select inefficient cooling appliances, for example because they have the lowest capital cost, there will be unnecessarily high peak electrical demands created. These must be met by building extra power stations and by creating larger electricity transmission and distribution networks. Working in this way leads to:

- Unnecessarily high electricity use and cost to the end user through use of an inefficient appliance.
- Further extra cost, as the price of electricity will need to reflect the excessive peak demands created by the widespread use of inefficient appliances. Ultimately these extra costs must also be paid by end users.

To overcome this issue, there needs to be close cooperation between the parties involved, to create a more integrated approach to the delivery of more cooling and to optimise the balance of capital investment between new cooling equipment and power generation. By encouraging end users to only use the most efficient equipment, the overall cost to the country or region can be minimised. This type of integration can be considered in a number of different ways:

- By ensuring that cooling appliances meet high standards of efficiency, for example by using Minimum Energy Performance Standards (MEPS).

- By informing users about the energy efficiency differences between products offered on the market, for example by Energy Labels.
- By supporting buyers to overcome the financial challenge of a higher investment cost, for example by offering different types of financing schemes or incentives.
- By incentivizing power supply companies to support investments in high efficiency cooling.
- By facilitating it for end users to "sell" the rejected heat from their cooling equipment to other users that require heating. For example, supermarkets could sell their rejected heat to a district heating system.

Step 5: Shift to renewable energy sources with an integrated approach to cooling and heating of individual buildings or whole cities

To maximise the cost-effective uptake of renewable energy it is important to integrate the design of energy supply systems (supply side) with the design of energy using systems (demand side). This means, for example, that buildings need to be considered as a key element of the energy infrastructure with heating and cooling demand being at the core of long-term planning.

An important opportunity is to ensure optimal use of energy between different categories of users (residential/ commercial/industrial), by coordinating building clusters at local and at city level. Such an approach enables the provision of minimal energy input, without sacrificing the functionality of the system (whether dedicated to comfort, manufacturing processes, or other functions).

Examples for system integration include:

- District heating and cooling systems for individual large buildings, building clusters or whole cities, enabling the development of highly efficient cooling systems operated with low carbon energy and optimised with sophisticated technologies such as energy storage.
- Decentralised systems such as heat pumps or photovoltaics to relieve burden from the electricity infrastructure, while guaranteeing delivery of energy without interruption, thus increasing supply reliability.
- On-site energy storage where cold (and heat) are used as thermal energy batteries and demand response schemes, where heating and cooling systems provide flexibility to the grid and shift peak demand which is increasingly important with the transition to renewable energies.
- Integration of decentralized systems into thermal networks empowering consumers to help share cooling and heating capacities, be it on a local level or on the level of building clusters. Again, this can be a great opportunity to increase efficiency and flexibility while reducing investment in large central heating and cooling plants.
- Use of rejected heat from cooling systems (heat recovery) to further enhance energy efficiency and system integration by supporting other heating needs (heat recovery).

Concluding Comments

There will be significant growth in the use of cooling over the coming decades, delivering many benefits including better health and well-being in the built environment, improved healthcare, higher work force productivity, reduced food loss and food waste, responsible consumption and production, affordable and clean energy, reduced climate impact, etc. We need to ensure that this growth is delivered with sustainable cooling solutions for the sake of people, the environment and the EU economy and competitiveness on a global level. Many of the required technologies are already available, and the cooling industry is continuing to innovate and provide further improvements.

To get the maximum benefits in the most cost effective way it is essential that there are coordinated efforts at national and EU level, to bring together experts from the power sector and the cooling industry, as well as from the public and the private sector to address all the opportunities as described in the 5-step process of EPEE's White Paper.

THE EUROPEAN HVACR WEEK AND EUREKA 2019

AREA, the Italian Associazione Tecnici del Freddo ATF, EPEE and EVIA have joined efforts to emphasise the importance of the Heating, Ventilation, Air-Conditioning and Refrigeration sector during the first ever "HVACR Week", which took place from 6 to 12 June 2019.

The associations hosted two showpiece events, namely the 18th European Conference in Milan on 6-7 June, and EUREKA 2019 in Bruges on 11-12 June. The next edition will happen in 2021 with the 19th #EUconfRAC on 10-11 June 2021.

"We want the HVACR Week to be a highlight of our sector's calendar for years to come," said Marco Buoni, President of AREA. "Six months after the entry into force of the Kigali Amendment, two weeks following the European elections, and at a time when climate change is a major concern for worldwide citizens, this is the perfect time for our sector to gather, stop and think about how it can help make the world a better place."

"Cooling and ventilation are not a luxury, but a necessity", said EPEE's Director General Andrea Voigt. "Our sector contributes significantly to a number of Sustainable Development Goals (SDGs), but is far from getting the attention it deserves. Technologies and solutions are readily available but still not sufficiently deployed. This is even more worrying as current trends such as urbanisation, an ageing population and a warming climate will fuel market growth, as well as energy demand."

That's why this year's EUREKA focused on the role of cooling and ventilation in view of the SDGs. The event explored opportunities for sustainable cooling and ventilation technologies and their role as part of the transition towards smart and sustainable cities and regions, as well as the wider challenges the sector is facing such as skills, employment and gender participation.

HFCs Illegal Trade in Europe

Fionnuala **WALRAVENS**

Campaigner
Environmental Investigation Agency - EIA

Paper presented at the 18th European Conference bit.ly/EUconfRAC2019

ABSTRACT

The Environmental Investigation Agency presents an analysis of Hydrofluorocarbon (HFC) trade data and information from industry and Member States relating to the illegal trade in HFCs. Illegal trade of HFCs undermines the European Union's (EU) F-gas Regulation, results in additional HFC emissions that fuel global warming and significantly reduces government income and the profits of legitimate businesses.
EIA analysis suggests that as much as 16.3 million tonnes of carbon dioxide equivalent (MtCO2e) of bulk HFCs were illegally placed on the market in 2018, equivalent to the annual emissions of four coal fired power stations. This represents more than 16% of the 2018 quota and is in addition to illegal imports of HFC-containing equipment and illegal HFCs that are undoubtedly being smuggled under the radar of customs. These findings are supported by EIA's industry survey which shows widespread illegal trade in HFCs across the EU. This paper highlights the methods commonly used and proposed various tools member states, customs and the European Commission can use to tackle HFC smuggling.

EIA Campaigner Ms Fionnuala Walravens presenting the report at the 18th EU Conference; Presidents (left to right): Alberto Cavallini, Niccolò Costantini, Ayman Eltalouny, Didier Coulomb, Stephen Yurek, Wolfgang Zaremski, Francesco Scuderi .

INTRODUCTION

HFCs were introduced as replacement chemicals to Ozone-Depleting Substances (ODS), which are being phased out by the Montreal Protocol due to their impact on the ozone layer. Although HFCs do not deplete the ozone layer, they are potent greenhouse gases, with global warming potentials (GWP) of the commonly used HFCs ranging between 675 and 3,922.[1] In the past two decades, global emissions of HFCs have soared and, in 2015, baseline emissions were predicted to reach 4.0-5.3 billion tonnes of carbon-dioxide equivalence per year ($GtCO_2$/year) by 2050.[2]

The need to address HFCs has long been recognised by the European Union (EU). In 2014, the EU significantly strengthened the old F-gas Regulation (which had been predominantly based on a model of containment), to include an economy-wide phase-down in HFC supply and a number of bans on HFC use in certain equipment and products.[3] The new F-gas Regulation aims to cut HFC use by 79% by 2030 from the 2009-2012 baseline. Starting in 2015, it stipulates a step-wise decrease in HFC supply, with major reductions from the baseline of 37% in 2018 and 45% in 2021. The placing on the market of HFCs is controlled through a quota system which allocates allowances to companies based on CO_2e.

As early as 2016, reports of illegal (non-quota) HFCs in European markets began to emerge. Major HFC producer Honeywell claimed that 10 million tonnes CO_2e of HFCs had been illegally imported in 2015, equivalent to more than 5% of the total quota allocation.[4] Such reports have since grown both in frequency and severity, with 2018 witnessing a deluge of reports of illegal HFC use and trade throughout the EU.[5] EIA analysis suggests that the amount of non-quota HFCs being imported continues to grow.

Illegal trade of HFCs undermines the EU F-gas Regulation, results in additional HFC emissions that fuel global warming and significantly reduces government income and the profits of legitimate businesses. Governments are losing considerable tax revenues due to the illegal HFC trade. Through direct loss of VAT and import duties as well as through the indirect impact that illegal trade on the profits of legitimate HFC importers. A recent report from Polish NGO PROZON estimated that Poland's treasury lost € 7 million in 2018 due to illegal refrigerant imports valued at € 55 million.[6] Losses to the Lithuanian and Greek exchequers have been estimated at € 5 million[7] and € 20 million[8] respectively.

TRADE DATA ANALYSIS

The Environmental Investigation Agency (EIA) utilised European customs data to examine trade in bulk[9] HFCs from 2016-18. 2018 marked a significant step in the EU HFC phase-down with HFC supply being cut by 37% from the baseline. We would therefore expect to see a corresponding drop in HFC imports. Although customs data shows that EU total bulk HFC imports fell in 2018 compared to 2017 it increased compared to 2016. EIA's analysis of European customs data suggests that bulk HFC imports were some 16.3 $MtCO_2$e above the available quota of 101.2 $MtCO_2$e, more than 16% over the allowable quota. This could be characterised as open smuggling of HFCs (i.e. imports openly shipped through customs).

At a member state level, EIA identified a trend of significantly increased imports over 2016-2018 in a number of countries that could indicate illegal trade hotspots. For example, imports of HFCs in 2018 were more than 100% higher than 2016 imports in Austria, Belgium, Denmark, Greece, Ireland, Latvia, Malta, Poland, Portugal, Romania and Sweden. Although these could be explained by more accurate end-country reporting as the Netherlands, the EU's largest importer, reported a decline in imports during this period.

EIA then compared European customs data to company reported HFC Registry data presented by the European Environment Agency (EEA) between 2016-2017. For both years customs data showed consistently higher levels of HFCs being placed on the market than that reported to the HFC registry. In 2017, the discrepancy was 14.8 $MtCO_2$e (equivalent to 8.7% of the total quota for 2017).

Reports to the HFC Registry are self-declared and there is currently limited or no cross-checking with customs data, giving clear potential for manipulation of HFC Registry reported data. A possible explanation for this discrepancy could be that companies with HFC quotas are under reporting HFC imports or over reporting HFC exports to the HFC Registry.

Finally, EIA compared Chinese reported HFC exports to the EU with EU reported HFC imports from China during 2016-17. Chinese reported HFC exports to the EU in 2016 were 10.2% higher than European reported HFC imports from China. This figure dropped to 3.2% in 2017. Consistently higher Chinese reported exports could be explained by a time lag between export and import or incorrect assignment of transit country as an end destination, but it could also be an indication of HFCs being mis-declared at the point of import into the EU.

HFC PRICES

The HFC phase-down works by cutting supply and raising prices of HFCs to the EU market to incentivise transitions to low-GWP alternatives. 2017 saw European HFC prices soar in anticipation of the 2018 HFC quota cut. By the second quarter of 2018, the price of HFC-410A was 859% higher for Original Equipment Manufacturers (OEMs).[10] Similar prices hikes have been seen for other HFCs. According to the latest price monitoring report by Öko-Recherche, prices in 2018 have flattened out to a large extent and demand for refrigerants, despite the large quota cut, was said to be low. Potential reasons for this include stockpiling in previous quarters (i.e. in 2017), increased care in handling refrigerants, reduced demand due to transitions to lower GWP technologies and possible illegal trade.[11]

EIA INDUSTRY SURVEY

In September and October 2018, EIA sent a questionnaire to a range of European heating, ventilation, air-conditioning and refrigeration (HVACR) representatives, including industry associations, refrigerant suppliers and contractor associations.

The survey requested information on refrigerant prices, the scale and severity of illegal HFC use, potential drivers of illegal trade, awareness of current penalty regimes in member states and recommendations for improving enforcement of the F-gas Regulation.

Responses were received from 18 companies, primarily refrigerant suppliers and industry associations, in 11 EU member states. Reports from industry indicate that large-scale illegal HFC trade and use is occurring in an absence of effective enforcement by member states. More than 80% of companies surveyed by EIA were aware of or suspected illegal HFC trade and 72% had seen or been offered refrigerants in illegal disposable cylinders.

EIA asked whether respondents were aware that disposable cylinders were illegal and if they had been offered HFCs in disposable cylinders or seen any in use. Disposable cylinders facilitate illegal trade because they are easy to transport and difficult to trace; they have been banned from being placed on the market in the EU since 2006. Only one respondent felt that its clients/members were unaware of the ban. Despite this, 72% of respondents had seen or been offered refrigerants in disposable cylinders. Respondents from Denmark and Greece noted that although their clients are aware of the ban, they may still buy disposable cylinders as they

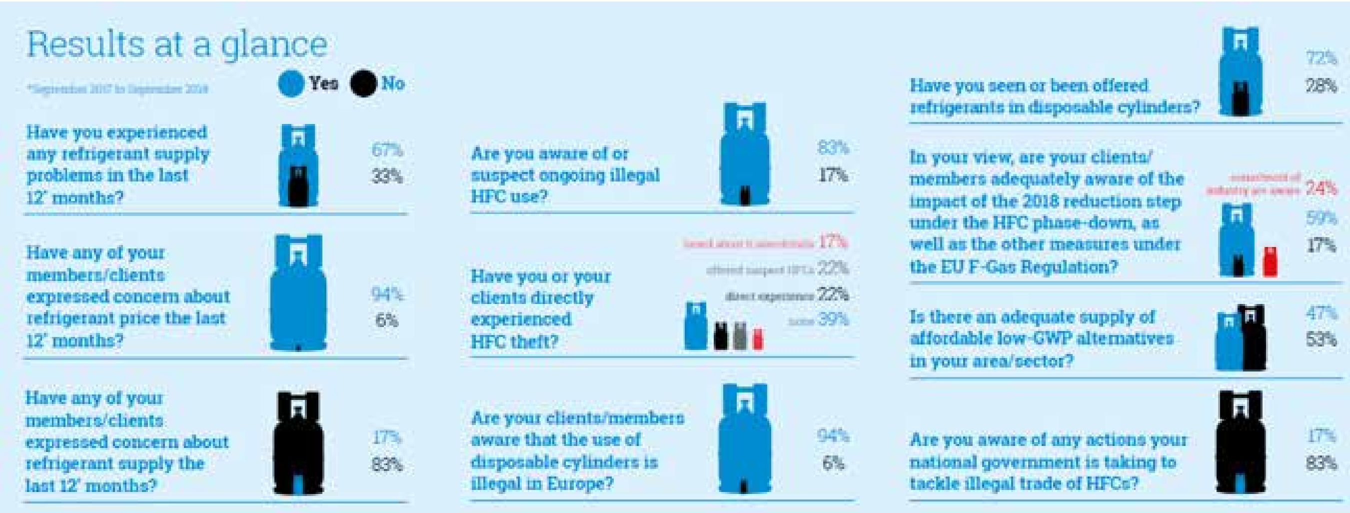


Figure showing the findings at a glance. Detailed information can be found in EIA's report "Doors Wide Open: Europe's flourishing illegal trade in HFCs"[12]

are cheaper and easily available. The automotive sector was highlighted as an area where they are used heavily. Trading platforms such as eBay and Facebook were mentioned as key selling tools for disposable cylinders.

METHODS AND SCALE OF ILLEGAL TRADE IN HFCS

Information from industry stakeholders alongside media reports and trade data analysis suggests a growing prevalence of illegal HFC trade across the EU. HFCs appear to be coming into Europe from China directly and via EU-border countries, in particular via Russia, Ukraine, Turkey and Albania. Poland has been repeatedly highlighted as a first point of import for illegal HFCs entering the EU. Although many other countries are swamped with illegal HFCs, with multiple industry sources reporting that illegal refrigerants constituted 50-80% of the Greek, Bulgarian and Romanian markets.

The prevalence of illegal HFC-134a in the mobile air-conditioning (MAC) servicing market has also been repeatedly raised. In Italy, around 5-10% of the mobile air-conditioning HFC market is estimated to be illegal[13] while in Poland illegal HFC imports have been estimated to amount to approximately 40% of the entire Polish market.[14]

There are various ways in which non-quota HFCs can enter the European market:

- *Open smuggling.* This is where companies import non-quota HFCs openly labelled as HFCs through the normal customs channels. The companies responsible could be registered in the HFC Registry or not.
- *HFCs can be concealed either physically or through fraudulent documentation.* For example, mislabelling the type, purpose or destination of the HFC shipment. The significant discrepancies between Chinese export and European import data could be an indication of fraudulent import declarations.
- *Offloading in transit.* For example, instances of refrigerants coming through Greece 'in transit' from non-EU countries to other non-EU countries, but then offloaded and replaced with empty cylinders to ship onwards have been reported.
- *Smuggling via land and sea borders.* There have been multiple accounts of illegal HFCs entering the EU via Russian and Ukraine EU land borders in vehicles. The recent seizure of 25 tonnes of illegal HFCs imported to Poland from Ukraine suggests that this may be a significant problem.[15]
- *Shipments in large tanks:* To date EIA is not aware of any seizures of illegal HFCs shipped into the EU in large tanks or ISO tanks. However in EIA's experience, such large shipments are rarely checked by customs officials due to unfamiliarity with the process, lack of adapters needed to take a sample or lack of facilities to test the refrigerants.
- *Illegal internet sales:* Online platforms are a popular way of selling illegal HFCs. Some enforcement efforts have enabled suspicious adverts to be removed, however the actual seller is rarely prevented from posting a new advert the following day.

WHY IT PAYS TO BREAK THE LAW

In March 2018, a two-day inspection of cars crossing the Polish-Ukraine border at Dolhobyczow highlighted the lucrative nature of black market trade in HFCs.

Three attempts to smuggle HFCs hidden in LPG tanks were prevented by customs officers. The cars contained between 64-90 litres of refrigerant; two of the cases were confirmed to be smuggling HFC-134a, with a market value of PLN4,600 (€ 1,060)-PLN6,500 (€ 1,510). The culprits were fined between 15-21% of the market value.[16]

According to PROZON, the culprits and the cars, with refrigerant still in them, were sent back to Ukraine, leaving them at liberty to make another attempt at smuggling the HFCs into Poland. This not only highlights the potential scale of illegal HFCs flooding into Poland from non-EU border countries but also shows the need for more effective enforcement through confiscation of illegal refrigerant and higher fines to deter repeat offenses.

REGULATORY LOOPHOLES

The current regulatory system is inadequate to allow customs officials to control HFC trade at the European border:

1. Quotas and authorisations are not needed for imports of less than 100 tCO_2e of HFC per year (in equipment or as bulk gas). This is almost 70kg of HFC-134a.
2. Although customs officials have access to the HFC Registry, where they can check whether or not an importer is registered and access the importer's annual quota allocation or authorisation, there is currently no access to real time information that can tell customs how much a company has already imported. Even if an importer was clearly importing an amount in excess of the company's annual quota (e.g. in one shipment), customs are still not able to determine that the shipment is in contravention of the F-gas Regulation since the importer could claim (legitimately or otherwise) that part of the shipment is for re-export outside the EU, and therefore outside of the quota system. This allows a company to legitimately exceed its annual quota as long as it exports any excess by the end of the reporting year.
3. Units declared on the Single Administrative Document (SAD) at customs are in kilogrammes or tonnes, whereas HFC quota is measured in tCO_2e. This puts the onus on customs officials to estimate tCO_2e, potentially a complicated task, particularly for equipment imports.
4. There is no obligation to cross check data reported to the HFC Registry with EU customs data. This is of particular concern given the huge influx of new entrants, i.e. new companies joining the Registry. A total of 1,699 companies reported during 2017, 33% more than the previous year. [17]

TOOLS TO COMBAT ILLEGAL TRADE

- *HFC licensing:* EU trade in ODS was controlled via a per shipment licensing system. Issued on a per shipment basis, HFC licences could be used to ensure a company stays within its quota. For example if a company wishes to export HFCs it would only receive that credit back on its quota once the export has occurred. HFC licensing would also enable customs to cross check importer declarations with exporter information.
  The EU is currently looking at automatically linking customs declarations with the data in the HFC Registry through the Single Window environment for Customs, which could allow real-time access to remaining quota. However efforts to mandate CO2e as a mandatory measure on the TARIC code, to enable comparison between customs and HFC Registry data, have so far failed. Moreover the system is not operational in all EU Member States and will take several years to set up.
- *Banning Non-Refillable Containers:* Although the placing of non-refillable ('disposable') containers of HFCs on the market has been banned in the EU since 2006, those placed on the market before 2006 as well as cylinders sold where provisions are made for their return and refilling are exempt. These exemptions make it difficult to enforce the ban. A comprehensive ban on the use of disposable cylinders should replace the current 'placing on the market' ban.
  There are also indications that high refrigerant prices are driving a trade in 'disposable refillable' cylinders, whereby refillable cylinders are being illegally placed on the market, without provisions for return and refill.xviii Member States need to give clear guidance on a comprehensive system to ensure cylinders are returned and refilled.

EIA & Legambiente taking part in the debate during the 18th European Conference in Milan.

CONCLUSION

Given the availability of cheap HFCs outside the EU, it is not surprising that much of the illegal trade is reported to be occurring at EU border countries. The current HFC reporting system does not allow customs authorities to determine whether or not HFC shipments are within quota and a number of loopholes in the system allow unscrupulous traders to reap quick profits, exploiting a demand for cheap HFCs with little risk of punitive measures.

Enforcement of the F-gas Regulation is clearly hampered by the absence of a system whereby customs officials can determine if an import of bulk HFCs or HFCs in equipment is covered by quota and have the power to prevent a shipment which takes an importer over its quota. This is an essential requirement of a licencing system, which is now required under the Montreal Protocol's Kigali Amendment, and should be implemented without delay.

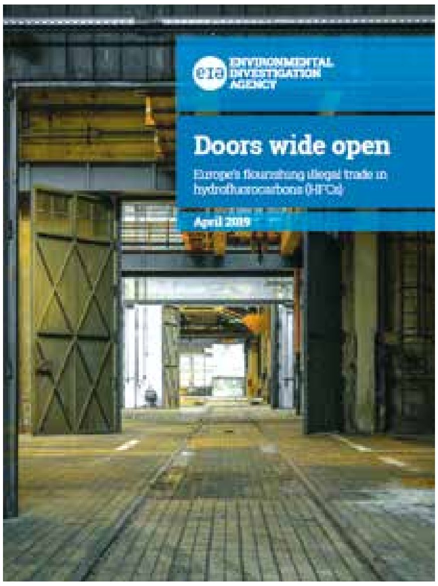
This is particularly critical in light of the significant rise in the number of companies registered to trade. Thousands of companies are now, to some extent, legitimised at customs level through their company name being registered in the HFC Registry, however customs has no way of assessing whether they are importing within their quota or reporting actual imports to the HFC Registry. Allocating quota at cost would also help deter illegitimate traders from joining as new entrants in the future.

The widespread use of disposable cylinders in the illegal trade warrants efforts by member states to make legislative changes to ease the enforcement challenge. The current ban under the F-gas Regulation should be strengthened to ban the use (not just the placing on the market) of all non-refillable cylinders. The EU and industry should also push for a global ban on disposable cylinders.

Finally, there is an urgent need to immediately improve enforcement. Member states need to coordinate decisive action on HFCs and tighten border control. Member states need to seize, prosecute and apply sufficiently high penalties. Penalties that have been determined by member states are generally not high enough to deter HFC smuggling and are rarely applied.

RECOMMENDATIONS FOR INDUSTRY TO SUPPORT AND RAISE WITH MEMBER STATES AND THE EUROPEAN COMMISSION

- *Implement a fully functional per shipment HFC licensing system*, which allows customs officials to obtain necessary real-time information to determine if HFC imports are within the specified quota for a particular company.
- *Make the HFC Registry more transparent* in order to improve accountability. Names of new entrants and data on quotas allocated to individual companies should be publicly available.
- *Allocate HFC quotas at cost* to reduce the pressure on customs from the rapid rise in new incumbents and to help fund the HFC licensing system.
- *Revise the ban on non-refillable cylinders* to prohibit the use of all disposable cylinders.
- *Set up a system to systematically compare HFC registry data with customs data* and investigate discrepancies.
- *Increase penalties* for Regulation infractions and ensure they are regularly applied and communicated through industry and media channels.



The cover page of EIA's latest report.

ACTIONS INDUSTRY CAN TAKE RIGHT NOW

- *Improve capacity-building*, engage with training and support for customs
- *Provide greater resources to investigate illegal HFC trade*, carry out regular market surveillance and inspections including online marketplaces, share these findings within industry and the wider enforcement community
- *Carry out regular targeted awareness raising* amongst customers
- *Promote low-GWP energy efficient technologies* through incentives and support additional bans on HFC-containing equipment.
- *Invest in the installation and servicing sector*, ensuring contractors are trained and equipped to work with flammable refrigerants and to ensure the efficient recycling and reclamation of HFCs.
- Reduce further demand for illegal HFCs by *increasing incentives and reducing barriers for HFC reclamation.*

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Ensuring a Safe Refrigerant Transition

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Paper presented at the 18th European Conference bit.ly/EUconfRAC2019

Now that the historic Kigali Amendment to the Montreal Protocol has been ratified by the appropriate number of countries around the world and entered into force in January of this year, there is considerable work yet to be done to ensure a safe transition from high GWP hydrofluorocarbon (HFC) refrigerants.

The current situation in the U.S. with respect to a national phase down or participation in a global phase down is unclear, as the U.S. Administration seems not yet ready to submit the treaty for ratification.

The legislative outlook also becomes less clear by the day as the 2020 presidential election looms on the horizon, casting every legislative effort in stark political terms and increasing the difficulty of success.

Add to that a mix of state-level activities and the path perhaps becomes even rockier. See Figure 1. California has a policy goal to reduce emissions 40 percent by 2030, which is 5-10 years ahead of the Kigali Amendment. See Figure 2.

But even in the face of uncertainty, the industry's path forward is clear: A new generation of lower global warming-potential refrigerants is on the horizon and both refrigerant producers and equipment OEMs are moving forward at a smart pace.

In addition to legislative and regulatory avenues, manufacturers and producers have, under the auspices of AHRI, been researching suitable alternative refrigerants for the many necessary applications since 2011. The most promising of those are currently ASHRAE-classified as either mildly flammable (A2L) or flammable (A3) and thus are prohibited from use in many areas and for many applications.

Figure 1.

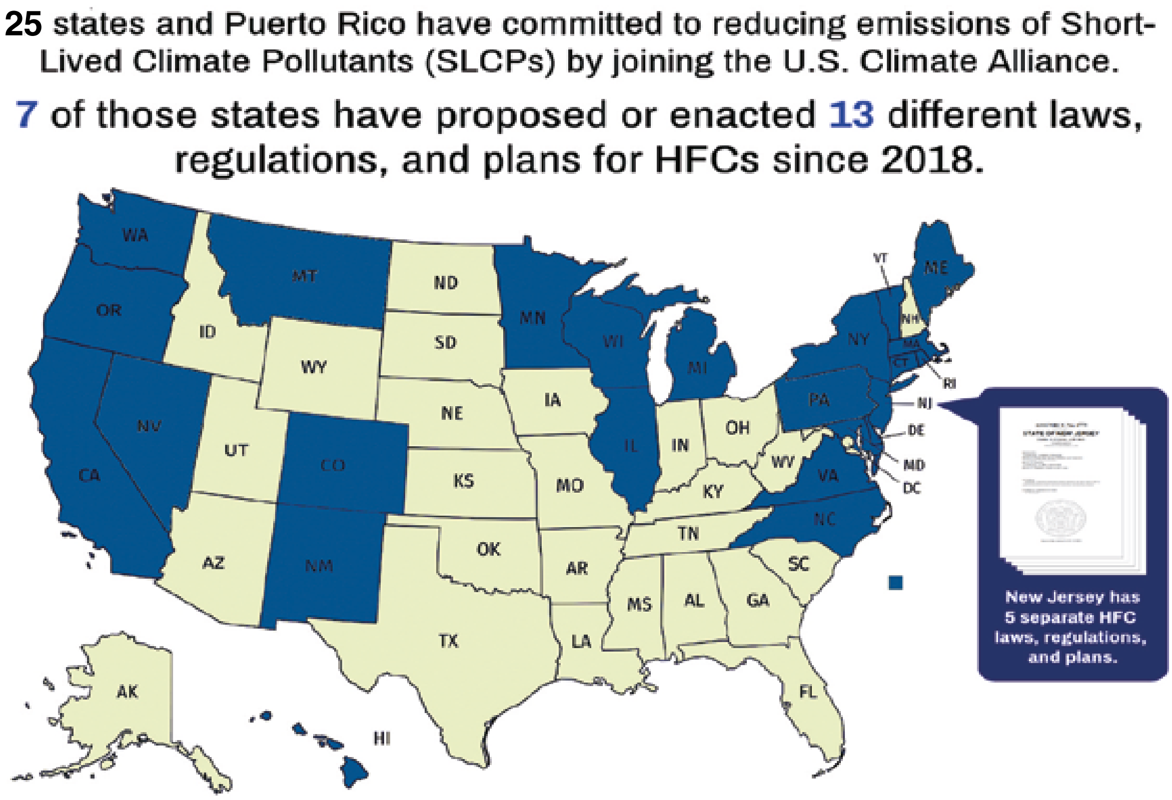

Figure 2.

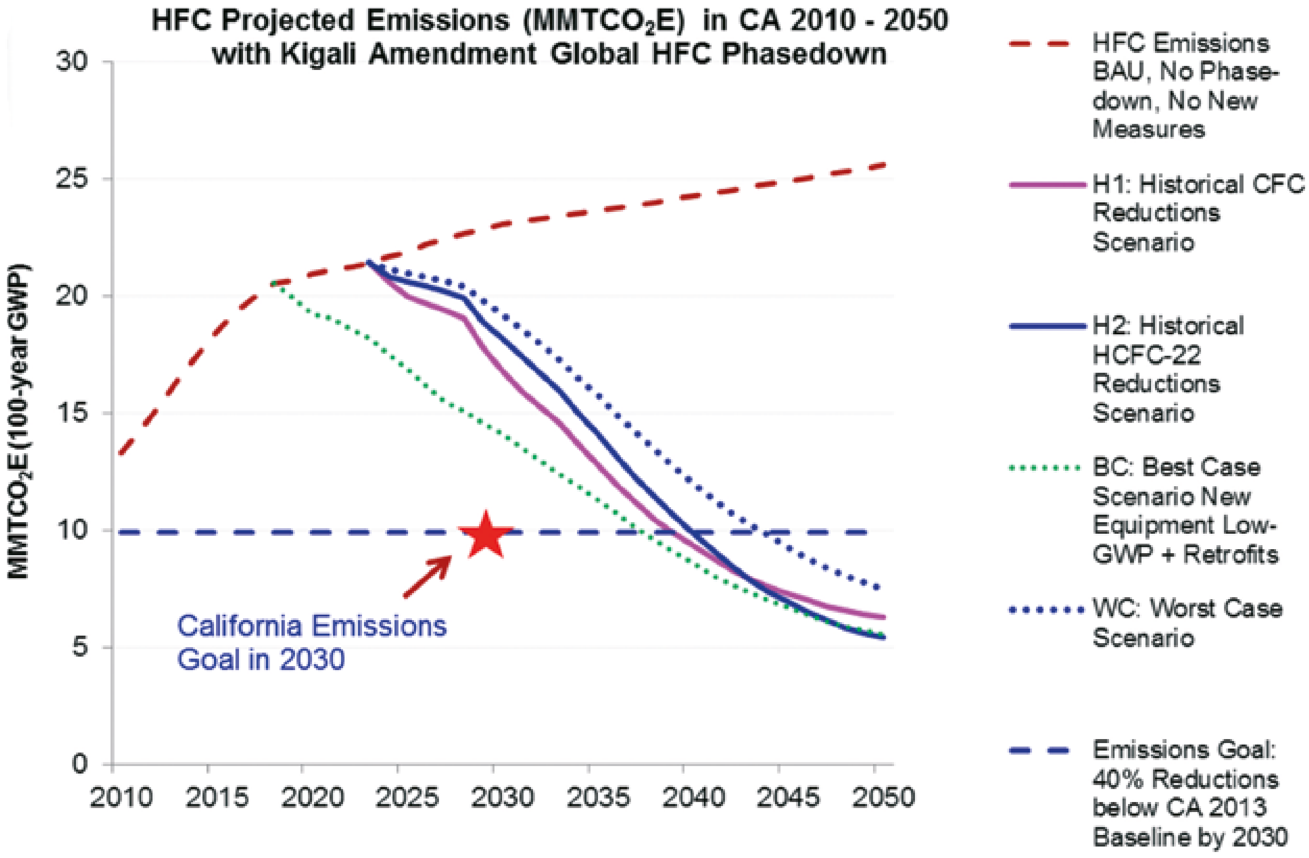

Figure 3.

Equipment	A2Ls	A3 (R290)
PTAC	X	X
Mini-split		X
RTU	X	
Residential AC	X	
Reach-in cooler	X	X
Walk-in	X	
Service error and elec. feedthrough failure	X	

Current real-world flammable refrigerant research involving the U.S. Department of Energy, AHRI, ASHRAE, and the State of California is now well underway, with several projects having been completed. See Figure 3.

Results of this research clearly indicate the suitability of many A2Ls with the proper mitigations, as most household ignition sources and hot surfaces cannot ignite these refrigerants.

The suitability of A3s for most applications is far less clear, however, as the research has shown them to be not just flammable but in some cases explosive.

Additional research either underway or soon to be underway includes assessment of refrigerant detector characteristics for use in HVACR equipment, a combustion byproducts risk study, and assessing the effectiveness of mitigation requirements.

Regardless, for them to be considered suitable for use in homes and businesses, safety standards and building codes both in the U.S. and in much of the rest of the world would need to be revised.

AHRI is working with standards' committees, code officials, building officials, and firefighting organizations to keep them apprised of the latest research that will ensure the safe use of these refrigerants.

The bottom line is this: Our industry is ready for this coming transition, but there is much work still to be done. It is imperative that we all work together for our industry, which is critical to the continued comfort, safety, and productivity of the world's citizens.

Recent Refrigerant and System Developments in Japan

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Paper presented at the 18th European Conference bit.ly/EUconfRAC2019

INTRODUCTION

In refrigeration and air conditioning field, refrigerant is an important factor that influences the equipment performance. Becoming global environmental problems more serious, we must pay attention to the influence of refrigerants on the environment, especially the contribution to global warming. To maintain the global environment, it is necessary to take measures as quickly as possible.

Refrigerants are roughly classified into two groups: compounds synthesized by containing fluorine atom in the molecular structure, so-called fluorocarbons, and natural refrigerants such as carbon dioxide, ammonia, propane, isobutane, and air.

Global warming substances, so-called greenhouse gases released into the atmosphere are roughly divided into carbon dioxide, nitrous oxide, methane, and HFCs, perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3), as well as others such as unsaturated HFCs and HCFCs (hydrochlorofluorocarbons), so-called hydrofluoroolefins (HFOs). Despite being emitted in smaller quantities relative to the other principal greenhouse gases, if HFCs continue to be released into the atmosphere, the average temperature will rise about 0.4 K by 2100[1)].

PARIS AGREEMENT AND KIGALI AMENDMENT

The Paris Agreement, adopted by COP21 in 2015 as a measure for the greenhouse gas issue, attempts to reduce the global average temperature rise before the industrial revolution to less than 2 K. Japan aims for a 26% reduction over fiscal 2013 by 2030. With this promise, the four gas emissions including HFCs should be reduced to less than 28.9 million t-CO_2 by 2030[2)]. The Kigali Amendment by the Parties of the Montreal Protocol on Substances that Deplete the Ozone Layer, was issued in 2019, and the consumption of HFCs in Japan, about 71 million t-CO_2 of 2011-2013, should be phased out by 85% by 2036, which means a reduction to about 11 million t-CO2[3)].

DEVELOPMENT OF NEW REFRIGERANT AND REDUCTION IN REFRIGERANT DISCHARGE TO THE ATMOSPHERE

In addition to restrict production of HFCs, it becomes an important key not to discharge them to the atmosphere. Furthermore it's required to develop low-GWP refrigerants and their equipment which contribute less to global warming.

There is a lot of equipment with HFCs in the Japanese market (e.g., room air-conditioners, RAC: app. 100,000,000 and automobile air-conditioners: app. 80,000,000)[4)]. Due to the large amount of HFCs leakage from the refrigeration and air conditioning equipment, it is necessary to reduce the leakage during their operation, emission at maintenance and failure, and to recover refrigerant when discarding equipment.

To promote the reduction of HFCs leakage, there are laws and regulations as follows.

- The Act on the Protection of the Ozone Layer through the Regulation of Specific Substances
- Re-commercialization of Specific Household Appliances
- Law on the Rationalization of the Use of Fluorocarbons and the Appropriate Management
- Law on Recycling of End-of-life Vehicles
- Global Warming Measure Plan

Table 1.
Target GWP and year for refrigeration and air conditioning products.

Designated products	GWP Goals	Target Year	Typical currently used refrigerants (GWP, safety code*1)	Alternative refrigerant examples	Developing situation
Household air-conditioner*2	750	2018	R 22 (1810,A1) R 410A (2090,A1) R 32 (675,A2L)	R 32 (675,A2L) R 290 (3,A3)	← In market (All products) ← Under review
Air conditioner for stores and offices	750	2020	R 22 (1810,A1) R 32 (675,A2L) R 407C (1774,A1) R 410A (2090,A1)	R 32 (675,A2L) R 410A (2090,A1)	← In market ← In market
Automotive air conditioner*3	150	2023	R 134a (1430,A1)	R 1234yf (4,A2L) R 744 (1,A1)	← In market ← Finish
Condensing unit *4 ---------------------- Stationary type refrigerator and refrigerating unit*4	1500	2025	R 22 (1810,A1) R 134a (1430,A1) R 404A (3920,A1) R 410A (2090,A1) -------------------------- R 22(1810,A1) R 404A (3920,A1) R 410A (2090,A1)	R 290 (5,A3) R 744 (1,A1) R 407H (1495,A1) R 410A (2090,A1) R 448A (1273,A1) R 449A (1282,A1) R 463A (1377,A1)	←Under review ← In market ← For retrofit ← In market ← In market ← Under development ← In market
Centralized refrigeration equipment*5	100	2019	R 22 (1810,A1) R 717 (<1,B2L) R 744 (1,A1)	R 717 (<1,B2L) R 744 (1,A1)	← In market ← In market s
Rigid urethane foam insulation*6	100	2020	R 245fa (1030,B1) R 365mfc (795,-)	R 1233zd(E) (1,A1) R 744 (1,A1)	← Under development ← Under development
Dust blower*7	10	2019	R 134a (1430, A1) R 152a (124,A2) R 744 (1, A1) DME (1)	R 744 (1,A1)	← Under development

*1: the capital letter corresponds to toxicity and the digit to flammability.
*2: Excluding floor-mounted type.
*3: For passenger cars excluding those with a capacity of 11 or more.
*4: Excluding rated compressor output of 1.5 kW or less.
*5: For newly shipped for freezing refrigerated warehouse of 50,000 m3 or more.
*6: For spray foam for house building materials.
*7: Excepting non-flammable applications

- The Action the Rational Use of Energy, etc.
- High Pressure Gas Safety Act

COUNTERMEASURES FOR GLOBAL ENVIRONMENTAL PROBLEMS

In order to comply with these laws and regulations, development of low GWP refrigerants, adoption of low GWP refrigerants in equipment of new and existing models, reduction of leakage during operation/maintenance of equipment, recovery from discard of equipment, reclamation of recovered refrigerant including recycle, and destruction of unnecessary refrigerant including recomposition should be promoted taking into consideration the refrigerant management circle from refrigerant production to regeneration/destruction as shown in Figure 1. In addition, it is recommended to take effective measures referring the refrigerant amount in the main process from flowchart [4,5)].

Development of low GWP refrigerants and equipment: Low GWP refrigerants have been developed according to the laws/regulations as shown in Table 1. However, new refrigerants are in the development process in some equipment products including non-listed products yet, e.g., medium-sized freezing and chilling, package air conditioners (PAC) and variable refrigerant flow/volume (VRF/VRV). In addition, even if it has been developed, the performance of the equipment used is inferior in terms of CO_2 emissions during operation. There may be problems with safety designated by safety code, such as combustibility and toxicity, and stability as a refrigerant.
Some refrigerants become expensive for stable supply. In addition, although investigations on refrigerant mixtures in which substances are mixed as shown in Table 2 have been advanced as new refrigerants, there may be problems in handling and heat transfer characteristics in heat exchanger with respect to non-azeotropic mixtures. Therefore, the Japanese government have established some subsidy sys-

Table 2.
Component substances of new refrigerant mixture.

Refrigerant	Safety Code	GWP (00Yr)
R 32	A2L	675
R 125	A1	3500
R 134a	A1	1430
R 143a	A2L	4470
R 152a	A2L	148
R E170	A3	1
R 227ea	A1	3220
R 290 (propane)	A3	3.3
R 600 (butane)	A3	4
R 600a (isobutane)	A3	3
R 601a (isopentane)	A3	<20
R 1123	A2L	0.3
R 1233zd(E)	A1	1
R 1234yf	A2L	4
R 1234ze(E)	A2L	6
R 1270 (propylene)	A3	1.8

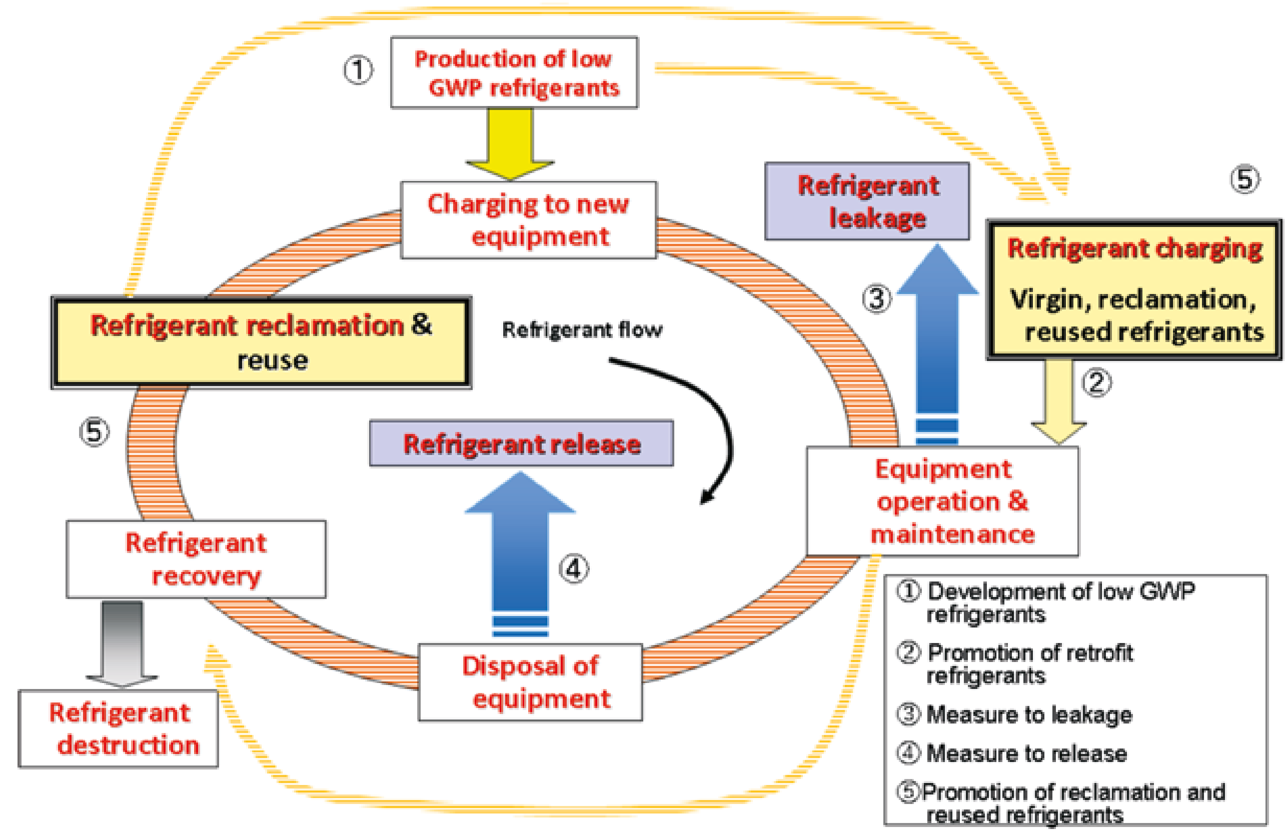

Figure 1. *Refrigerant circle from production to regeneration/destruction.*

tems: Accelerate the introduction of energy saving natural refrigerant equipment for the early realization of a CFC-free, low carbon society with the aim of developing natural refrigerant equipment in the field of refrigeration, Fluorocarbon environmental research comprehensive promotion cost aiming at improvement of recovery rate, and NEDO business research, Development of optimization and evaluation method of next-generation refrigeration air conditioning which can achieve energy saving and low global warming effect / Regarding safety and risk evaluation concerning next-generation refrigerant. We are trying to promote the development and introduction of new refrigerants and equipment.

Since some refrigerants filled in existing equipment have very high GWP, it is important to try changing them to low GWP refrigerants, so-called retrofit and drop-in, and are being promoted in EU and the United States.

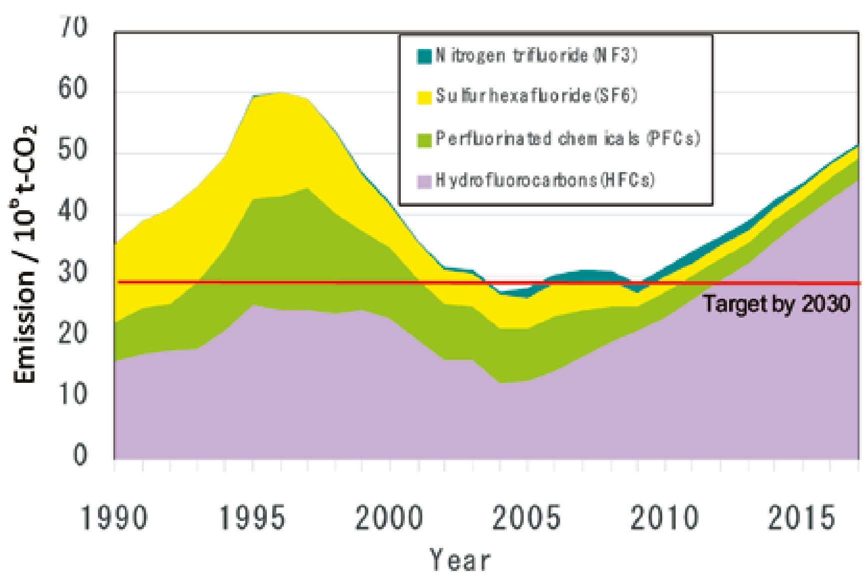

Figure 2. *Emissions of greenhouse gases.*

Reducing leakage during equipment operation: It is necessary to investigate the cause. There are many leaks at the time of installation from connectors, etc., and leaks due to long-term operation from compressors, heat exchangers, pipes, etc.

Leakage reduction at the time of equipment disposal: It is effective to improve the recovery rate by reducing emissions. Development of the refrigerant recovery equipment and design of refrigeration and air conditioning equipment that can easily recover refrigerant are desired.

Regeneration of recovered refrigerant: Reclamation (distillation, equipment component adjustment) and

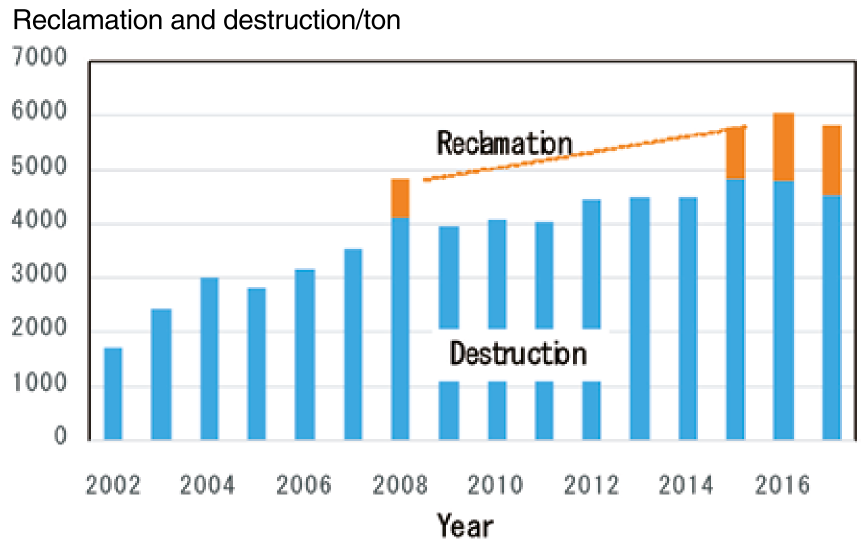

Figure 4. *Reclamation and destruction*
Commercial refrigeration and A/C only

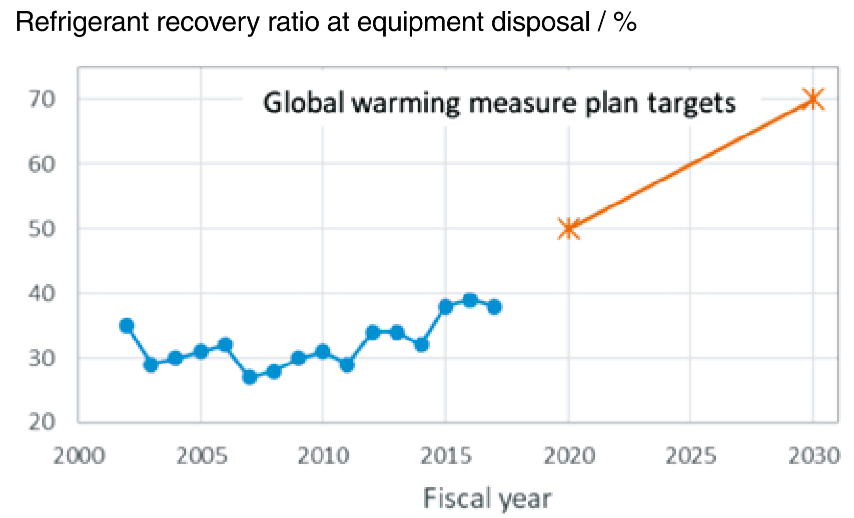

Figure 3. *Recovery ratio at equipment disposal*
Commercial refrigeration and A/C only

recycling (simple regeneration) of the recovered low GWP refrigerant should lead to reduction of the refrigerant production amount, reduction of refrigerant leakage, and improvement of the recovery rate.

Destruction of unwanted refrigerants: Destruction, especially high GWP refrigerants, is effective. It is desirable to destroy the refrigerant and use it for the production of low GWP refrigerants or other products.

One measure to improve the recovery rate is applying economic methods. In Japan, there is currently nothing to be characterized excepting recycle tickets of automobile air conditioners and home appliances and penalties in each law and regulation, but in the future, it is desirable to take measures for the spread of reclaimed refrigerants.

EFFECTIVENESS OF MEASURES

Not much time has passed since the legal regulations on global warming were in Japan, and there are many existing equipment with high GWP refrigerants, so no remarkable effects can be recognized. The emissions tend to increase, and the recovery rate does not improve so much (Figures 4[6] and 5[7]). The HFCs consumption8) was decreased from 51.5 million t-CO_2 in 2015 to 49 million t-CO_2 in 2017 (47 in 2016). The amounts of the regenerated refrigerant and the destructive refrigerant keep almost constant (Figure 6[8]).

CONCLUSIONS

Global warming is the biggest crisis facing humanity. In order to overcome this crisis and build a sustainable world, we need to alleviate the problem. However, there seems to be a long way to go in Europe, the United States, and Japan, where laws/regulations and measures are in progress. To reach the limit value and target value regarding refrigerant, the restrictions on the market input of refrigerant including total amount restriction are carried out in each country. However, the development of new GWP refrigerants for medium-sized freezing and chilling equipment, and VRF/VRV are still in their middle stages.

The environmental problems that the refrigeration and air conditioning field has are very serious. In order to solve this problem as quickly as possible, concerned parties should strive for development and cooperation in the world, and should be carried out to develop and to sustain the refrigeration and air conditioning field.

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Toward the development of Food Cold Chain with optimised sustainability

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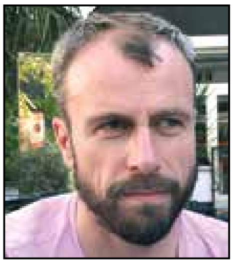


"The authors wish to acknowledge the invaluable contribution to this work, from the most regretted ***Eric Prieur****. Eric pioneered much of the GFCCC work presented in this paper. On his way to present some of this at the UNEA-4 meeting in Nairobi, he unfortunately happened to be on the flight from Addis-Abeba that crashed on March 10, together with several other colleagues and friends from UN and other organizations. To honor his memory and continue his work, an "Eric Prieur Memorial Research Fund" is being launched to help finance research and pilot projects on expanding sustainable Food Cold Chain in developing countries, the cause to which he was so fully dedicated".*

1. INTRODUCTION

A number of studies show a clear trend towards a rapid increase in global demand for refrigeration over the next decades, especially in developing countries: a large part of the population of developing countries lives in hot climates, where the need for refrigeration is most crucial.

There are numerous benefits of refrigeration, many of which align with the UN's Sustainable Development Goals (SDGs). Even in moderate climates, it is impossible to support a modern urban economy without refrigeration.

This will be even more drastic in developing countries because of the population growth, massive growth of urbanisation and expected global warming.

Yet, while the benefits of refrigeration are unquestionable, there is also a widespread concern that its development may generate undesired consequences such as skyrocketing emissions of GHGs (Green House Gases), directly from the leaks of refrigerants to the atmosphere, and indirectly through the associated energy consumption. These concerns are being addressed by international agreements, especially the Montreal Protocol and its Kigali Amendment, and the Paris Climate Agreement; but many questions remain about implementing these agreements. Other concerns are the infrastructure required for the generation and distribution of energy, the need for qualified labour, etc.

The two major sectors where refrigeration is needed are thermal comfort A/C (Air conditioning) and FCC (Food Cold Chain). Other applications exist, such as in industry (chemical, pharmaceutical…), cooling of data centres, etc. Over the past years, the A/C sector has been the centre of focus; the current markets and anticipated needs have started to be identified, as well as possible road maps to achieve the desired targets. But the FCC sector is not nearly as well analysed. It is closely interlinked with critical issues related to nutrition, like food production and waste, land use, cultural behaviours towards food, etc. Therefore, there is an urgent need to set a mapping of the current state of FCC, perspectives of development, and possible consequences. Starting by determining the existing food production that needs to be refrigerated, which is still an issue, particularly in developing countries and their development perspectives. Several initiatives have been launched to achieve this goal; some of them will be presented in this paper.

2. SCOPE OF FCC, TECHNOLOGIES AND CHALLENGES

2.1 Scope

In general, FCC encompasses all the refrigeration required for food production, processing, storing and distribution "from farm to fork". There are seven major sectors of application: primary production (fishing and farming), processing and packaging (dairy, meat, and fresh produce…), bulk storage, transport, retail (shops and vending machines), food service (eateries, catering) and domestic refrigeration. The medical sector (hospitals, tertiary, transport and storage of pharmaceuticals) is also included in some of the studies.

2.2 Technologies

Most of the refrigeration needs for FCC are at two typical temperature levels: around 0 to 5 °C for processing and storage of fresh produce, or around -20 °C for frozen products. A few applications such as dry freezing or high-quality freezing require substantially lower temperatures, as low as -60 °C.

Cooling capacities range from a few

hundred watts for small household fridges to several megawatts for large warehouses or food processing plants. Small systems like home fridges or small vending machines are self-contained hermetic systems. Large systems are usually "flooded", using liquid refrigerant pumped to various applications from a central machine room. Intermediate systems are based on condensing units feeding refrigerants to a few "dry-expansion" cooling coils at various points of use.

In medium and large systems, the refrigerant HCFC R-22 used to be dominant, as well as ammonia. R-22 has been mostly replaced by the high-GWP HFC R-404A in developed countries. Solutions generally exist to replace R-404A with lower GWP fluids in new and existing systems, except for the retrofit of large flooded R-22 systems.

There are also satisfactory solutions for small self-contained systems. A detailed review of the various sectors, technologies and trends can be found in the series of "Cold Chain Technology Briefs" published by the IIR and UNEP: bit.ly/IIRInformatoryNotes

2 Zero hunger; 3 Good health and well-being; 11 Sustainable cities and communities; 12 Responsible consumption and production; 13 Climate action	**Reduced food loss and food waste**. A robust cold chain can significantly reduce the loss of food caused by spoilage between food production and food retail. In developing countries, more widespread use of residential refrigeration can significantly reduce the waste of food at the point of use. Current levels of food loss and waste are estimated to be around 30% of all food produced. This creates significant GHG emissions which can be avoided by improving the food cold chain
3 Good health and well-being; 10 Reduced inequalities	**Improved healthcare**. Around 50% of medicines are heat sensitive and require a robust cold chain to avoid wastage and dangerous degradation of products. Many types of sophisticated medical equipment (such as scanners) require refrigeration and refrigeration is crucial for blood and tissue storage.
7 Affordable and clean energy	**Affordable and clean energy**. The increased use of renewable energy sources comes with challenges to balance the electricity supply and demand. Cooling, as well as heating by heat pumps, can provide solutions to optimise the balance, for example by demand side management as well as storing energy (cold and hot storage, also called thermal storage batteries).
12 Responsible consumption and production; 13 Climate action	Addressing undesired consequences of refrigeration through the use of sustainable refrigeration aligns with the important SDGs related to **climate action and responsible consumption and production**. A sustainable refrigeration approach also implies to responsibly use of the natural resources to produce the refrigeration equipment (for example copper, aluminium, steel, refrigerants.). This includes the need to reduce, recover and reuse these materials, contributing to a circular economy approach.

Source: EPEE

3. BENEFITS OF FCC TO ACHIEVE SDGs

The SDGs (Sustainable Development Goals) were set by the UN in 2015 for 2030, as part of Agenda 2030 for Sustainable Development.

They consist of 17 goals aimed at improving livelihoods and achieving sustainable development with regards to environmental, social, and economic global equity. The 17 goals (and associated targets) cover areas of concern such as poverty and poor health outcomes, as well as implementation groundwork like partnerships and financing. The development of refrigeration is strategic to achieve many of these goals; see table.

4. REGULATORY BACKGROUND

4.1 Kigali Amendment and Paris Agreement

Countries that have ratified the Kigali Amendment to the Montreal Protocol and/or the Paris Agreement accept the obligation to take actions at multiple levels. Regarding the refrigerant fluids, the phase-out of HCFCs (including R-22) is nearly finished in "Article-2" countries (essentially, developed countries, per the Montreal Protocol terminology), but is still ongoing in "Art-5" countries (developing countries), implementing their HPMPs (HCFC Phase-down Management Plan) according to the Montreal Protocol, which they have ratified; but there is now an additional level of complexity with the need to combine it with the phase-down of HFCs. This phase-down is underway in the EU per the F-Gas regulation; it is starting in other Art-2 countries per the Kigali Amendment, and will have to be taken into account in Art-5 countries.

Wider objectives regarding GHG emissions also need to be worked out by countries that ratified the Paris Agreement, according to their NDCs (Nationally Determined Contributions). In any case, limiting energy consumption is an absolute necessity everywhere for many reasons, including the critical need to reduce air pollution in many cities.

So, countries that ratified the Kigali Amendment and the Paris Agreement have to implement their HPMP when relevant, comply with HFC phase-down per the Kigali Amendment, and work out their NDCs (Nationally Determined Contributions) per the Paris agreement, all these targets being interlinked. Even the countries that did not ratify Kigali and/or Paris will be strongly impacted by the same trends. For this reason, some countries like China, India, Rwanda, already developed national CAPs (Cooling Action Plans), while many others are working on one. Irrespective of legal obligations, such plans are needed everywhere to address the many challenges raised by the necessary development of refrigeration.

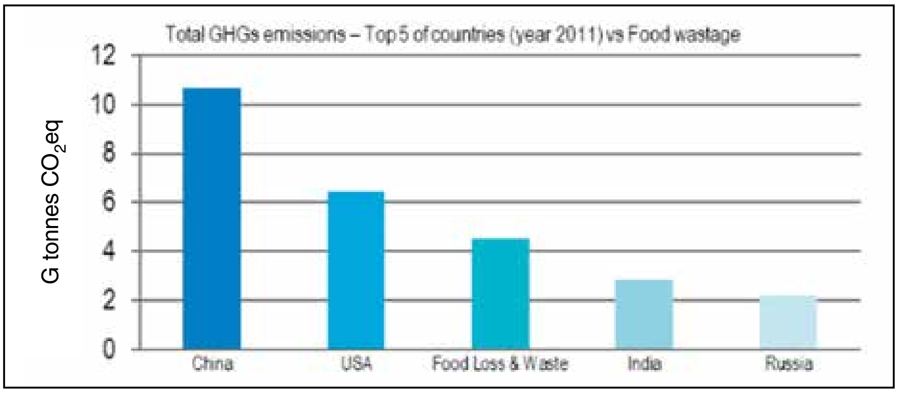
4.2 UNEA Resolutions to prevent Food Loss and Waste

In addition to the aforementioned international agreements, action is also driven by some resolutions of UNEA (UN Environment Assembly) regarding Food Loss and Waste. UNEA is the governing body of UNEP and, with a universal membership, is composed of all 193 UN member states; it meets every two years to set international priorities for global environmental policy and law. The Assembly UNEA Resolution 9 (2016) recognises that national governments and international institutions play a central role in contributing to solving global food loss and waste problems; organisations should:

a) Promote market-based incentives, co-operation with stakeholders in cold chain sustainability, and improving measurement of food loss and waste.
b) Implement programs that reduce food wastage and reuse of edible food that might otherwise be wasted.

Resolution 9 (2019) states that organisations and institutions should:

a) Contribute to solving food loss and



waste with an orientation towards addressing environmental, socio-economic, and public-health problems.

b) Engage with stakeholders in food systems and participate in international efforts.

5. SUSTAINABILITY OF THE FCC: A PARADOX?

While there is no doubt about the benefits of refrigeration in general and more specifically of FCC, some concerns are being raised that its expansion could have undesired environmental consequences through emissions of refrigerant fluids, increased energy consumption, etc. However, this must be put in perspective with the substantial benefits of FCC from an environmental standpoint. Studies show that nearly 30% of the global food production is lost or wasted, while the production of this food has a large carbon footprint. If food loss and waste were a country, it would be considered the third largest emitter of Greenhouse Gases (GHGs). Therefore, all efforts to minimize food loss and waste will positively and significantly contribute to Climate Actions. Since a substantial part of food losses are due to a lack of refrigeration, expanding the FCC will indirectly reduce the GHG emissions from food loss.

One could wonder if the FCC expansion is "sustainable" in the sense that its GHG emissions would be compensated by the reduction of food loss. It is an interesting question, and studies will attempt to answer it. Yet, it is also somewhat irrelevant: FCC expansion is a necessity to fulfil vital human needs, and it must be made as sustainable as possible, whether it be to limit its undesired consequences… or optimise its benefits.

6. NEEDS FOR FCC MAPPING

In order to identify the future needs for FCC, various approaches are possible. One approach is to start from statistics about the production, imports and exports of agricultural products in various countries. It is a good starting point, as the FAO (Food and Agriculture Organization of the United Nations) has rather robust statistics on these data; but it is not enough: while almost two thirds of global food loss is estimated to be due to a lacking cold chain, very little is known about the practices that cause this:

- Need for overarching sectors approach.
- Need for understanding of the economic and social failures.
- Industry/ culture / environment failures.
- Fragmentation in the sector (scattered data and no holistic approach).

Further analysis is thus needed. Various organisations are working on this subject from various perspectives.

6.1 Different Initiatives and Groups Addressing the Subject

GFCCC (Global Food Cold Chain Council) is a coalition of companies involved with the global food supply. The Council aims to reduce emissions and food wastage in the cold chain by expanding and improving energy efficient, low-GWP infrastructures and technologies. This is achieved through research, outreach, and implementation of projects.

UNEP UN Environment is the leading global authority on environmental issues and sustainability. UNEP partners with a range of actors to create and implement sustainable development and environmental strategies. UNEP is a leader in Champions 12.3 and established a number of initiatives and projects.

Champions 12.3 is a coalition of bottom-up, top-down, expert, and commercial groups committed to addressing SDG 12.3 - *"by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses."* The Coalition does this through a range of projects that include knowledge and best practices information sharing, publicizing food wastage and promoting sustainability, identification of opportunities that enhance and encourage food sustainability.

FAO is a specialised agency whose central objectives are achieving food security and eliminating hunger and malnutrition. They work with governments and international organisations to promote awareness and develop policies; facilitate coordination amongst food supply chain actors; and educate consumers on safe food handling, food storage, and identifying spoiled foods to prevent food waste.

International Energy Agency IEA promotes energy sustainability through analysis of all energy sources, energy efficiency, supply and demand, technologies, markets, and demand side management. They partner with countries and organisations to support economic development, environmental awareness, and energy security.

IIR Last but not least, the International Institute of Refrigeration (IIR) is the only independent intergovernmental science- and technology-based organisation that promotes knowledge of refrigeration and associated technologies that improve quality of life in a cost-effective and environmentally sustainable manner including: food quality and safety from farm to consumer, comfort in homes and commercial buildings, health products and services, low-temperature technology and liquefied gas technology, energy efficiency, use of non-ozone-depleting and low global warming refrigerants in a safe manner. The IIR has published Informatory notes on the subject: "The role of refrigeration in worldwide nutrition" in 1996 and 2009 and is currently preparing an updated version for 2019. The IIR published with the FAO an Agroindustry policy brief: "Developing the cold chain in the agro-food sector in Sub-Saharan Africa" in 2016, following a joint seminar in Cameroun in 2012. The IIR organises conferences on "Sustainability and the cold chain" since 2010 every two years on average (the next one will take place in Nantes, France, in April 2020) and built a working group "Cold chain in hot countries" headed by Halima Thrayah, IIR delegate of Tunisia, in 2015.

7. AN AMBITIOUS PROJECT: THE COLD CHAIN DATA BASE MODEL

7.1 Purpose of the project

To address the aforementioned issues, the UNEP and GFCCC have jointly initiated the project of development of a solid database for Food Cold Chain Modelling. The expected benefits for the various countries are to have suitable data to be prepared to fulfil their obligations as per §-4.1 and to prepare relevant national policies about energy, infrastructure, etc. To do this, the initial and longer-term objectives are:
Initial objective: understanding the current status, with assessment of the stock of refrigeration equipment in different sectors of FCC, energy usage and related CO_2 emissions, refrigerants usage and related CO_2 emissions, levels of food loss linked to the lack of FCC. Longer term objectives: assessing future scenarios with different levels of improvements to FCC, with assessment of investments required, potential benefits (e.g. GHG reduction, financial value of food saved), and potential impacts (e.g. additional use of energy and refrigerants, CO_2 emissions). Finance will also be a major issue to deploy solutions. For this reason, it will be critical to have a robust analysis to define suitable solutions, and also to build confidence to investors that the solutions are reasonable and optimised.

7.2 Data collection

A key part of the project will be the collection of data. It will start with background research, using international data sources such as the FAO statistics and the wealth of data and previous studies already conducted by the IIR (cf. publications and papers of IIR conferences mentioned supra, available on the IIR website www.iifiir.org.) Then, more detailed analyses will be conducted at national levels. A "stage 1" will report about national data sources and results from dedicated surveys to be answered by the countries. This will include the collection of available statistics on production, number of relevant FCC facilities, level of food loss, etc. In a "stage 2", more detailed data will be gathered, based on customized investigation plans and detailed data from this plan.
This data collection will first be conducted in five or six pilot countries, then extended to others after validation of the methodology. Relevant local contacts will initially be the National Ozone Officers of the countries, but will also involve the local networks of the various organisations involved in the project, like the commercial networks of the companies participating in GFCCC, the IIR networks, trade associations, etc. who will also contribute with their technical expertise.
All data collected by the countries during the pilot stage and shared with partners to the cold chain model for review and analysis, will be dealt with in confidential manner and shall not be shared without the consent of the respective country.

8. IMPORTANCE OF THE INVOLVEMENT OF THE PRIVATE SECTOR

A key feature of this project is the implication of the private sector. This is very important on various levels. Industry partners were involved at earlier stages to set the structure of the model by market sectors and sub-sectors, jointly with other experts like from IIR. This expertise will also be important to analyze the results, draw some conclusions, envision scenarios for the future and anticipate implementation.
The refrigerant transition indeed has to be addressed. It is desired to "leap-frog" some of the currently used technologies when feasible. But refrigerants issues are only a small part in the puzzle, wherein energy and costs are the key issues. Just making a "copy-and-paste" of solutions currently used in developed countries would not be satisfactory. Energy use must be reduced both in developed and developing countries, with an adequate mix of use of the currently existing BATs (Best Available Technologies), and of innovation. Current BATs must be deployed because the systems to be installed in the forthcoming 10 years or so are bound to be among solutions that are already commercially available today, or at an advanced stage of development; but the less efficient ones would result in unacceptably high energy consumptions. Simultaneously, innovation is needed to develop more energy-efficient solutions for the future. Yet, there are limits to the efficiency of thermodynamic machines.
Besides improving them, most of the improvements are expected to come from reduction of cooling loads, e.g. by better building envelopes, and better integration of systems. This will require a close scrutiny of local needs and current practices, for which the database is expected to be a useful tool. The involvement of industry at this early stage is also expected to be very beneficial to develop reasonable road maps.

9. CONCLUSIONS

The development of refrigeration in general and FCC in particular will be critical for human well being and to achieve many of the SDGs in the forthcoming decades, but it has to be planned carefully to avoid undesired consequences, especially from an environmental standpoint. FCC had drawn little attention from policy makers until recently, but is now quickly gaining some visibility. Several initiatives are being initiated to design suitable road maps.
One of the key initiatives was presented with joint efforts from UNEP and GFCCC to make a fact-based analysis of this sector, jointly with other organisations like IIR or FAO. There is great hope that this approach will allow for meaningful progress in this direction. A key feature of this project is that it directly involves policy makers, the industry, and a wide range of experts from various sectors. It is hoped that this initiative will make possible a successful development of a sustainable FCC, including solutions optimised to various contexts, and facilitating the financing to deploy suitable solutions.

Investing in Sustainable Energy Technologies in the Agrifood Sector (INVESTA)

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Paper presented at the 18th European Conference bit.ly/EUconfRAC2019

BACKGROUND AND INTRODUCTION

The FAO project *"Investing in Sustainable Energy Technologies in the Agrifood Sector" (INVESTA)* supports innovative and sustainable approaches to accelerate the uptake of clean energy solutions in agri-business in developing countries and emerging regions. The project developed a methodology to analyse energy interventions in the agrifood sector. The main purpose of the methodology is to assess costs and benefits associated with renewable energy and energy efficiency practices, and to highlight hidden socio-economic and environmental impacts of such interventions. This is important for decision-making, to better target investments that will result in a net benefit to the society. The cost-benefit analysis (CBA) has been applied to specific energy interventions in the milk, vegetable, rice and tea value chains in Kenya, the Philippines, Tanzania and Tunisia.

This paper summarizes the results of the INVESTA methodology applied to three cooling technologies in the milk

- domestic biogas-powered milk chillers,
- solar milk coolers,
- solar cold storage for vegetables.

METHODS

The project is divided into two phases. In the first phase, costs and benefits of clean energy technologies are assessed at intervention level (e.g. for the entrepreneur, farmer or food processor). The methodological approach highlights hidden environmental and socio-economic costs of interventions, such as government subsidies to fossil fuel, which are often borne by non-economic operators. Such costs and co-benefits are therefore included in the analysis and compared to a simple financial analysis to inform about the "real" impacts of the investments.

In financial analyses, all costs and benefits are valued at market prices, since the main goal is to examine the financial returns to the individual agents performing the investment. Instead, economic analysis is undertaken from the perspective of the overall economic system and it deals with the (economic, social and environmental) costs and benefits for the society. The main differences between financial and economic analysis are three:

- The economic analysis attempts to quantify "externalities", such as GHG emissions, water savings, and other environmental and social impacts resulting from the project;
- The economic analysis removes transfer payments, such as subsidies (economic costs for the society) and taxes (economic benefits for the society);
- The economic analysis makes use of "shadow prices" that eliminate market distortions and reflect the effective opportunity costs for the economy.

After having assessed the impacts at the single intervention level, in the second phase the technical potential of a technology is estimated for a given country. The INVESTA CBA for the country case studies highlights the initial investment required (at country level), the investment horizon (the expected lifetime of the technology), the financial attractiveness—in terms of internal rate of return (IRR) and net present value (NPV)—and the economic NPV, which includes socio-economic and environmental costs and co-benefits. Depending on the country conditions and on the benchmark choice, the impact of the same energy intervention can be significantly different (see example 2).

RESULTS

Example 1. Cost-Benefit Analysis (at intervention level) of a Domestic Biogas-Powered Milk Chiller

The domestic-scale biogas digester and milk chiller is a technology suitable for smallholder dairy farmers with few dairy cows, since it can only cool up to 10 litres of milk per day (FAO and GIZ, 2018). The milk chiller requires about 1 thousand litres of biogas per day (with a heat value of 25 MJ/l) to cool 10 litres of milk. Another cubic metre of surplus biogas is available to fuel one or more cookstoves for 1 to 2 hours per day. The commercially available SimGas system used for the analysis (costs and performance detailed in FAO and GIZ, 2018) includes digester, milk chiller and cookstove. It has a capital cost of US$ 1,600 and a lifespan of 20 years (lifetime of the digester, while the milk chiller lifetime is less than 10 years).
Costs and benefits of the technology over its lifetime are summarized in Figure 2. It shows that the benefit from investing in a milk chiller are: financial revenues from additional milk selling, more value added along the value chain, the production of slurry and digestate that can be applied on farm, and the biogas cookstove (which reduces indoor air pollution and allows savings on traditional fuelwood and charcoal, thus reducing GHG emissions).
Variable costs are for maintenance, replacement of spare parts and labour. Maintenance starts from year three of adoption, costing on average US$ 20 per year. The main cost of the system is the additional work needed to feed the digester with cow manure every day. Non-monetized benefits (improved soil quality and access to energy) and possible negative impacts (increase in water consumption and impact on time saving) are represented by the circles.

Example 2. Cost-Benefit Analysis (at national level) of Solar Milk Coolers

The technology and performance of the solar milk cooler is based on the “MilkPod” system that has been operated in Kenya since 2015 (FAO and GIZ, 2018). Manufactured by Full-Wood Packo, a Belgian company, it can chill and store 500 to 2,000 l of milk per day, relying just on solar power. The system is a complete milk collection and chilling station, including a milk receiving and testing section, a rapid milk chilling section and a milk storage section.

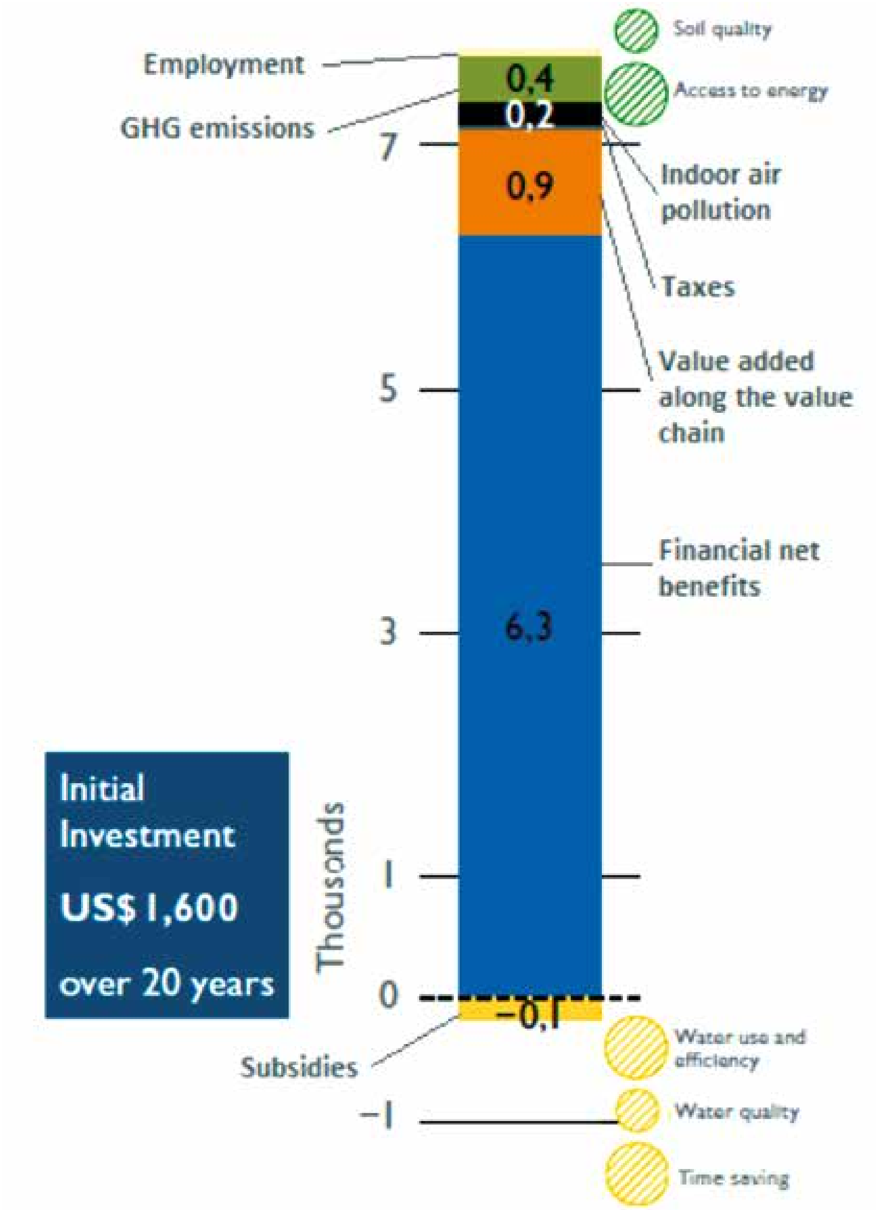

Figure 1. *Financial and non-financial benefits (positive) and costs (negative) for a domestic biogas milk chiller.*

The cost of one MilkPod with a capacity of 600 litres, imported from Belgium, is US$ 40,000. The system includes a cooling unit with ice bank (US$ 15,200); a 6 kW solar PV system (about 20 panels of 250 Wp); four 24 V, 3,500 Ah batteries; an inverter and a controller (US$ 19,290). The system is built in a shipping container with insulated walls and roof, LED lighting, a stainless steel wash sink with hot and cold water connections, a water heater and a stainless steel table (US$ 5,510). The system is shipped and installed by the manufacturer who also trains the future operators. Expected life of the cooling tank, ice bank, PV panels, water heater, waste heat recovery unit from the compressor (using a plate heat exchanger) and the other steel components in the container is 20 years. It is assumed the batteries will be replaced every 10 years for a cost of about US$ 3,000. Routine maintenance includes washing the tank once a day and cleaning the solar panels six times a year. The ice bank capacity can cool 2,500 l of milk, and can chill and maintain milk at 4 °C for 3 to 5 days with no solar input.
Costs and benefits of the technology depend on the benchmark situation. Therefore they are different in different countries (Figure 3).The solar milk cooler can be a greenfield investment (e.g. in Tunisia and Tanzania) or it can replace an existing regular 100 kWh/year refrigerator powered by a diesel-fuelled generator (example of Kenya) (FAO and GIZ, 2019). Monetized financial, economic, social and environmental costs and benefits in different situations are shown in Figure 3. In particular, the milk coolers reduce milk waste and spoilage and add value along the value chain.

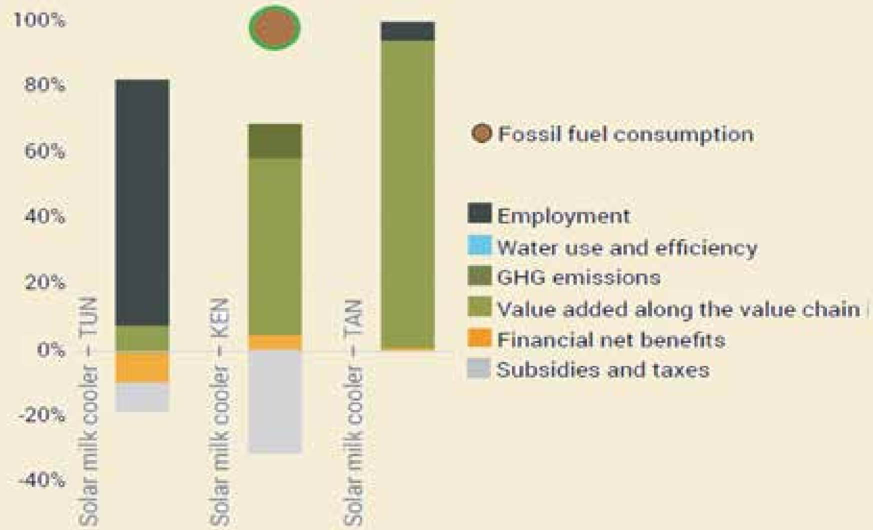

Figure 2. *Costs and benefits of the 3 solar milk cooler case studies in Kenya (KEN), Tunisia (TUN) and Tanzania (TAN), as percentage of the investment capital cost.*

Note: the shares reported take into account only the monetized impacts. The non-monetized impact on fossil fuel consumption is reported above the bars and is positive (green outline).

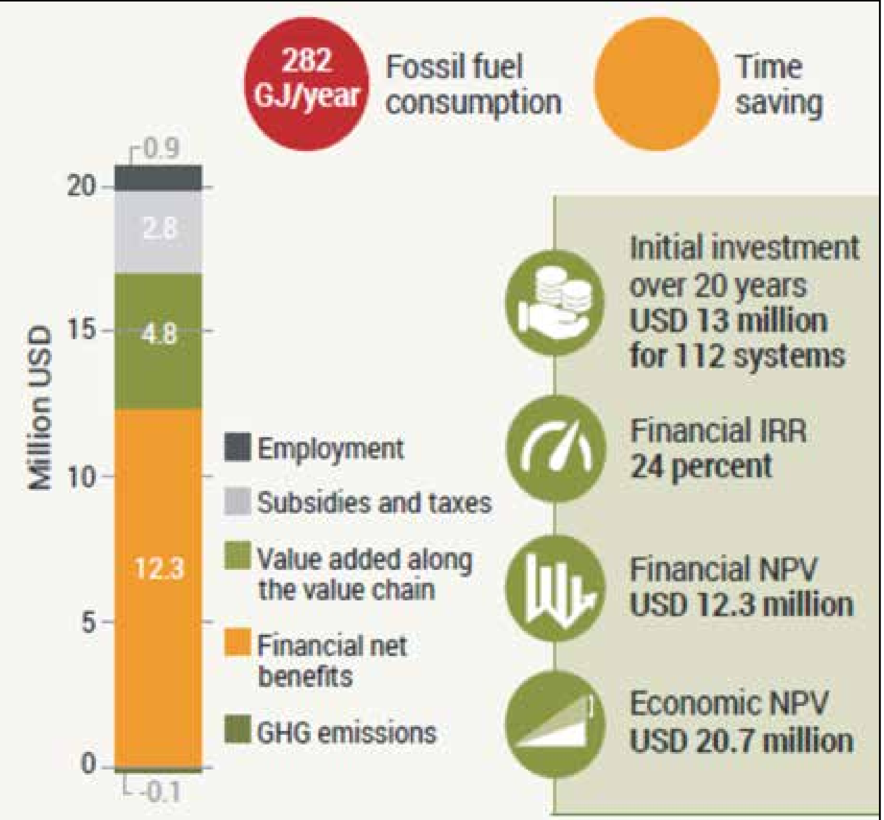

Figure 3. *Financial versus economic attractiveness of solar cold storage for vegetables at national level.*

Example 3. Cost-Benefit Analysis (at national level) of Solar Cold Storage for Vegetables

The 25 m^3 refrigerated cold storage system, designed for tomatoes and green beans, is powered by electricity from a 11 kWp solar PV array. The system is built in a 20 feet shipping container (6.1 m x 2.4 m x 2.4 m). The analysis is assuming the costs and technical performance of refrigerated container systems such as those commercialized by SunDanzer. These systems are suitable for refrigeration in locations with an intermittent grid as they are equipped with batteries for energy storage and (optionally) a PV system.
The capital cost of a refrigerator of 35 m3 with an internal refrigeration capacity of 25 m^3 ranges from US$ 90,000 to 110,000, plus around US$ 25,000 for the solar system. For larger systems with several units, the capital cost per unit of refrigeration capacity slightly decreases.

Table 1.
Policy support interventions to overcome barriers to deployment of solar milk coolers.

	Possible support intervention	Barriers to be tackles	Responsible actors
Target setting	Setting of minimum milk quality standards	Lack of incentive for a farmer to improve milk quality and hygiene	Ministry of Agriculture
Regulatory schemes based on legal responsibility and jurisdiction	Enforce stricter quality check at collection points	No strict milk quality check at the collection stage reduces incentives for farmers to improve the hygiene and cool their milk	Ministry of Agriculture Dairy Board
Knowledge and education scheme	Programs for educating and training technicians Use public extension services, associations, private sectors and local NGOs to educate users on the benefits and effective use of the technology Initiate informative programs to promote the technology	Lack of awareness of the technology Shortage of qualified technicians in rural areas to install and maintain the system.	Private sector companies Local Government Authority (LGAs) Livestock extension officer at LGA Local NGOs Sector associations
Facilitate access to finance	Financial incentives to make technology more affordable The incentives should be in terms of low interest subsidized loans or loan guarantees Introduce a price premium for refrigerated quality milk	Low financial returns High initial investment costs for dairy smallholder groups Lack of financing solutions for dairy smallholder groups Lack of incentive for a farmer to improve milk quality and hygiene	Ministry of Agriculture, Livestock and Fisheries Ministry of Finance Commercial Banks MFIs IFIs Dairy Board Dairy companies

In Kenya, the tomato and green beans value chains are analysed since they are two important perishable crops, with growing markets. At the national level, there is potential for about 112 grid-connected solar cold storage systems for tomatoes and green beans that could be installed to serve farmer groups or associations at collection points. Figure 4 summarizes costs and benefits associated to the technology.

DISCUSSION

Barriers to technology adoption and support interventions

During field visits in the case study countries and meetings with national stakeholders, specific national data and information on the energy technologies and the value chains under analysis were collected. For each clean energy intervention assessed in a specific value chain, the main barriers to technology adoption and possible solutions were presented and discussed in each country. The following categories of barriers to technology adoption have been identified:

- knowledge and information;
- organization/social;
- regulations/institutions;
- support services/structures;
- financial returns;
- access/cost of capital.

Possible support interventions to overcome each barrier, led by governments, donors, private sector actors, investors, international financial institutions (IFIs) and NGOs, were subsequently identified and classified as: target setting; regulatory schemes based on legal responsibility and jurisdiction; financial incentive schemes including guarantees; and knowledge and education schemes. Table 1 provides an example of barriers to technology adoption and support interventions for the solar milk cooler technology. Other examples can be found in the FAO/GIZ report (2019).

ACKNOWLEDGMENT

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Energy Efficiency and Refrigerant Containment in Supermarkets in Argentina

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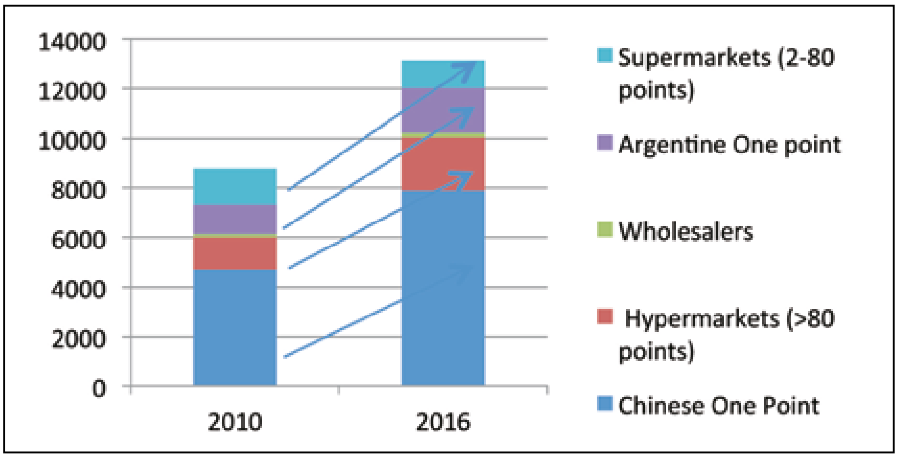
Since the beginning of the implementation of the international commitments made by Argentina in the framework of the Montreal Protocol, our country has encouraged the adoption of technologies with low or no potential for global warming, making great management efforts to promote collaboration between the industry, end users and policy makers to encourage the use of clean refrigeration technologies.
In order to promote awareness in the supermarket sector of the new technological trends and the ongoing HCFC phase out driven by Montreal Protocol and the impact that these will have on the sector, OPROZ (Oficina Programa Ozono) together with UNIDO as implementing agency started working with this sector in 2014 as part of the activities financed by the Multilateral Fund for the Implementation of the Montreal Protocol.
We saw this initiative as a great opportunity to continue working towards a near future for a clean and efficient cooling in the supermarket sector, due to the rapid expansion of the sector and its high consumption of energy and refrigerants, thus initiating a triple benefit path not only for helping to restore the ozone layer but also reduce global warming and the consumption of electricity with the consequent economic benefit.



The supermarket sector in Argentina

Supermarket sector in Argentina has consistently grown over the past years and a future growth is expected. Between 2010 and 2016 the five biggest chains grew 63%. The total estimated points of sale were of 8,672 in 2010[1], reaching around 13,000 in 2016[2].[3] This number includes the categories of wholesalers, hypermarkets, supermarkets and single- store entities. It is also remarkable that small proximity self-service markets had a substantial growth from 2001 to 2016, boosted by the opening of this type of format by the big players of the sector.
HCFC-22 has been the most popular refrigerant over the past decades for retail food refrigeration systems and it is still mainly used in the supermarket sector. The sector growth could increase HCFC-22 and high GWP HFCs consumption in this segment, until new refrigerants take over the role of HCFC-22.

Demonstration project on replacement of high GWP refrigerants with trans-critical CO_2 for warmer climate in a mid-sized supermarket in Argentina

Key parameters

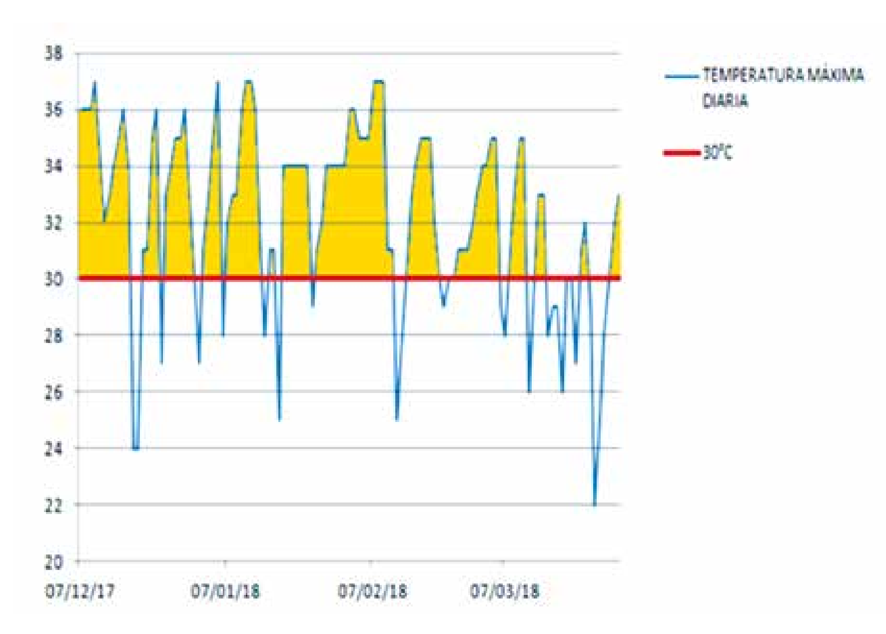
At the time the project was formulated, the main barrier for introducing low GWP alternatives, especially CO_2 in the supermarket sector in Article 5 countries was the lack of knowledge and experience as well as the limited

[1] Informe Relevamiento sobre Supermercados en Argentina. 2011. Federación Argentina de Empleados de Comercio y Servicios.

[2] Informe de Actualización: Evolución del Sector Supermercadista. 2016 Federación Argentina de Empleados de Comercio y Servicios.

[3] Encuesta de Supermercados. Informes Técnicos vol. 1 nº 65, Comercio vol. 1 nº 9. INDEC, Febrero de 2017.

availability of equipment components and know-how related to the new technology, as well as the still high initial cost implication.
For these reasons, even when the end users decide to phase out HCFCs in their installations, the likelihood that they would opt for HFCs is rather high as it is a well-known technology and it is in use in Argentina since 2008. Such conversion requires less modifications and thus it will be the less costly solution.
Therefore, Argentina decided to implement a project to evaluate the feasibility of introducing a technology with low global warming potential, and demonstrate that it is energy efficient in temperate climates, in particular taking into account the long-term sustainability of the alternative, and other technical issues related to its ease of installation and cost, so that it can be replicated both in our country and in countries of the region, thus promoting the use of refrigerants with low global warming potential in the assembly sector as a substitute for HCFC-22.
The project was approved by the Executive Committee of the MLF in May 2016 with a budget of U$527,169 with UNIDO as implementing agency and an implementing period of 30 months.
After thorough review of the available technological options suitable for supermarkets located in warm climate conditions, it was decided to introduce a transcritical CO_2 booster system with parallel compression and subcooling. In order to use natural refrigerants for all the system it was decided to incorporate a R290 subcooler.
The CO_2 transcritical system design was developed locally by EPTA Argentina -who was the awardee of an international call for bid done by UNIDO- with the assistance from their design headquarters in Italy and UK following UNIDO and OPROZ consultants guidelines. A critical point was the design, calculation and manufacturing of the R290 subcooler. The refrigeration system was built by EPTA using a subcooler of an Italian manufacturer. All piping calculations were adjusted locally.
To quantify the impact of the technology, the electricity consumption was continuously measured during the year prior to the start-up of the new system, and data collected was used to determine the pre-conversion baseline electrical consumption level. The measurements and data collection continued throughout one-year of post conversion period. Thus, a comparison of pre- and post-conversion energy consumption based on real data was performed.
Temperature, as well as, general climate condition information were registered for all the measuring period from the nearest meteorological station.
It is important to note that in the summer period monitored from December 2017 to March 2018 the average maximum temperature was 32 °C, and most of the time over 30 °C, as shown in the following figure:



Supermarket
La Anonima´s Lincoln branch, Province of Buenos Aires, Argentina, located in a moderately warm climatic zone (GPS coordinates: Latitude: 34º 51’ 49.6” S, Longitude: 61º 31’ 42.062” W) was selected for the project implementation. The total sales area is of 1,258 m^2.

The Old System
In the baseline, the supermarket had two R22 central refrigeration systems, one for low and another for medium temperature and a number of self-contained freezer units (islands and upright reach-in cabinets) working with R-404A.

The New System
Central CO_2 transcritical booster system with parallel compressor and R290 subcooler.
The self-contained R404A freezer units (islands and upright reach-in cabinets) of the baseline installation were replaced and the new ones were integrated into the CO_2 centralized system.
The layout of the supermarket remained similar to the baseline system.

The CO_2 Transcritical Refrigeration Rack

R290 subcooler

Cooling Capacity	MT 69Kw LT 10Kw
Compressors	Bitzer • 2 x 2KSL-1K (LT) • 1 x 4FTC-20K (MT1)+1 x 4HTC-15K (MT2) • 1 x 4JTC-15K (PARALLEL)
Gas cooler	• LU-VE XAV9X 9912 H 2VENT (1X2) - CO_2 - EC fans
Controller	Carel pRack PR300T
Energy saving devices	• Parallel compressors • Inverter on: - 1° MT compressor - 1° LT compressor - 1° parallel compressor • Subcooler Heat Plate Exchanger that work with a R290 chiller EKO.E 91S
Design conditions	• Evaporating temperature LT: -32 °C • Evaporating temperature MT: -9 °C • Maximum pressures: - HP 120 bar - MP 53 bar - LP 30 bar

During the implementation of the conversion process the smooth operation of the supermarket had to be maintained, thus the baseline machinery was maintained in operation The old machinery was dismantled and destroyed only after successful start-up and trial runs of the new system.

Economic and technical incentives and barriers

The initial cost of a CO_2 transcritical system used to be substantially higher than an HFC system but the price difference is decreasing due to the standardization of several components. Today the difference in price is around 20% in the Latin American Region depending on the size and characteristics of the system.

Cost of installation of a CO_2 system due to the high-pressure requirements is still very high in Argentina because TIG brazing is made by specialized companies.

The first charge of CO_2 was supplied by EPTA, industrial gas vendors like Praxair and Air Liquide are located in Argentina and it is easily available.

R290 has been supplied to EPTA by a local refrigerant importer and EPTA maintains a stock for emergencies.

An adequate training of the service staff was necessary.

OPROZ also offered during 2017 and 2018 all over the country trainings for more than 700 technicians on Good Practices in Handling Low GWP refrigerants which included CO2.

Parts to be replaced most frequently are manometers and valves, these devices are now available in Argentina.

Availability of CO_2 transcritical system vendors in the local market is low. CO_2 central refrigeration systems as well as the evaporators and subcooler were manufactured in Italy. The size of the market is still not sufficient for manufacturing it locally.

Compressors in our case were manufactured by Bitzer whose service center is located in Brazil, so the project vendor has a reduced stock for emergency.

Exhibitors are manufactured by EPTA locally at their Rosario manufacturing plant but some of the components are imported.

Most electrical components are available locally but some cables as well as special connectors are imported.

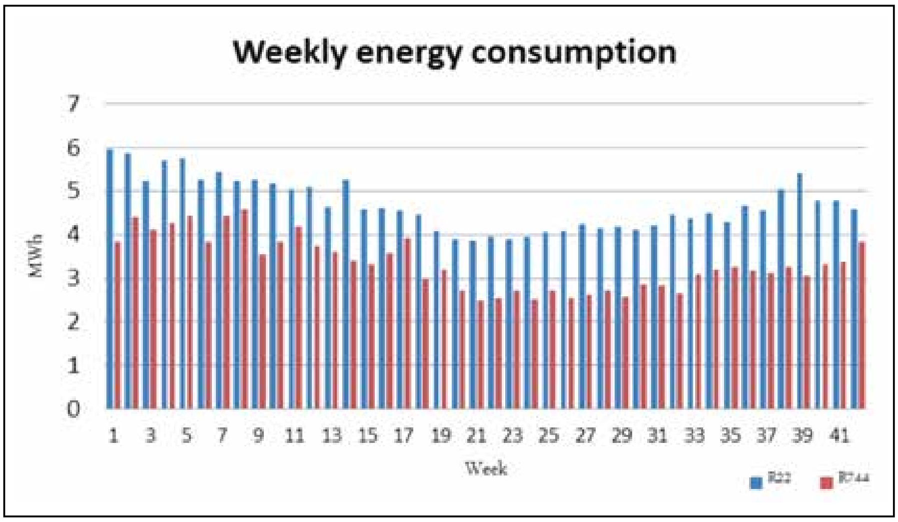
Carel control systems for CO_2 transcritical installations are manufactured in Italy so the project vendor maintains a complete control system in stock as well as pressure transducers to be able to assist in case of emergency. Carel is based in Brazil and has distributors in Argentina.

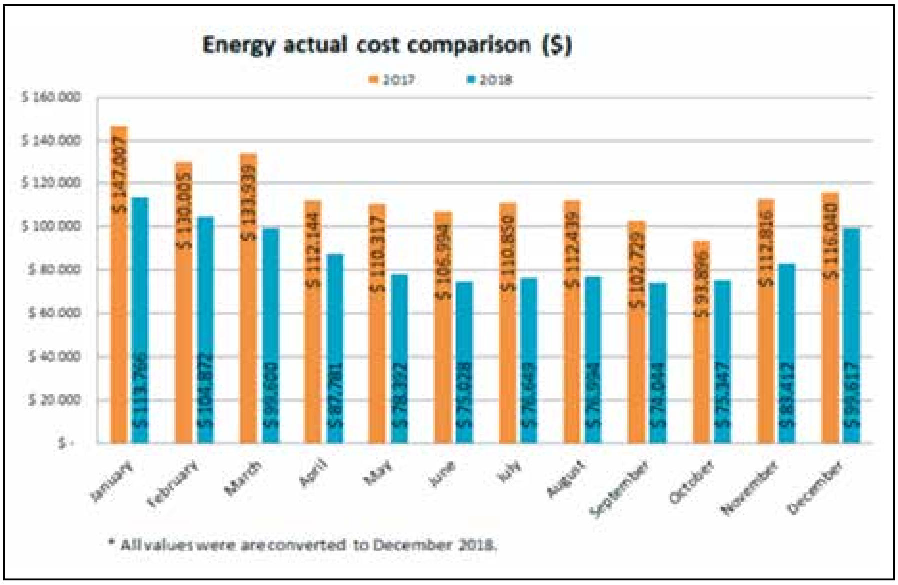
Results

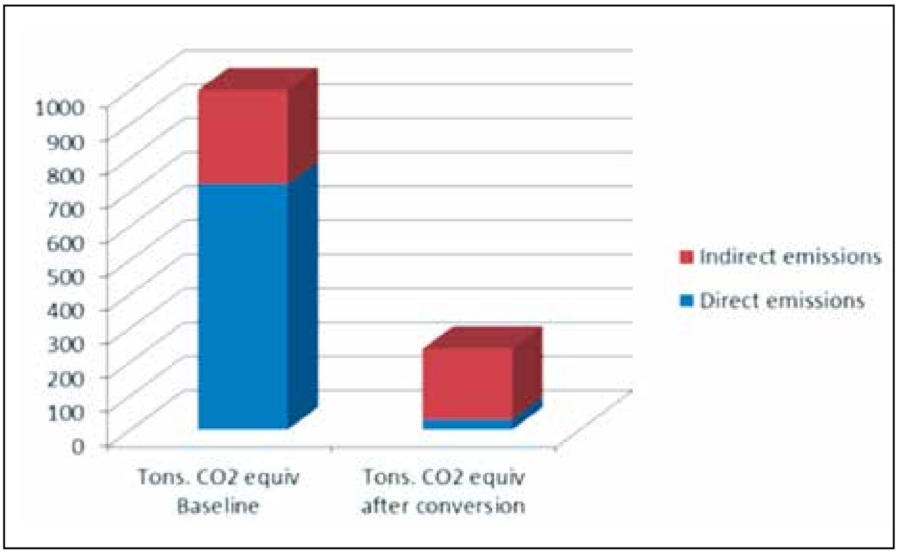
The results obtained in the project demonstrated a significant saving in the consumption of electric energy and avoid emissions to the atmosphere of greenhouse gases, thus allowing the decrease of both direct and indirect emissions and consequently of the carbon footprint.

- During the trial period the electricity consumption of the CO_2 transcritical system was 28,8% lower compared to the baseline. In the following figure, the weekly electricity consumption of the new CO_2 transcritical system is presented versus the baseline registered during the test period from January to mid-November.
- The electricity bills showed a 27% reduction in total branch electricity consumption and a year saving of pesos $343.673 (U$S 9,200, exchange rate January 2019) The following graph shows energy cost comparison based on electricity bills of 2017 and 2018:

* The average annual consumption of refrigerants at Lincoln La Anonima supermarket amounted to some 300 kg with a refrigerant cost of U$S 5,700.







- The total reduction of climate impact per year after the conversion is of approximately 760 metric tons CO_2 equivalent. For illustration, this number is equivalent to the annual CO_2 release of approx. 340 passenger cars running 15,000 km in a year! (A currently used mid-size car releases 150 - 180 g CO_2 per km.)

Replicability

This project has been very important for our country since it allowed to disseminate this new technology along with developed countries, and has allowed since then a rapid adoption of it in several supermarkets in the country, being Argentina to date, the country of the region that currently has the largest number of transcritical CO_2 facilities in supermarkets.

At the time the project was formulated, there was only one supermarket in Argentina using a transcritical CO_2 centralized refrigeration system in Caleta Olivia, Province of Santa Cruz at the south of Argentina (Patagonia region), a location with a very cold climate condition.

Based on the good results obtained in the project, the recipient company La Anónima, has adopted the modified transcritical CO_2 as the default technology for its new branches as well as for updating or refurbishing of current ones, whenever it is feasible.

The project helped to create confidence in the technology. It demonstrated its feasibility, removed many barriers and accelerated the adoption of this technology even for warmer climate zones of our country (e.g. Córdoba, Santa Fe, Salta and Tucuman). The number of supermarkets using CO2 transcritical systems in Argentina increased to a total of 17 belonging to nine different supermarket chains.

At regional level, the same vendor has installed from 2017up to now 3 more systems in Chile and 12 in Ecuador.

Technical assistance to reduce refrigerant leaks in supermarkets

General Background

Consumption of refrigerants in the supermarket´s servicing sector is still very relevant in Argentina. HCFC-22 consumption is estimated in around 750-800 MT while R-404A in 250 MT.

The high leakage rate is frequently caused by a poor or inadequate maintenance of the cooling and freezing systems and sometimes bad quality installations. Maintenance generally is performed by their own staff and in many cases these technicians are not well trained so the preventive maintenance is not well addressed.

Thus, the only remaining option was to focus our efforts in this sector where the leakage rates are very high ranging from 35% for big and medium size installations to 70% for small installations. Leak prevention is crucial not only for direct environmental benefits but also for reduction of energy consumption. These high leakage rates need to be reduced too in order to comply with the country's longer-term obligation of phasing out HCFCs and HFCs consumption in the servicing sector.

While the refrigerant consumption is generally accounted for, the actual losses are not tightly monitored and the costs related to the purchase of refrigerants are not in the focus of management. Since these issues are not carefully addressed by most companies, their owners and the respective management are not aware neither of the environmental nor the economic impact of unreasonably high refrigerant consumption and excessive energy consumption.

Thus, a project for the provision of technical assistance and related equipment (refrigerant leak monitoring, energy consumption measuring equipment and data logging system) to 29 supermarket branches was developed.

The technical assistance project will validate the environmental and economic benefits of introducing good practices in the refrigeration systems maintenance in real case scenarios of 29 supermarkets operating in diverse climatic and location conditions in Argentina. This will also open avenues for replication on country level by creating awareness that an adequate maintenance can reduce leakage rates and as a direct consequence also the energy consumption addressing in this way both direct and indirect emissions.

The project

The objective of this project is to reduce refrigerant leaks, enhance energy efficiency, and check the impact on energy efficiency and refrigerant consumption of the interventions introduced, to demonstrate the importance of good preventive maintenance practices.

The 29 branches were selected out of 53 proposals received, based on location in different climatic regions, pertaining to different chains (5), with leak rate > 30 %/yr. and different quality in maintenance practices.

The project has been designed in three stages.

Stage I (May-June) included a diagnosis fact-finding visit to each of the supermarkets to review and record the type and condition of their cooling equipment. A component identification checklist and a leak search list was filled. Energy and Refrigerant consumption registered on the last twelve months was required to the customer to estimate the Carbon Food print base. This stage allowed the contractor to prepare expert recommendations and an action plan for the reduction of refrigerant leaks and decrease of energy consumption.

It was followed by the installation of the monitoring system (July-August 2019) comprising the assembly of 10 Carel DPWLA07000 refrigerant leakage sensors, RS485 network wiring, MT300W3200 energy meter and installation of monitoring system PlantWatchPRO3.

Stage II comprises three quarterly follow-up visits (September, December and March 2020) to review the implementation of the recommendations and action plan specified in Stage I and to check the functioning and readings of the installed monitors and download the data collected by the monitoring system and its results.

Stage III (July 2020) will include a final Visit to verify the monitoring system, its results and the implementation of the recommendations followed by the Final Reports drafting containing the conclusions such as: major findings; lessons learnt; bottlenecks; costs incurred; reduction of refrigerant use compared to the baseline; energy savings compared to the baseline; financial savings; and resulting environment benefits.

The project results will be shared with other supermarkets, commercial refrigeration service companies and independent technicians at a seminar organized by OPROZ.

The benefits expected are to minimize ODS and green-house gas emissions to reduce the footprint of the refrigeration systems in supermarkets and cost savings in the operation of the selected supermarkets, by the reduction of refrigerant and energy consumption.

UNIDO-CSG Train-the-Trainers course on flammable refrigerants renews collaboration between Italy and Argentina

Two years later, UNIDO and Centro Studi Galileo are cooperating again for the safe and efficient management of alternative and flammable refrigerants in Argentina. After two successful seminars held in Buenos Aires and Rosario back in 2017, in cooperation with the "Oficina Programa Ozono, Subsecretaría de Cambio Climático y Desarrollo Sustentable", a United Nations delegation of 22 Professors and high-level representatives from Argentinian Bodies and Government gathered in Casale Monferrato, Italy, to attend a train-the-trainers course on flammable refrigerants from 24 to 29 June.

As the main topic of the course, the safe and competent management of alternative and natural refrigerants is currently becoming more and more relevant and is a fundamental skill to be gained by everyone involved in the RAC sector, from servicing technicians to design engineers. These gases, and in particular hydrocarbons, present the characteristics of high pressure and/or flammability, with a direct, crucial consequence: a major need of high-level training for their proper handling.

Supermarket Refrigeration Systems The use of Low GWP Refrigerants

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Indian Society of Heating, Refrigerating & Air Conditioning Engineers

Supermarket refrigeration systems will be very different in the future , predict Industry experts .

Low GWP Refrigerants applied in Refrigeration Systems will soon replace the use of HFCs or even HCFC, wherever they are still in use in legacy systems .

Large supermarkets have central direct-expansion (DX) systems consisting of display cases on the floor that are connected by long runs of refrigerant piping to Condensers and condensing units located outdoors or in a remote mechanical room or on the roof. These systems are designed to be easy to access and service, as all the mechanical equipment is located in one area; however, the sizeable amount of piping can mean a greater chance for refrigerant leaks, which is becoming a growing environment concern.

A typical, large supermarket's refrigeration system has a refrigerant charge of 2000 kg with an average annual leak rate of about 25 percent based on high operation pressures and less than perfect maintenance. That means leaks could cause a supermarket to annually emit up to 500 kg of refrigerant – usually HFCs or even HCFCs — every year. Multiply that by thousands of supermarkets across India, and it is possible to see how this may be cause for concern.

Refrigerant phase down regulations are another reason why change is coming, as HCFCs are already mandated to be phased out , given their high global warming potential (GWP) and HFCs will likely be phased down by 2030 as well. At some point, Supermarkets will need to start considering low GWP alternatives such as HFO blends, as well as zero GWP refrigerants such as propane R 290 , ammonia R717, or CO_2 R744 for their refrigeration systems, that work 24 hours a day and 365 days a year .

This article looks at 3 natural refrigerants that apply to Supermarket Refrigeration

Multinational Food brands favour the use of Propane refrigerant systems in self contained refrigeration Units such as display shelves. The use of multiple self contained refrigerated display shelves are far more flexible than central DX systems. So if a supermarket decides to highlight a brand new soft drink, they could move a propane refrigeration case to a prominent place near the front without disrupting the floor plan or making costly changes to the rest of the refrigeration equipment in the store.

In addition, self-contained propane units have been designed for safety . They contain only a small charge (no more than 150 grams per refrigerant circuit) and have a very low leak rate of about 2 percent. Depending on the size, a Supermarket using only self-contained refrigeration equipment could theoretically only have 50 kg of propane.

Another factor leading to change is that young people are increasingly moving to densely populated cities to live in remote suburban areas where they may not have ready access to supermarkets. Supermarket owners

FOOD COLD CHAIN AND THE MONTREAL PROTOCOL

are likely to start opening smaller stores to cater to suburban markets .
Self-contained refrigeration cases may be a good solution, particularly if a supermarket is taking over an existing building that offers less flexibility with the layout.

Supermarket owners may have even more choices of self-contained units in the near future, because several industry groups are trying to raise the maximum charge size for flammable refrigerants such as propane in commercial self-contained cases from 150 to 500 grams. That is because while 150 grams of propane is adequate for small-to-medium-sized display cases, the larger display cases need more propane for cost-effective operation. Safe design and more efficient systems will allow larger charge systems to be acceptable .

Larger self-contained propane units will take time to become available because of current limitations on maximum charge and supermarket owners await that . Refrigeration contractors, however, may not be as excited about the widespread adoption of self-contained units. That's because these units typically require less maintenance than large rack systems, and since they're virtually plug-and-play . Supermarket owners may choose to buy a new unit rather than pay to have an older one repaired. Although in a world with a shrinking base of service technicians, perhaps that's a good thing. That way experienced service techs could be used to work on the complex refrigeration systems that will likely still be used in the large megastores for many years to come.

Another natural Refrigerant that is fast gaining application in Refrigeration systems is Carbon dioxide . Carbon dioxide as a refrigerant is not a new concept. CO_2 as an operating fluid in refrigeration systems was in use until the second half of the 19th century. It is with the development of synthetic refrigerants like CFC, HCFC and HFC that CO_2 was put to rest as a refrigerant.

But with such unique properties, CO_2 has made a comeback as a refrigerant with the development of Transcritical CO_2 Systems since the early 2000s. Such systems put CO_2 , in a trans critical cycle, meaning CO_2 is made to undergo different phases with varying pressures and temperatures.

One of the main advantages of the trans-critical system is that CO_2 is abundantly available in the environment. Waste produced CO_2 can also be used in this system reducing the overall greenhouse gases in the environment.

With all these advantages, the trans-critical system is still not perfected yet. But we might be closer, with India's first trans-critical refrigeration system developed at IIT Madras (Indian Institute of Technology) – a premier Engineering & Research Institute in South India.

Researchers from the Department of Mechanical Engineering at the Indian Institute of Technology, Madras, presented India's first CO_2 trans-critical system recently . It's the first of its kind in India, and it's operating successfully in very high ambient temperatures of up to 45 °C according to Professor Maiya, a member of the research team and a member of ISHRAE's Technical Committee .

The researchers tweaked the system by adding a liquid ejector and flooding the evaporator in the system. This resulted in an improvement of the CO_2cooling stability and an overall reduction in power.

In recent years, there is a rapid increase in the cooling demand. Hence, not only the consumption of energy, but also the quantity of the refrigerants released into the air is increasing globally leading to planetary heating.

Carbon dioxide (CO_2, R744) is a natural refrigerant which is emerging as a potential replacement for HFCs and HCs nowadays because of its attractive properties.

However, to avoid liquid entry into the compressor, conventional systems are designed and optimized to keep the exit part of the evaporator dry ensuring no liquid exits the evaporator. This requires superheating of the fluid which also contributes to internal irreversibility leading to lower COP. Hence, the liquid ejectors appeared as the potential option to improve the system COP, by facilitating complete use of the evaporator by avoiding superheating and securing a safe return of liquid refrigerant.

It is observed that the increment in evaporator pressure and decrement in compressor power consumption are 4.5% and 5.5% respectively. From the reduced superheat, the design reduces the heat transfer area in the evaporator due to nonlinear refrigerant distribution and thus contributes to energy saving.

This design shall result in commercial applications such as in Refrigeration systems for supermarkets typically used in supermarkets, hospitality catering and medical storage with significantly lower energy consumption

Synthetic refrigerants – HCFCs and HFCs are very harmful to the environment . Natural refrigerants including Propane, CO_2 and Ammonia shall soon be the green replacements that the world is looking for.

So perhaps the Refrigerated supermarket facilities of the future will turn out to be a win-win for everyone based on changes in the Refrigerants they use.

A third Natural refrigerant is Ammonia. The use of Ammonia is on the rise as a choice of refrigerant not only because it's safer for the environment, but it's more energy efficient than other traditional refrigerants. It absorbs large amounts of heat during evaporation, it can pass through smaller pipes, but maintain the same amount of refrigeration capability as other refrigerants. Ammonia has been traditionally used as a Refrigerant in Cold Storages in India since the early part of the 20th century , long before Freons overtook their use in the 1960s. The thermal capacity of Ammonia enables it to use less energy than other refrigerants, particularly when used in industrial applications, like supermarket refrigeration systems. This is a good thing since supermarkets are high energy users. In fact, more than half of their energy usage is attributed to refrigeration .

Supermarket owners that look to apply ammonia should be confident that a properly implemented system can be extremely safe and efficient. Beyond this, there are no deterring code restrictions preventing its use. Utilizing ammonia commercially doesn't require the reinvention of the wheel. Ammonia systems have been used in India and around the world for many years in various types of industries and applications – and more recently – in supermarkets."

With the success of ammonia-based refrigeration systems so far, it makes sense for supermarkets to take a further look at the new technology.

To date there are at least five U.S. supermarkets that have installed a refrigeration system that use a hybrid of ammonia, along with CO_2. This makes an NH_3/CO_2 system one of the most unusual of natural refrigeration technologies (propane/CO_2 is in use too), with the efficiency and environmental advantages it offers. We see such systems being installed in India too, given the historical use of both NH_3 and CO_2 long before freon became popular.

However Supermarket owners have a reason for slow adoption of ammonia namely : fear of leaks causing toxicity. The fear stems from ammonia's toxic properties as well as the noxious odour it exudes; an ammonia leak is not something they would accept.

From a safety standpoint there is no need to be overly concerned about having 100 kg of ammonia at multiple locations in a supermarket when correct equipment location and easy venting can be a part of the installation design.

One US Store, is the first all-natural refrigerant store that uses ammonia on the roof on the high side with CO_2 circulated in the store in a cascade configuration. It also employs a redundant R407A system to run energy-efficiency comparisons with the ammonia/CO_2 system. The energy consumption of the ammonia/CO_2 system and versus the redundant R407A system, found the former to be12%-16% more efficient than the latter.

This study is certainly good guidance for early adoption of natural refrigerants in an extended Central refrigeration system in Supermarkets around the world .

While anxiety about ammonia appears to be an obstacle that can be overcome, the high cost of hybrid ammonia/CO_2 systems remains a major deterrent to the implementation of these systems by food retailers, who operate in a very low-margin business.

Some of the ammonia/CO_2 systems in US supermarkets have demonstrated energy-saving capabilities just via the refrigeration cycle efficiency. At one particular store, an ammonia refrigeration Unit consumed 22% less energy on an average compared to similar application HFC refrigeration unit , during a four-month period.

Natural refrigerants – Propane, CO_2, Ammonia and hybrid Ammonia CO_2 Refrigeration will soon be common in Supermarkets in Europe, the US, because of the rapid push to phase down HFCs by Governments. It will take a little longer in India. However good research and regulation will hasten the process.

Installation and operation safety protocols must be in place before their adoption. ISHRAE (Indian Society of Heating, Refrigerating & Air Conditioning Engineers) has taken up the task to conduct Research as well as guide protocols .

Synthetic refrigerants – HCFCs and HFCs are harmful to the environment. Natural refrigerants including Propane, CO_2 and Ammonia shall soon be the green replacements that the world is looking for.

So perhaps the Refrigerated supermarket facilities of the future will turn out to be a win-win for everyone based on changes in the Refrigerants they use that shall protect the environment.

Cold Storage as a Means to Avoid Excessive Power Production from Renewable Energy Generators

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NOMENCLATURE

Abbreviations

COP	Coefficient of Performance
PV	Photovoltaic
EEG	German Renewable Energy Law
LCCE	Levelized Cost of Cooling Energy
DoD	Depth of discharge

Indices

th	Thermal
el	electrical
r	cold (refrigeration)
p	peak
DC	Direct current

ABSTRACT

This article investigates under which conditions the use of a photovoltaic-based refrigeration system with storage of excess energy is economically feasible. The plant configurations investigated include (i) common battery storage, (ii) a storage tank with phase change material (PCM) and (iii) a PV system without storage as a reference plant. It is shown that economic operation with storage is possible, but a reduction of the storage costs is necessary to compete with the reference cost. For a storage tank with phase change material and an installed PV peak power of 112 kWp, lower levelized cost of cooling energy (LCCE) can be achieved, however only if a cost reduction of -39% for storage investment cost can also be achieved. The use of battery storage currently generates higher costs. For a battery storage and an installed PV peak power of 112 kW_p, lower LCCE can only be achieved if a cost reduction of -84%. for storage investment cost can also be achieved. It can be summarized that both battery and PCM storage allow economic operation for the described cold store if the calculated cost reductions for the individual storage component can be achieved in the near future.

Key words: Photovoltaic modules, solar cooling, phase change material, levelised cost of energy, battery, PCM

1. INTRODUCTION

Grid-connected photovoltaic power (PV) plants with a fixed feed-in tariff according to the federal renewable energy law (in German: Erneuerbare Energien Gesetz, EEG) have been installed in Germany since 2000. In 2020, the 20-year commitment to the feed-in tariff will expire for the first of these plants. Figure 1 shows the number of roof-mounted PV systems with a peak power greater than 100 kWp for which the feed-in tariff expires in the years from 2020 onwards (Germany only). These plants have a reduced efficiency but are still fully functional – and fully depreciated. Given the latter, it can be expected that the owners/operators of these plants will want to keep them in operation. This poses the question which operational mode for these PV plants is most economic.

There are several options for this. Firstly, the PV plant owner could keep feeding the generated electrical energy completely into the grid. For this, he would have to negotiate an independent feed-in contract (power purchase agreement, PPA) with his distribution grid operator. Chances are that this option is not economically reasonable because the offered purchasing price for the PV energy might be too low.

Secondly, the owner could try to use as much as possible of the generated electrical energy in own consumption. In this case, the pattern of electrical energy production and own consump-

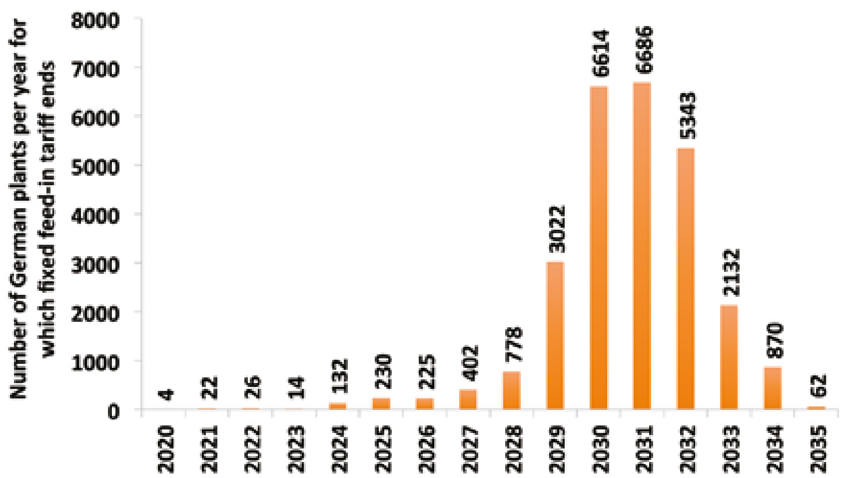

Figure 1. *Number and year of roof-mounted PV plants in Germany with a peak power > 100 kWp for which fixed feed-in tariff ends* [1]

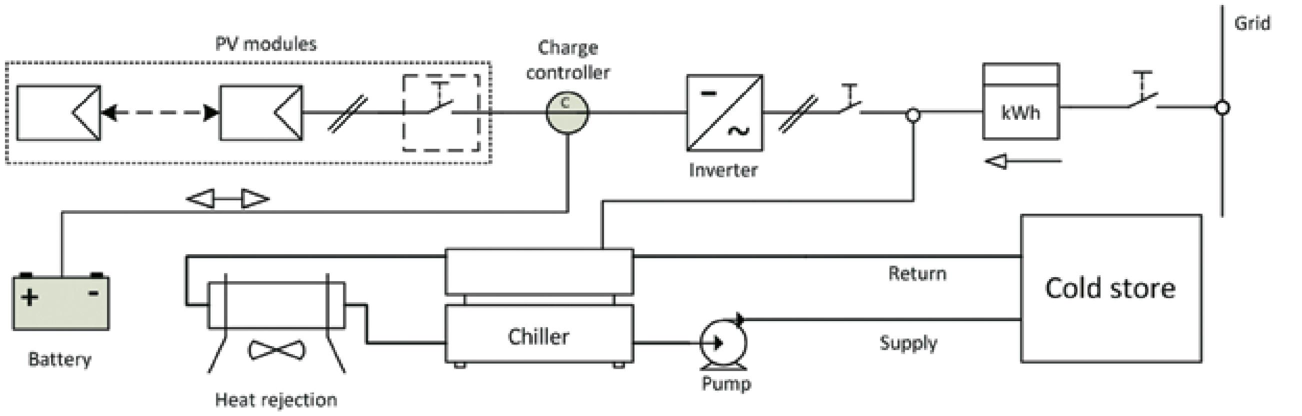

Figure 2. *Schematic of PV plant with battery storage*

tion should be synchronised, both in terms of performance and timing. This is not always the case, as it depends on plant size, load pattern and solar resource. A PV plant installed under the German Renewable Energy Law has typically been sized for maximum energy generation and not according to load pattern and / or generation time. Therefore the use of electrical energy storage is a sensible third option to increase the share of own consumption of such a PV plant [2]. This article investigates under which conditions the use of a photovoltaic-based refrigeration system with storage of excess energy is economically feasible. The plant configurations investigated include (i) common battery storage, (ii) a storage tank with phase change material (PCM) and (iii) a PV system without storage as a reference plant.

2. METHODOLOGY

The investigations were undertaken for a fictional cold store with a floor area of 1.250 m^2, a store volume of 10.000 m^3, a design store temperature of 0 °C, an installed refrigeration plant with a thermal power of 129 kWr and a specific electrical energy consumption of 65 kWhel/(m^3*a) [3].
It is assumed that the roof area of the cold store is covered with PV modules which have already been in use for 20 years. They are installed facing due South and inclined at 15° to the horizontal.
There is no feed in tariff for the electrical energy generated from these modules. It is further assumed that the existing power purchase contract of the cold store owner does not allow feeding PV power back into the grid. This means that excessive PV energy generated at peak times cannot be used at all if the generated power exceeds the own consumption load. To be able to use excessive PV energy, two options for storing peak electrical energy are being investigated in this paper.
Figure 2 shows the common (conventional) option of storing electrical energy using a battery, Figure 3 shows the option of storing thermal energy using a phase change material (PCM) tank. Both options have been investigated for Stuttgart, Germany. Climate and solar radiation data were taken from Meteonorm data base [4].
Figure 2 shows the mode of operation of a PV plant using battery storage. Generated PV energy is used directly to power the chiller, excess energy can be stored in the battery (DC). If there is no PV power and the battery has been discharged to its lower limit (DoD), power is drawn from the grid.
Figure 3 shows the PV plant with a PCM storage tank instead of a battery. In this option, all generated electrical energy is converted into thermal energy via the chiller. The thermal energy is removed from the brine that is pumped through the PCM tank, thus cooling it. Eventually the brine is cold enough to freeze the PCM material. Pumping warm return brine from the cold store through the tank results in the reverse phase change, i.e. thawing the PCM material, thus adding the removed heat from the cold store to the PCM material in the tank.
Massflow-controlled operation of both pumps in the two brine circuits allows charging or discharging the tank as well as bypassing it, therefore transporting the removed heat from the cold store directly to the chiller.
The tank operates as a hydraulic switch. Converting electrical into thermal energy using a chiller results in larger absolute amounts of energy, since the COP of the chiller is usually greater than one. Hence the PCM tank has a larger storage volume than the battery. Also, the chiller in the PCM option has a bigger cooling capacity than the chiller in the battery option.
Two scenarios have been investigated for the options described above. The first scenario assumes that only

Table 1.
Overview of PV plant scenarios

PV plant	Scenario 1 Roof area only	Scenario 2 Roof and ground area
Peak power installed	112 kW$_p$	224 kW$_p$
Plant azimuth	South (180°)	South (180°)
Plant inclination angle	15° to horizonta	15° to horizonta
Plant inclination angle	15° to horizonta	15° to horizonta
Cold store location	Stuttgart/Germany	Stuttgart/Germany

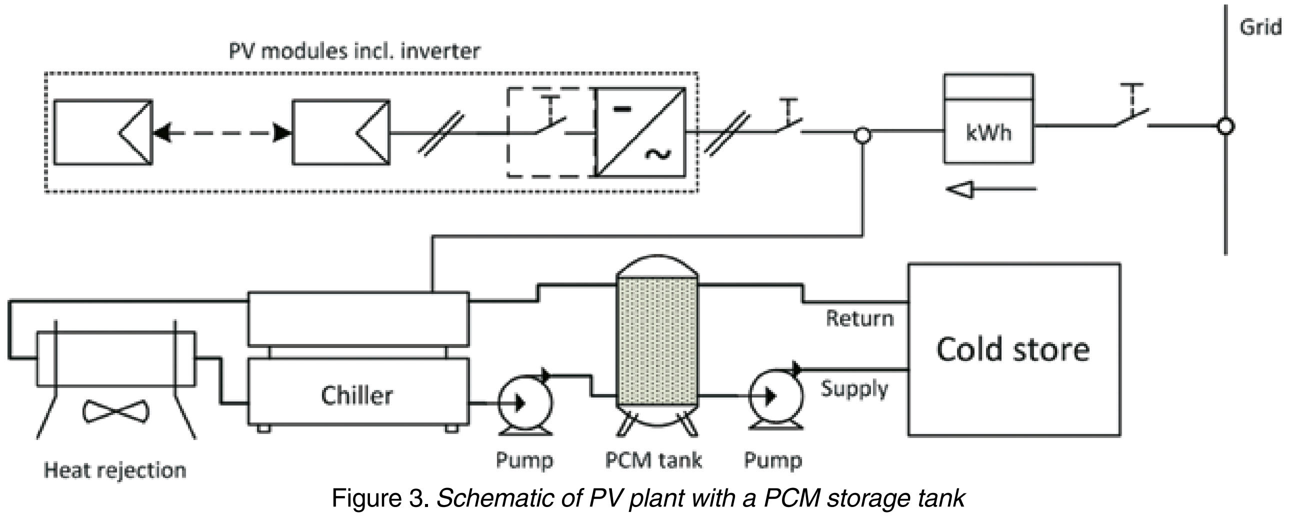

Figure 3. *Schematic of PV plant with a PCM storage tank*

the roof area of the cold store is covered with PV modules.
There are no other PV plants in the vicinity of the cold store. In the second scenario it is assumed that the total installed PV power is twice as large as in the first scenario. This power cannot be installed on the roof alone, therefore an additional PV area on the ground is assumed in the near vicinity of the cold store[1]. Table 1 shows the installed PV power of both scenarios.
The following assumptions have been made for both scenarios:

- The annual operation and maintenance cost (O&M) for the chiller equals 6% of the total investment cost of the chiller
- The annual average coefficient of performance (COP) of the chiller is 2.0
- The PV module degradation after 20 years of operation is 0.8% p.a. [5]
- There is no feed-in of PV energy into the grid.

The economic comparison of the scenarios has been conducted using the Levelised Cost of Cooling Energy, LCCE. For the evaluation of yield and technical parameters software-based simulations using PV*Sol [6] have been made.
The total investment cost I0 was assumed to be additional, newly invested expenditure for the individual storage components in the scenarios. The PV plant and chiller have been assumed as existing and were not included in the total investment cost.

Table 2. **Assumptions for economic calculations**	
Assumptions for economic calculations	All scenarios
Expected lifetime of plant n	20 years
Expected lifetime of chiller	20 years
Expected lifetime of PV modules, inverter excluded	20 years [2]
Expected lifetime of inverter	20 years
Expected lifetime of battery	15 years
Expected lifetime of PCM tank	20 years
Inflation rate	+1,0 %/a
Discount rate i	5,0 %
Purchase cost of grid power	0,1646 €ct/kWh_{el}
Annual change of purchase cost of grid power	+0,5 %/a

[1] A direct cable link between the inverter of the ground-based PV plant and the cold store load must be feasible.
[2] Here: 20 years from the start of this comparison, i.e. 40 years of total lifetime assumed.

$$LCCE = \frac{I_0 + \sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}$$

I_0: total investment cost [€]
C_t: O&M cost in the year t [€]
E_t: available cooling energy in the year t [kWh_r]
i: discount rate [%]
n: expected lifetime of plant [a]

However, over the expected lifetime of plant of 20 years the individual lifetimes of the main components have been accounted for, see Table 2. This means that components which have to be replaced during the 20 year period were included in the annual O&M cost with their respective discounted replacement cost, see Table 3.

3. RESULTS AND ANALYSIS

For the owner/operator of a 20 year old PV plant the question arises as to the most economically favourable mode of operation without a fixed feed-in tariff.
Figure 4 shows the solar fraction for the operation of the PV plant in both scenarios with and without energy storage (regardless of storage technology).
The solar fraction SF is defined as follows.
Solar fraction can be increased using an energy storage component but approaches a maximum value.

Table 3.
Cost assumptions

Storage technology	Unit	Battery	Battery	PCM	PCM
Installed PV peak power (Year 1)	kW_p	112	224	112	224
Specific investment cost battery	€/kWh_{el}	750	750	–	–
Annual cost degression of battery	%/a	-2,5	-2,5	–	–
Specific investment cost PCM tank	€/kWh_{th}	–	–	41	41
Annual cost degression of PCM tank	%/a	–	–	0	0
Investment cost for storage, installed, excl. GST	€	243.750 €	487.500 €	26.941 €	53.882 €
Nominal cooling capacity installed	kW_r	129	129	129	129
Additional installed cooling capacity for PCM operation	kW_r	–	–	20	169
Investment cost for additional installed cooling capacity for PCM operation	€	–	–	20.000 €	64.988 €
O&M cost for additional installed cooling capacity for PCM operation	€/a	– €	– €	1.441 €	5.365 €
Total investment cost for storage and additional cooling capacity (Year 1)	€	243.750 €	487.500 €	46.941 €	118.870 €

$$SF = 1 \frac{\text{Resulting power purchased from grid (Year 1)}}{\text{Annual elettrical energy consumption of cold store}}$$

For the following investigations the storage size has been chosen as given in Table 4. Larger storage sizes increase the solar fraction only marginally but cause significantly higher investment cost which influences the economics in a negative way. The results of the technical and economical calculations are shown in in Table 4.

The purchase of electricity from the grid for cold store operation is reduced by using an energy storage system, Table 4. This is because excessive energy generated by the PV system can be stored and used again at a later time. The results show that the surplus energy of a 112 kW_p plant is on average around 17 MWh_{el}/a, that of a 224 kW_p plant on average around 91 MWhel/a. Accordingly, these amounts of energy result in saved annual electricity costs, which must be offset against the additional investment costs for the respective storage technology.

The Levelised cost of Cooling Energy (LCCE) for the use of a storage technology is shown in Figure 5 for the selected PV capacities, storage sizes and assumptions. Also shown is the LCCE without storage, these are 7.2 € ct/kWhel for the scenario with 112 kWp and 6.8 € ct / kWh_{el} for the scenario with 224 kW_p. The use of a battery storage system results in LCCE of 10.4 € ct/kWh_{el} (in the scenario with 112 kWp) or 12.3 € ct/kWh_{el} (224

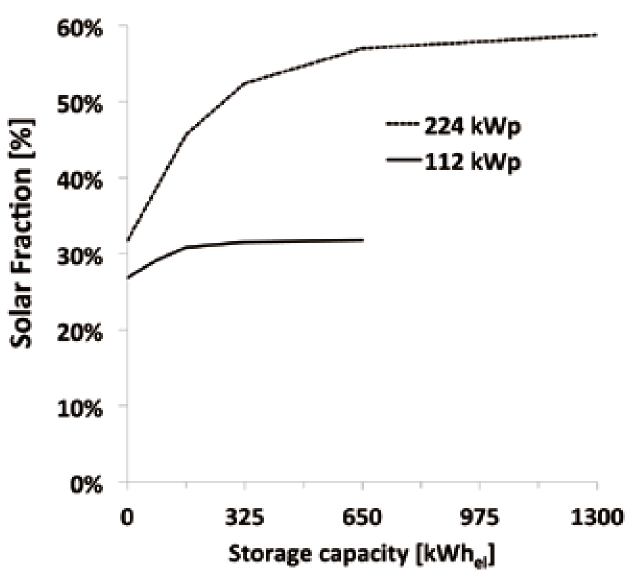

Figure 4. *Solar fraction of PV plants with and without energy storage*

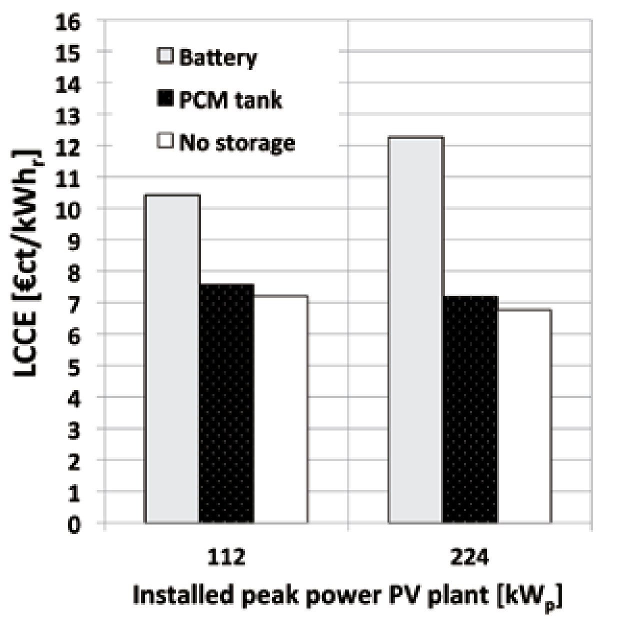

Figure 5. *LCCE for expected lifetime of plant*

Table 4.
Overview of simulation results

Storage technology	Unit	No storage 112 kW_p	No storage 224 kW_p	Battery 112 kW_p	Battery 224 kW_p	PCM 112 kW_p	PCM 224 kW_p
Installed PV peak power (Year 1)	kW_p	112	224	112	224	112	224
Size of battery	kWh_{el}	–	–	325	650	–	–
Size of PCM tank	kWh_{th}	–	–	–	–	650	1300
Annual electrical energy consumption of cold store	kWh_{el}/a	325.569	325.569	325.569	325.569	325.569	325.569
Generated electrical energy from PV plant (Year 1)	kWh_{el}/a	87.428	103.261	87.383	117.396	105.298	202.208
Resulting power purchased from grid (Year 1)	kWh_{el}/a	238.141	222.308	222.817	139.971	220.271	123.351
Solar fraction	%	27	32	31	57	32	62

kW_p), the use of a PCM storage including increased cooling capacity results in LCCE of 7.6 € ct/kWh_{el} or € 7.2 ct/kWh_{el} (112/224 kWp).
Comparing the additional costs of the two storage options in Figure 5, the PCM tank is the cheaper option. However, given the underlying assumptions, the LCCE of the option without storage is the lowest. This means that the additional cost for a storage technology exceeds the potential financial savings of electricity purchasing cost from the grid.
By means of a sensitivity analysis, it is now determined to what extent the additional cost for the storage technologies would have to be reduced in order to generate an economic advantage over the option without storage, Figure 6 and Figure 7. The reference variable in this case is the specific additional cost for storage operation c_{Sp}, which was calculated as follows:

$$C_{Sp} = \frac{I_{0,Sp}+I_{0,KKM}}{Q_{Sp}}$$

$I_{0,Sp}$: total additional investment cost for storage [€]
$I_{0,KKM}$: total additional investment cost for chiller (PCM only) [€]
Q_{Sp}: Storage capacity [kWh_{el} oder kWh_{th}]

Figure 6 and Figure 7 show that economic operation with storage is possible, but a reduction of the storage costs assumed in this paper is necessary. In the case of the PCM tank and a PV peak power of 112 kW_p, lower cooling costs can be achieved at specific additional costs for storage below € 44/kWh_{th}, which corresponds to a required cost reduction of -39%. If a PV plant with an installed peak power of 224 kW_p is available it will result in lower cooling costs at specific additional costs for storage below € 76 / kWh_{th}, which corresponds to a required cost reduction of -16%. The use of a battery storage currently generates higher LCCE. Lower LCCE for the scenario with 112 kWp can only be achieved with additional costs for storage below € 120 / kWh_{el}, which corresponds to a necessary cost reduction of -84%. In the scenario with 224 kW_p, lower LCCE can be achieved below additional costs for storage of € 220 / kWh_{el}, which equals a cost reduction of -71%.

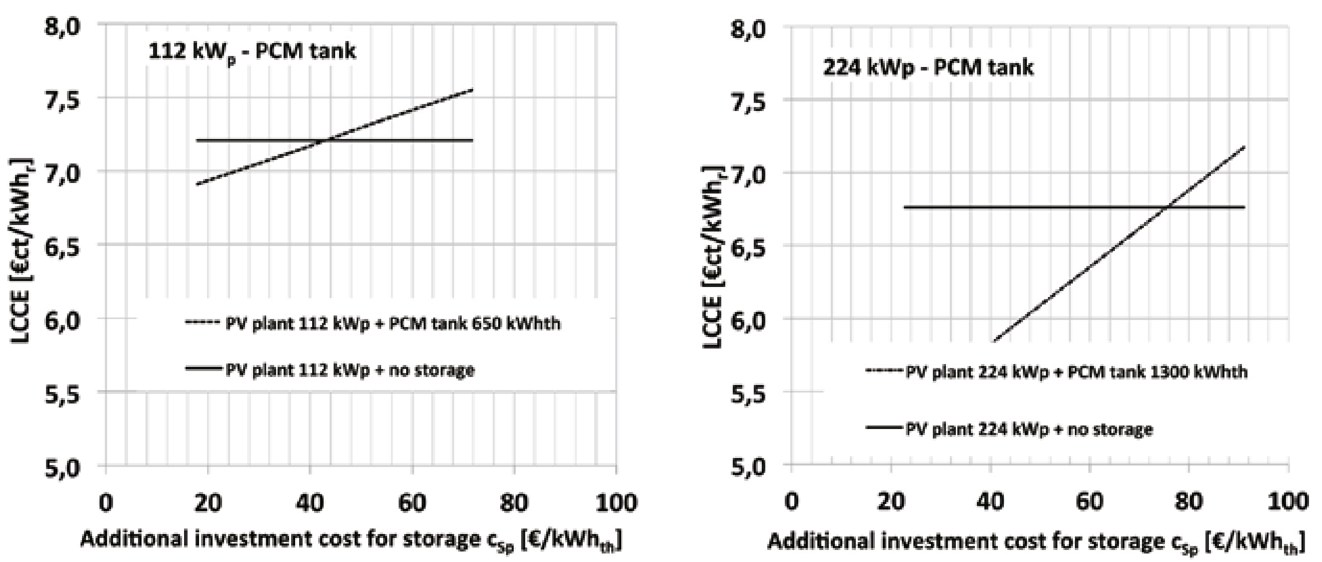

Figure 6. *Sensitivity analysis for additional storage cost – PCM tank*

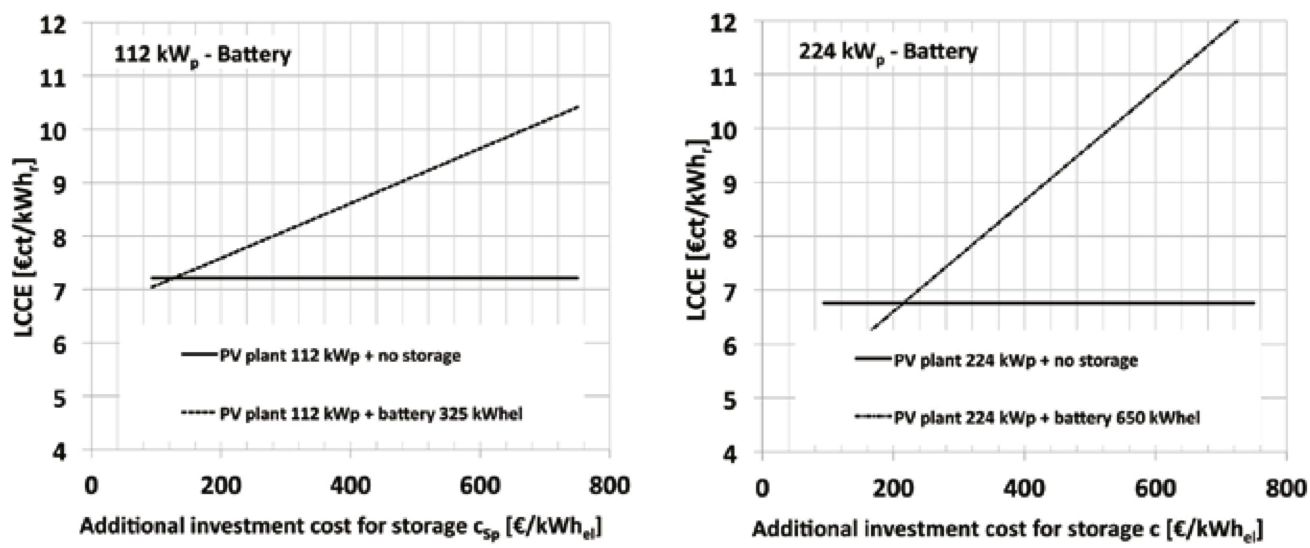

Figure 7. *Sensitivity analysis for additional storage cost – battery*

4. SUMMARY AND CONCLUSIONS

This article examines whether the use of electrical or thermal storage is economically feasible for photovoltaic plants supplying power to a cold store. It is assumed that the PV plant does not receive a feed-in tariff for the electricity generated and that the PV plant can not feed excess electricity into the grid. The use of energy storage components can increase the own consumption of the cold store.

The economic conditions for the installation and operation of a battery and a phase change material tank (PCM) are examined in this article. Using above assumptions and current cost for the respective storage technology, it is shown that economic operation with storage is possible, but a reduction of the storage costs is necessary.

In the case of the PCM tank and a PV peak power of 112 kW$_p$, lower levelized cost of cooling energy (LCCE) can be achieved at specific additional costs for storage below € 44 / kWh$_{th}$, which corresponds to a required cost reduction of -39%. If a PV peak power of 224 kWp is available this will result in lower LCCE at specific additional costs for storage below € 76 / kWh$_{th}$, which corresponds to a required cost reduction of -16%.

The use of battery storage currently generates higher costs. Lower LCCE for the scenario with 112 kW$_p$ can only be achieved with additional costs for storage below € 120 / kWh$_{el}$, which corresponds to a necessary cost reduction of -84%. In the scenario with 224 kW$_p$, lower LCCE can be achieved below additional costs for storage of € 220 / kWh$_{el}$, which equals a cost reduction of -71%.

It can be summarized that both battery and PCM storage allow economic operation for the described cold store if the calculated cost reductions for the individual storage component can be achieved in the near future.

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PRAHA-II: Continuing the Process while Partnering with the World

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FORWARD

The Executive Committee of the Multilateral Fund of Montreal Protocol approved, in its 76th meeting May 2016, stage-II of the PRAHA (Promoting Low-GWP Refrigerants for the Air Conditioning Sectors in High Ambient Temperature Countries) project which is now called PRAHA-II.
The main objective of PRAHA-II is to maintain the momentum generated by PRAHA-I and advance the technical capacities of stakeholders in high ambient temperature countries to enable the adoption and use of low-GWP sustainable technologies.
PRAHA-II has three main goals:
1) to build the capacity of the local industry in designing and testing products using efficient low-GWP flammable refrigerants; 2) to evaluate and optimize the prototypes built for PRAHA-I; and 3) To build a risk assessment model for the high ambient temperature (HAT) countries.
The meet these goals, PRAHA partnered with international associations with expertise in these fields.

LOOKING FOR EXPERTISE

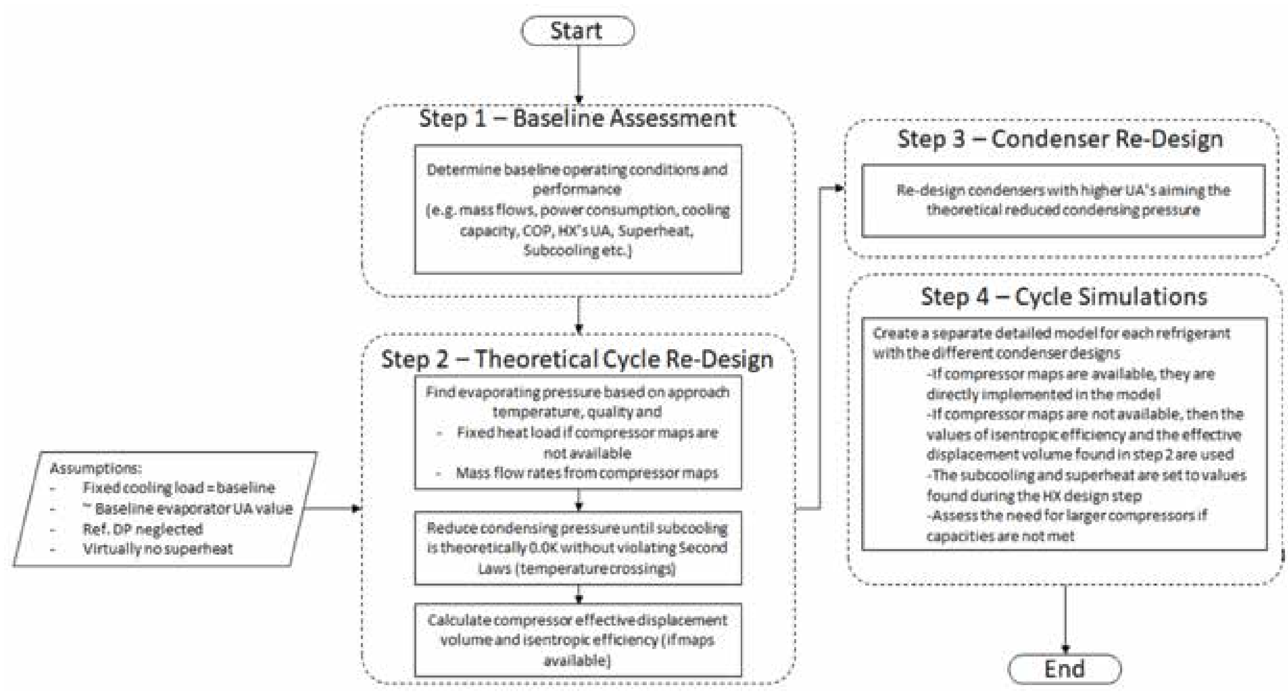
PRAHA-I outcome pointed to viable refrigerant alternatives for HAT applications in the air conditioning sector using three main technologies: flammable (A3) refrigerants, namely HC-290; lower GWP HFCs like HFC-32; and blends of saturated and unsaturated HFC's also known as HFOs. In working with stakeholders on PRAHA-I, it also became evident that these three technology directions are going to shape the choice of alternatives for residential air-conditioning worldwide. PRAHA-I had tapped into these main technology centers coordinating with stakeholders to supply samples of refrigerants and prototypes of compressors working with these refrigerants. The interest and support that manufacturers and suppliers in the three centers gave to PRAHA were exemplary and very encouraging.

WORKING-OUT CHALLENGES

PRAHA-I stakeholders had to work their way through many obstacles to participate in the project. Refrigerant manufacturers had to deal with intellectual property rights issues of sub-

(Right) JRAIA Instructors at the Risk assessment workshop in Tokyo, Japan – April 2019. (Left) Representatives from CHEAA and the China Ozone Office with reps from UNEP, UNIDO and MLF Secretariat at the Workshop in Ningbo - China, April 2017

System design framework used for Optimization component by the International lab



stances some of which at that stage were still in the research and development phase and were not even identified by the globally accepted ASHRAE reference, or R number.
Confidentiality and non-disclosure agreements had to be signed and memoranda of understanding developed and agreed upon. Then there was the issue of the level of support by the refrigerant suppliers to the participating OEMs without going into complicated technology transfer agreements that neither side was ready to get into.

On the compressor side, it became evident that there was limited development on models to support the new alternatives that are capable of working at the required high ambient temperatures and for 50 & 60Hz which were the frequencies used in the countries participating in the project.
Development of new compressors usually takes up to one year by the time all the different tests and trials were completed. PRAHA-I had a limited time scope and compressor manufacturers were asked to cut the development time down to a few weeks.

Partecipants at the HC-290 International Workshop in Ningbo - China, <april 2017.

PRAHA-I LESSONS LEARNED

The experience of working on PRAHA-I gave UN Environment and UNIDO the confidence that international stakeholders support the goals of the project and that the outcome will be beneficial to all beyond economic gains. On the other hand, and simultaneous to the efforts by the PRAHA project to create awareness about HAT challenges and the work done through the different symposia held in the HAT countries that were participating in the PRAHA project, the HAT countries themselves were bringing up the issues at the different meetings of the Parties whether at the Open-Ended Working Group (OEWG) meetings or the Meeting of the Parties (MOP).
The lessons from PRAHA-I on cooperation were used when developing the different elements of PRAHA-II. These are:

- Industry associations in the technology exporting countries play a pivotal role in the process. Associations are the voice of the industry in their respective countries, they facilitate con-

R447B Leak Test Summary Results

System			*Liquid Line Leak*		*Vapor Line Leak*	
		Full Charge	Low Charge	Re-Charged	Low Charge	Re-Charged
Refrigerant	-	R-447B	R-447B	R-447B	R-447B	R-447B
Charge	lbs.	6.625	4.27	6.625	4.23	6.77
Cooling Capacity	BTU/hr	31,073	14,216	30,865	15,171	30,587
Energy Balance	%	4.21%	-34.72%	0.35%	-31.55%	1.87%
Compressor Power	kW	3.18	2.93	3.18	2.94	*
Fan Power	kW	0.95	0.98	0.98	0.98	0.98
Total Power	kW	4.13	3.90	4.16	3.92	*
EER	BTU/hr. W	7.52	3.64	7.42	3.87	*

*Compressor power consumption was not properly recorded for this test; the error was identified after the fact and the team was unable to retrieve that information.

tact and give confidence to their members when working with foreign entities;

- HAT countries outside the six countries from West Asia that are partners on the PRAHA project have a vested interest in the results and the learning process. They are keen on joining when given the chance.

These key leaning points guided the process for the different elements of PRAHA-II. The project in its second phase enlarged its scope of cooperation and inclusion which led to excellent results.

BUILDING THE PARTNERSHIPS WITH REFRIGERATION ASSOCIATIONS

UN agencies are no strangers to international cooperation in its different forms especially on technical matters. These agencies foster cooperation with experts and form committees to tap into the expertise that is available worldwide.

Cooperation on the Montreal Protocol between UN agencies and refrigeration industry and relevant engineering associations increased notably over current decade leading to providing state-of-art technological services to the Montreal Protocol Article 5 parties.

One of the main partners that PRAHA process had is AHRI (Air Conditioning, Heating, and Refrigeration Institute). The Technical Research arm of AHRI is known as AHRTI. PRAHA-I partnered with AHRI to provide insight on the prototype testing procedures by providing guidance and lessons learned from AHRI's own AREP (Alternative Refrigerant Evaluation Program) refrigerant testing project.

PRAHA-II partnered with AHRTI on the prototype optimization element of the project. AHRTI provided valuable support to that element of the PRAHA-II project by overseeing and coordinating the work done by the contractor. AHRTI formed a committee of AHRI members who provided their added expertise to the work process.

The other major association PRAHA partner is JRAIA (Japan Refrigeration and Air Conditioning Industry Association). JRAIA is the main partner on the risk assessment element of PRAHA-II helping experts from the HAT region to build a risk assessment model suitable for the region.

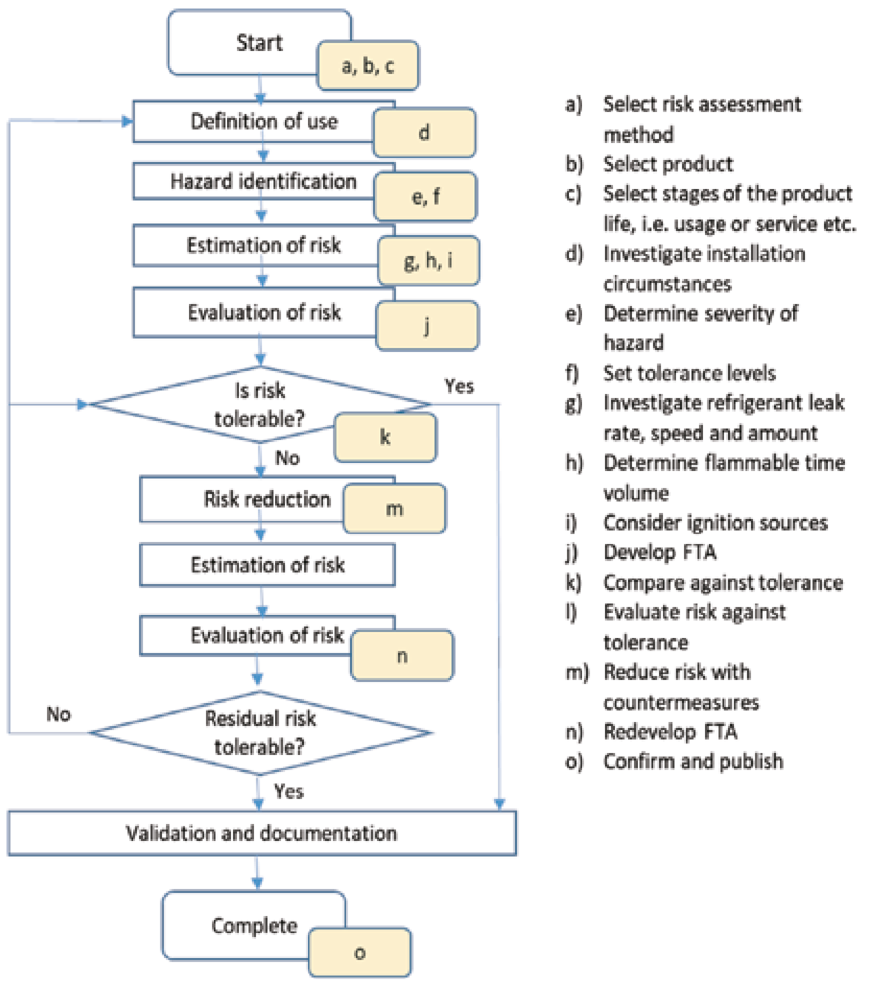
They worked with PRAHA team since the beginning, In PRAHA-I they offered technical support to train and orient local manufacturers about A2L related technologies with focus on HFC-32. In PRAHA-II, they are co-leading the component of building Risk Assessment Model for the use of flammable refrigerants. Their support included cooperating in the program of one international workshop and co-organizing two technical meetings (Kuwait & Egypt) as well as one site visit to research labs (Japan).

Other partners also joined the process of providing information and technical assistance in presenting issues, related to analyzing and mitigating risks of flammable refrigerants, namely UL (Underwriters Laboratory) Navigant consultancy, AHRI and ASHRAE.

PRAHA partnered with ASHRAE and AHRI for the organization of all the HAT symposia held in the West Asia region since 2011 where 5 rounds of the international symposium were organized successfully. moreover, and as part of the capacity building activities of PRAHA-II, stakeholders were invited to attend a refrigerant course given by ASHRAE. PRAHA consultants and project managers also used the ASHRAE annual meetings, over years, to update on the project through dedicated sessions.

CHEAA (China Household Electrical Appliances Association) partnered with PRAHA on the HC-290 technology helping in arranging study tours of the production facilities and showcasing major projects with safe HC-290 installations. The study tour which was held in 2017 included a workshop in Ningbo on “Designing and Risk Assessment with HC-290 Refrigerant”. The workshop discussed the key points on safety for Class A3 refrigerants to which HC-290 belongs and risk assessment during installation and maintenance. The workshop was enlarged at the request of CHEAA and the Chinese Ozone Office to include participants from the fire and safety departments and experts from research institutes.

Fault Tree Analysis (FTA) for Reterative Process



PARTNERING WITH PARTIES TO THE MONTREAL PROTOCOL

The Parties (countries) are the beneficiaries of the PRAHA project; moreover, they were also actively involved in the organization of events that took place in the region. Kuwait Environment Public Authority (KEPA) and the United Arab Emirates Standardization and Metrology Authority (ESMA) were major organizers of the HAT Symposia in Kuwait City and Dubai. Kuwait also helped organize the risk assessment roundtable in 2017. The roundtable coincided with Kuwait’s celebrations of the 30th anniversary of the Montreal Protocol and special events were held in parallel to the meeting to commemorate that anniversary.

Organized by: UN environment, UNIDO, 30 Montreal Protocol caring for all life under the sun

In Cooperation with: AHRI, JRAIA

Partners at the Kuwait Roundtable Meeting – October 2017

The partnering with Parties went further when several countries not originally involved in PRAHA asked to be included in the capacity building process. Tunisia and Vietnam sent representatives to the workshop in Ningbo, China. Algeria joined a previous study tour organized under PRAHA-I.

The EGYPRA project (Promotion of Low-GWP Refrigerants for the Air Conditioning Industry in Egypt) stakeholders joined study tours to both Japan and China under PRAHA-II capacity building element of the project. In parallel, Egypt became a full partner on the risk assessment element with experts joining the PRAHA-II team that is building the risk assessment model; as a matter of fact, the second risk assessment meeting was held in Cairo, Egypt as mentioned earlier.

PRAHA-II MAIN FINDINGS

PRAHA-II delivered tangible and beneficial results which can be summarized as follows:

Capacity Building: The capacity building element was successful in providing a platform of cooperation between governments, research institutes, industry associations, and the industry in general and became a process for the sharing of information and results among the different stakeholders. The experience of working on PRAHA-I gave UN Environment and UNIDO the confidence that international stakeholders support the goals of the project and that the outcome will be beneficial to all and beyond economic gains.

Design Optimization: The original scope and schedule were modified during the project as new findings and challenges surfaced. The original baseline test data was used for comparison with tests done on the optimized units built according to the modeling work done even though the latter tests included measurements and metrics not typically performed in energy certification tests of the type done under PRAHA-I (see below figure for system design framework). A resume of the conclusions:

- For systems operating in considerably higher temperatures (greater than 46 °C), the resultant impact on performance must be considered since performance will degrade as compared to operating under more temperate conditions.
- The design assessment through modeling provided good insights on adequate component design and/or selection for proper system functioning when using novel refrigerants;
  - o Rebuilt and tested units exhibited a considerable reduction in power consumption at the high ambient test condition (46 °C) as compared to the original test data. This indicates the importance of proper compressor selection.
- Because of the differences in saturation curves from the simulation analysis, refrigerant with wider saturation curves tend to result in systems with higher efficiency and less charge when no modifications to the hardware are made. The results showed however, that by making appropriate component selection, such as compressors with larger displacement volumes and higher mass flow rate, the cooling capacities and overall performance of the other refrigerants were of the same order of magnitude.
- Refrigerant fractionation as evidenced by the leak tests, does not appear to be a great concern since less than 2% change in cooling capacity was observed after the system's re-charge. Below table shows leak test summary for R-447B which exhibits the highest glide amongst the refrigerants evaluated under the project.

Risk Assessment: The work on risk assessment required resources beyond the traditional RACHP expertise that is required for the balance of the project. The different usage and servicing practices used in the region needed to be considered in order to assess the risk of using flammable refrigerants. The initial concern about the effect of high ambient temperature on the increased risk of ignition was removed and the focus is on actual practices.

The recommendation is for HAT countries to continue the risk assessment based on analyzing local situations and reduce the risk by implementing various measures that are verified such as minimizing ignition probability and advancing local codes/standards.

THE WAY FORWARD

In general, PRAHA-II outcomes will be of benefit to all 35 countries defined by the Montreal Protocol Parties at the OEWG-37, 2016 as "High Ambient Temperature Countries". A HAT symposium scheduled for March 2020 will convey these results to representatives from those countries. UN Environment and UNIDO intend to transform the PRAHA initiative into a live process with continuous feedback and support to HAT countries.

Experimental Investigation on the Effect of Refrigerant Charge and Capillary Tube on the performance of R290 Household Air Conditioners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Nomenclature

COP	Coefficient of performance
HCFC	Hydrochlorofluorocarbon
ODP	Ozone depletion potential
GWP	Global warming potential
HFC	Hydrochlorofluocarbon
HC	Hydrocarbon
M	Mass of refrigerant, (kg)
ρ	Liquid propane density, $kg \cdot m^{-3}$
V	Volume, m^3
Subscripts	
ref	Reference refrigerant charge
con	Condenser
evap	Evaporator

ABSTRACT

R290 is an excellent ecofriendly alternative option in household air conditioners. But its flammability and explosibility severely restricts its application.
This paper presents an experimental investigation on the effect of refrigerant charge and capillary tube on the performance of an R290 split type household air conditioner.
Newly designed condenser and evaporator are proposed to not only enhance the system performance but also to reduce the system internal volume, in such a manner that the propane charge is far less than the limitation required by IEC 60335-2-40. Particularly, heat exchange copper tubes of 5 mm in diameter are employed in both condenser and evaporator for the first time. The effect of propane charge amount, capillary tube and indoor air volume flow rate on the coefficient of performance (COP) is evaluated.
Extensive tests have been performed under the ISO 5151: 2017 standard capacity rating test condition in a psychrometric room (outdoor conditions: 35 °C dry bulb and 24 °C wet bulb; indoor conditions: 27 °C dry bulb and 19 °C wet bulb).
By using the combination of propane charge amount of 260 g and capillary tube specification ∅ 1.4x500 mm, the COP of 3.66 together with a cooling capacity of 2801 W for the current air conditioner can be obtained. The present work is beneficial for the improvement of security and efficiency of R290 air conditioners.

Key words R290; Air conditioner; COP; Charge amount; Capillary tube.

1. INTRODUCTION

In the past decades, conventional hydrochlorofluorocarbons (HCFCs) refrigerants have been universally used in household applications because of their excellent thermal and physical properties [1-4].
However, the HCFCs are typically characterized as high ozone depletion potential (ODP) and global warming potential (GWP). For this reason, the Montreal and Kyoto protocols strictly limit the use of HCFCs in the field of refrigeration and air conditioning systems [5].
For the present widely used hydrochlorofluocarbon (HFC) refrigerants such as R410A (GWP=2090) and R32 (GWP=675), such high GWP alternatives are assumed to exacerbate the global warming effect [6-8]. Hence, the Kigali Amendment to the Montreal Protocol in 2016 announced the phasing down progress of the HFCs [9]. By now, lots of investigations concerning drop-in replacements have been emerged and increasingly more attentions have been focused on the development of new refrigerants using hydrocarbons (HCs) or hydrocarbon mixtures due to the severe climate change effects faced by the humankind [10].
Assessment of a new refrigerant should be implemented from the aspect of environmental impact and system performance. Propane (R290) is an outstanding and high-profile alternative refrigerant which offers desirable environmental requirements such as not only zero ODP but also a negligible GWP [11-14]. Furthermore, R290 has the advantage of low cost, excellent thermophysical properties and good compatibility with both mineral and synthetic oils. However, as R290 is highly flammable and explo-

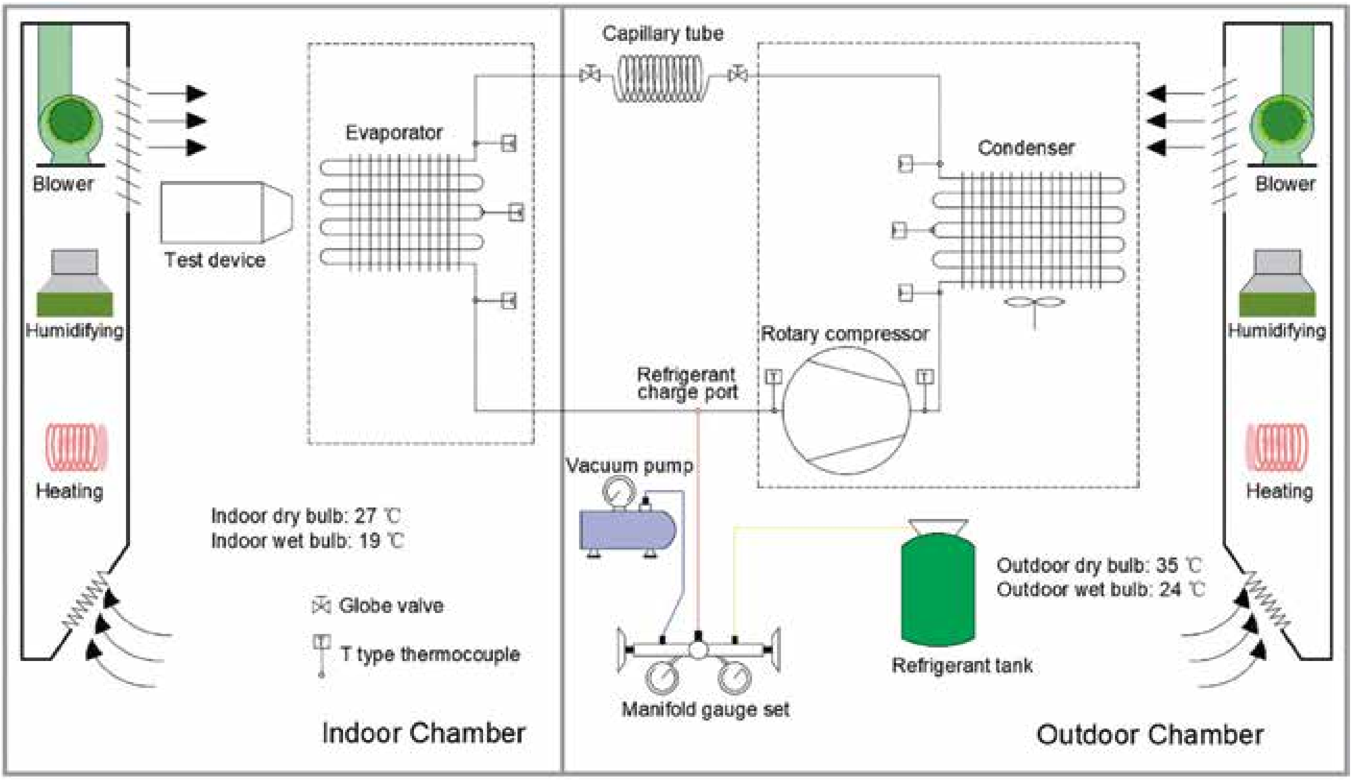

Figure 1. *Schematic diagram of the experimental set-up.*

sive, the safety issue is always accompanied with its application. As per ISO 5149-1: 2014, R290 is classified as a kind of A3 refrigerant, the explosion concentration of which is from 2.1% (lower flammable limit) to 9.5% (upper flammable limit) by volume. The application and maximum charge amount of R290 are severely restricted according to EN 378 and IEC 60335-2-40 [15]. No doubt that the air conditioner unit will be much safer for a smaller propane charge. Hence, much emphasis has been placed on the reduction of propane charge in household appliances [16-20]. After all, safety takes the highest priority for all concerned.

Devotta et al. [21] evaluated the performance of R290 as a drop-in substitute to R22 in a window air conditioner. In comparison with R22, it was found that the cooling capacity of R290 is lower whereas the COP of R290 is higher. In an effort to reduce the refrigerant charge amount, Gao et al. [22] compared the effect of different types of R290 rotary compressors on room air conditioner system and refrigerant charge amount. They concluded that reducing the refrigerant contained in compressor can improve the circular refrigerant amount and thus to enhance the system performance and safety. Recently, Padalkar et al. [23] simulated and analyzed the performance of R290 in a split air conditioner for different system component operating conditions.

The results revealed that the R290 system requires smaller channel condenser and more energy efficient compressor. Ghoubali et al. [24] discussed the possibilities of charge reduction for a R290 heat pump water heater. It was found that the refrigerant charge might be reduced to an extremely low level mainly by selecting condensers with high thermal efficiency and low internal volume. Instead of condenser, Jin et al. [25] studied the performance of R290 fin-tube evaporator with small tube diameter. The simulated results indicated that the heat transfer efficiency of the R290 heat exchanger is better when the tube diameter is reduced from 7 mm to 5 mm. Tang et al. [26] experimentally measured the performance of R290 in a 13 kW air source heat pump. They found that the diameter of the tube of air-to-refrigerant heat exchanger could be reduced and the high efficiency plate-type heat exchanger could be employed so as to reduce the refrigerant charge amount. More recently, Zhou and Gan [1] proposed a potential approach for reducing the propane charge required in air conditioners by introducing micro bare-tube heat exchangers as the condenser and evaporator. For the optimal refrigerant charge of 248 g, the system coefficient of performance could reach 3.40 with a cooling capacity of 3645 W. From the literature review above, it can be observed that few research has been focused on developing an air conditioning system which has a high COP and also a low propane charge.

The main objective of this paper is to present an experimental investigation concerning the effect of refrigerant charge and capillary tube on the performance of an R290 air conditioner. Great emphasis is placed on achieving a maximum COP and a lower propane charge for the desired cooling capacity. Both the condenser and evaporator are specially designed to not only enhance the system performance but also to reduce the internal volume. In particular, heat exchange copper tubes of 5 mm in diameter have been employed in both condenser and evaporator for the first time. Various combinations of capillary tube and refrigerant charge amount have been tested in a psychrometric room under the standard capacity rating condition.

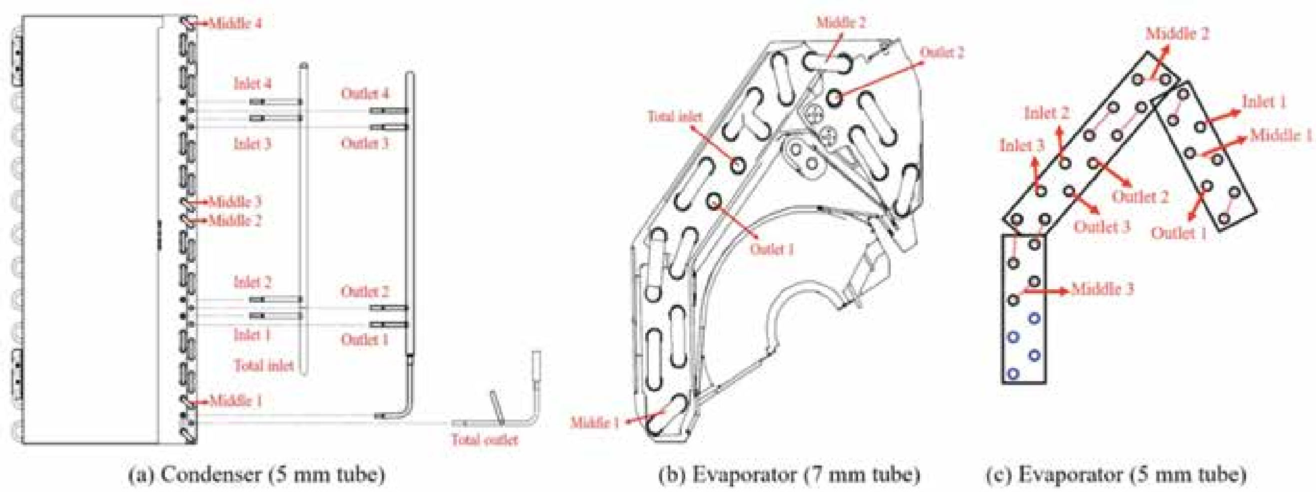

Figure 2. *Schematic diagram of the flow paths in each heat exchanger.*

The influence of capillary tube, refrigerant charge amount as well as the indoor air volume flow rate on system performance is discussed in detail. This work could provide valuable information and guidance for improving the performance of a household air conditioner and promote the future use of R290 as an alternative.

2. EXPERIMENT DESCRIPTION

2.1 Test apparatus

Figure 1 shows the schematic diagram of the experimental set-up. As can be seen, the air conditioner is tested in a psychrometric laboratory consisting of an indoor chamber and an outdoor chamber, each of which has a wind tunnel inside. The wind tunnels are used to regulate air flow rates and perform the measurements of inlet and outlet air dry bulb and wet bulb temperatures.

The ambient conditions are controlled by the environmental control system which is composed by air conditioning units, electrical and humidity control equipment. The R290 split type household air conditioner consists essentially of a rotary compressor, an evaporator, an air cooled condenser and a capillary tube. These components are connected by pipelines in which the propane circulates.

A commercial R290 rotary compressor with displacement of 17.0 ml/rev is used as the pressure generator. The rated evaporating temperature and condensing temperature of the compressor is 7.2 °C and 54.4 °C, respectively. The rated COP of the compressor is 3.35 with an input power of 777 W (at 220 V). For the tested air conditioner, the nominal cooling capacity is 2637 W. All the tests have been performed as per the ISO-5151: 2017 standard capacity rating test conditions. During experiment, the ambient conditions are maintained stable by the environmental control system which incorporates refrigerating machines, electrical heaters and humidifiers.

The main aim of the experiment is to identify the optimal combination of capillary tube geometry and refrigerant charge. In an effort to improve the system performance and lower the refrigerant charge, extensive tests have been conducted by varying refrigerant charge and specifications of the capillary tube. For the sake of recording temperatures simultaneously using data acquisition, a series of T-type thermocouples with an accuracy of ±0.1 °C are pasted on the copper tubes at different locations, including the inlet and outlet of the compressor, the inlet, outlet and middle of the pipe paths of the condenser and evaporator units, as illustrated in Figure 1. In experiment, constant cooling load is imposed for the air conditioner unit. The condenser is located in the outdoor chamber which is maintained at 35 °C dry bulb temperature and 24 °C wet bulb temperature. The evaporator is put in the indoor chamber which is maintained at 27 °C dry bulb temperature and 19 °C wet bulb temperature. Four platinum resistances (PT-100) are employed to measure the dry bulb and wet bulb temperatures respectively, with an accuracy of ±0.1 °C. The indoor air volume flow rate is measured through an air flow passage, in which a set of nozzles are installed.

2.2 Test procedures

The split type air conditioner selected for test is equipped with instrumentation at appropriate locations. The temperatures and relative humidity in the psychrometric room are monitored and recorded during the test to prevail the experimental conditions. Initially the whole system is evacuated by vacuum pump to less than 10 Pa. Then the predetermined amount of propane gas is charged into the circuit. With reference to Figure 1, the detailed schematic of charging device is plotted. Although the propane distributes in each refrigeration unit and pipelines throughout the system, the majority of it exists in the condenser and evaporator in a liquid state. According to the empirical correlation provided by Tian et al. [27], a rough estimated refrigerant charge amount can be calculated by:

$$M_{ref} = \frac{2}{3}\rho_{con} V_{con} + \frac{1}{3}\rho_{evap} V_{evap} \quad (1)$$

where ρ_{con} and V_{evap} are the liquid refrigerant density in the condenser and evaporator, respectively. V_{con} and V_{evap} represents the condenser volume and the evaporator volume, respectively. During the charging process, the

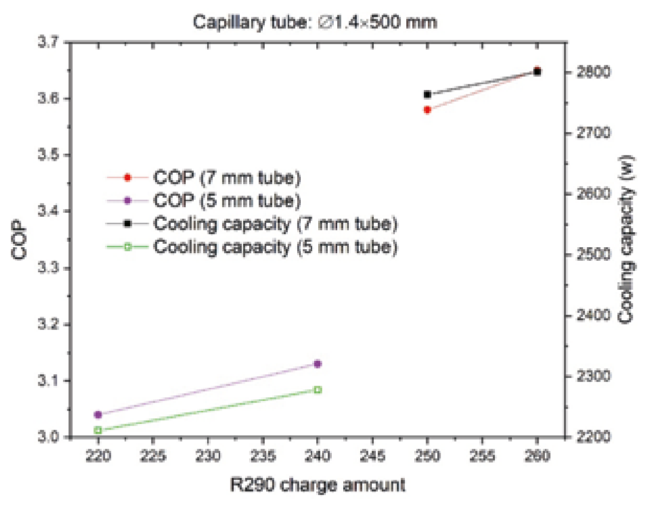

Figure 3. *Performance comparison between evaporator with 7 mm tubes and that with 5 mm tubes.*

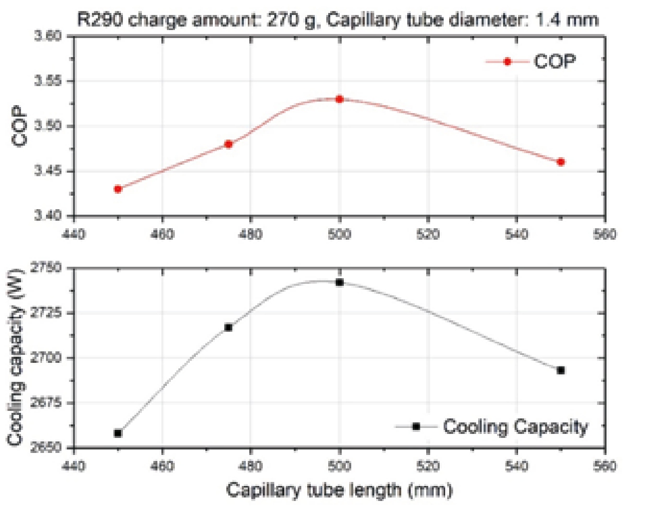

Figure 4. *The variation of COP with respect to capillary tube length for propane charge of 270 g.*

charge amount is ensured with the help of precision electronic balance having an accuracy of ±1 g. The propane charge amount strictly follows the regulations of EN378-1: 2016 in each group of test.
Two globe valves are attached to both ends of the capillary tube, whenever the length of the capillary tube needs to be adjusted, these valves are closed and the capillary tube is replaced during the compressor off time. On the contrary, in the undercharged case, the propane charge is increased as the test is going on. Unfortunately, if the refrigerant is overcharged, then the system should be evacuated again and the charging process needs to start all over. In experiment, the refrigerating temperature is set at 16 °C. Note that all precautions have been taken while charging and testing the unit with R290.

2.3 Optimized condenser and evaporator

Propane is a promising alternative refrigerant in domestic air conditioners. However, due to safety concern, the use of propane requires further improvements in design and optimization of components to reduce the refrigerant charge. One potential way is to reduce the diameter of copper pipes used in heat exchangers.
The small diameter pipes can not only make the heat exchangers more compact, but also make for the reduction of internal volume and thus help to reduce the amount of refrigerant charge. As long as the safety risk is cut down and well controlled, R290 which is flammable but environmentally friendly can be widely put to use. Compared with R22, the saturated liquid density of R290 is lower, but the heat transfer coefficient is higher due to its larger latent heat.
The larger heat capacity allows the liquid propane to be capable of absorbing much more heat from the surroundings under the identical working conditions. Such thermodynamic properties make it possible to use small diameter heat exchanger tubes to reduce the propane charge amount. Another aspect, the smaller diameter tends to bring about a higher pressure drop inside the tube, which can be compensated by reducing the refrigerant circulating velocity through increasing the number of tubes.
The heat exchanger design is of paramount importance to improving the system efficiency in an air conditioner. Indeed, from the view point of heat transfer, the heat exchangers should first meet the requirement of condensation load and cooling load. Normally, the larger-diameter heat exchanger has a larger heat-transfer area such that it allows a greater amount of energy transfer.
However, the tube column number is limited by the heat exchanger size. To make matters worse, a large outer diameter implies a large void volume, which indicates that the required propane charge will also be greater. In this work, both the condenser and the evaporator are newly designed and optimized to achieve a higher system performance as well as a lower propane charge.
For the considered air conditioner, the condenser and the evaporator are of finned type. By selecting condensers with high thermal efficiency and low internal volume, the refrigerant charge can be reduced to extremely low levels [24]. Different from conventional heat exchanger tubes with outer diameter of 7 mm, the internal thread copper tubes of 5 mm in diameter are used. Figure 2 displays the schematic diagram of the flow paths in each heat exchanger. As can be seen from Fig.ure 2(a), the refrigerant flow is dispensed into four branches in the condenser. Unlike the condenser, the evaporator with copper tubes of 7 mm in diameter and that with copper tubes of 5 mm in diameter are taken into consideration.
The 7 mm copper tube is able to achieve to a larger heat transfer area for a limited size, which is definitely beneficial to the improvement of system performance. As shown in Figure 2(b), The evaporator incorporates two flow paths. For each flow path, there exists 7 U-tubes. Figure 2(c) shows the evaporator with copper tubes of 5 mm in diameter, in which the refrigerant flow is dispensed into three branches and each path has 4 U-tubes. Basically, an equal number of pipes in each flow path is satisfied to

avoid problems such as uneven distribution of the refrigerant.

3. RESULTS AND DISCUSSION

3.1 Performance comparison between evaporator with 7 mm tubes and that with 5 mm tubes

In comparison with the 7 mm tube evaporator, even though the 5 mm tube evaporator allows a further reduction of internal volume and thus contributes to a lower propane charge, whether the system performance could be satisfactory still needs to be explored. Concerning the two type evaporators, several tests have been implemented with capillary tube ∅1.4x500 mm. The system COP and the cooling capacity with respect to different propane charge amounts are summarized in Figure 3. A prerequisite for optimizing the heat exchangers is to ensure the system performance. However, it can be seen from Figure 3 that the propane charge amount is reduced at the cost of the COP and the cooling capacity. When the 5 mm tube evaporator is tested, the propane charge amount is cut down by 4% from 250 g whereas the COP and the cooling capacity falls by 12.57% and 17.58%, respectively.

By comparison, one can see that the air conditioner system shows a sharp decrease in COP and cooling capacity despite a small reduction of propane charge when the 5 mm tube evaporator is put to use, which indicates that the 7 mm evaporator performs much better than the 5 mm evaporator under such circumstances. Therefore, it makes no sense to continue selecting the 5 mm tube evaporator in the current work. Note that the data shown in later chapters are obtained by using the 7 mm tube evaporator.

3.2 The effect of capillary tube length on COP

Expansion device acts as one of the most important factors affecting the system capacity and performance. It is critical and vital to select an appropriate capillary tube which is compatible with the variations of the propane charge. On the basis of Eq. (1), the estimated refrigerant charge for the current air conditioner is about 270 g. This is just a reference value during the initial charging process, which is not necessarily the optimal charge amount indeed.

For the purpose of assessing the effect of capillary tube length on COP, several tests have been performed in the case of different capillary tube lengths, as shown in Figure 4. One can see that the COP presents a clear maximum value with a propane charge of 270 g for the capillary tube ∅1.4x500 mm.

More concretely, the COP gradually goes up as the capillary tube length increases from 450 mm to 500 mm. However, the COP tends to fall down with an augment in the tube length when the capillary tube is longer than 500 mm, indicating that the COP is not simply correlated with the capillary tube length. In general, there exists an optimal capillary tube specification for obtaining the best COP on the condition of a specified propane charge.

In terms of the cooling capacity, it can be found that the growing trend of the cooling capacity with the capillary tube length is well consistent with that of the COP. The system COP and cooling capacity of R290 are observed to have peak values under the same conditions. For various capillary tube lengths, the cooling capacity also achieves the maximum value when the capillary tube length is as long as 500 mm. In other words, the COP and the cooling capacity can be enhanced simultaneously.

3.3 The effect of refrigerant charge amount on COP

An inappropriate refrigerant charge amount may adversely affect the system performance. For this reason, intense efforts have been made to seek out the optimal charge amount for the tested air conditioner. For capillary tube ∅1.4x500 mm, the variation of COP with respect to R290 charge amount is shown in Figure 5. As can be seen, the system COP and cooling capacity increase with the propane charge until reaching a maximum point after which it decreases slightly. Specifically, the COP increases with an increase in propane charge initially. Later, the COP begins to decline gradually when the R290 charge amount is increased from 260 g to 270 g. After this point (270 g), if the refrigerant charge continues to increase, the COP increases slightly but still remains lower than that for propane charge amount of 260 g.

The results reveal that the split type air conditioner system is very sensitive to the propane charge, especially when the charge is insufficient. Hence, refrigerant charge must be more precisely controlled in the R290 system to achieve better refrigerating performance. It is evident that there exists an optimal propane charge for the best COP since the compressor work increases with the refrigerant charge amount. However, from the perspective of safety, it is suggested that a propane charge of 250 g is better for the current capillary specification. After all, on the condition of a sufficient cooling capacity, the smaller the propane charge amount, the better.

Not also from Figure 5, one can see that the cooling capacity shows similar growing trend with the COP for various R290 charge amount. The cooling capacity achieves the maximum value for a 250 g R290 charge amount. When the propane continues to be charged into the system by 10 g, the cooling capacity shows an obvious decreasing behavior. This is because the evaporator can hardly satisfy the requirement of heat transfer when the refrigerant is overcharged. A deficit or an excess of charge degrades the COP of the system, and it seems that a deficit has greater impact.

3.4 The conjoint effect of refrigerant charge and capillary tube on COP

A reasonable match between capillary tube and propane charge is of crucial importance to an R290 air conditioner. In fact, the capillary tube geometry and the optimal charge amount are coupled parameters, rather than independent parameters.

Both the propane charge and capillary tube have substantial effects on the cooling capacity and system performance. The objective of the present work is to find the finest combination of capillary specification and refrigerant charge to optimize the air conditioning performance.

It has been recognized that the COP is not associated with one specific

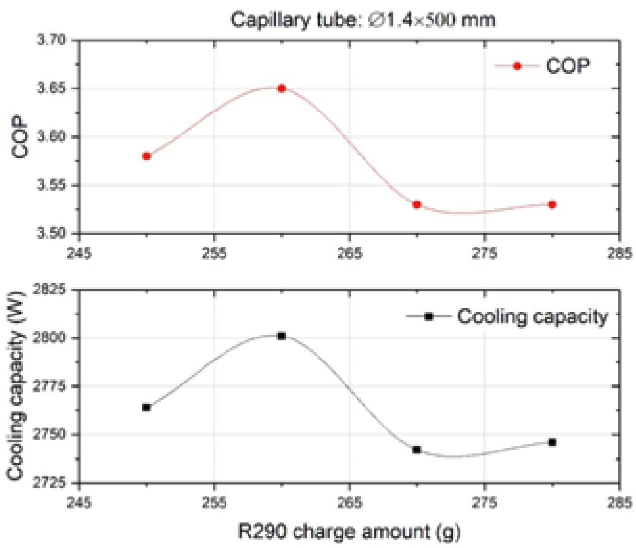

Figure 5. *The variation of COP against R290 charge amount for capillary tube ∅1.4x500 mm.*

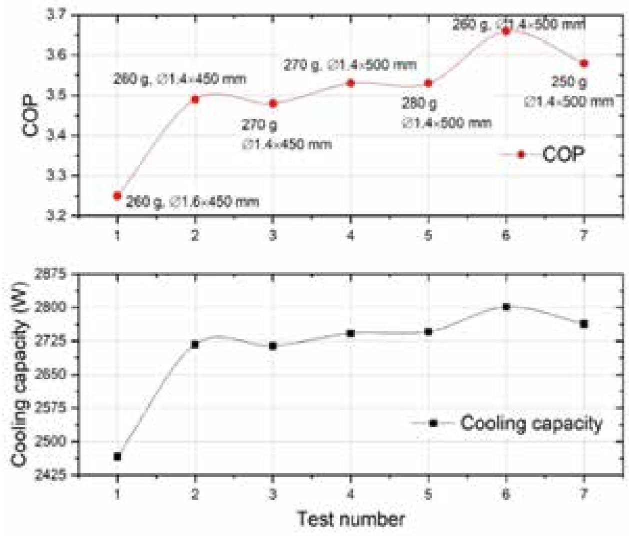

Figure 6. *The conjoint effect of propane charge and capillary tube on system performance.*

variable. Instead, the COP is related to almost every refrigeration unit of the system. Here, the conjoint effect of refrigerant charge and capillary tube on COP is investigated in detail, as presented in Figure 6.

Based on the estimated propane charge amount and engineering experience, the first test is performed on the condition of propane charge 260 g and capillary tube specification ∅1.6x450 mm. It can be seen that the COP is only 3.25, which is much lower than expected.

Subsequently, the capillary tube is changed to ∅1.4x450 mm to enhance the throttling effect. One can see that the COP is increased by almost 7.4%, together with an obvious augment in cooling capacity. Moreover, the suction temperature is increased to 13.85 °C. For the purpose of further improving the COP, more efforts have been made by adding more propane into the system or increasing the capillary tube length. However, the COP is just marginally increased from test 2 to test 5, the same as the cooling capacity, showing inconspicuous variations. In such a situation, it is considered to charge less propane into the system. As can be seen, when the refrigerant charge amount is reduced from 280 g to 260 g, with an interval of 10 g, the COP first increases to 3.66 and then falls down to 3.58, still higher than that of the previous cases. From the perspective of achieving a higher COP, the optimal combination of propane charge and capillary tube for the current air conditioner is 260 g and ∅1.4x500 mm, respectively. On the assumption of a mounting height of 2.2 m and room area of 12 m^2, this propane charge amount is 18.75% lower than the allowable maximum charge as per IEC 60335-2-40.

3.5 The effect of indoor air volume flow rate on COP

The indoor air volume flow rate has a paramount influence on COP because it is directly related to the heat transfer efficiency of evaporator. On one hand, the liquid refrigerant in evaporator will not be fully evaporated due to a shortage of air volume. One the other hand, excessive air volume means much more power consumption and louder noise, which is definitely detrimental for the improvement of COP and user experience. To find an optimal indoor volume air flow rate is essential to achieve a higher COP and better user experience.

The effect of indoor air volume flow rate on air conditioner is illustrated in Figure 7. As can be seen, the system COP increases with an increase in indoor air volume flow rate when the air volume flow rate is less than 631 $m^3 \cdot h^{-1}$, along with the cooling capacity. Even though the heat transfer is enhanced at the cost of more power consumption, the COP still goes up for the reason that the increase of heat exchange is more pronounced than that of power consumption.

Another aspect, the growth rate of COP with the air volume flow rate gradually declines, different from that of the power consumption. And when the air volume flow rate is up to 693 $m^3 \cdot h^{-1}$, on the contrary, the COP starts to decrease slightly. For a small indoor air volume flow rate, it is possible that the heat transfer area of the evaporator cannot be utilized to the fullest. As a result, the cooling capacity drops and there is high chance that the refrigerant returns with liquid, which can seriously deteriorate system the performance and reliability.

With respect to the outlet air temperature, one can see that the outlet air temperature increases with the indoor air volume flow rate. Basically, the outlet air temperature reflects the extent to which the air can be cooled through the evaporator. Since the potential cooling capacity of the system is determined, a large air volume flow rate produces a relatively high outlet air temperature in general.

4. CONCLUSIONS

Energy conservation and consideration of safety issues are of great importance for an R290 domestic air conditioner. This paper discusses the use of R290 as a safe and energy ef-

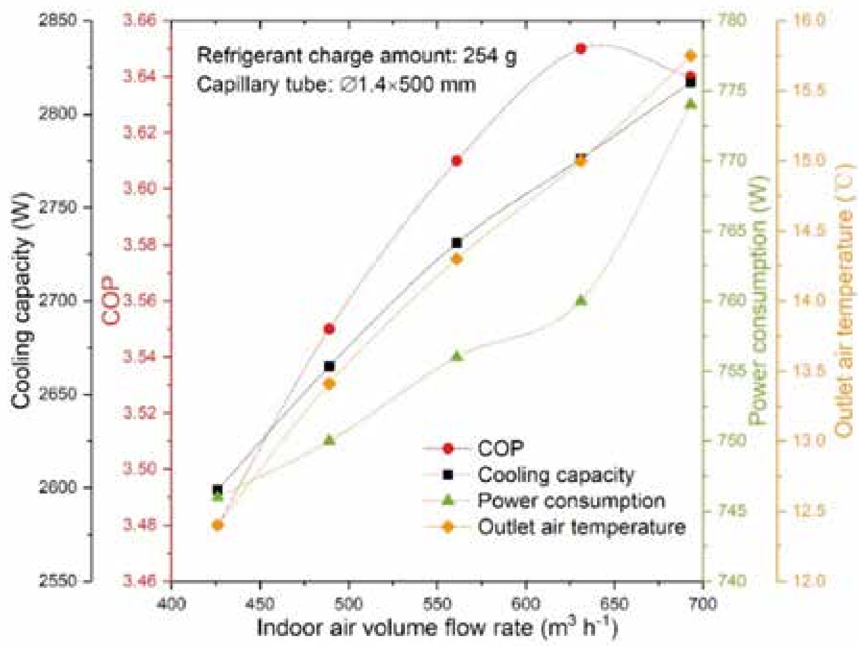

Figure 7. *Experimental results for various indoor air volume flow rates.*

ficient alternative refrigerant in a typical split type air conditioner with nominal cooling capacity of 2637 W. Newly designed heat exchangers are proposed to reduce the R290 charge amount and enhance the system performance. The effect of capillary tube, propane charge amount as well as the indoor air volume flow rate on COP has been explored in detail. The results of this research could be beneficial for the promotion and application of R290 as an environmentally friendly substitute in the near future. The main conclusions are drawn as follows:

(1) The use of 5 mm diameter copper tubes in condenser could be an effective approach to reducing the propane charge in a split type household air conditioner. In addition, the 7 mm tube evaporator performs much better than the 5 mm tube evaporator in COP and cooling capacity despite a small increase in propane charge.

(2) For R290 as working fluid, the dispersion flow mode in heat exchangers helps to make full use of the heat exchange area and improve the heat transfer efficiency.

(3) For a specific propane charge, the maximum system COP can be achieved by using an appropriate capillary tube. While for a specific capillary tube, the COP could also be optimized by charging a proper amount of propane.

(4) In general, there exists an optimal combination of capillary tube and refrigerant charge amount for air conditioners. For the current combination of refrigerant charge amount 260 g and capillary tube ∅1.4x500 mm, the COP is as high as 3.66 and the cooling capacity is up to 2801 W.

(5) The system COP shows an increasing behavior as the indoor air volume flow rate increases. However, when the air volume flow rate is high enough, the COP is no longer increased or even reduced with an increase in air volume flow rate.

Acknowledgement

The authors acknowledge the Haier Group for supporting the research project.

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Refrigerant Driving License (RDL); The Journey of Creating a Global Program to benchmark refrigerant best practices

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FORWARD

Born out of the necessity for a responsible transition to next generation refrigerants, the Refrigerant Driving License (RDL) is a comprehensive refrigerant management qualification program jointly developed by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and United Nations Environment Programme – OzonAction and supported by key international industry associations. The RDL sets minimum competencies and skills for the HVAC&R (Heating, Ventilating, Air Conditioning and refrigeration) servicing network (individuals and companies) and creates an international recognition program through industry and governments.

The program will be an important tool for technician training, education, and benchmarking of essential competencies and skills required for the proper and safe handling of refrigerants, which will support the completion of the phase-out of HCFCs and smooth the start of the HFC phase-down in Article 5 countries, as stipulated in the Kigali Amendment of the Montreal Protocol.

The initiative was launched as a concept by UNEP and AHRI at the 37th OEWG meeting in July 2015. Since then, AHRI and UNEP have promoted the RDL amongst key HVAC&R associations while holding meetings in the margins of relevant industry events. Consequently, an RDL Advisory Committee was established consisting of key industry associations that support the RDL including ABRAVA, ACAIRE, AREA, AREMA, EPEE, JRAIA, the Alliance for Responsible Atmospheric Policy, and ASHRAE[1]. The Advisory Committee serves as the technical and review body for RDL to ensure that suggested deliverables do not conflict with any existing certification scheme in any country or region, evaluate the work at different stages of the initiative and recommend and/or promote regions/countries to pilot RDL.

RDL CATEGORIES & COMPETENCIES

Definitions of RDL categories were discussed and agreed by RDL Advisory Committee as follows:

- **Category (A) Small Applications**: Air conditioners and heat pumps with less than a 20kW/65kBtu/h cooling capacity and, Refrigeration equipment with less that a 6kW/20kBtu/h cooling capacity. (Examples: Packaged AC, ductless mini-split AC, multi-capacity AC, heat pumps, refrigerators, dehumidifiers, display

[1] ABRAVA: Brazilian trade association that represents refrigeration, air conditioning, ventilation, heating, and air treatment equipment manufacturers, ACAIRE: Colombian air conditioning and refrigeration association that represents business, institutes, professional members, technicians, correspondents, and students in the industry, AREA: Air conditioning and Refrigeration European Association, AREMA: Air conditioning and Refrigeration Equipment Manufacturers Association of Australia, ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers, EPEE: European Partnership for Energy and the Environment & JRAIA: Japan Refrigeration and Air Conditioning Industry Association.

Table 1. **RDL Competencies**			
Competency Requirements	(A) Small Applications	(B) Commercial Refrigeration	(C) Commercial Air-Conditioning
Basic Knowledge (Environment, Refrigerants classifications/types, applications and relevant policies)	X	X	X
Handling, transportation, storage and management of refrigerants' containers	X	X	X
Servicing skills of leak detection, R&R, evacuation, charging and system tightness	X	X	X
Logging and Record Keeping	X	X	X
Tools and equipment for the job	X	X	X

cases, coolers and other unitary and hybrid equipment).

- **Category (B) Commercial Refrigeration**: Commercial refrigeration equipment with greater than a 6kW/20k Btu/h cooling capacity. (Examples: Storage and display refrigerators, freezers, commercial unit coolers, condensers, chillers, heat exchangers, vending machines and other traditional and hybrid equipment).
- **Category (C) Commercial Air-Conditioning**: Commercial air conditioners with greater than a 20kW/65k Btu/h cooling capacity. (Examples: Split AC, unitary large AC, VAV AC, CAV AC, VRF AC, chilled beams, heat pumps and other traditional and hybrid equipment)

During 2016-2018, AHRI and UNEP worked in consultation with the RDL Advisory Committee, to review and analyze[2] the existing globally recognized certification programs, to explore the qualification categories and agree on the operational modality of the RDL. After thorough analysis and in-depth consultation, the RDL Advisory Committee adopted four categories for the start-up of RDL (Table 1). Additional categories will be considered in the future such as handling ammonia and CO_2 applications.
However, RDL Advisory Committee concluded that the Pilot stage should only focus on testing the program for Category-A, i.e. RDL-Small Applications in order to measure feedback and adjust the program before developing the technical documentation for the other categories.

BUILDING CONTENT

The development of comprehensive technical documentation for RDL Category-A (RDL-Small Applications) included several steps:

- Development of competencies/skills documentation (benchmarking) required for Category-A.
- Development of a bank of questions for the testing.
- Development of sample training materials for train-the-trainers and following training sessions including syllabus and power point presentations.
- Development of comprehensive documentation for procedures of conducting the training, exam, preparatory work, qualification of trainers/assessors, setup of hands-on sessions and practical checks, evaluation and monitoring and roles of local stakeholders i.e. NOUs vs. Training Centres.
- Development of supporting tools i.e. checklists, guidance for exams, printing plans, etc.

It's also worth mentioning and acknowledging the support received from Centro Studi Galileo (CSG) and North American Technician Excellence (NATE) for the valuable contribution in development of the technical documentation, model exam and marking criteria of the RDL program.
All the technical documentation was discussed, reviewed and endorsed by the RDL Advisory Committee. An invitation to interested member states was offered, through regional OzonAction teams, for piloting RDL where special sessions, in the margins of network meetings, conducted to present and discuss the RDL with detailed explanations about possible options for linking RDL to ongoing training and/or certification programs or use the program as an alternate qualification program for countries that are facing difficulties in building a local certification scheme. After several rounds of discussions and with the support from CAP regional teams, the countries expressed interest and agreed to pilot the RDL, in conjunction with ongoing training activities under HPMPs, including Grenada, Maldives, Rwanda, Sri Lanka, Suriname and Trinidad & Tobago.

*UNEP International Partnerships Coordinator – **Ayman Eltalouny**, AHRI and NATE representatives – **Michael LaGiglia** and **John Lanier**, five Master Trainers – **Graeme Fox**, **Greg Jourdan**, **Manuel Azucena**, **Gianfranco Cattabriga** and **Madi Sakandé**, were welcomed in Casale Monferrato by CSG's Director General **Marco Buoni**.*

[2] Comprehensive report about major certification programs, around the globe, and their characteristics was developed as part of the preparatory stage of RDL program.

RDL CURRICULUM

- Agenda of refrigerant management knowledge areas
  - Theoretical Training: Installation, Service, Safety, Types of refrigerant, Tools
  - Practical Training: Leak Checking, Evacuation, Charging, Recovery
- Syllabus of RDL training
- PowerPoint presentations of refrigerant management skills
- Training guidance of RDL Job Task Analysis knowledge areas
- Hand-outs and flyers with information on refrigerant management
- RDL Exam "How to take the Exam" information
- RDL Pre-test "How to take the Pre-test" information
- Checklist for preparations and printing plans
- Checklist of practical training tasks
- Checklists for monitoring

Workplans were developed for the selected pilot countries starting with train-the-trainers/assessors and followed by training of around 100 technicians as part of the pilot. The arrangements for the Pilot stage were also formalized through official communications with the pilot countries.

PILOTING RDL

Before the start-up of the training sessions, 5 international experts were identified to be the International Master Trainers for delivering Train-the-Trainers' sessions in the six (6) pilot countries. A special coordination session was organized for the International Master Trainers to go through the details of the process, materials and ensure that delivery will be consistent across all pilot countries. Between June-August 2019, six (6) Train-the-Trainer sessions were successfully completed as follows:
1. 24-27 June (Rwanda)
2. 13-16 Aug (Trinidad & Tobago)
3. 8-11 July (Maldives)
4. 20-23 Aug (Grenada)
5. 23-26 July (Sri Lanka)
6. 20-23 Aug (Suriname)

Local trainers were trained and tested in each country in accordance to the RDL program. The schedule of training is set for the six (6) pilot countries to complete the following RDL training by first quarter of 2020. All tests and hands-on checks are being collected and sent to the RDL administrator (AHRI and UNEP OzonAction) for analyzing the level of skill, knowledge and competencies of the local trainers and then local technicians with the aim of mapping variances of level across different A5 countries and ensure that the final model and bank of questions will ensure a minimum level of competency and be suitable to a variety of country settings.

THE WAY FORWARD

While pursuing completion of the pilot stage and extract lessons to help in preparing the RDL documentation in its final format for global enrollment. The RDL Administrator are working on drafting the final operational setup and procedures to allow offering RDL widely to all interested NOUs, training centers and individuals. In principle, three tracks are being examined for the final operational model of RDL which are:
- **Track-A**: RDL to be the local refrigerant management qualification program managed by the NOU.
- **Track-B**: RDL to be an industry qualification program acknowledged by local TVET Authority.
- **Track-C**: Mixed approach i.e. offering RDL in parallel to standard certification programs.

This multi-track setup will allow RDL the needed flexibility to cater to the different needs of A5 countries in supporting local certification programs or filling gaps. An additional piloting would be needed during 2020 to ensure the feasibility of the final model, several NOUs expressed interest to use the RDL program. A comprehensive report will be made available about outcomes of the RDL pilot stage, suggestion for the operational modalities and options for further consideration about final setup of the RDL.

During the two days' meeting, the group revised and updated the ***training and assessment material*** *that was presented during the first pilot sessions, also testing such* ***tasks in practice*** *in CSG's laboratory, fully supplied with all the necessary equipment and tools. Names of the experts: see photo on the previous page..*

Training and Assessment for Technologies that Replace HFC's (Flammable Refrigerants)

Kelvin **KELLY**

Training Director, Business Edge

Paper presented at the 18th European Conference bit.ly/EUconfRAC2019

With the impact on the HFC quotas beginning to impact across Europe there is now a real need to change to low GWP Refrigerants. In the main, these low GWP Refrigerants are of greater benefit for the environment but at a price.
This being the increased health and safety risk, in particular flammability. Even though the F-Gas regulations do not require technicians to be specifically assessed in the safe handling of these flammable refrigerants, there is growing impetus to encourage technicians to upskill voluntarily. Within the UK the Air Conditioning and Refrigeration Industry Board created a specification to enable attendees to understand the properties of and the application of all A2L, A2 and A3 class flammable refrigerants.

The assessment specification is split into several sections including:

Legislation

- Regulations
  - – The Management of Health and Safety at Work
  - – The Control of Substances Hazardous to Health
  - – Dangerous Substances and Explosive Atmospheres
  - – Classification, Labelling and Packaging
  - – Etc
- Codes of practice
- European standards

Differences between different refrigerant classes

- Electrical devices (including devices specifically designed for use with flammable refrigerants)
- Electrical enclosures
- Compressors (including starter and associated electrics)
- Critical charge systems
- Oil compatibility

Properties of flammable Refrigerants

Flammability	Lower flammability limit	Practical limits
Low boiling point	Upper flammability limit	Density
Asphyxiation	Sources of ignition	

Information kindly supplied by Chemours

REFRIGERANT CLASSIFICATIONS FROM ISO817									
Refrigerant	Classification	Sat Temp. °C	Practical Limit kg/m³	LFL kg/m³	LFL %	UFL kg/m³	UFL %	Densità kg/m³	MIE mJ
R600a	A3	-11.8	0.011	0.043	1.8	0.203	8.4	2.44	0.25
R290	A3	-42.1	0.008	0.038	2.1	0.192	10.1	1.83	0.25
R1270	A3	-47.6	0.008	0.046	2	0.253	11.1	1.74	0.28
R170	A3	-88.6	0.0086	0.038	3	0.253	12.4	1.24	0.24
R152a	A2	-24	0.027	0.130	3.9	0.563	16.9	2.76	0.38
R32	A2L	-51.7	0.061	0.307	14.4	0.680	29.3	2.15	30-100
R1234yf	A2L	-29.5	0.058	0.289	6.2	0.573	12.3	4.77	5k-10k
R1234ze	A2L	-19	0.061	0.303	7	0.443	9.5	4.77	61k-64k
R454A	A2L	-48.3	0.056	0.278	8	0.522	15	3.34	300-1k
R454C	A2L	-45.9	0.059	0.293	7.7	0.569	15	3.78	300-1k

- Leakage implications (direct and indirect)
- Thermodynamic properties
- Cooling capacity and energy efficiency
- Density
- Odour
- Risks associated with retro-filling

Specific requirements when installing or servicing systems charged with flammable refrigerants

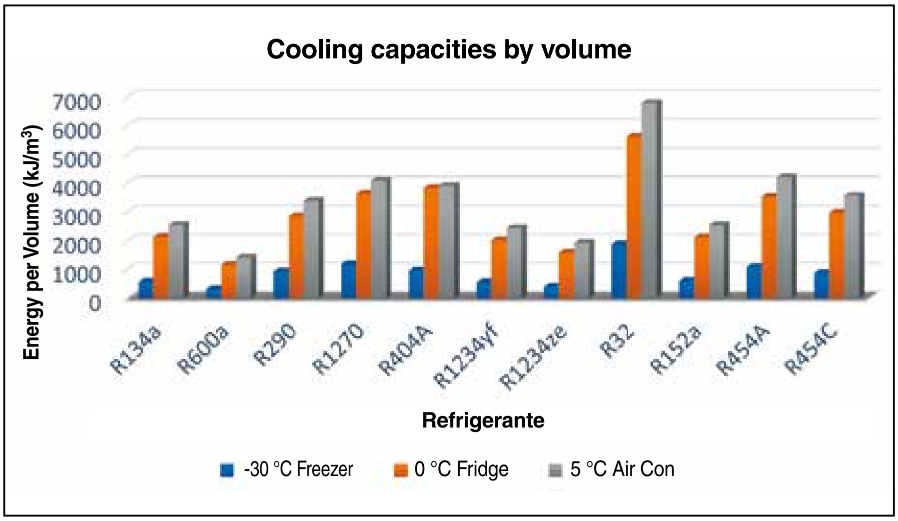
- Completion of a site specific risk assessment
- Selection of PPE
- Flammable gas leak detector
- Ventilation fan of natural ventilation
- Recovery unit (safe for use with flammable refrigerants)
- Vacuum pump (safe for use with flammable refrigerants)
- Manifold set (safe for use with flammable refrigerants)

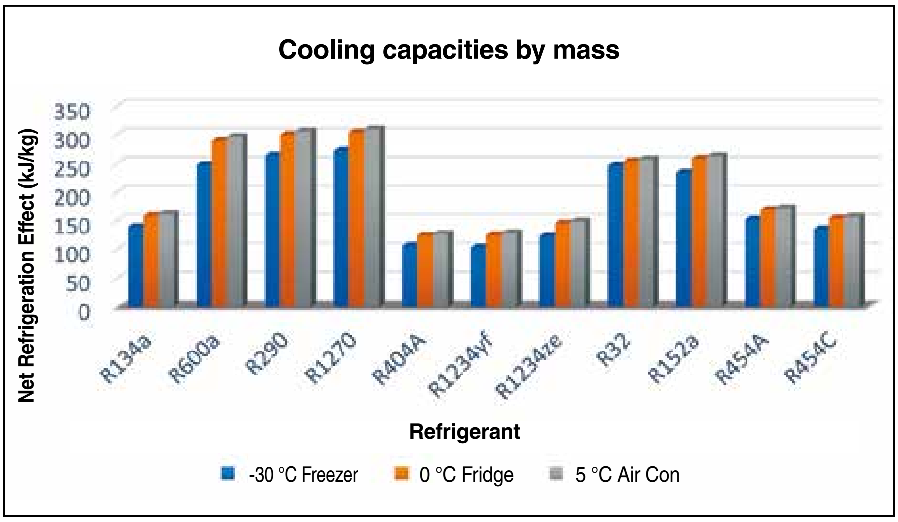
Specific requirements for installing and testing RACHP systems

- Identification of access category as designated in safety standards (BS EN 378, ISO 5149)

A2L recovery unit

Ventilation fan



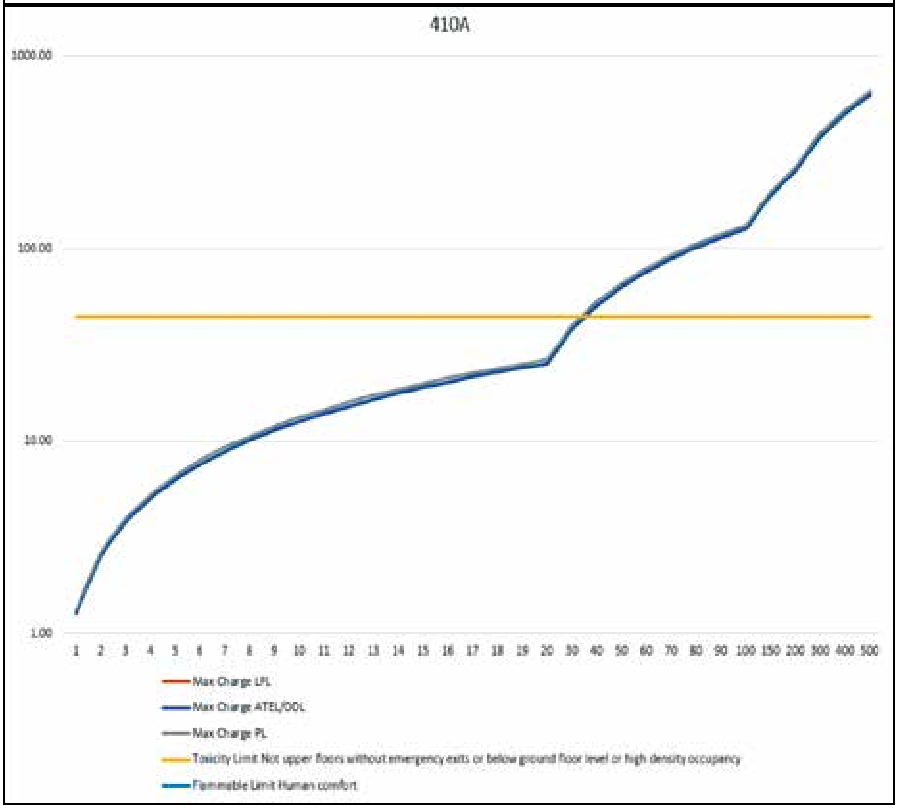


- Maximum refrigerant charge based on location classification
- Calculate the maximum charge based on the toxicity and practical limit
- Determine from calculations the system specific maximum charge
- Methods and procedures for:
  – strength testing
  – tightness testing
  – leak testing
  – evacuation and dehydration
  – charging systems
- Determining charge size
- Commissioning of systems
- Record keeping
- Labelling of systems
- Safely vent less than 0.15kg of hydrocarbon refrigerant to atmosphere
- Procedures for purging/evacuating the circuit prior to carrying out hot works whilst monitoring lower flammability level

The main challenge for the attendees

The implementation of the refrigerant's handling certification in Bahrain, project by UNEP-ATF/Italy

Safety Class	Refrigerant	Room Height	LFL	ATEL/ODL	PL	Room Area
A1	410A	3	NF	0.42	0.44	33.3
GWP	2088					
ODP	0					
Toxcity						
Toxcity Class	Access Category	Location Class	1	2	3	
A	a	II	43.956	26.400	0.15	
	a	I				
	b	II				
	c	III				
		IV				
Toxicity Limit	Not upper floors without emergency exits or below ground floor level or high density occupancy					
43.96						
Flamability						
Flam Class	Access Category	Location Class	1	2	3	4
1	a	II		NA	NA	0.15
	a	I	alternative			
	b	II				
	c	III				
		IV				
M_1	M_2	M_3	M_3 x 1.5	M_2 x 1.5	20% x LFL x m^3	
Flammable Limit Human comfort						
FALSE						
Flammable Limit Other Applications						
Non Flammable						
Flammable limit below ground						
FALSE						
Flammable limit above ground						
FALSE						
Flammable limit < 1 person per $10m^2$						
FALSE						



are the calculations to determine charge limits in accordance with BS EN 378. The first step is to determine the appropriate access category and location. The access category options are

a General access (Hospitals, theatres, supermarkets hotels etc)
b Supervised access (Professional offices, laboratories etc)
c Authorised access (Abattoirs, factories, cold stores etc)

Then the location of the equipment:

IV Ventilated enclosure (All refrigerant containing parts are located)
III Machinery room or open air
II Compressors in machinery room or open air
I Mechanical equipment located within the occupied space

The flammability class of the refrigerant (A2L, A2 or A3). Then the charge limit can be calculated from table C2 within BS EN 378 or use the formula 2.5 x $LFL^{1.25}$ x ho x √A or M1 x 1.5 for sealed refrigerating systems for class 2L or M1 for sealed refrigerating systems for class 2 or 3 or 150g for sealed refrigerating.

For Example

- Step 1: Access: a. Location Class: II
- Step 2: A (R410A ATEL = $0.42kg/m^3$ PL = 0.44 kg/m^3) therefore we use $0.44kg/m^3$
- Step 3: Toxicity limit (0.44) x room volume
  – An example using C.1 of $100m^3$ would give a refrigerant charge of 0.44 x 100 = 44 kg. Or if using C.3 QMLV x room volume 0.42 x 100 = 42kg, but if complying with at least two specified measures then the max limit of 150kg can be used.

Unfortunately due to the fact that there is no mandatory requirement for additional training on the safe use of flammable refrigerants, the take up is relatively small within the UK. At the time of writing this article it is estimated that approximately 200 technicians have successfully completed the assessment. Hopefully within mainland Europe other schemes and training courses set up by Governments or industry bodies or indeed the Real Alternatives 4 life blended learning will be more successful to ensure that a well-trained and competent work force is prepared for the increased use of flammable refrigerants.

Technical capacity building of trainers in the sector: refrigeration, air conditioning and customs officers

Youssef **HAMMAMI**

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Chef de service, Agence Nationale de Protection de l'Environnement (ANPE)

Tunisia, upon accession to the Vienna Convention and the Montreal Protocol on 25 September 1989, established a national program for the control and phase-out of ozone-depleting substances (ODS). The National Ozone Unit of Tunisia, created in 1994, was the driving force behind the implementation of ODS management projects.

This program enabled Tunisia to phase out 1026 MT of CFCs by the end of 2009, and the reduction of HCFC imports and consumption by 36% by the end of 2018, meaning a reduction of 472410 tonnes CO_2eq at through the HPMP project approved in 2014 by the Executive Committee of the Multilateral Fund of the Montreal Protocol.

With the HPMP project, Tunisia highlighted the vital role of trainers operating in the refrigeration and air conditioning (RAC) sector towards the sound management of HCFCs and HFCs and the adoption of environmentally friendly alternatives in particular, natural refrigerants, as well as the role of customs officers in controlling imports and exports of substances controlled by the Montreal Protocol and the identification of HCFCs and HFCs refrigerants to combat illicit trade in these refrigerants.

Tunisia is in the process of finalizing the establishment of a national certification system for technicians and service companies operating in the RAC sector, with the collaboration of the United Nations Industrial Development Organization (UNIDO) and the technical assistance of Centro Studi Galileo (CSG) of Italy.

During the period 2016-2018, 60 trainers from the Tunisian Agency for Vocational Training (ATFP) were trained and certified category I with a validity of ten years, according to the European regulation (EC 842/2006 and EC 517/2014). These trainers are spread over six vocational training centers in the Tunisian territory and will subsequently play the role of certifying trainers.

The preparation of the training manual to be adopted for the Tunisian certification system has been completed and includes seven modules which are:

– Environmental impacts of refrigerants and regulations and corresponding environmental standards,
– Basic concepts of refrigeration,
– Refrigerants,
– Leak detection in RAC systems,
– Good service practices during servicing, maintenance and decommissioning of RAC systems and equipment - refrigerants, recovery, recycling and reuse,
– Good service practices when servicing and maintaining RAC systems and equipment - Refrigerant tightness, suction, and refill test
– Tubes in RAC systems,

Two train-the-trainer sessions were already carried out (April and June 2019) on the content and application of the aforementioned modules in theory and in practice.

These two sessions allowed the participation of 53 trainers, in which 15%

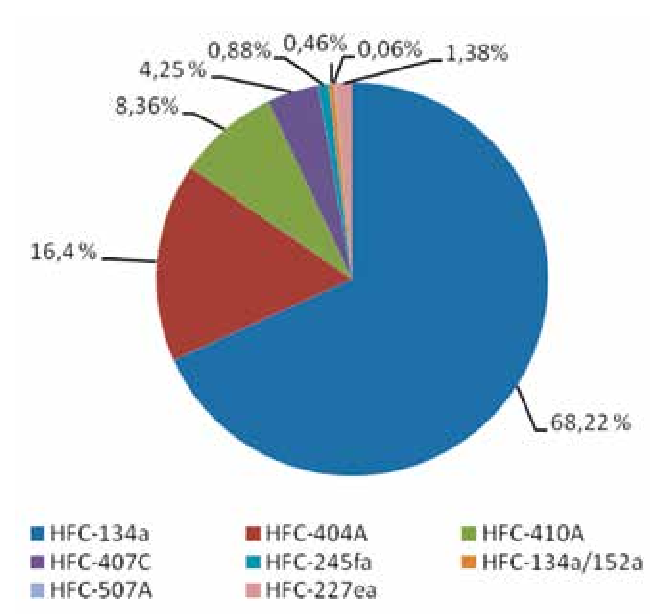

Figure 1: *Average distribution of HFC consumption over the period 2012-2015*

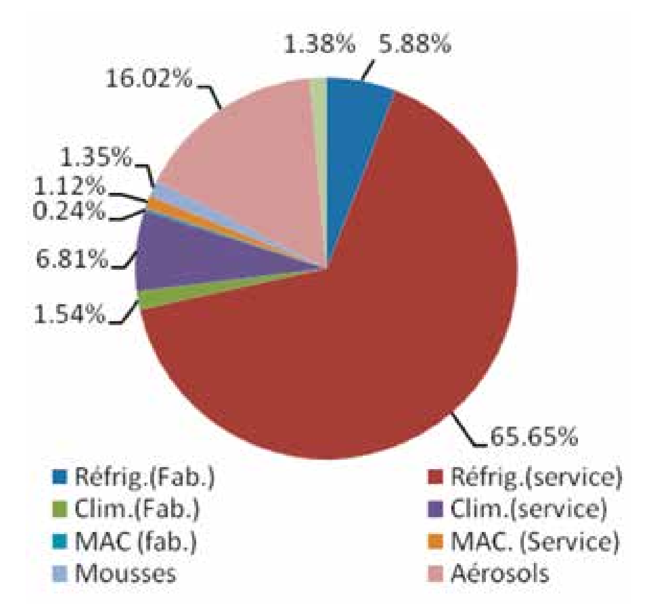

Figure 2: *Sectoral distribution of HFC consumption over the period 2012-2015*

of participants were women.

Similarly, two training sessions on natural refrigerants were also conducted (February and April 2019) with the support of the German Technical Cooperation "GIZ" for the benefit of the trainers. Fifty-three trainers benefited from these trainings, where themes mainly focused on:

– The use of low GWP natural refrigerants such as R600a and R290 hydrocarbons, CO_2 (R-744) and ammonia (R-717), their current and future applications: barriers and challenges,
– Energy efficiency in the refrigeration and air conditioning sector,
– Safe handling and maintenance measures for natural refrigerants,
– Safety standards and risk assess– International laws and standards that regulate the use of natural refrigerants,
– Good management practices and recovery measures, Recycling and Regeneration (RRR) of refrigerants SAOs and HFCs in stocks,

The certification of technicians and service companies operating in the RAC sector will enable the sound management of HCFC refrigerants (R-22) as well as HFCs which are rapidly evolving since their adoption as alternatives to CFCs.

The ODS alternatives survey recently completed in Tunisia shows that in the period 2012-2015, an average amount of almost 485 metric tonnes (mt) of HFCs has been consumed every year. This amount is equivalent to more than 930,000 tCO_2, which represents 99% of the total global warming potential (GWP) of the ODS alternatives consumed in the country. The substances HFC-134a (68%), HFC-404A (16%) and HFC-410A (8%) are the most common HFCs for all sectors. In terms of GWP, these substances have the biggest share: HFC-134a represents 51% of the total HFCs' global warming potential; HFC-404A, 33%, and HFC-410A, 9%.

The largest consumption of HFCs in Tunisia in metric tonnes occurs in the

Conduct of theoretical and practical training sessions

refrigeration and air conditioning servicing sector (66% of total HFC consumption), followed by the aerosols (16%) and the air-conditioning servicing sector (7%).
The use of HFC-134a is mainly focused on the refrigeration servicing sector (66% of total HFC-134a consumption in metric tonnes) and the aerosols sector (23%). On its turn, the use of HFC-404A occurs mainly in the refrigeration servicing sector (97%), while HFC-410A is used mostly in the air-conditioning servicing sector (82%).
The annual evolution of HFC-134a and HFC-404A during the period 2004-2018 showed the following:

– An increase of 270% in the import and consumption of HFC-134a,
– An increase of 620% in the import and consumption of HFC-404A,

In 2018, an in-depth training program was initiated with the training director of the Tunisian Customs and in collaboration with the United Nations Environment Program (UNEP) to create a customs training body.
Therefore, five training sessions for 122 Tunisian Customs officers on 4 sites in the Tunisian territory were organized, with a view to strengthening their technical capacities in terms of identification and control of identification operations, imports and exports of ODS and HFCs, including refrigerants. The sessions were conducted as follows:

– A theoretical training session: focused on the basic concept of the formation / destruction of stratospheric ozone, role of the ozone layer for the protection of the earth against harmful UV for all forms of life on earth , current ODS applications in particular in Tunisia, national and international regulations on ODS disposal issues, ODS import / export document verification methods and further knowledge of the import licensing system / export of ODS as well as the granting of annual ODS import quotas, and finally cases of illicit trade in other countries.
– Practical training session: During this session the participants closely followed the operating mode of refrigerant gas identification and analysis devices using the Neutronics identifier / analyzer. Several hands-on exercises have been conducted using this high-end technology device worldwide, while noting that 39 such identifiers have been distributed to Customs.
– An assessment test: A knowledge assessment test was conducted to select a number of participants to create "Customs Trainers" through other in-depth training.

The technical capacity building activities being implemented will enable Tunisia to properly manage the high-global-warming refrigerants that account for the majority of HFCs consumed in the country, and to honor its commitments towards the Kigali Amendment to the Montreal Protocol and Achieving the Objective 13 Targets of the Seventeen Sustainable Development Goals Adopted by the United Nations General Assembly in 2015 " Climate Action ".

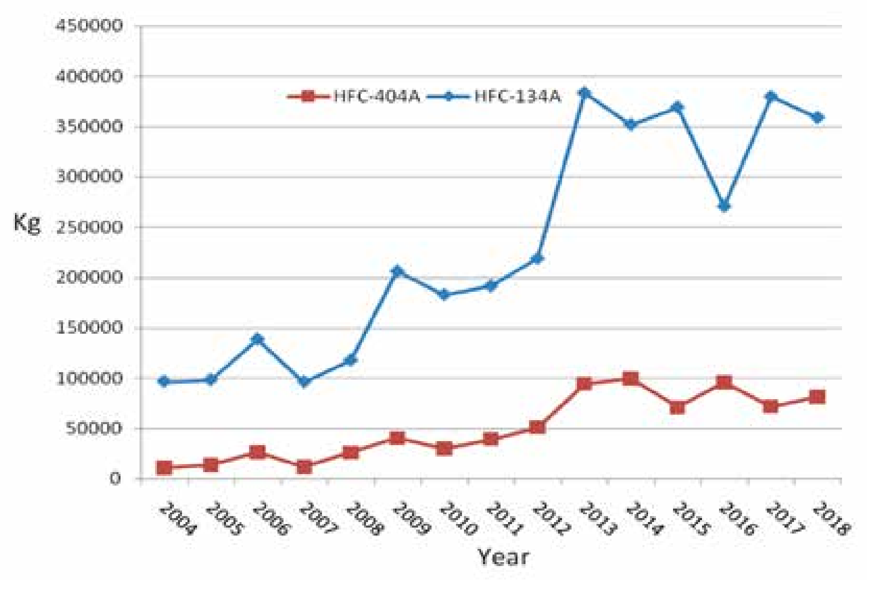

Figure 3: *Annual trend of HFC-134a et HFC-404A*

Conducting training sessions for customs officers

World Refrigeration Day

Stephen **GILL**

World Refrigeration Day Secretariat

Madi **SAKANDÉ**

Expert trainer of Centro Studi Galileo

Inaugural World Refrigeration Day united industry leaders, influencers, policy-makers in raising awareness of our vital sector to the general public.

June 26th 2019 saw the first World Refrigeration Day. It has been established as an annual event with the support of UNEP's OzonAction and though agreement with trade associations and professional bodies worldwide to serve as a means of raising awareness and understanding of the significant role that the refrigeration, air-conditioning and heat-pump (RACHP) industry and its technology play in modern life and society. WRD is also being championed by governments and agencies to point financiers and policy makers to developing poorer countries' cold chains and sustainable human comfort.

As the inaugural day approached, interest and support grew such that by June 26th over 200 trade associations and professional bodies representing in excess of 2 million individual members expressed support for WRD. These bodies extended beyond to trade to include end-user associations and associated industry sectors such as building services, the energy sector and sustainability

Support from industry at both organisational and individual level was significant too with commercial and businesses across the globe taking the opportunity to promote the industry in many creative ways. These included outreach days to educational centres or open day invitations to raise awareness to young people of the science and application of RACHP engineering as well as the skills involved and career opportunities,

Physical events were held in at least 153 countries, in additional to numerous webinars and other online activities. This was a truly world-wide occasion uniting the global RACHP industry. The WRD logo was translated into 35 different languages ranging from Afrikaans to Zulu, by volunteers with a further 5 being requested by not completed.

WRD attracted the attention of the media and governments. News items appeared in many publications and by broadcasters also giving it mentions. News of WRD also appeared on a small number of official national government websites. Leading organisations such as the World Bank, and the EU Commission used their social media accounts to post about WRD.

As first year awareness campaign go, the success was remarkable with all the indications being that next year's WRD will receive significantly greater support.

WRD has managed to unite, mobilise and galvanise the global cooling and sustainable heating community.

WRD celebrated in Casale Monferrato, Italy, with the mayor Federico Riboldi. National Radio24 broadcasted the news, interviewing Marco Buoni President of AREA

WRD 2019 in Burkina Faso

The World Refrigeration Day 2019 (WRD 2019) organized in Burkina Faso recorded a participation of nearly 500 people with the supportof Exhibitions, Stand visits, Educational animations, Video presentations.

The organization of this Day in Burkina Faso was initiated by the NEW COLD SYSTEM Company (NCS), the Association of Professionals and Actors of Refrigeration and Air Conditioning (APFC) and the Association of Engineers and Refrigeration Technicians of Burkina Faso (AITFB).

WRD 2019 recorded the participation of delegations from Côte d'Ivoire, Niger and the Republic Democratic of Congo. The official opening ceremony was chaired by Mr. SANOU Stéphane, Secretary General of the Government and the Council of Ministers. This ceremony was marked by the interventions of the following personalities:

- SAKANDE Madi, General Manager of New Cold System and Promoter of WRD19 in Burkina Faso;
- KABORE Amidou, President of the AITFB;
- KOUABLAN Omer Affian, President of the National Union of Professional Refrigeration Technicians of Côte d'Ivoire;
- KONE Moussa, President of the National Chamber of Agriculture (CNA) and Sponsor of the WRD19
- SANOU Stéphane, patron of the ceremony representing the Minister of Energy, Dr. Bachir Ismael MAIGA.

The broadcast of the co-sponsor's video recordings, His Excellency the Ambassador of Italy to Burkina Faso Mr. Andrea Romussi and Didier COULOMB, Director General of the International Institute of Refrigeration (IIF) closed this opening ceremony.

At the end of the opening, the officials and participants were able to appreciate the equipment and materials used in the field of HVAC-R sector through a guided tour.

One of the highlights of this WRD was the organization of the Cold Panel which brought together several actors:

- The public sector: the Ministry of Energy through the National Agency for Renewable Energy and Energy Efficiency (ANEREE) and the Directorate General of Energy Efficiency (DGEE), the Ministry of Youth and Promotion of Youth Entrepreneurship (MJPEJ), the Ministry of Environment, Climate Change and Green Economy (MECCEV) represented by the National Ozone Unit,
- The delegations of refrigeration associations from Côte d'Ivoire, Niger and the DRC
- National Chamber of Agriculture and the Chamber of Trade and Industry
- Joseph KI-ZERBO University of Ouagadougou, 2iE Institute, NEW COLD SYSTEM, FPAC, AITFB
- Cold industry leaders and / or their representatives
- Technicians, students and learners.

At the end of the exchanges, the panel proposed Recommendations to serve as a compass for the continuation of the dynamics operated from this WRD19. These recommendations were read at the closing ceremony of the WRD19 chaired by Mr. NAGOLO Firmin, Chargé de Mission, representing the Minister of Energy, Dr. Bachir Ismael OUEDRAOGO. This ceremony was organized around the following interventions:

- SEMPORE Francis, Moderator of the Panel for the reading of the Recommendations resulting from the exchanges;
- Adlain EYARMWEN NKIE AKAN, President of the African Network of Cold Professionals (RESAF);
- OUEDRAOGO Elie, President of the APFC;
- NAGOLO Firmin, Project Manager at the Ministry of Energy.

A special mention is made to Mr. Joachim VOKOUMA for his commitment through the communication actions carried out around this WRD19.

The organizers send their sincere thanks to the Minister of Energy, the Secretary General of the Government, his Excellency the Ambassador of Italy to Burkina Faso, the President of the National Chamber of Agriculture and all the actors who have allowed to hold the bet of a successful World Refrigeration Day in Burkina Faso.

Recommendations for public authorities

1. Give pride of place to the HVAC-R sector by integrating its promotion in policy documents and development strategies (establishment of a favorable legal framework for the development of refrigeration, construction of refrigerated infrastructures at the zone of production and consumption, promotion of youth entrepreneurship, application of community guidelines on crafts, framework for the promotion of the cold chain ...)
2. Involve professional organizations and associations in the field of refrigeration and air conditioning in the development and implementation of policies and strategies and in activities related to refrigeration and air conditioning.
3. Develop vocational training centers while ensuring their proper functioning, their equipment in appropriate teaching materials and facilitating accessibility (offer of scholarships ...).
4. Engage in reflection on zero-rating and / or exemption of refrigeration equipment and equipment, which is not a luxury but a necessity for ensuring the socio-economic development of the country.

Recommendations for professional organizations

1. Build the capacity of technicians with, among other things, the establishment of an appropriate training plan on the following topics: basic principles, use of refrigerants, energy efficiency, use of renewable energies ...
2. Ensure a synergy of actions at national level but also at regional and international level.
3. Develop a framework of tariffs for services in the field of refrigeration.
4. Development of structuring projects in the field of refrigeration.

Recommendations to all stakeholders and stakeholders

1. Set up a HVAC-R Working Group in Burkina Faso.
2. Develop a reference document or a detailed overview of the HVAC-R in Burkina Faso.
3. Develop a directory of all actors involved in the field of refrigeration and air conditioning in Burkina Faso and Africa.
4. Institutionalize the organization of the World Refrigeration Day in Burkina Faso and all African countries.
5. Make operational the application of the structure of the tariffs of the services.
6. Ensure the financing of structuring projects in collaboration with the technical and financial partners.
7. Promote the certification of professionals in the refrigeration trades.
8. Ensure that the design and engineering components are taken into account in the various cooling and air conditioning projects.
9. Integrate GENDER into all activities related to the promotion of HVAC-R.
10. Establish a network of journalists and communicators on refrigeration and air conditioning at the country level and also at regional level.
11. Set up a communication platform between the various actors involved in the HVAC - R in Burkina Faso and Africa.
12. Develop an action plan for HVAC - R Promotion activities incorporating World Refrigeration Day and World Ozone Day.
13. Make Ouagadougou the "African Capital of the HVAC - R".

CSG-EEC-UNITED NATIONS courses, conferences and seminars reach more than 140 countries worldwide

(for details visit www.centrogalileo.it)

About us

Centro Studi Galileo has been a global leader of training for refrigeration and air conditioning technicians for over forty years and has delivered theoretical-practical courses to installers, maintenance technicians, designers and companies in the sector, both in Italy and abroad. Alongside the European Energy Centre in the UK and the Association of Italian Refrigeration Technicians, Centro Studi Galileo collaborates with the world's leading experts from universities, organizations and associations such as IIR in Paris, American ASHRAE and AHRI, European AREA, EPEE, Eurovent, the Italian Anima and Assoclima, as well as the Agencies for the Environment and Industrial Development of the United Nations UNEP, UNDP and UNIDO. The countries involved in courses, exam sessions and conferences delivered by CSG-EEC-ATF are featured on the world map.

NORTH AFRICA

- **Tunisia, CSG-UNIDO**
"Training for local trainers by rewarding excellence"
Five theoretical-practical courses in the cities of Tunis, Djerba, Nabeul, Tabarka and Kairouan for more than 60 experienced Tunisian engineers, future teachers and examiners for the five Centres of Excellence in the country, accompanied by round tables and cooperation with the Ministry and the National Agency for the Protection of the Environment aimed at drafting national legislation to certify the skills of technicians.
- **Algeria & Morocco, CSG-UNIDO**
"Courses and consulting on new technologies"

NORTHERN AND CENTRAL AMERICA

- **United States, Washington DC & Manhattan, CSG-EEC**
"Renewable Energy at The George Washington University"
Courses on Renewable Energy Market Trends and Finance, Electric Vehicles and Solar Photovoltaics.
- **Little Antilles & Suriname, Grenada, CSG-UNIDO**
"Train-the-trainers sessions: Flammable Substances"
Study of the management of training centres and courses: theoretical-practical training and certification for teachers.

SOUTHERN AMERICA

- **Argentina, Buenos Aires & Rosario, CSG-UNIDO**
"Workshop on commercial refrigeration: Experiences with the latest low-GWP alternatives"
Training seminars organized with the Italian and Argentinian Ministry of the Environment and Sustainable Development, in collaboration with UNIDO and 10 of the largest Italian refrigeration companies, aimed at Argentinian technicians, industry experts, production companies and end-users.

- **Colombia, Bogota, CSG-EEC**
"Renewable Energy at the Engineering Centre"
Course on photovoltaic, thermal, wind, biomass and heat pumps.

CENTRAL AFRICA

- **Gambia, Banjul, CSG-UNIDO**
"Sustainable development on the Atlantic Ocean"
Theoretical-practical training courses on the reduction of harmful ozone substances with high global warming potential through the transfer of skills and technologies in the refrigeration and industrial air conditioning sector.
- **Ghana, CSG-UNDP** *"Training course on handling hydrocarbons with the support of the Ministry of the Environment"*
- **Benin, Cotonou, CSG-UNEP**
"Refrigeration in Francophone countries"
Meeting of the Coordinators of the Ozone Program in French-speaking Africa for the Ministry of the Environment and thematic meetings to assist in drafting the certification scheme for refrigeration technicians. Additionally, the creation of Refrigeration Associations for technical officers of French-speaking countries and a course to provide the Refrigeration Certificate.

- **Rwanda, Kigali, CSG-UNEP & Eritrea, Asmara, CSG-UNIDO**
"European Refrigeration Certificate for English-speaking Countries"
- **Ethiopia, Addis Ababa, CSG-UNEP**
"Eliminate the ODS in the Horn of Africa for the implementation of projects in UNEP's HPMP programme"
- **Nigeria, Lagos, CSG-EEC**
"Courses on Carbon Management and Trading"

PERSIAN GULF

- **Iraq, Iraqi delegation to Casale Monferrato, CSG-UNEP**
"Best practices in Iraq"
UNEP, CSG and ATF collaborate for the implementation of the National Elimination Plan of the HCFCs in the Country in order to work safely with commercial hydrocarbon systems.
- **Bahrain, Manama, CSG-UNEP**
"Certification Scheme in Bahrain"
Broad cooperation project with the Ministry of the Environment and the authoritative Company of Bahraini Engineers to draft the National Certification Scheme, accompanied by additional training and certification sessions for expert engineers and future teachers-examiners in the Country.

- **Saudi Arabia, Rowa & Dammam, CSG-UNEP-UNIDO**
"Air Conditioning in the desert"
Workshop on best practices and Certificate for refrigeration technicians of a well-known manufacturer of split air conditioners (50+ technicians).

EUROPE

- **United Kingdom, EEC-CSG**
"Renewable energy in the UK: University of London, Edinburgh Napier University & Heriot-Watt University"
Courses on technical and economic management of renewable energy - including wind, solar photovoltaics, biomass and tidal power, as well as solutions, management, finance and blockchain for Renewable Energy and electric vehicles. Round tables with the Scottish Government.
- **France and Germany**
"Round tables with the United Nations for the Environment"
- **Belarus, Ukraine, Tajikistan, Uzbekistan, CSG-UNDP**
"Progress and training in Indo-European countries"
Train-the-trainers theoretical and practical training certification courses for the elimination of ODS (harmful substances for the ozone) delivered to RAC experts from Countries within the Indo-European Region.
- **Bosnia and Herzegovina, Sarajevo, CSG-UNEP**
"The birth of Bosnian refrigeration"
Training and certification course and the inauguration of the Bosnian Refrigeration Technicians Association.
- **Montenegro, Podgorica, CSG** *"Refrigeration Certificate in the Balkans"*
Updating courses and awarding the Refrigeration Certificate for experts from Albania, Serbia, Macedonia, Bosnia and Montenegro.
- **Turkey, Istanbul & Izmir, CSG**
"Courses and conferences in the Bosphorus"
Successful cooperation between Italy and Turkey. The respective "refrigeration capitals" of the two countries, Casale Monferrato and Izmir, were united by the project "Adding value to the future", the results of which were presented during the international conference "Strengthen HVAC" at Izmir. Courses for obtaining the European Refrigeration Certificate held in Istanbul.
- **Italy** *"Courses and exams in 15 CSG seats"*
Courses on refrigeration, air conditioning and heat pumps in major cities including Turin, Milan, Rome, Bologna, Padua, Treviso, Naples, Bari, Cagliari and Palermo, primarily at CSG headquarters, Casale Monferrato. Over the last ten years, CSG-EEC have successfully organised more than 1500 courses in the classroom and online (e-learning) leading to the certification and recognition of more than 10,000 technicians globally.

CONTINENTAL ASIA

- **China, Chinese delegation, CSG-UNEP**
"Alternative and natural refrigerants for refrigeration in east Asia"
Theoretical-practical train-the-trainers courses on the competent and safe utilisation of alternative and flammable refrigerants. Delivered to 18 University Professors and Technical Institutes in China, including site visits to production facilities.

- **India, Maldives, Sri Lanka, Thailand and Jordan, CSG-UNEP**
"Conferences and Workshops on refrigeration and renewables"
Conferences and seminars on energy efficiency and new refrigerants in collaboration with UNEP and local associations.


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The new Regulations (CE) 517/2014 and 2067/2015 confirm the certification requirement for Personnel and Companies involved in the use of Fluorinated Gases (the Person's Certificate is familiarly called "License for Refrigeration Operator").
In absence of the above Certificate, Personnel and Companies cannot carry out activities such as installation, maintenance, repair, recovery and dismantling of the equipment containing these fluorinated gases, nor buy greenhouse refrigerant gases, seeing therefore limited their work and risking heavy fines.
CEPAS is accredited by Accredia and approved by the Ministry of the Environment for all the certification activities of Personnel and Companies operating in this sector and can help technicians and companies to meet this legal obligation.

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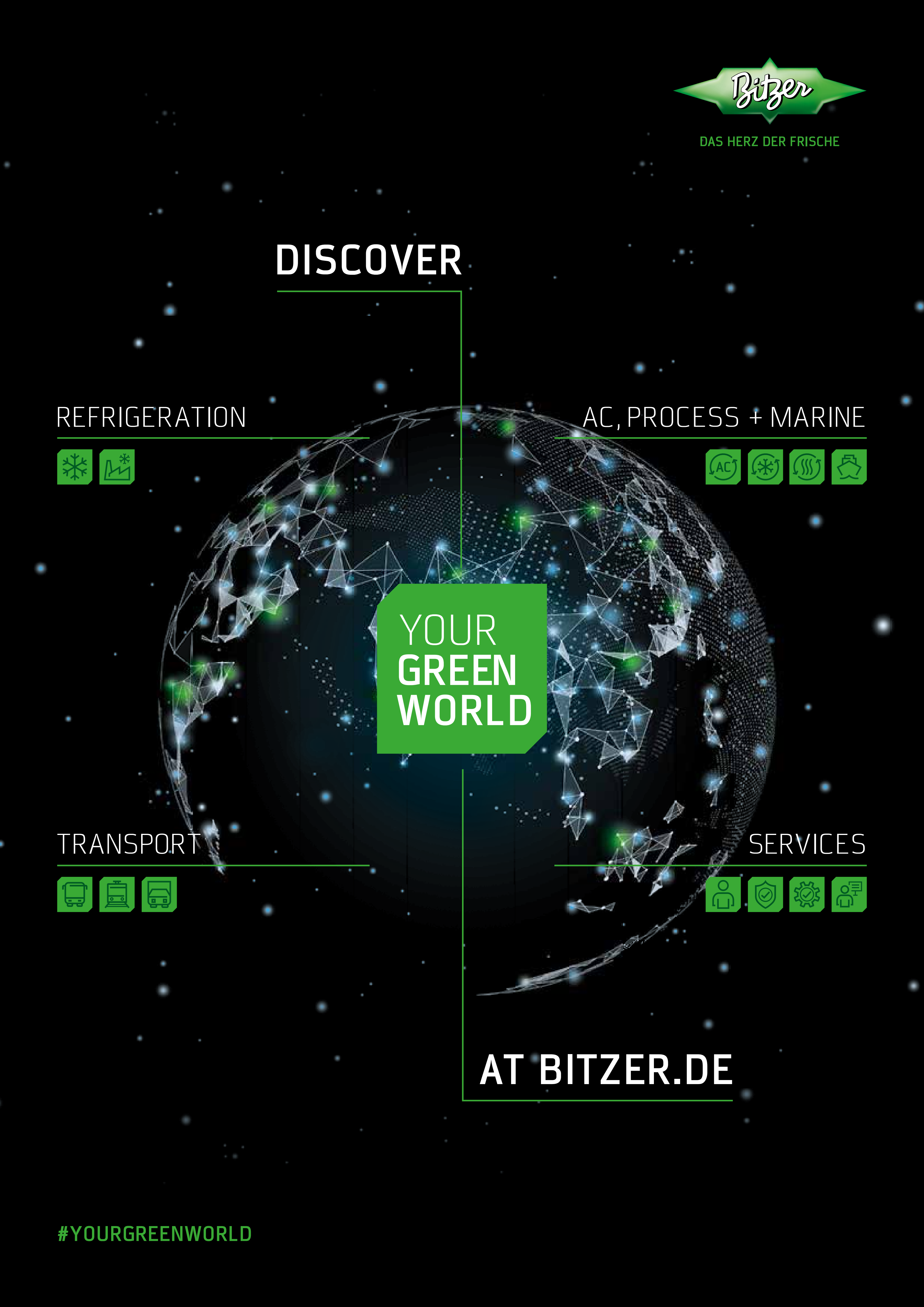

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