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and European Energy
Centre (EEC)

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special international issue 2010

refrigeration and air conditioning

EEC

COOLING WITHOUT WARMING

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UNEP

GREEN NEW DEAL IN REFRIGERATION AND AIR CONDITIONING

EEC

ASSOCIAZIONE DEI TECNICI DEL FREDDO
ATF
full member
Air conditioning and Refrigeration European Association

UNDER THE AUSPICES OF THE ITALIAN MINISTRY OF THE ENVIRONMENT

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Contents

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From the left picture of the cover of ISI 2006 and ISI 2008

About the picture on the cover: as ISI 2006 and ISI 2008 this image of Achill Island, off the most North-Westerly point of Ireland, illustrates:

- **Ozone protection**
  the sky: the blue sky contains our Earth's ozone shield.
- **Climate change**
  the sea: higher temperatures could lead to sea level rise and extreme weather events.
- **Energy efficiency**
  the waves: renewable energy sources such as waves are waiting to be harnessed.

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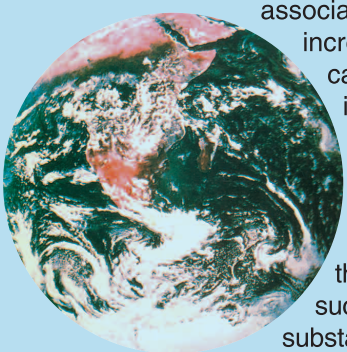
FOREWORDS

International efforts to protect the ozone layer - the shield that protects life on Earth from harmful levels of ultraviolet rays - are a success and have stopped additional ozone losses and contributed to combating climate change.
Given that many substances that deplete the ozone layer are also potent greenhouse gases, the report says that the Montreal Protocol has "provided substantial co-benefits by reducing climate change." In 2010, the reduction of ozone depleting substances as a result of the Montreal Protocol, expressed in CO_2-equivalent emissions (about 10 Gigatonnes per year), were five times larger than those targeted by the first commitment period (2008-2012) of the Kyoto Protocol, the greenhouse emissions reduction treaty.
Many ozone depleting chemicals, such as CFCs (chlorofluorocarbons), once present in products such as refrigerators and spray cans, have been phased out. Demand for replacement substances called HCFCs (hydrochlorofluorocarbons) and HFCs (hydrofluorocarbons) has increased. Many of these are powerful greenhouse gases.
This represents a further potential area for action within the overall climate change challenge and one that has the potential to deliver quick wins alongside reductions of other non-CO_2 pollutants such as black carbon, methane and tropospheric ozone. These wins are certainly needed.
An international group of modellers working with UNEP recently concluded that current commitments and pledges linked with the Copenhagen Accord are unlikely to keep a global temperature rise to under 2 °C by 2050. The gap between scientific reality and ambition is estimated to average around 4.7 Gigatonnes of CO_2 equivalent per year- a gap that needs to be urgently bridged over the next decade or so if the 2 °C target is to be met.
Action to protect the ozone layer has not only been a success, but continues to deliver multiple benefits to economies including on efforts to meet the Millennium Development Goals. The contribution to combating climate change is one, but so are the direct benefits to public health. For without the Montreal Protocol and its associated Vienna Convention atmospheric levels of ozone-depleting substances could have increased tenfold by 2050. This in turn could have led to up to 20 million more cases of skin cancer and 130 million more cases of eye cataracts, not to speak of damage to human immune systems, wildlife and agriculture.



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

The Montreal Protocol on Substances that Deplete the Ozone Layer is the world's most effective multilateral environmental agreement, successfully phasing out 95% of production of ozone-depleting substances since its adoption 23 years ago in 1987, placing the ozone layer on a path to recovery. The Protocol has also delivered substantial climate benefits. From 1990 to 2010 the phase-out of chlorofluorocarbons (CFCs) has already reduced emissions by 135 billion tons of carbon dioxide equivalent ($GtCO_2$-eq.) and delaying climate change by up to 12 years. Strengthening the Montreal Protocol will result in additional emissions reductions and further delay climate change.
The positive results achieved to date surely depend from the combination of different aspects such as the global participation and cooperation among countries, the wide involvement of developing countries through a well functioning Multilateral Financial Mechanism, flexibility in implementation, a robust compliance regime. Among those aspects, I believe that a crucial one has been the involvement of industries, and their acceptance of the challenges to evolve and innovate. Although the Montreal Protocol established targets that were initially beyond the reach of existing best-available technologies, at the end, thanks to the dynamic role of industries appropriately "stimulated", the goals became in fact achievable. It is indeed thanks to their development of technology alternatives to ozone-depleting chemicals for uses such as refrigeration, foams, solvents that it was possible to achieve the remarkable results we are experiencing today.
An excellent work has already been done, but some opportunities to synergize and maximize climate and ozone benefits still remain. For instance, the energy efficiency of refrigeration and air conditioning applications also has improved dramatically. This provides significant climate benefits, because improving energy efficiency decreases the climate emissions from fossil fuel use, which provides greater climate benefits than reducing direct refrigerant emissions over the life of the equipment or switching to low GWP substitutes. This approach was also recognized by the G8 Summit Declaration that states that "improving energy efficiency is the fastest, the most sustainable and the cheapest" way to reduce climate emissions.
Keep on building on the development of more energy efficient equipments and that can work with substances that have a low or zero global warming potential is the right way to go forward. To this end the innovative work carried on by the Centro Studi Galileo in partnership with UNEP is unique and will surely contribute in the future to boost the "technological revolution" in the refrigeration sector that the Montreal Protocol has initiated trough its work.

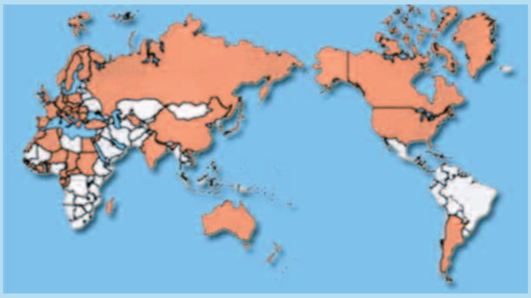
Stefania Prestigiacomo - Italian Minister of the Environment

IIR - International Institute of Refrigeration for sustainable development

The International Institute of Refrigeration (IIR) is an independent intergovernmental science and technology based organization which 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 is an intergovernmental organization, comprising 61 member countries, developed, developing or emerging countries, from all continents (see MAP below).
About 500 commission members, nominated by countries, provide us with expertise.
Almost 600 corporate and private members (private companies in equipment, utilities, food and health products … consultants, universities) receive our information services.
Our tools for valuable and updated information provided to our members are:



- selection of scientific, technical and economic articles from all over the world, in various languages, placed in a database, Fridoc, which currently comprises 87 000 entries, 3 000 keywords and 50 000 authors;
- publication of periodicals: the International Journal of Refrigeration (IJR) comprising peer-reviewed scientific articles. It has the best impact factor in its field; a Newsletter; the Bulletin;
- publication of books and guides, such as “Saving Energy in Refrigeration, Air-Conditioning and Heat Pump Technology”, “Ammonia as Refrigerant”, “Properties of Secondary Working Fluids for Indirect Systems”…;
- publication of reference documents: brochures and diagrams on refrigerants, the International Dictionary of Refrigeration comprising 11 languages..;
- publication and organization of training courses: “Refrigeration Fundamentals”…);
- participation in the definition of international standards;
- publication of review articles, of Informatory Notes for governments, public agencies…;
- publication of statements for international events, such as the United Nations Conferences on Ozone Depletion and on Climate Change, on Sustainable development or food safety;
- dissemination of outcomes of research projects and organization of Working Parties, such as “Direct Emissions of Greenhouse Gases”, “Energy Labelling”, “Cold Chain in Developing Countries”,..
- organization of international conferences in our various member countries (3–6 IIR Conferences per year and 8–15 cosponsored events per year), specialized in various technologies and uses in the refrigeration and air-conditioning sectors, and congresses every 4 years.

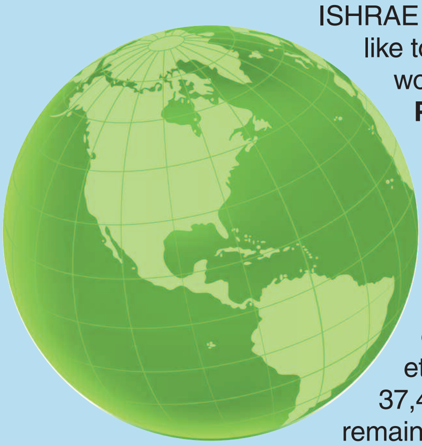
Didier Coulomb - Director IIR

The next 14th European Conference by Centro Studi Galileo and the Italian Association of Refrigeration Technicians is organised in cooperation with the International Institute of Refrigeration-IIR, the United Nations Environment Programme-UNEP and the European Energy Centre-EEC and will take place on the 21st January 2011 at Heriot-Watt University, Edinburgh. The second session of the same conference will be held on the 10th-11th June 2011 at Politecnico of Milan.
This conference on the latest technologies in Renewable Energy, applications in Cooling and Heating, will see the first part (in Edinburgh) focusing on energy efficiency and the second part (in Milan) focusing in refrigeration and A/C . Both conferences are organised under the auspices of the Italian Council of Ministers.

ISHRAE - Indian Society of Heating, Refrigerating and Air-Conditioning Engineers

ISHRAE is an Associate Society of ASHRAE. ISHRAE is engaged in promoting the Arts and Sciences of HVAC & R and Allied Disciplines via the 35 Chapters and 90 Student Chapters spread across India. Besides this, the Society is actively pursuing the cause of Sustainability, Energy Efficiency and Water Conservation through Technical Seminars, Workshops, Training Programs, Publications and Expositions.
ISHRAE works closely with the Government of India in writing Industry Standards, in association with AHRI.
ISHRAE has worked with the BEE (Bureau of Energy Efficiency, Government of India) in developing Building Codes for Energy Efficient Buildings and Building Energy Labeling Programs.
ISHRAE works closely with the Indian Green Building Council to promote Sustainable Developments, Water Conservation and development of alternative Energy Resources, not just for Commercial Spaces, but also for Living Habitats. The Society takes its Learning Programs to Engineering & Architectural Institutions, and via the K-12 Initiatives, to the young minds in our Schools to truly foster and nurture the concepts of Sustainability, Energy and Water Conservation, Reduce Waste, Re-use and Re-Cycle to protect our environment, so that we may leave behind an enduring legacy for future generations.
ISHRAE compliments this initiative from the International Institute of Refrigeration, and, would like to reach out to other like-minded Associations so that we may, together, help make the world a better place.

Pankaj Shah - President ISHRAE



ABRAVA - Energy Efficiency in Brazil

In Brazil 77,3% of the electric power production is done by hydroelectric power plants, the automobiles are "flex-fuel", operate with ethanol or gasoline which possesses 20% of ethanol. Considering the total Brazilian energy consumption, 37,4% come from Petroleum, 6,0% from Mineral Coal and the remaining 57,6% come from Clean Sources, 45,8% are renewable.
So, ten years ago, the energy efficiency of HVAC-R Systems didn't worry the consumers, including because the energy costs was not so big.
But during the year 2000, after a big period without rains, the hydroelectric plants water reservoirs levels, came to below of its minimum limits; people and government became alert!
This climatic problem, had the virtue of provoking the rescue of a 10 years old bill, transforming that in the "Energy Efficiency Law" (10.295 of 17/10/2001). The law and its regulation (4.059 of 19/12/2001) brought several progresses as the creation of the Energy Efficiency Levels Indicators Manager Committee, that created the PBE (Federal Labeling Program) for electrical motors, lighting, domestic equipments, and for the window and splits equipments. Later on, developed the regulation for the maximum consumption level in commercial and public buildings, etc.
ABRAVA has been strongly acting in this area and possesses representatives in the government's work groups. We already included the ASHRAE 90.1 Norm, as base line for HVAC-R equipments and right now, we are revising the regulation and including in it the recently Brazilian Technical Norm - ABNT 16406, that includes other requirements as the Internal Air Quality, for instance. This norm was developed by the Technical Committee 55, that is sponsored by Abrava and operates in our headquarters. Many other punctual actions are in development by, Abrava alone or together with partners entities with quite exciting results.
Another important point is the substitution of the fluids refrigerants, Brazil as signatory of the Montreal Protocol already eliminated CFCs and at this time is preparing the plan for the elimination of HCFCs through PBH (Brazilian Plan for elimination of HCFCs). Brazil has included an extra phase, previous to the freezing foreseen for 2013, since January of 2009 launched a Normative Instruction (IN 207) that restricts the import of HCFC limiting the growth so that in 2013 we can freeze and begin the phase out in 2015. The PBH at this time is preparing the proposal to be presented in the end of this year where the two fluids chosen are R22 and R141b. It is under study to propose a reduction of 15% and not of 10% as foreseen by the Montreal Protocol.
More two regulations are under public consultation, the Nr. 197 (Revision of the Requirements for the Energy Efficiency Level of Commercial and Publics Services Buildings) and the Nr. 190, (Revision of the Requirements for Air Conditioning equipments). In both, Abrava possesses a fundamental paper to present improvements and to tread more and more the road of the sustainability, through united actions with associates, users, customers' associations and in the development of the HVAC-R professionals.

Vieira De Souza - President ABRAVA

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers: engineering a sustainable Future

The American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE), long history is renowned for its focus on energy efficiency in heating and cooling. Our mission, "promoting HVAC&R to serve humanity and promote a sustainable world," clearly sets a path for us in providing guidance for sustainable design, construction and operation of buildings, systems and equipment.

We provide this technical guidance in a variety of ways – such standards, publications, research, education and conferences. Of note are new projects, including ANSI/ASHRAE/USGBC/IES Standard 189.1, Standard for the Design of High-Performance Green Building, first standard in the United States developed for high-performing buildings, a new building labeling program known as Building Energy Quotient, a new research strategic plan that sets out research goals for the next five years and continued development of our series providing advanced energy design guidance.

Another way ASHRAE provides technical guidance is through its work with sister and partner organizations around the world. By working with others, we can develop a worldwide best practices databank of innovative and successful technologies that can serve the HVAC&R community.

We are particularly pleased to have furthered our work with UNEP, with whom we signed a memorandum of understanding in 2007.

ASHRAE and UNEP recently launched a joint program of work in order to reduce emissions and encourage energy-efficient refrigeration and air conditioning systems and building designs.

This year, I am focusing on Modeling a Sustainable World, calling on use of modeling and integrated design to guide the industry in optimizing system and building performance. Our challenge is to approach every project with innovation, not repetition, and to challenge ourselves to find the elegant solutions that will minimize energy use and provide exceptional indoor environmental quality.

Today, we are called to become the giants of our industry, to set the example of innovation and dedication that future generations will remember when they look back on the time when buildings ceased being net consumers of energy and became net-zero-energy, and even producers of energy.

I invite you to join with ASHRAE in setting the example in energy efficiency, in elegant, innovative solutions to meeting the energy needs of today and the future. To model a sustainable world.

Lynn G. Bellenger - P.E., Fellow ASHRAE - ASHRAE President, 2010-11

IIAR - International Institute of Ammonia Refrigeration

The International Institute of Ammonia Refrigeration provides education and advocacy for the safe use of ammonia and other natural refrigerants for industrial and commercial applications.

It is, therefore, appropriate for us to congratulate you on this new publication as ammonia is the most widely used industrial refrigerant and certainly the most efficient and environmentally friendly.

The use of ammonia as a refrigerant began in the 1800's and continues today in applications from the International Space Station to the local food storage facility.

Ammonia is rapidly increasing as the preferred refrigerant for even more applications because it is so efficient and does not contribute to Global Warming or Ozone Depletion.

The IIAR and its members continue to find innovative ways to reduce energy consumption from refrigeration systems and increase the use of the rejected heat from these refrigeration processes.

This work includes the use of sophisticated motor and system controls as well as the most basic designs that reduce the refrigeration loads in the first place.

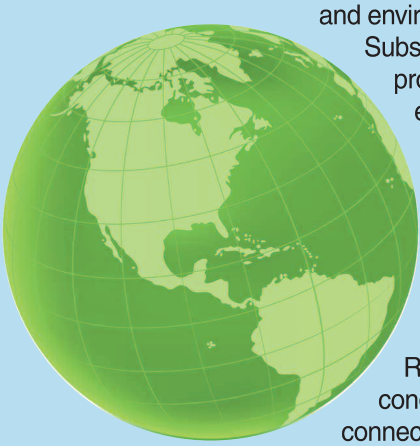
All of these systems employ natural refrigerants that provide the most efficient operations without harming our environment.

Bruce Badger - President IIAR

EPEE - European Partnership for Energy and the Environment

The European Partnership for Energy and the Environment (EPEE), represents the refrigeration, air-conditioning and heat pump industry in Europe. Founded in the year 2000, EPEE's membership is composed of 40 member companies and national associations across Europe realising a turnover of over 30 Billion Euros and employing more than 200,000 people in Europe. As an expert association EPEE is supporting safe, environmentally and economically viable technologies with the objective to promote a better understanding of the sector in the EU and to contribute to the development of effective European policies. EPEE's main priorities for the coming years are: • The promotion of energy efficiency in the HVACR sector by supporting EU policies designed to encourage the use of more efficient products (e.g. Eco-design, Energy label, Eco-label, Energy Performance of Buildings Directive, Green Procurement policies, Promotion of Energy from Renewable Energy Sources), thereby leading to a reduction in CO_2 emissions. • The promotion of the most efficient and sustainable refrigerant choices taking into account the refrigerants' environmental impact, responsible handling, optimal energy performance, and safety in use. For example, EPEE is currently actively involved in: The Ecodesign of energy using products (EuP): By providing timely technical input to the Commission, EPEE ensures that eco-design requirements are technically and economically sustainable. EPEE aims to create a level-playing field allowing fair competition between manufacturers on the EU market. The Renewable Energy Sources Directive (RES): To achieve a 20% renewable energies share, EPEE is promoting the proper and speedy implementation of the directive in all EU Members States, thereby ensuring that all types of heat pumps (air, water, ground source) are recognized and supported as renewable energy technologies. The F-Gas Regulation: EPEE focuses on the responsible use of refrigerants including lower GWP and natural refrigerants by engaging in a proactive dialogue with EU institutions. EPEE stresses that the choice of refrigerant should be based on its intended application with appropriate regard paid to proven energy efficiency, safety, technical viability, direct and indirect greenhouse gas emissions, and environmental and economic viability in a life cycle approach. The Restriction of Hazardous Substances (RoHS): By establishing clear methodologies for granting exemptions to certain products and applications, EPEE aims to ensure that the scope of the directive remains clear, even if the scope is enlarged to all electric and electronic equipment.

Andrea Voigt - President EPEE



REHVA - Federation of European heating, ventilation and air-conditioning associations

REHVA, Federation of European heating, ventilation and air-conditioning associations (www.rehva.eu), established in 1963, connects European professionals in the area of building engineering services (heating, ventilating and air-conditioning for energy efficient healthy buildings) and representing more than 100 000 engineers from 28 European countries. REHVA´s main activity is to develop and disseminate economical, energy efficient and healthy technologies for buildings. REHVA is the leading professional organization in Europe, dedicated to the improvement of health, comfort and energy efficiency in all buildings and communities. It encourages the development and application of both energy conservation and renewable energy sources. In these areas, REHVA has a significant impact on National and International strategic planning and research initiatives, as well as on the associated educational and training programmes. REHVA provides networking and cooperation opportunities for both member associations and companies with European and International organizations, which have similar goals in the building sector. This is achieved through the exchange of technical information, practical experience and research results by REHVA's working groups, seminars, publications of guide books, and journal (www.rehvajournal.com). REHVA also published an International Dictionary of building services in 12 languages, which is being extended to some 13000 terms (www.rehvadictionary.eu). REHVA regularly keeps the contact with CEN and most important Directorates in European Commission; DG Energy and Transport for energy issues, and DG Health and Consumer Affairs for indoor environmental issues and informs them regarding the needs of HVAC industry, and also REHVA´s members regarding the upcoming directives, regulations and standards in Europe. REHVA organizes CLIMA international congress every 3 years, gathering between 500 - 1000 participants in the building services sector. Besides the Plenary, Technical and Poster sessions, a dense program of Technical Workshops is also offered to the attendees. These technical workshops offer the perfect platform for peer exchanges on current hot topics and are therefore the ideal place to present, discuss and disseminate projects results. Last CLIMA2010 was organized in Antalya, Turkey, May 9-12, 2010 where more than 1000 participants shared the technical sessions and 25 parallel workshops. Next CLIMA conference will be held in Prague, June 16-19, 2013. REHVA being a large network of European associations active in building services, its strength lies in the fact that its national associations can serve as strong communication vehicles.

Francis Allard - President REHVA

ECSLA - European Cold Storage and Logistics Association

The refrigerated cold storage and logistics operators across Europe will need to concentrate their efforts on the energy consumption of their cold stores in the upcoming years. This will require strategic choices of refrigerants as well as very strict monitoring of their procedures and cold production. Cold store operators have been under great pressure in the last few years with regards to the refrigerants used to produce the temperatures required to preserve goods. Tremendous financial efforts have been made to convert HCFC-operated cold stores towards solutions with lesser ozone depleting effects. Regulatory constraints in certain EU Members States as well as the technical difficulties, and therefore the costs, of converting an HCFC R22 plant to ammonia made ammonia a difficult and costly choice and certain operators turned to HFCs as a less expensive alternative. Thanks to effective lobbying at local level, it seems that the administrative burdens on the use of ammonia have been removed and converting to ammonia or CO_2 can now be seriously considered. The high greenhouse effect and the lower energy efficiency of HFCs should make them questionable alternatives to HCFCs. They are, however, very widely used in certain applications such as air conditioning and mobile refrigeration. A great number of cold stores in Europe, whether run by third party logistics operators represented by ECSLA, or by private owners across the food chain (manufacturers, producers, and retailers) still run on HCFCs and need to meet the 2015 deadline. Immediately linked to the choice of refrigerant is that of energy consumption, be it direct or indirect. Energy prices are rising and so is awareness of the need to reduce energy consumption, both from an economics and from a sustainable development point of view. Energy can be saved in many areas: by choosing higher energy performance refrigerants such as ammonia, by closely monitoring the running of the plant (door openings, cold production during off-peak energy hours, strict maintenance of equipment such as condensers (defrosting), vigilance on frost build-up in storage rooms, by considering alternative sources of energy, …). No two plants are alike and no single solution can be applied across the sector. Cold store operators need to analyze their procedures and define codes of best practices. Also, they will need to find well documented technical experts who will be able to carry out critical analysis of alternatives in order to advise them Serious consideration must be paid to all aspects of refrigerant conversion and short term savings must not alleviate long term recurring costs.

Wim van Bon - President ECSLA

CAR - Chinese Association of Refrigeration

Chinese Association of Refrigeration (CAR) was founded on April 25th, 1977. CAR is a national scientific organization in the field of refrigeration and air-conditioning industry and trade, which is subordinated to China Association for Science and Technology (CAST). CAR formally joined in the International Institute of Refrigeration (IIR, headquarter in Paris) in January 1978, and became a second category membership country. Up to now, CAR has 480 company members, more than 10,000 private members. CAR always aims at solidifying and serving members and technical personnel in the field of refrigeration. For the development of science and technology of China refrigeration, CAR has conducted many activities, such as facilitating domestic and international scientific communication, formulating and revising standards of the technologies and products in the field of refrigeration. As one of the top scientific organizations in China, CAR promotes and conducts positively domestic and international scientific technology communication. Every year more than 20 conferences are held or jointly organized by CAR. At present, a number of conferences sponsored by CAR become very famous and popular, such as Annual CAR Conference, Annual National Conference of Heating, Ventilation, Air Conditioning, and Refrigeration, National Food Cold Chain Conference. For the past thirty years, CAR has established science and technology cooperative relations as well as economic and trade connections with academic bodies and enterprises in US, UK, France, Russia, Japan, Italy, Sweden, Switzerland, Norway, Denmark, Germany, Poland, Austria, Canada, Korea, India, Australia, New Zealand, Belgium, Turkey and Columbia, and has made contributions towards our refrigeration and air-conditioning industry in promoting academic exchanges and trade with foreign countries. CAR has successfully held almost thirty international conferences and twenty international refrigeration exhibitions in China. CAR has also organized domestic delegations to visit foreign countries for inspection and trade. The Secretariat of the National Refrigeration Standardization Technology Committee (SAC/TC119) was located in CAR. According to the instruction of Standardization Administrator of China (SAC), SAC/TC119 is responsible for the establishment of general basic national refrigeration standards, commercial refrigeration equipments standards, etc. It also is in charge of the connection with the Refrigeration and Air-conditioning Standard Committee of International Organization for Standardization (ISO/TC86). Authorized by National Office for Science and Technology Awards, the CAR Science and Technology Awards were founded in 2003, including Technological Invention Awards, Science and Technology Progress Awards, Outstanding Contribution Awards, Young Researcher Awards. The CAR Science and Technology Awards issued every two years are the highest-level awards in the field of refrigeration industry in China. In addition, CAR also carries out the refrigeration engineer qualification, publications, china refrigeration exhibition for the development of science and technology of China refrigeration.

Yang Yifan - President CAR

UNEP

UNITED NATIONS ENVIRONMENT PROGRAMME
INTERNATIONAL INSTITUTE OF REFRIGERATION
CENTRO STUDI GALILEO - ASSOCIAZIONE TECNICI DEL FREDDO

XIV EUROPEAN CONFERENCES ON

TECHNOLOGICAL INNOVATIONS IN AIR CONDITIONING AND REFRIGERATION INDUSTRY

WITH PARTICULAR REFERENCE TO ENERGY AND ENVIRONMENTAL OPTIMIZATION, NEW REFRIGERANTS, NEW EUROPEAN REGULATION, NEW PLANTS, THE COLD CHAIN

10th - 11th June 2011 - Politecnico di Milano

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First Session
NEW REFRIGERANTS AND PERSPECTIVES. ENERGY SAVING

Second Session
NEW COMPONENTS AND EQUIPMENT IN RELATION TO ENERGY SAVING AND ENVIRONMENTAL ISSUES NEW REFRIGERANTS RESULTS AND UPDATES IN NEW SYSTEMS

Third Session
OPEN DISCUSSION ON ENERGY AND ENVIRONMENTAL ISSUES, NEW FLUIDS, NEW COMPONENTS AND NEW PLANTS IN REFRIGERATION AND AIR CONDITIONING: REVIEW EUROPEAN REGULATION ON F-GASES

Fourth Session
F-GAS REGULATION, EUROPEAN AND INTERNATIONAL LAWS, CERTIFICATIONS AND LICENCES IN REFRIGERATION AND AIR CONDITIONING AND ENERGY SAVING

Fifth Session
NEW CONTROL TECHNOLOGIES, THE COLD CHAIN, COLD STORAGE AND TRANSPORT

EEC

Policy Centre TERRE

THE LATEST TECHNOLOGIES IN RENEWABLE ENERGY, APPLICATIONS IN HEATING AND COOLING to lower CO_2 emissions

"Getting Ready for Renewable Energy - Green New Deal"

HERIOT WATT UNIVERSITY

21st January 2011
Heriot-Watt University
Edinburgh - UK

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Member of Scottish Parliament (invited); R. SHENDE United Nations - UNEP; D. COULOMB IIR; G. FOX, M. BUONI AREA; A. CAVALLINI University of Padova - IIR; E. MACCHI Politecnico of Milan; A. PEARSON IOR; S. ROAF, T. MALLICK, J. WILSON Heriot-Watt University; T. MUNEER Edinburgh Napier University; P. CREANEY ACR Today; W. CHAKROUN ASHRAE; S. RUSSELL University of Edinburgh; P. LUNDQVIST IIR; J. ROY CREST Loughborough University; M. MASOERO Politecnico of Torino; G. PANNO University of Palermo.

First Session
THE NEW COMPONENTS AND EQUIPMENT IN RELATION TO ENERGY SAVING AND ENVIRONMENTAL ISSUES TO CUT CO_2 EMISSIONS: RESULTS AND UPDATES IN NEW PLANTS IN HEATING AND COOLING

Second Session
EUROPEAN AND INTERNATIONAL LAWS AND CLIMATE CHANGE. CERTIFICATIONS AND LICENCES IN ENERGY SAVING. ENERGY CERTIFICATION OF BUILDING DIRECTIVE. NEW CONTROL TECHNOLOGIES IN RENEWABLE ENERGIES

Third Session
OPEN DISCUSSION ON: ENERGY AND ENVIRONMENTAL ISSUES, GOVERNMENT SUBSIDIES AND THE ENVIRONMENT: EXPLORING THE LINKS WITH GND BRIGHT PROSPECTS IN RENEWABLE ENERGY TRAINING AND EUROPEAN REGULATIONS

WORKING TOGETHER WITH THE MAJOR EXPERTS TOWARDS "THE FUTURE OF REFRIGERATION": XIV EUROPEAN CONFERENCE UK-ITALY

UNEP offices in Paris: from the left D.Coulomb-IIR, R.Shende-UNEP, M.Buoni-ATF, J.Curlin-UNEP.

The European Conference UNEP-IIR-CSG-ATF will be held in Milan on the 10th-11th June 2011: www.centrogalileo.it

Last Conference about Renewable Energy -Green New Deal, organised few months ago in Pune, India, under the auspices of the Italian Government. On the podium Marco Buoni, director CSG, secretary ATF, Vice President AREA Air conditioning and Refrigeration European Association.

The XIV European Conference about the latest technology in refrigeration and air conditioning with particular reference to the energy issues will be organized by CSG-ATF, by the United Nations Environment Programme-UNEP and by the International Institute of Refrigeration-IIR on the 10th-11th June 2011 in the Politecnico of Milan.

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

The last ISI2008 of Centro Studi Galileo, United Nations Environment Programme, International Institute of Refrigeration presented in Doha UN conferences. From the left Alessandro Peru, Italian Ministry of the Environment, Didier Coulomb IIR, the representative of Kuwait, Rajendra Shende UNEP, the representative of Qatar.

On the right photo, the presidents of the XII European Conference in Milan who took part to the agreement UNEP-ASHRAE: Prof. Cavallini - Padoa University, K.Isa - Iseda Turkey, R.Shende - UNEP, E.Macchi - Polytechnic of Milan, T.Phoenix - ASHRAE, D.Coulomb - IIR, M.Buoni - ATF (www.centrogalileo.it)

Beginning of the New Journey

Interview with RAJENDRA SHENDE Head, OzonAction, UNEP, Paris

by Marco Buoni, Vice President AREA

2010 marks corner stone in the progress of the protection of the ozone layer. The production and consumption of the CFCs, the man made refrigerant gases which served the humanity to preserve the food, medicines and create comfort cooling , have been totally eliminated starting from year 2010 due to their life threatening destructive properties that deplete the ozone layer. Having closed the Chapter of CFCs, the last chapter under the Montreal Protocol on substances that deplete the ozone layer has begun i.e. the chapter f eliminating the use of HCFCs, yet another group of refrigerants.
Mr. Rajendra Shende, of United Nations Environment Programme (UNEP) who is spear heading the assistance to the developing countries to enable them to comply with the Montreal Protocol , speaks at this critical juncture with Marco Buoni-Vice President of Air Conditioning and Refrigeration European Association – AREA, on the opportunities and threats facing to the refrigeration and air conditioning industries.

The Refrigeration and Air conditioning industry is from 2010 crossing an important mile stone in its history. What are your reflections on this occasion?
The world has just closed the chapter on Chlorofluorocarbons (CFCs). As of 1st January 2010, the production of CFCs, once upon a time called as miracle refrigerant gases, has been halted all over the world. The last CFC-manufacturing facilities from the developing countries have rolled down their shutters. The refrigerant gases that served the humanity for nearly seven decades would now be part of history books. We have to rewrite the text books of chemistry and also the history of science.
25 years back, in 1985, the life-menacing Ozone Hole was discovered over the Antarctic. Within short span of two years from then the governments and industries got their act together to set in motion, what can now be called as the first ever the global rescue mission in the history of the mankind. The Montreal Protocol - a global accord to prevent the disaster - was agreed in 1987 and the ‘operation rescue’ began. Today, in year 2010, we can all proudly look back into the quarter of century on the extraordinary achievement of the Refrigeration and Air conditioning (RAC) industry. CFCs have gone but the RAC industry has thrived. It has undergone an overhaul with modern and more efficient 21st century technologies. Many predicted 25 years back that RAC industry would go bankrupt and would result into tens of thousands of job losses. Nothing of that sort happened. Ingenuity and perseverance of those connected with RAC industry prevailed. Not only RAC industry survived but it signaled that it is ready for seminal transformational changes when faced with crisis any time in the future. When I look back on the last 25 years of the efforts of the RAC industry, I cannot stop thinking that only ‘constant’ in RAC industry is CHANGE!! As we close the door on the first decade of the 21st century, the environmental crises of climate change that the world faces today require actions beyond even the scale to which the world responded to the ozone depletion emergency. At this juncture my thoughts are more focused on how we can use the lessons from the implementation of the Montreal Protocol for addressing the climate change.

What have we learned from success of the Montreal Protocol in general and achievements of the RAC industry in particularly?
Firstly, efforts to achieve single focused results always result into multitude of benefits. The Montreal Protocol had a singular objective of protecting the ozone layer by phasing out the ozone depleting substances. As the world advanced in those single focused efforts, it reaped numerous and far reaching rewards. Today, the Montreal Protocol is not simply a multilateral global accord designed to get rid of ozone depleting substances. To define it like that would be to describe the telescope simply as a tube that has lenses on each end.

What were theses other benefits?
As Noble Laureate, Mario Molina has said, “The Montreal Protocol is widely considered the most successful environmental treaty, phasing out almost

100 ozone-depleting chemicals by 97% and placing the ozone layer on the path to recovery by mid-century (18). It also is the most successful climate treaty to date, because chlorofluorocarbons (CFCs) and most other ozone-depleting substances (ODSs) that it has phased out are powerful GHGs". In addition to eliminating the global consumption of ODSs, the Montreal Protocol's control measures have reduced greenhouse gas emissions by the equivalent of 135 gigatons of CO2 during the period 1990-2010. This can be translated to 11 gigatons a year, four to five times the reductions targeted in the first commitment period of the Kyoto Protocol that ends in 2012. This unprecedented achievement contrasts even more remarkably given that global CO2 emissions instead of decreasing have in reality increased by more than 35 % since 1990.

In phasing out the vast majority of ozone depleting substances, the Montreal Protocol created a whole range of new job opportunities in industrialized and developing countries. The activities like recycling, retrofitting, containment and best practices in servicing and maintenance have given rise to new work areas of emission reduction. In addition, the designing and enforcement of new energy standards and labeling opened up new vistas of business. Developing country enterprises benefited from a new wave of technological innovation by upgrading their production lines, deploying the latest energy and resource efficient technologies. Countries like China were able to phase out not only ODS but even the inefficient enterprises, enabling industrial rationalization and the achievement of an economy of scale.

Are there concrete examples of such benefits?

Let me give you two examples. While the industries do create the environmental problems, they have amazing potential to solve them. And while solving them, the industry further innovates. While phasing out CFC-12 from the domestic refrigerators, industry not only found the most appropriate replacement to CFC12 but went beyond to improve the energy efficiency of the refrigerators. Today the energy efficiency of the refrigerators is 40 to 50% better than those manufactured before the implementation of the Montreal Protocol started. Further, the quantity of the alternative refrigerants used is much less than CFC 12. Thus the material and energy efficiency were both better. Another example is of Centrifugal Chillers, used for the air conditioning of the large buildings.

Before the advent of the Montreal Protocol the centrifugal chillers used CFC 11 as the refrigerant. It had to be purged regularly for the effective operations, thereby emitting CFC 11 to the atmosphere. While CFC 11 has now been replaced by more ozone friendly alternatives, the emissions have also been reduced from nearly 10-25% to less than 1 to 3 percent.

It is difficult for the common man to understand these important benefits, as they are quite technical in nature. How these results could be translated into easy to understand benefits?

It is true that the Montreal Protocol is victim of its own success as the results achieved are related to technical issues. But indeed there is human face of the Montreal Protocol. The latest bulletin from NASA and WMO (world Meteorological Organization) issued in September 2010 have shown that Ozone layer is now stabilized and is on the path of recovery. If climate change does not worsen and if there are no unexpected events like volcano eruptions of high magnitude, we could see the full recovery by year 2060.

The advantages to human health are enormous. As we know the increased incidences of the UV rays due to ozone depletion, result into cataracts, skin cancers, reduced immunity to fight the diseases and reduced plant growth. One recent study published by USEPA in July 2010 has estimated that by year 2060 the avoided cases of cataracts due to the successful implementation of the Montreal Protocol in USA alone would be 22 million. If we consider the average cost of treatment of cataract is about US$ 3000, the cost saving due to avoided cataracts would be US$ 66 billion. Globally, the avoided deaths by skin cancer are estimated to be 2 million. The benefits of avoided health problems arising out of reduced immunity would also be huge.

As the Ozone Layer is well on the path to recovery, Planktons, the bedrock of many marine ecosystems, is now much more protected from deadly UV radiation. As Planktons are protected from deadly UV rays, the marine food chain is also protected.

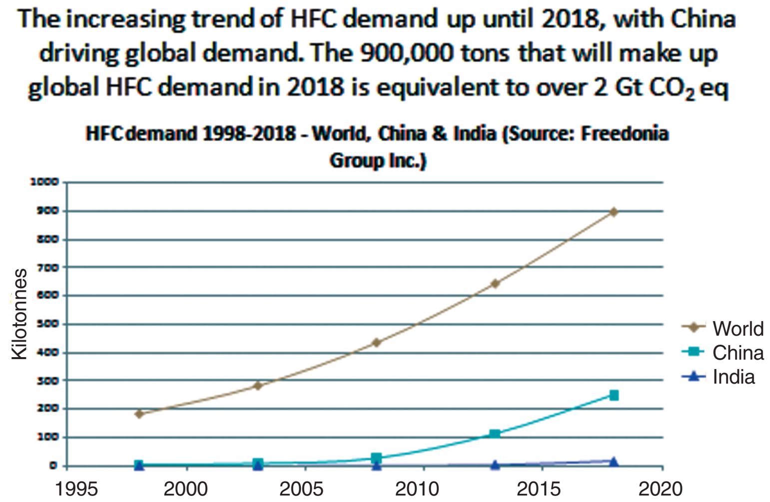
The very foundation on which the biodiversity flourishes is now protected.

Elimination of Methyl Bromide, another Ozone depleting substance, helped in reducing the depletion of the Ozone layer. At the same time useful bacteria in soil that are key to agricultural productivity would now been safeguarded due to the elimination of Methyl Bromide in soil fumigation. Methyl bromide is broad spectrum pesticide that eliminates all the bacteria in the soil-good as well as bad. Now the alternatives would selectively kill the only bad bacteria. Methyl Bromide is also carcinogenic. Hence, elimination of the Methyl Bromide would also protect farmers from being exposed to this carcinogenic substance.

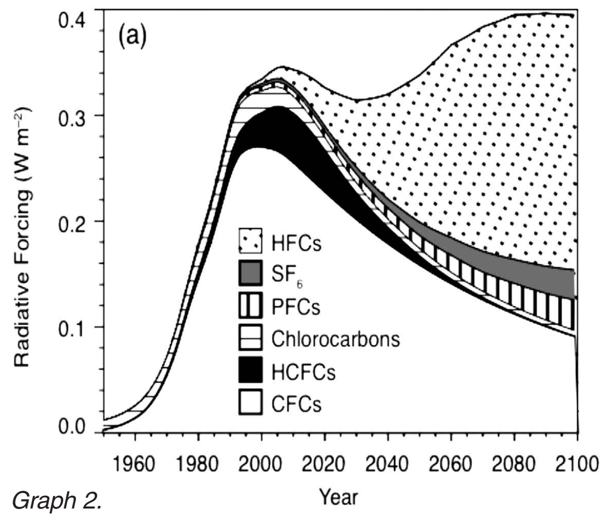
Mankind has shown, through the genius of the Montreal Protocol, that while the man is often at the root of serious environmental problems, it can also invent the elixir that cures them.

How do you see the accelerated elimination of HCFCs agreed globally in 2007?

While the Montreal Protocol has achieved much more of what it set out to do, it still has formidable challenges ahead. The last group of the ozone depleting substances to be eliminated is HCFCs. HCFCs have about 5 to 10% of the Ozone depleting potential as compared to CFCs, they are more powerful Green House Gases (GHGs) as compared to Carbon dioxide, mostly known GHG. Thus elimination of the HCFCs would benefit climate change more than the Ozone layer. And if we consider the possible improvements in energy efficiency while replacing HCFCs - the way it happened while replacing CFCs - then the advantages to climate, and economy would be extraordinary. The peer reviewed estimate by the scientists show that just by eliminating HCFCs by low GWP alternatives, the world would benefit from reduction of up to 25 Giga tons of Carbon dioxide equivalent by year 2040. If we consider the possible



Graph 1.



Graph 2.

improvements in energy efficiency this figures would be much higher.

Those are great opportunities. RAC industry is well placed to derive these benefits. What is needed to get those full benefits?

The core issue would be to deploy low GWP technologies to replace HCFCs. The bad news is that most of the HCFC phase out that has occurred in the industrialized countries by High GWP substitution like HFC-134a. While HFCs have zero ozone Depleting Potential (ODP), they have GWP which are 2000 times more than CO2. Such transformation is likely to be, unfortunately, setting example to the developing countries that would begin their journey to phase out HCFCs in 2013.

The pace of development of low-GWP alternatives is not keeping up with the stringency of the accelerated HCFC phase-out schedule set for the developing countries. Many countries may have no choice but to transition to high-GWP HFCs to meet their HCFC commitments in the near term. This is particularly true in the refrigeration and air conditioning sector. Similarly, the policy incentives needed for the use of low GWP alternatives are not being set in accelerated manner to match the accelerated phase out of HCFCs. The projected growth of HFCs in business-as-usual scenarios is alarming. Forecasts indicate that the share of HFCs in the global fluorocarbon market will jump from 35% in 2008 to 58% in 2018. The 900,000 tons that will make up annual global HFC demand in 2018 is equivalent to over 2 Giga tons CO_2-eq. (see the graph 1).

The graph below from the 2005 IPCC/TEAP report makes clear that if high-GWP HFCs become the primary replacements to HCFCs, then by 2050 the Montreal Protocol will become a net and significant contributor to climate change (see the graph 2).

That appears to be great threat to the environment. What is expected from RAC industry to dilute such risk?

Indeed, it is the Wake up Call! Today, this threatening estimate may appear like distant thunder but I consider it as a storm at our doorstep. The reputation of the Montreal Protocol is at stake. Without immediate action to address these challenges and strengthen the treaty, the Montreal Protocol is in danger of becoming a liability to the global commons. RAC industry needs to rapidly develop and commercialize low GWP and energy efficient technologies. Co-operation with low GWP refrigerant supplier is essential. The technology cooperation between industrialized countries and emerging developing countries would be important step. The research institutes and the industry should undertake joint technology development projects particularly for the low GWP alternatives that are needed in high ambient temperatures that exist in most of the developing countries.

In 2005 IPCC/TEAP Special report on safeguarding the Ozone layer and climate system the issue of ODS banks has been highlighted. How serious is the issue and what needs to be done?

It is very serious issue that needs urgent attention. As per the report you sited, 21 Giga Tones of CO_2 Eq of CFCs, HCFCs and HFCs are contained in old and new equipment in 2002. The banks of CFCs are decreasing due to their escape into the atmosphere. The banks of HCFCs and HFCs are growing. It is estimated that leakage rate could be between 1 to 2 Giga tons of CO_2eq per year unless they are destroyed by incineration.

The international community has shown how to bail out financial banks, it now needs to focus on ODS banks! The costs and efforts required are formidable but not insurmountable. RAC industry has a role to play.

What is your message as RAC industry begins new journey?

While, we are justified in celebrating in the success of the Montreal Protocol so far, this is certainly no time to snooze. I recall what Mahatma Gandhi said once, “Your beliefs become your thoughts; your thoughts become your words; your words become your actions; your actions become your habits; your habits become your values; your values become your destiny”. The destiny of RAC industry lies in setting sustainable business with care for the environment and creation of new jobs and leading towards Green Economy. RAC industry is starting a new journey amidst the threats. But on the way there are low hanging fruits and exceptional opportunities.

Those opportunities should be part of our value system.

●

Didier Coulomb and Marco Buoni on the right (Vice-President AREA, Secretary ATF, Director CSG).

Global warming: a key issue for refrigeration and air conditioning

DIDIER COULOMB

Director International Institute of Refrigeration - IIR

This topic will be discussed in the next 14th EU Conference in UK and in Italy

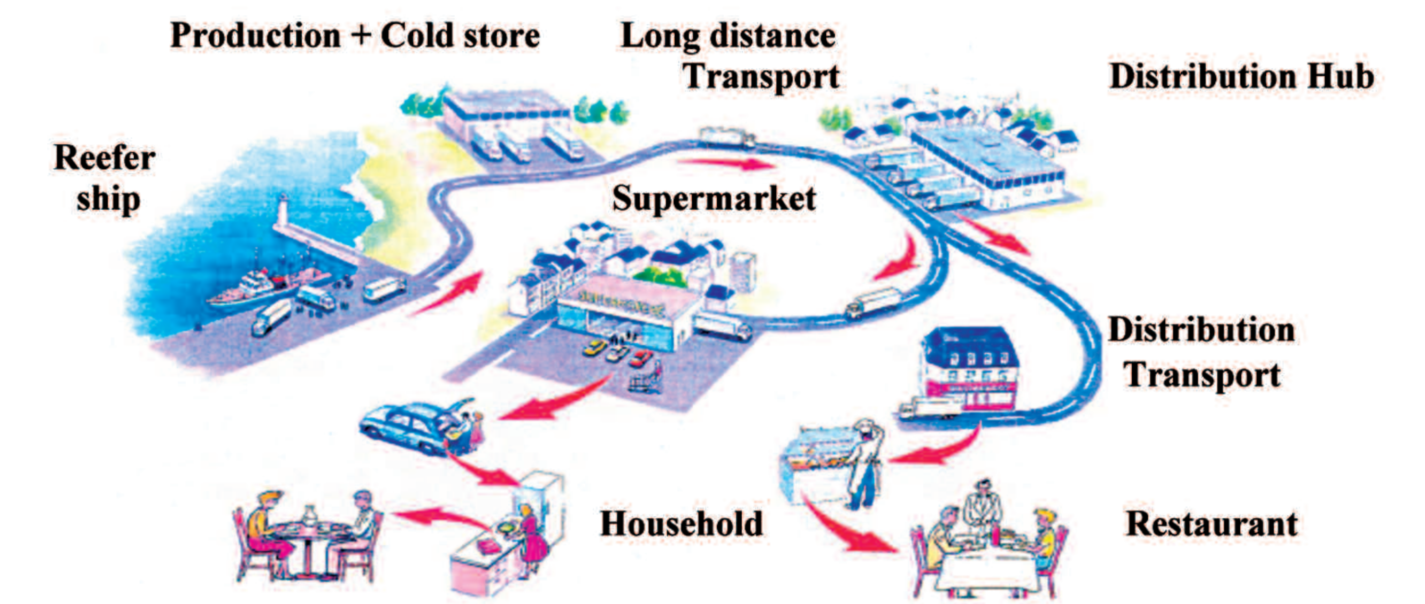
INTRODUCTION

Refrigeration, including air conditioning, is necessary for life and will continue to expand worldwide. Its impact on environment is huge, even if refrigeration technologies can also be part of solutions for mitigating global warming (new sources of energy, heat pumps...). Many efforts have already been made. However, reduction in CO_2 emissions and fluorinated gas emissions are challenges to be addressed on an ongoing basis.

REFRIGERATION IS NECESSARY FOR MANKIND

Temperature is a magnitude and a key variable in physics, chemistry and biology, and characterizes the state of matter and liquid, solid and gaseous phases, which is vital to all living beings.
Thus, thanks to research and development for almost 200 years, refrigeration technologies have progressively led to the providing of goods and the setting up of services vital to mankind:
- Cryogenics: air separation for medical uses (cryosurgery, anaesthesia); petrochemical refining, steel production..; space propulsion fuels, superconductivity for large research instruments, energy (thermonuclear fusion…), medical applications (scanners..), transport and distribution of natural gas or hydrogen, manufacturing of semi-conductors, sequestration of CO_2, conservation of species…
- Other health uses: preservation of cells, tissues, organs, embryos… surgery and operating theatres, manufacturing and transport of drugs, vaccines..

The Cold Chain



- Air conditioning: vehicles, living areas, integrated systems (heating and cooling) with heat pumps, offices and factories, particularly in hot climates but also for technologies (electronic components, computer technology, data centres, biotechnology)…
- Food: manufacturing (texturation, formulation, freeze-drying, fermentation, concentration and separation), storage, transport, commercialization, domestic refrigerators.
- Energy and environment applications: cryopreservation of genetic resources, capture and underground storage of CO_2, heat pumps, new energies…
- Public works, leisure activities….

Moreover, these applications will continue to expand not only because they are needed for our whole current way of life (e.g. air conditioning for data centres and computer technology...) but also because they are necessary for life itself. Needs in terms of health will dramatically increase:

- according to the FAO[1], about 1 billion people are undernourished.

The population is predicted to rise from about 7 billion now to probably a little more than 9 billion people in 2050[2]. The global food energy intake per person is increasing too. The global food supply must increase considerably in order to achieve global food security in an equitable manner. The most commonly cited solutions in order to raise production are: i) expansion of the quantity of arable land; ii) higher crop frequency (often through irrigation); and iii) increased crop yields thanks to improved agricultural production technology. The lack of arable land along with limited water resources in many parts of the world is likely to hamper the first two solutions. Therefore, increasing agricultural production alone may prove insufficient to address food security and safety. Greater emphasis on a holistic solution, that encompasses the reduction of post-harvest losses, is an additional sustainable way of increasing food availability.

Greater use of refrigeration technologies would ensure better worldwide nutrition, in terms of both quantity and quality.

Foodstuffs of animal and plant origin are highly perishable and can host pathogens. Significant causes of food borne diseases and spoilage are bacterial contamination, survival and growth. The use of refrigeration substantially reduces bacterial growth in foods. A study[3] indicates that annually, an estimated 1777 people die every year from known pathogens, out of a total of 5000 deaths from all foodborne diseases in the USA. Analysis of data on causes of foodborne illnesses suggests that over 90% of these illnesses are at least partly associated with poor temperature control.

Global food production comprises roughly one third of perishable products requiring preservation. In 2003, out of a total global food production (agricultural products, fish, meat products and dairy products) of 5500 million tonnes, it was estimated that only 400 million tonnes were preserved thanks to refrigeration (chilled or frozen), whilst at least 1800 million tonnes required refrigeration[4]. This results in huge losses.

- the population, both in developed and in most developing countries, will become older, more urban and will need better food safety and moreover more health care and products, more air conditioning… and thus more refrigeration equipment.

The huge development which is forecast must be sustainable.

REFRIGERATION AND AIR CONDITIONING HAVE AN IMPORTANT IMPACT ON THE ENVIRONMENT

On the stratospheric ozone layer

More than 90% of refrigeration equipment relies on vapour compression using refrigerants and this figure will not change in the near future: other technologies do not generally have enough efficiency.

Chlorinated refrigerants (chlorofluorocarbons – CFCs, and to a lesser extent, hydrochlorofluorocarbons - HCFCs) contribute to the depletion of stratospheric ozone if released into the atmosphere due to equipment leaks or if refrigerants are not properly recovered when disposal of the equipment takes place.

CFCs and HCFCs are gradually being phased out thanks to the Montreal Protocol. Current measurements of the ozone layer show overall stability and probable recovery to the previous level around 2060.

They are often replaced by hydrofluorocarbons (HFCs) which do not deplete the ozone layer but are potent greenhouse gases, as are HCFCs, when released into the atmosphere. CFCs were also greenhouse gases and their global warming potential was much higher. The impact of the Montreal Protocol is thus also positive regarding global warming.

However, it is not enough.

On global warming

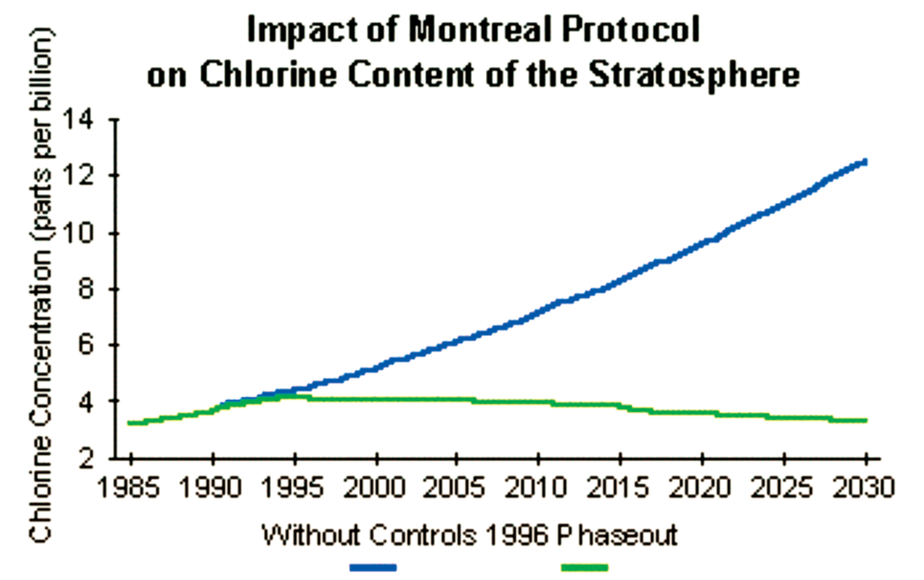
Refrigeration and air conditioning have an impact on global warming in three ways:

- release into the atmosphere of CFCs, HCFCs and HFCs. The contribution of these refrigerants represents between 1-2% of greenhouse gas emissions. It has been reduced considerably since 1987 (signature of the Montreal Protocol) (cf. the following graph).

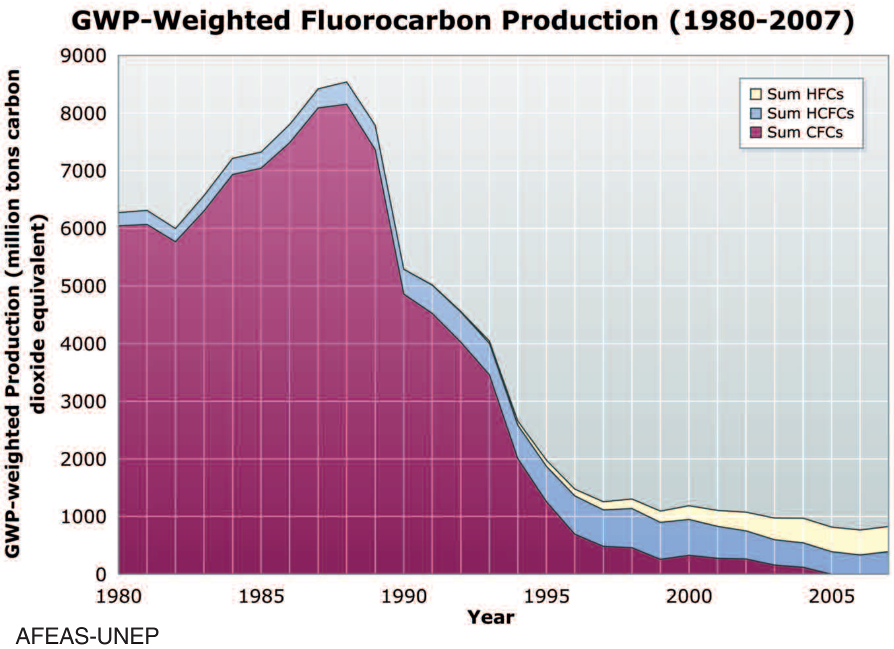
However, the impact of refrigeration and air conditioning on global warming is likely to increase again because of the huge increase in refrigeration equipment uses and thus of HFCs taking place now.

- the energy consumption of the equipment. It represents about 15% of worldwide electricity use and this percentage is even higher (more than 20%) in some developed countries. Electricity is generally produced thanks to fossil fuels (coal, oil, gas) in most countries. Electricity consumption thus represents the major impact of refrigeration equipment on global warming.

There are several solutions: improving the coefficient of performance of refrigeration equipment, thus reducing the electricity consumption per unit; building more integrated and controlled systems of energy consumption in a whole building (heating, cooling, lighting...), in a whole district, in a transport system…; using renewable energy for producing refrigeration or air conditioning, especially solar cooling. Of course, reducing the fossil fuel component of electricity production, thanks to nuclear energy, hydropower, biomass, wind and solar energy…



• The GWP-weighted production of CFCs + HCFCs + HFCs has decreased by 90% between 1988 and 2005



AFEAS-UNEP

NOTES:
1. Calculated from production reported to AFEAS with global warming potentials for a 100-year time horizon from the Scientific Assessment of Ozone Depletion: 2006 (which contains a homogeneous set of GWP values). [Note: The Kyoto Protocol is based on actual emissions, not production.]
2. CFC production was not reported to AFEAS in 2005, 2006 and 2007

would mitigate this huge impact.
- Conversely, refrigeration can be a solution for reducing sources of global warming.
For instance, heat pump technology embodies refrigeration equipment either used for heating, or used for both heating (in winter..) and cooling (in summer..) - reversible heat pumps. This source of energy for heating uses electricity but its impact on global warming is much lower than traditional means of heating; it is thus considered as renewable technology per se under certain conditions in the European Union and its market is expanding very rapidly, particularly in Europe and Japan.
Refrigeration is also needed for liquefaction of gases, providing new sources of energy: liquefied natural gas (natural gas is a greenhouse gas, but exerts less impact than fuel produced by coal and oil); liquefied hydrogen (an energy of the future?).
New sources of cooling (expanding the cooling effect of liquefied nitrogen or liquefied CO_2...) can be more efficient in certain applications than traditional vapour-compression systems; experiments in refrigerated transport are currently being performed in Europe and in the USA.
New solutions for mitigating global warming also need refrigeration technologies (capture and storage of CO_2…)

MANY EFFORTS HAVE ALREADY BEEN MADE BUT WE STILL HAVE HUGE CHALLENGES

Fluorinated gas emissions

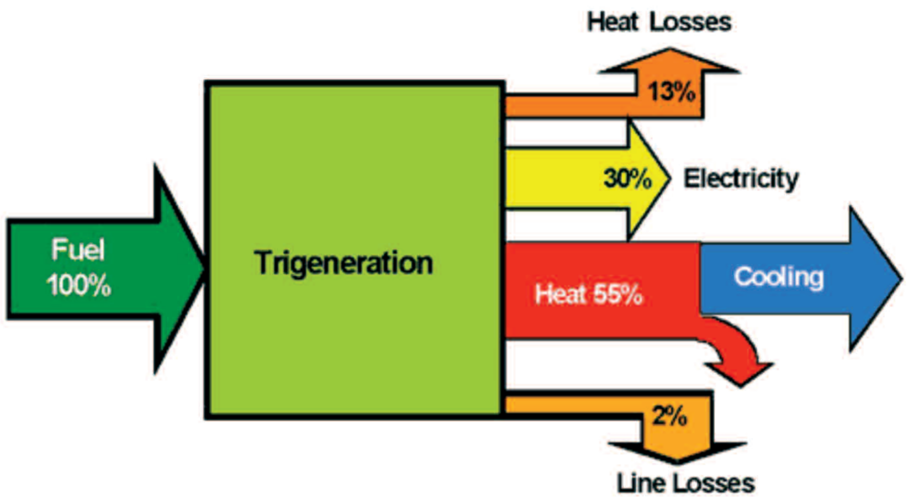
As explained above, these direct emissions have been reduced considerably since 1987. However, we need to act in order to avoid a new increase:
- Set up reliable fluorinated refrigerant recovery all over the world (scrapping of equipment...)
- Reducing leakage through design, proper maintenance, training and certification of technicians and plants. This is the aim for instance of the F-gas regulation in the European Union which will soon be reviewed. Even before that regulation, the leakage rate, which was about 30% in the 1980s is now (on the average) about 5 – 10%;
- Reducing refrigerant charge (secondary loops, micro-channel technology, heat exchangers..) and thus refrigerant emissions per refrigeration unit with the same capacity. It is also a solution which avoids safety problems when using low global warming potential (GWP) refrigerants.
- Promoting low-GWP refrigerants, especially natural refrigerants (ammonia, CO_2, hydrocarbons, water...), which already enable efficient solutions to be developed for most applications. Even if technical solutions were often initially developed in developed countries and in cold climates, applications also exist in China, India, Australia…
- taxing or banning certain high GWP refrigerants in certain applications (e.g. the Mobile Air Conditioning

Regulation in Europe or taxes in certain European countries)
- Promoting alternative solutions (solar cooling, magnetic refrigeration…)
However, all these solutions must be energy efficient. All technical solutions must take into account both direct and indirect effects on global warming (TEWI) under similar conditions (exterior temperature…).

Indirect CO_2 emissions
The coefficient of performance (COP) of refrigeration systems has already been improved. For instance, in commercial refrigeration, it was about 2.5 in 1960 and it is now about 4; new refrigerators used four times less energy in 2008 than 35 years ago. The IIR[5] estimates that a reduction in the energy consumption of refrigeration plants by 20% by 2020 is still perfectly possible.
General policies, such as energy labelling can help: such policy already exists for domestic refrigerators in many countries for instance. Average energy savings of 15% have been achieved in new refrigerators within a few years in these countries[5]. It could be applied to other kinds of equipment, provided that we agree on the system to be labelled (e.g. transport refrigeration: shall we consider only the refrigeration equipment or the whole vehicle, comprising insulation, motorization…?)
Insulation must also be improved. This is obvious for buildings. Many incentive measures have already been taken in order to encourage people to better insulate houses, apartments… However, this can also be achieved in refrigerated transport and in commercial refrigeration. For instance, the design of display cabinets (ways to open during the day, covered at night…) are a major source of energy savings. New technologies, such as phase- change materials, can improve insulation in buildings.
General policies on energy production and uses certainly have huge impacts on the energy consumption of refrigeration equipment: integrated systems, trigeneration (heating, cooling, electricity production) in a whole system, use of renewables in electricity production.
Regulations on safety, on noise… could also have indirect impacts, e.g. the use of liquefied nitrogen or CO_2…
Refrigeration is the heart of many equipment and uses: even regulations on subjects which are not related to refrigeration and air conditioning could have indirect impacts on electricity and energy consumption.

Maintaining solar panels in Mali

Trigeneration principles



CONCLUSION

Refrigeration equipment must be adapted to the global warming challenge. It needs long-term policy. The current phase-out of HCFCs, even if it requires a huge effort on the part of the refrigeration sector, provides an opportunity to design new equipment using renewables as energy sources and using technologies with good energy efficiency. Existing equipment can and must be improved. However, the progressive renewal, within about 20 years (lifespan of equipment) on the average, of refrigeration and air–conditioning equipment, using environmentally friendly technologies, is a key factor and could represent a major part of worldwide efforts for mitigating global warming until 2030. •

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Efficient Refrigeration Technologies – a prerequisite for sustainable development

PER LUNDQVIST

President of commission E2 Heat Pumps and Heat recovery of the IIR
The Royal Institute of technology - Dept. of Energy Technology - Sweden

It is clear that refrigeration in various forms is essential to mankind. It is a prerequisite for sustainable development, to minimize harvest losses, enable vaccine transport and provide human comfort and so on. It is also clear that the use of these technologies contribute to emission of climate gasses, direct emissions of working fluids (mainly CFC, HCFC and HFC´s) but also, to an even greater extent with indirect emission of CO2 for the associated power production and thus, also to resource depletion. However, there is a huge potential to improve the performance in all respects and, also, to save huge amount of primary energy by utilization of the heat pumping capability of refrigeration technologies. This article highlights two examples illustrating the ongoing process towards higher energy efficiency and reduced environmental impact for refrigeration technologies as a whole.

Background

It has been estimated that refrigeration and air conditioning counts for more that 15% of the electrical demand worldwide with significantly higher fraction in cities in hot and humid climates (IIR, 2002). We can also assume that Refrigeration demand will continue to grow in a considerable manner in the future, particularly in developing countries. This will in the shorter perspective inevitable lead to increased primary energy use even if more efficient technologies find their way to the market.

It is therefore essential to seek all opportunities to meet the challenge to make these technologies more sustainable taking containment of working fluids and significantly higher energy efficiency as the top priorities. However, refrigeration technologies are often "systems in systems" meaning that the need for air condition or refrigeration also can be mitigated by better building design, more efficient display cases in supermarkets and so on. *Basically, a wider systems approach is needed for the future*. One kind of refrigeration technology namely heat pumps are also able to directly save for the future. Several recent comprehensive studies have pointed out heat pumps as one of several key technologies for a more sustainable global energy system. Example here is the so-called blue map scenario developed by the IEA (OECD/IEA, 2008), cool planet study (Tanaka, 2008) but also IPCC through the AR4 report (Barker T., et.al., 2007). Several concepts have been introduces to evaluate the environmental l impact of refrigeration technology. The most well know are typically referred to TEWI, or LCCP methods. These methods have however been focussed on determining the CO_2 equivalent emissions due to direct emissions of working fluids and the indirect emission caused by power production. The focus is thus strictly on the refrigeration plant itself.

Two machines in a similar environment may be compared but, as we will argue further in this article, a comparison of overall energy efficiency is more difficult since the applications and the boundary conditions vary significantly.

Overview of applications of refrigeration technologies

The scope of refrigeration is wide. It has applications embracing a huge range of fields we all encounter in our everyday lives. We know that refrigeration:

• can reduce post-harvest losses, preserves foods and makes it possible to provide the
safe, wholesome food all consumers have the right to expect;

• plays a key role in the healthcare sector, with safe vaccine storage, cryosurgery and cryotherapy have been made possible by the advent of advanced refrigeration technologies;

• promote economic and social development in hot countries thanks to air-conditioning providing decent indoor conditions,

• is necessary for many industrial processes in food, chemical, plastic and many other industries;

• enables liquid natural gas, an environmentally friendly source of energy, to be transported and stored;

• enables superconductivity to be applied in the medical field and, in the future, for transmission of electricity over long distances.

Further to this refrigeration cycles applied as electrically or heat driven heat pumps can be used for heating by utilizing renewable energy sources and waste heat.

The potential to improve energy efficiency

The potential to improve the overall energy efficiency is huge. Some estimates suggest between 30 to 50% better efficiency in the future. This is clearly demonstrated by the positive development going on in several sectors with the refrigeration field. A recent report issued by the European Commission's Joint Research Centre (JRC) shows that energy efficiency measures triggered by energy labelling and minimum energy efficiency standards, together with national policies and incentives have been contributing significantly to stabilize electricity consumption in the European Union.

For the first time since 1990, final electricity consumption decreased in EU households from 806.5 TWh in 2006 to 800.7 TWh in 2007 (Ibid.). Cold appliances (refrigerators and freezers) have contributed to this decrease since the energy efficiency index of cold appliances sales improved continuously between 1993 and 2007, reaching a remarkable 44% energy improvement over 14 years. In 2007, cold appliances were the second largest electricity consumer in EU households (122.0 TWh; 15.3%) representing around 191 million refrigerators and 84 million freezers. Electric heating was the largest consumer (18.8%) while air conditioning was the 12th largest consumer (17.0 TWh; 2.1%).

In the tertiary sector, the electricity consumption was almost constant in 2007 (760.4 TWh) in comparison with 2006 (757.3 TWh). Whilst indoor lighting in commercial buildings was in 2007 the largest electricity consumer (21.6%), commercial refrigeration was 4th (65.8 TWh; 8.7%) and air conditioning was 10th (21.6 TWh; 2.8%).

IIR (and others such as ASHRAE) have published several guidelines and publications dealing with detailed guidelines enhanced energy efficiency for refrigeration systems (IIR, 2007). The general principle is however relatively simple.

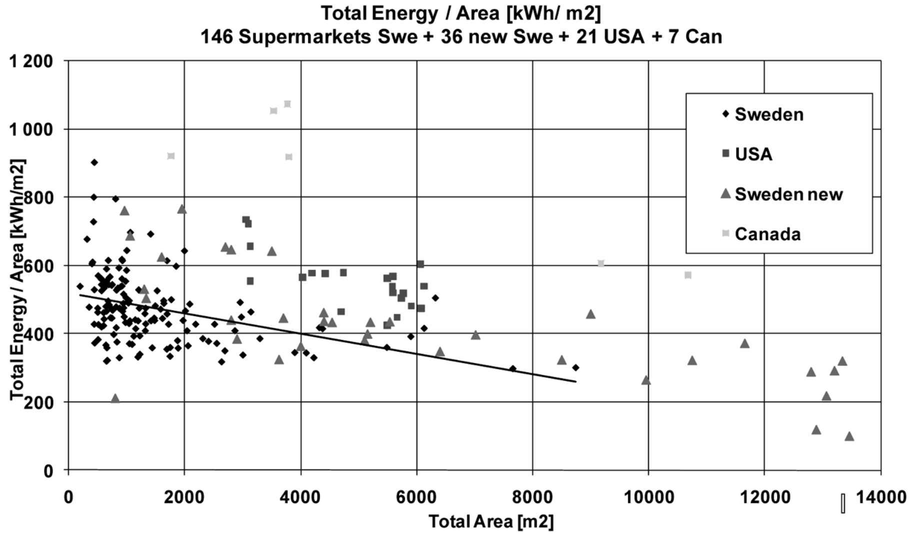
The energy usage can be minimized by either controlling the refrigeration demand (required cooling capacity, Q_2) or the required temperature lift (ΔT). A mechanically driven refrigeration system (in a supermarket, for example) with heat extraction at -10 °C from display cases in the store and heat rejection at an ambient temperature of +30°C (ΔT = 40 K) could theoretically achieve a COP_2 of:

$$COP_{2,max} = \frac{T_2}{T_1 - T_2} = \frac{263,15}{303,15 - 263,15} = 6,58$$

In practice, this number is typically 50% or less of what is theoretically possible. The reasons are losses in components such as electric motors, compressors, heat exchangers and so on. A system that reach 50% of what is theoretically possible would therefore reach a real COP_2 of 3, 29. However, if the desired temperature on the cold side is increased from -10 °C to 0 °C by better display case design (ΔT = 30 K) the maximum COP reaches 9,11 and the real COP would thus, with the assumptions, be 4,55 which is 38% better!

It is therefore important to design system for a minimum temperature lift while at the same time controlling the refrigeration capacity demanded. The same argument is valid for heat pump applications where heat pumps provide heating for buildings, or where heat pumps provide energy recovery in industrial processes. Two short cases will here be used to illustrate the potential.

Figure 1.
Ratio of annual total energy demand to nominal refrigeration capacity during a year versus total area in the supermarkets from Sweden, USA and Canada including 14 new Swedish supermarkets.



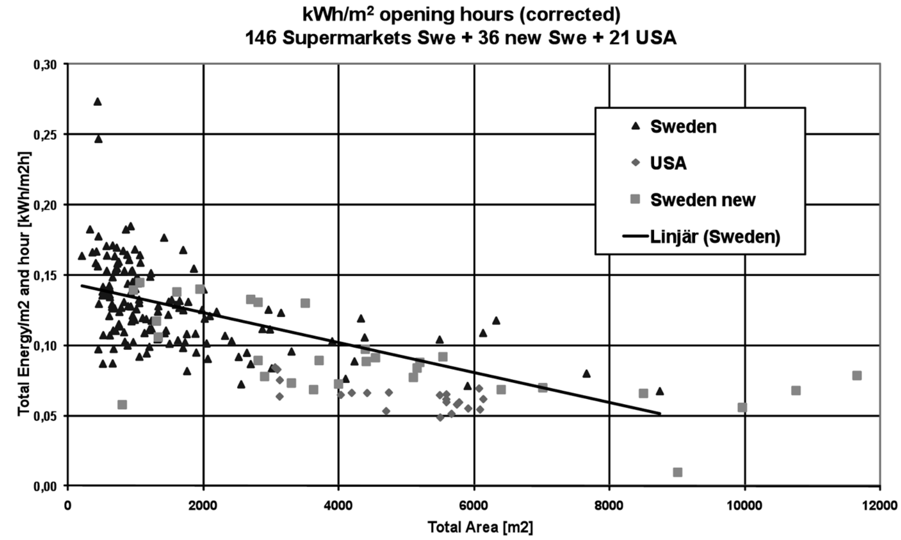
Case 1 - Supermarkets

Commercial refrigeration was one field of refrigeration identified in the aforementioned recent EU study. One way to illustrate potential energy efficiency improvements is thus supermarkets. A recent IEA project, Annex 31, Advanced Modeling and Tools for Analysis of Energy Use in Supermarket Systems, has compared energy usage in supermarkets in Sweden, US and Canada (Arias, et.al. 2010). Figure 1 shows total energy use per sqm for 210 supermarkets. It is clear that there is a huge variation between supermarkets of the same size thus indicating a huge potential in energy efficiency improvements by better overall design. It is also clear that the differences between differ stores cannot be explained by the efficiency of the refrigeration system only.

There is however several additional variables to take into account. The stores in figure 1 have different opening hours. If the results are adjusted also taking the opening hours into account we see that the energy efficiency is relatively similar in all three countries but the obvious variations between efficient and less efficient stores remains (Ibid.).

There are of course several reasons for the variations; one is that during recent year several new ideas and measures to improve supermarket

Figure 2.
Annual total energy demand per opening hours (corrected) versus total area in the supermarket for Sweden and USA including data from 36 new Swedish supermarkets.



energy efficiency have been introduced in different countries. Examples here are:

- Energy efficiency display cases with doors (minimizing cooling capacity)
- Heat recovery using heat pumps (minimizing heating energy)
- Energy efficiency lightning including smart control (timers)
- New efficient system solutions with natural refrigerants (mainly CO_2)
- Efficient secondary coolant systems utilizing so-called laminar flow heat exchangers
- Efficient control systems
- Etc.

Case 2 - Heat Pumps

There have been many recent attempts to quantify the potential of heat pumps (electric and heat driven) in reducing CO_2 emissions as well as in saving on primary energy. IEA Heat pump program, for example, estimates that heat pumps, fully utilized in all sector, can cut global CO_2 emissions by 8% (HPC, 2006). The recent Japanese governmental research program *Cool Earth – Innovative Energy Technology Programme* aims to identify the technologies with the greatest potential to mitigate global warming (Tanaka, 2008). The program identified 21 technologies to be developed to cut emissions of GHG´s by 50% by 2050. High-efficiency heat pumps is one these 21 technologies along with high efficiency housing and so on (Ibid.). Similar perspectives are put forward in the recent IEA publication: *Energy Technologies Perspectives – Scenarios and strategies to 2050* (OECD/IEA, 2008). The heat pump is highlighted as one of the key technologies to mitigate global warming but also for more efficient fuel utilization in general (Ibid.). In the recent IPCC 4th assessment report from WG III heat pumps are also highlighted as an important technology (Barker et.al. 2007). The IPCC reports states:

"Investments in the buildings sector may reduce the overall cost of climate change by simultaneously addressing mitigation and adaptation. The most important of these synergies includes reduced cooling needs or energy use through measures such as application of integrated building design, passive solar construction, heat pumps with high efficiency for heating and cooling, adaptive window glazing, high-efficiency appliances emitting less waste heat, and retrofits including increased insulation, optimized for specific climates, and storm-proofing"

The IPCC report continues:

"Although many practical and cost-effective technologies and practices are available today, research and development is needed in such areas as: high-performance control systems; advanced window glazing; new materials for insulated panels; various systems to utilize passive and other renewable energy sources; phase-change materials to increase thermal storage; high-performance ground-source reversible heat pumps; integrated appliances and other equipment to use waste heat; novel cooling technologies, and the use of community-wide networks to supply heating, cooling and electricity to buildings. Demonstrations of these technologies and systems, and training of professionals, are necessary steps toward bringing those new technologies to market"

It thus clear that the heat pump, as a technology, has an important role to fulfil in the future. One has however to bear in mind that a heat pump unit always is *part of a wider system (Lundqvist, 2010 a,b).* For example, an efficient heat pump unit in a building with unnecessary big heat losses due to poor insulation is not a good overall solution even though the heat pump has a fantastic COP. Thus, failing to make heat pump systems as a whole *efficient enough* must be avoided and some recent attempts to handle this dilemma is given in the new EU directive on renewable energy 2008/0016 (COD). The directive aims to promote the use of renewable energy sources within the framework to achieve the target of a 20% share of renewable energy sources in the final energy consumption by 2020. Notable here is also that the determining factor is Seasonal Performance factor, SPF, also taking supplementary energy into consideration.

The amount of ambient renewable energy captured by heat pumps *to be considered as renewable energy* for the purposes of this Directive, ERES, shall according to appendix VII B in the directive be calculated in accordance with the following formula:

$$E_{RES} = Q_{usable} * (1 – 1/SPF^1)$$

where

- Q_{usable} is the estimated total usable heat *delivered* by heat pumps fulfilling the criteria referred to in Article 5(5) of the directive, implemented as follows: Only heat pumps for which SPF > 1.15 * 1/η shall be taken into account.
- SPF = the estimated average seasonal performance factor for these heat pumps.
- η is the ratio between total gross pro-

duction of electricity and the primary energy consumption for electricity production and shall be calculated as an EU average based on EUROSTAT[2] data.

This means in practice that for a typical η of 35% (meaning an average efficiency for electricity production of 35%) the SPF should be larger than 1,15 * 1/0,35, i.e a SPF above 3,3 should be required. The fraction of the supplied energy that is *counted* as renewable is then calculated as:

$$E_{RES}/Q_{usable} = 1 - 1/SPF = 1 - 1/3{,}3 = 0{,}7 \rightarrow 70\%$$

This may seem like a paradox but the idea is clearly to promote highly efficient heat pump systems. It should be noted that a heat pump with a SPF = 3,3 entirely run on coal electricity produces a substantial amount of carbon dioxide emissions but, according to the proposed calculation procedure, it is 70% renewable energy! A heat pump with a SPF = 3 entirely run on green electricity on the other hand would give 0 % renewable energy!

The improvements in the field of heat pumps are fast and with good building design (low temperature heating systems) and a high temperature heat source (rock, sea water, air, exhaust air etc.) a SPF for heat pumps in new buildings of 6 is a realistic goal even though some recent studies indicate that a SPF of 8 might be achievable in the future.

The role of the International Institute of Refrigeration

The IIR has been particularly active with regards to the global warming issue in the field of refrigeration, air conditioning and heat pumps and has attended most of the Conferences of Parties to the UN Framework Convention on Climate Change. Statements and Informatory Notes presented at these events by the IIR have highlighted the level and impact of direct and indirect emissions from refrigeration systems[3,4]. Mitigation of emissions of greenhouse gases (GHGs) is and will increasingly become an issue of paramount importance. It will drive the development of new equipment and the running of it, particularly in those countries that have ratified the Kyoto Protocol. IIR serves also as the centre of scientific advancement in the field of refrigeration technologies and heat pumps and conferences dealing with all aspects are organised all over the world. IIR also provides the scientific community with a comprehensive search engine, Fridoc, providing access to virtually everything that is published in the field.

Trans-national legislation such as the European Ozone Regulation (EC 2073/2000) and the F-Gas Regulation (EC Regulation 842/2006) are driving improvements in the handling and reporting of the use of refrigerants. Individual countries have implemented additional legislation to restrict the use of HCFC and HFC refrigerants and promote alternatives. Initiatives to enhance the skills of refrigeration and air conditioning craftsperson and to increase the awareness of the impact of direct refrigerant emissions are also driving changes in attitudes, design and maintenance practices.

The role of the IIR with respect to the global warming issue is to promote environmentally friendly, safe, energy efficient and cost effective design, operation and end-of-life management of refrigerating systems and heat pumps. It is well placed to act as a forum for the collection, collation and dissemination of information relating to the direct emission of GHGs from refrigeration systems and their mitigation. Decision makers and refrigeration stakeholders could benefit from well-balanced information and recommendations on this issue.

Conclusions

Heat Pumps for heating of buildings and improved energy efficiency in supermarkets are two examples where refrigeration technologies are gradually improving and becoming more sustainable. Another important area with a significant impact is mobile air conditioning where a significant part of the fuel goes to climatization of the vehicles, especially in city traffic in hot and humid climates. The field with the fastest growth when it comes to electric demand is air conditioning and better, more integrated, building design and use of natural heat sinks such as sea water cooling are promising new alternatives although the major part of the market still is electrically driven split units for single family houses. Improved energy efficiency in this sector is a must. The last field to mention is the cold chain, from reefers, refrigerated storage, distribution cars and, of course, supermarkets all the way to the consumer. All these fields bear one thing in common – a potential for higher energy efficiency and, by smarter design and a more holistic view, lower refrigeration demand. Taken together this will inevitably lead to large energy savings, reduced cabon dioxide emissions and, not to be forgotten, huge savings for the users in reduced operating costs.

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1. SPF = Seasonal Performance Factor, i.e the total energy delivered by the heat pump system over a year divided by the driving energy including supplementary energy needed on cold days (if applicable).
2. http://epp.eurostat.ec.europa.eu/portal/page_page id=1090,1&_dad=portal&_schema=PORTAL
3. D. Coulomb. IIR statement to the UN Climate Change Conference (COP14 and CMP4) Poznan, Poland, 1-12 December 2008
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Ground source heat pumps for heating and cooling in the Mediterranean Countries

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This topic will be discussed in the next 14th EU Conference in UK and in Italy

Geothermal energy is becoming all around Europe one of the most interesting sources of renewable energy for heating and cooling by ground coupled heat pumps. The EU Ground-Med project aims at demonstrating the sustainability of heat pump technology for heating and cooling of buildings in the Mediterranean climate. Within the framework of this project eight ground source heat pump systems shall be built and monitored, with heating capacities spanning from 14 to 60 kW. The main objective of Ground-Med will be to demonstrate that a measured seasonal performance (SPF) higher than 5 can be obtained. As the SPF is determined not only by the heat pump unit, but also by its operating conditions, imposed by both the ground heat exchanger and the heating/cooling system of the building, integrated GSHP systems incorporating proper technological solutions are being developed. In the present paper some aspects of the Ground-Med heat pumps will be addressed.

INTRODUCTION

Ground source heat pumps (GSHP) are water source heat pump systems comprising ground heat exchanger (pipes buried within the ground where water is circulated as a heat carrier) and low temperature heating (and cooling) system (floor heating, fan-coils, etc.).

As they exploit the favourable ground temperature, which remains almost constant throughout the year, independently of external weather conditions, ground source heat pumps provide efficient heating, cooling and domestic hot water supply to the buildings.

A rapidly growing field of applications is emerging and developing in various European countries, utilizing shallow geothermal resources. In Central and Northern Europe, where most of the market development took place, due to the climatic conditions, the major use of heat pumps is for space heating, while cooling is rarely required. Therefore, these heat pumps usually operate mainly in the heating mode. Only in very recent years the installation of GSHP in Southern Europe, in particular in Greece Italy and Turkey, is on the way to exceed demonstration status.

Nowadays, the double use for heating and cooling is becoming increasingly important. In this sense, implementation of this technology to cooling dominated applications in mild and hot climates is still in the early stages.

Urchueguía et al. (2008) have recently reported the results of the European Project GeoCool, drawing a comparison between the energy performance of a ground coupled water to water heat pump system and an air to water heat pump system for heating and cooling in typical conditions of the European Mediterranean coast. They found, in their particular application, that the savings of the geothermal system in terms of primary energy consumption are around 40% in the heating season while they are around 37% in the cooling season.

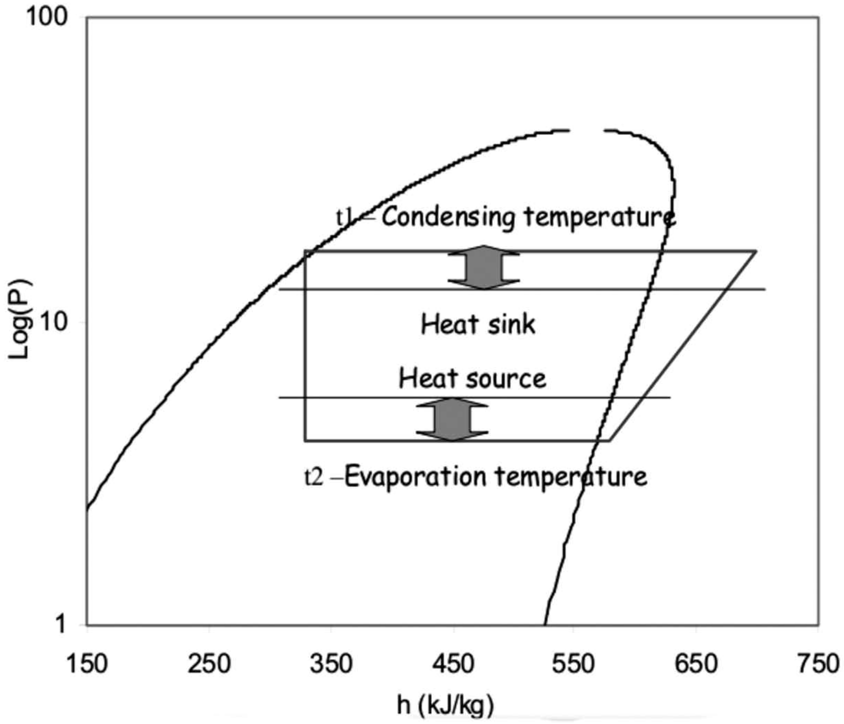
They also concluded that the oversizing of the capacity during milder heating or cooling periods causes considerable efficiency penalties and for these periods a capacity adaptation strategy would be advisable. The impact in electricity consumption of the auxiliary elements of the AC system such as circulation pumps and fan–coils was found to be large and should be taken into account to improve the system efficiency, pointing to the necessity of improved control strategies.

The European work programme for energy supports technology development and demonstration of ground source heat pumps aiming at increasing the coefficient of performance of the heat pump and of the overall system in order to reduce the electricity consumption and extend its usage in Europe and particularly to the Mediterranean regions. Ground-Med is a collaborative project which aims at demonstrating innovative ground source heat pump solutions in eight buildings in Mediterranean EU member States (Portugal, Spain, France, Italy, Slovenia, Romania, Greece). Twenty four European organizations join the Ground-Med consortium, including research institutes and universities, heat pump manufacturers, industrial associations, energy consultants. The University of Padova (Italy) is partner of the Ground-Med Consortium, which is coordinated by CRES (Greece). The heat pump manufacturers are CIAT (France), Hiref (Italy) and Ochsner (Austria).

GUIDELINES FOR IMPROVEMENT OF ENERGY EFFICIENCY

As a general rule, the energy performance of a vapour compression cycle is enhanced when the difference between condensing and evaporating temperatures (i.e. the temperature lift) is reduced. A qualitative description of the temperature levels in a vapour compression cycle is shown in Fig. 1. Typical values of COP for geothermal heat pump systems versus heat source temperature are given in Fig. 2. When operating in heating mode, the heat source temperature in Fig. 1 is given by the temperature of the ground. The heat sink temperature, instead, is given by the temperature of the water in the heating system. The heat sink temperature depends on the heating system adopted for the building, since when using floor/wall heating systems the temperature of the hot water can be reduced as compared to fan coils, and even more as compared to traditional radiators.

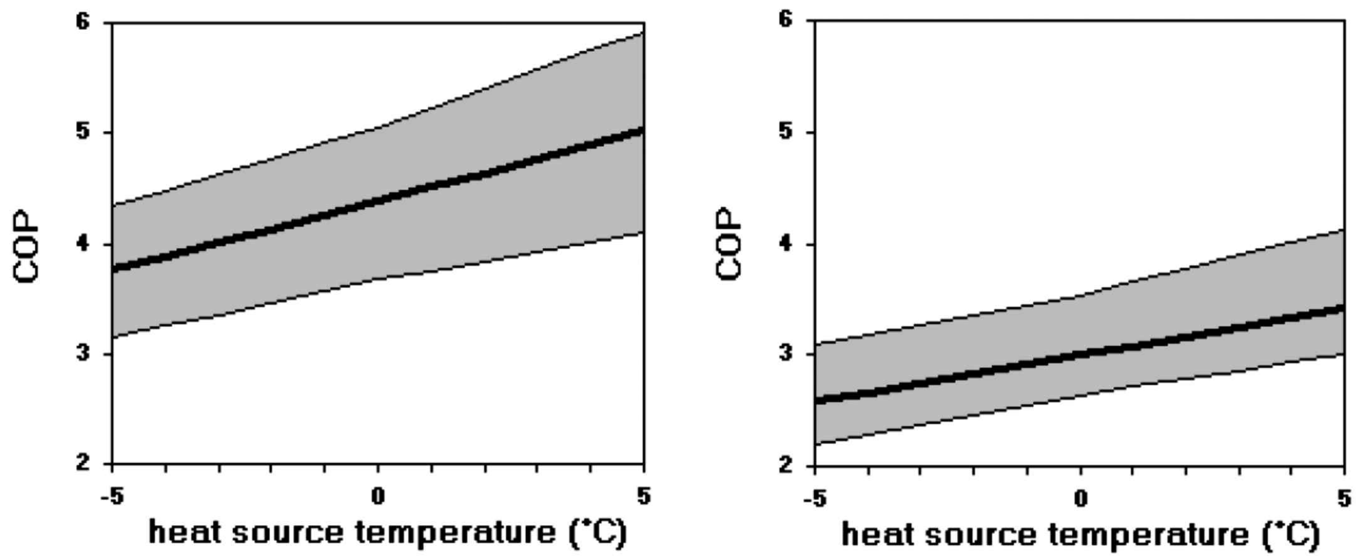
Figure 1.
Temperature levels in a vapour compression cycle.



A temperature difference exists between the heat source and the evaporating temperature because of the heat transfer processes in the borehole heat exchangers (between the ground and water) and in the evaporator (between the water and the refrigerant). Besides, a temperature difference exists also between the condensing temperature and the heat sink temperature because of the heat transfer between refrigerant in the condenser and water of the hydronic system.

Brazed plate heat exchangers are used as condenser and evaporator. To emphasize the importance of reducing the temperature approaches, the

Figure 2.
COP for brine/water heat pumps, as used in typical geothermal heat pump systems, at 35 °C outlet temperature (left) and at 50 °C outlet temperature (right). From Sanner et al. (2003).



change in COPheating for each degree increase in the evaporation temperature, or decrease in the condensing temperature can be calculated. These values, based on the COPheating of the Carnot cycle, are given for some conditions in table 1. As shown, the change in COPheating is from 1.7 to 4.2% per degree of reduction of the temperature difference between condensation and evaporation.

Table 1.
Influence on $COP_{heating}$ of decrease in temperature difference by 1 °C

$T_{evaporation}$	$T_{condensation}$	$COP_{heating}$ assuming 60% of Carnot	Change in $COP_{heating}$ with 1K higher evaporation temperature	Change in $COP_{heating}$ with 1K lower condensing temperature
-10	+40	3.8	2.0%	1.7%
0	+40	4.7	2.6%	2.2%
5	+40	5.4	2.9%	2.6%
-10	+30	4.5	2.6%	2.2%
0	+30	6.1	3.5%	3.1%
5	+30	7.3	4.2%	3.8%

It can be observed that the borehole heat exchangers thermal resistance is a critical factor for a geothermal heat pump. For a typical peak load extraction rate of 30 Wm-1, a borehole thermal resistance of 0.15 KmW-1 (i.e. badly constructed borehole) would need a 4.5 K temperature difference to drive the heat transfer, while with a thermal resistance of 0.08 KmW-1 (i.e. very well constructed borehole) the temperature difference would be 2.5 K. The corresponding COP improvement would be between 4% and 8%.

Scroll compressors are used in the heat pumps of the Ground-Med project. Experimental values from Corberán et al. (2008) of volumetric and compression efficiencies of scroll compressors are shown in Fig. 3. A semi-hermetic reciprocating compressor, a hermetic reciprocating compressor and a scroll compressor, all having similar volumetric capacities are compared in the graphs, using propane as the refrigerant. Scroll compressors are able to provide a higher efficiency over a central operation area, but beyond that area the efficiency decreases.

The Ground-Med heat pumps will use refrigerants R410A and R407C. Since the pressure ratio for a typical geothermal heat pump application, as estimated in Table 2, is small, it could be concluded, as a general rule, that scroll compressors are expected to provide a higher efficiency as compared to reciprocating compressors. It must be noticed, however, that the efficiency of the scroll compressor decreases very sharply by decreasing the pressure ratio.

An essential characteristic of the Ground-Med heat pumps is that they have to provide both heating and cooling. A simple way to obtain reversing mode operation is by shifting the secondary fluid from the evaporator to the condenser and viceversa.

Nevertheless, there may be two aspects against this solution: a) the cost may be higher in comparison to the use of a refrigerant four-way valve; b) this may not be appropriate when two different secondary fluids are used (in borehole heat exchanger and building loop). Within Ground-Med, two water-to-water heat pumps are reversed on the water-side. All the other heat pumps use a four-way valve on the refrigerant side. In this case, proper attention is paid to match the temperature profiles in the heat exchangers as much as possible. The simple use of the reversing valve, without changing the flow in the heat exchangers, may imply some penalty which depends on the heat exchanger and the refrigerant under use. Therefore, especially with R407C, a four way valve is used also on the heat transfer fluid side.

Figure 3.
Volumetric and compression efficiency for a semihermetic reciprocating compressor, a hermetic compressor and a scroll compressor (Corberán et al., 2008).

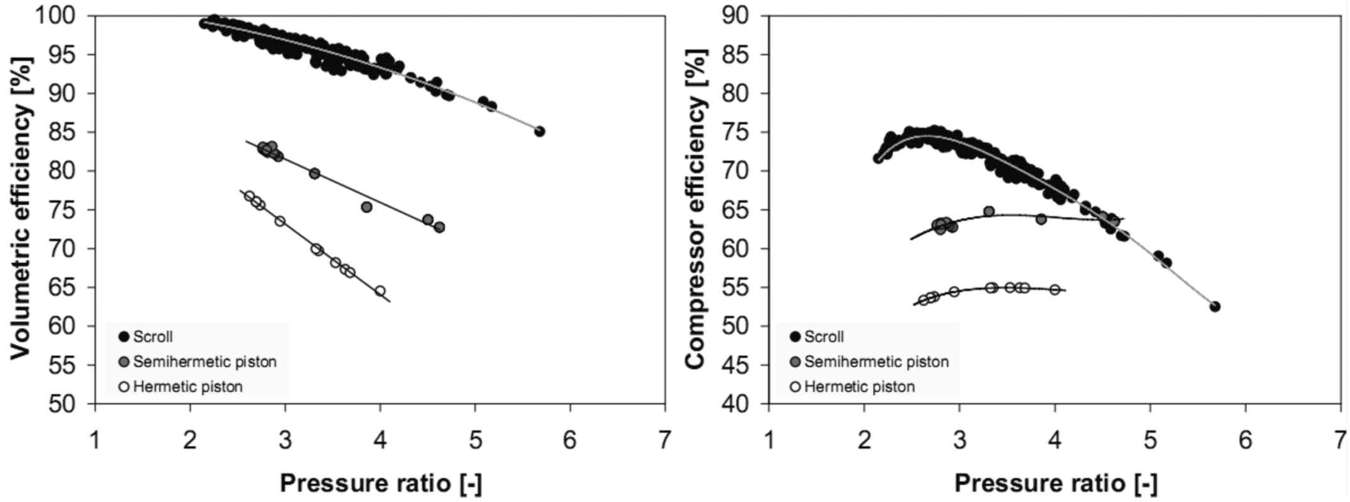


Table 2.
Pressure rations in ground source heat pumps.

	Water temp. to building	Water temp. from ground	Evap. Temp.	Cond. Temp.	Pressure ratio R410A	Pressure ratio R407C
Winter	40 °C	8 °C	3 °C	45 °C	3.1	3.4
Summer	10 °C	30 °C	5 °C	35 °C	2.2	2.4

OPERATION MODES OF GROUND-MED HEAT PUMPS

Compensated set-points

In order to minimize the difference between condensing and evaporating temperatures and maximize the equipment energy efficiency, the water temperature of the hydronic system should be as low as possible when operating in heating mode and as high as possible when operating in cooling mode. With this in mind, temperature compensated set-points improve COP. During the heating season, for example, at low external temperature, high heating water temperatures can be selected for the building, while at high external temperature low heating water temperatures can be selected. In this way, a system can be designed to provide peak capacity to the building during adverse weather conditions (with high pressure ratio at the compressor), while operating at much higher efficiency (lower compressor pressure ratio) during other times.

Part load operation

During their lifetime, heat pump systems often do not operate at design conditions, since the heating load is frequently a fraction of the design load. In order to ensure the desired level of comfort and simultaneously optimize the energy performance, matching effectively capacity and load is the most critical factor for a heating and cooling system.

Qureshi and Tassou (1995) summarised the potential available technologies. They examined the relative efficiency of various forms of compressor capacity control by means of a simulation study. Although this work was based on research from well over a decade ago, its findings are still relevant and give a good overview of some common compressor control techniques. Variable speed control by means of an inverter and deployment of multiple compressors were found to give the most efficient operation. It should be noted however, that effects such as motor and inverter efficiencies were not taken into account by the authors. Moreover the analysis was based on a modelling approach and therefore experimental verification is needed. On/off cycling energy losses and variable speed compressor inefficiencies are discussed in the literature by several authors.

In the Ground-Med Project, three solutions are adopted for the heat pumps: single compressor operating with on/off cycling, tandem compressor heat pump and variable speed compressor. The experimental analysis of the performance in each installation will provide useful information to draw conclusions on the advantages of each technological solution.

Figure 4.
Installation of borehole heat exchangers at Hiref, Tribano (PD), Italy.

SUMMARY

Geothermal heat pumps have already large applications in Northern and Central Europe for building heating. Nevertheless, in the recent years, more and more systems are installed for both heating and cooling in some Countries of Southern Europe. The EU project Ground-Med is aiming at demonstrating that a ground source heat pump system is a viable and energy efficient alternative to conventional systems for heating and cooling applications in the Mediterranean regions, provided that the system is properly designed and a proper control strategy is implemented during its operation.

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Solar cooling with small size chiller: state of the art

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This topic will be discussed in the next 14th EU Conference in UK and in Italy

Absorption refrigerating machines represent an interesting alternative to compression machines, especially when waste heat or heat produced by solar energy is available; the market is proposing small-size absorption machines especially designed for air conditioning in residential buildings. A survey of small-size absorption refrigerators is presented, covering a range of chilling power between 5 and 17 kW and highlighting the productivity of machines.
Since the main obstacle to the market penetration consist on an excessive spreading of prototypes, a study aimed on the definition of common Standard is analyzed, comparing the results with experimental campaigns conducted at the Labs of Department of Industrial Engineering of the University of Perugia.
A brief look on the economical aspects and perspectives of this technology completes the paper.

INTRODUCTION

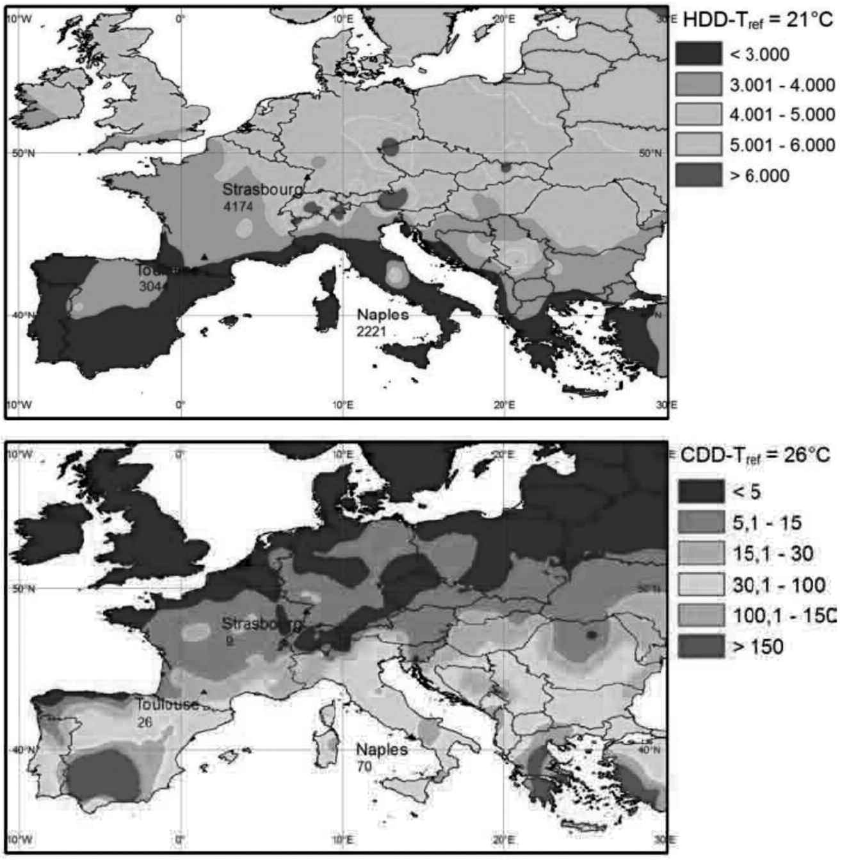
The need to ensure high levels of indoor comfort, both in winter and summer, increased sales of equipments for air conditioning.
This trend is also confirmed by the growth of electrical energy consumption in the residential sector all over Europe, which is actually responsible for more than 40% of total energy consumption [1]. A survey of 15 European Union countries estimated a total electricity consumption of about 90 TWh, with 33 TWh coming from Spain, 27 TWh from Italy and 10 TWh from France [2].
In recent years, a new role is played by solar energy, which found new interest in systems for the production of cold water (sorption machines) for air-conditioning; these applications are mainly encouraged by the simultaneity between high solar radiation and cooling demand.
The machines can be effectively incorporated into so called solar combi-plus systems, where solar energy is used to produce domestic hot water (DHW), space heating and cooling.
Thermal driven sorption chillers already know a mature technology in the high power range (chilling power >100 kW), but recently, machines with low chilling power (between 5 and 17 kW) became to enter the market, being included in solar combi-plus systems for small-size applications.

A SURVEY OF EXISTING SMALL-SIZE CHILLERS

Thanks to the interesting applicative aspects, some manufacturers began to produce small-size absorption chillers (5 – 17 kW of chilling power), designed to be fed by solar energy. Through an in-depth market research, 6 small size chillers have been individuated, satisfying the above stated requirements and so able to enter soon the market. Low power absorption chillers are not very common and there are no data available about their real performances in long-term applications.
So, the six machines, built by different producers, should be considered more as prototypes rather than as commercially available items [3][4]. The main characteristics of the various machines – identified with the letters from A to F - are reported below.
1) The chiller indicated with the letter A is produced in Sweden and it has an operating process that is based on a cycle of charge and discharge of two similar barrels, each one constituted by two heat exchangers (reactor – condenser, evaporator – absorber) which, alternating, are able to give or store energy. The working fluid is a solution of H_2O-LiCl.
In the charge phase the water evaporates in the reactor and condenses in the upper heat exchanger that now is working as condenser. During the discharge phase the water evaporates in the upper heat exchanger, that now is working as evaporator, and condenses in the reactor, that now is working

as absorber. This chiller can also operate with the inverse cycle, in this way it can be utilized during winter to produce heat.
2) The second system (B), investigated at the Technische University of Berlin and nowadays in the production phase, is a classic absorption chiller that uses H_2O-LiBr as working fluid.
This chiller, actually, seems to be the most promising one for the simplicity of the hydraulic system and the possibility of solar energy feeding. From the economic point of view, a preliminary analysis, showed a high ratio between initial investment and kW produced.
3) A German producer is launching in the international market a 15 kW absorption chiller (C). It is a system with tested performances but it requires a feeding solar power of 21 kW.
It is made up of two separate where evaporator-absorber and generator-condenser are positioned. This chiller realizes the classic absorption cycle and utilizes H_2O-LiBr as working pair.
4) The Spanish absorption chiller (D) works with the H_2O-LiBr pair and with a nominal refrigerant power smaller than the others (4,5 kW). Unfortunately it is no more in the production phase, because of the financial crisis. This model was very compact and it was available also with an incorporated cooling system that removes the cooling heat from the machine.
5) The Japanese model (E) presents the peculiarity of the absence of the internal circulation pump, and so it is characterized by a total independence of the refrigerant process from any electric feeding; on the other hand, the power output of the system is lowered.
6) Finally, an adsorption machine (F) is also produced recently in Germany, with the main feature that it can work with a thermal power supply of 60 °C.
The differences between the cooling capacity of the samples depend on the manufacturers' construction choices. Samples A and E are those the most influenced by their volumes, which considerably diminishes the relative capacity. Sample E shows poor performance at low cooling temperatures because of its intermittent functioning, which decouples the heat feeding and cooling production environments. Samples A and B behave similarly in terms of global COP, reflecting their common construction philosophy; it should be pointed out that samples A and E weigh twice as much as all the other absorption machines investigated [3].

Figure 1.
Heating and cooling degree days in Europe.



The market of small-size absorption chiller presents therefore machines able to function with a nominal temperature above 80 °C, with a COP higher than 0.70 and a chilling capacity from 4.5 kW to 17 kW. Adsorption machine can work properly at 60- 70 °C, with a relative COP of 0,56, so making this kind of solution also suitable to be joined to solar collectors in solar combi-plus systems.
However, three main reasons still prevent solar cooling (only chilling) and solar combi-plus system from spreading in chiller and air conditioning market:

- Difficulty to identify a standard configuration for single chiller.
- Low numbers of machines produced and high costs.
- Absence of knowledge of the system behaviour.

Costs of the investment and the need of experienced designers and installers constitute the most important barriers for a broad diffusion of solar cooling applications.
The definition of standardized system configurations might reduce considerably the design effort for each single application and it could be the basis for the development of package solutions manufactured with the advantage of the large scale production.

EFFORTS FOR STANDARDIZATION

Results of an European Research [5] defined a reduced number of system configurations, which can be promoted and applied similarly to the standardized systems for domestic hot water production, which work reasonably well in common applications and are independent by the specific machine considered.
This research started from an extended campaign of numerical simulations carried out in TRNSYS on two basic plant configurations derived from economical and technical analysis. Each

participant of the research opted for one of the two plant layouts, which best suited the working features of its own chiller. Within the basic systems, a number of parameters were varied: geographical location, chiller brand, collectors' type (flat plate, evacuated tube collectors), chilled/warm water distribution system (fan coils and chilled ceiling) and other technical parameters.
Results of comparative analysis showed that the chilled ceiling, wet cooling tower and evacuated tubes collectors configuration allows the solar comby-plus system to give the best compromise between technical and environmental requirements for the three main cities of Europe analyzed (Naples, Strasburg, Toulouse).
Two parameters (Heating Degree Days and Cooling Degree Days) are used to evaluate the energy demand of a building, based only on the external temperatures (Fig. 1). Both parameters compare the external temperatures with the in-house ones that always assure conditions perfectly acceptable inside the building all along the year (21 °C in winter, 26 °C in summer, calculated for a relative humidity of 50%).
In particular, the final report highlights that well-sized systems are equipped with evacuated tube collectors, with a specific surface of 3.5 – 5.0 m^2 per kW of chilling capacity, and a hot storage volume included between 50 and 75 litres per square meter of collector area. In these ranges, high total solar fractions can be obtained and the system operates close to the optimum in terms of primary energy savings and costs for each country of Europe.
The reason is easily explained considering that lower is radiation value, the lower is the chilling load; wider collector surfaces need further investments, that are not justified by the relative better performances in terms of higher solar fractions.
A sort of validation of the results obtained by the European Project solar combi-plus is found in the experimental campaigns conducted at the Department of Industrial Engineering of the University of Perugia, where research groups have been actively working on alternative refrigeration technologies and in particular on solar cooling absorption systems.
An absorption system plant [6] has been already manufactured in 2001 to identify the best configuration for producing chilling power from the sun with solar collectors. First results have showed that the absorption machine can work properly (COP 0.50 – 0.60) with a generator inlet temperature (70 - 80 °C, even lower than the nominal value); besides, it was showed that a specific surface of 5.0 – 6.0 m^2 of vacuum tube solar collectors per kW of chilling capacity is needed to drive the solar cooling system. At the light of the first results and trying to fit the experimental measurements with the theoretical analysis of the European Research [5], from 2006 a solar cooling system (with DHW production in winter) is running with a smaller size absorption machine. The main difference between the standard of the European Research is the tank volume. Theoretical data specify 50-75 litres per square meter of solar collectors, whereas Perugia's plant employs 25 litres per square meter; this value derived from the results of the first experiments, where it emerged that a lower volume of the hot tank had reduced the length of the unsteady state conditions, linked also to the inertial thermal loss of all the plant components.

COST ANALYSIS

A detailed market survey showed that the cost of small-size absorption and adsorption chillers stands around 3500 - 4500 € per kW of chilling power; for the solar collectors 1.000-1.300 euro/m^2 are needed, so the entire system has a cost range between 5.000 and 10.000 € per kW of chilling power.
Typically, the whole cost is split as follows: 1/3 chiller, 1/3 collectors and 1/3 the rest (pipeline, pumps, control systems and cooling tower).
Naturally, some differences are found among the various installations; for instance, the cost of Perugia's plant is about 50.000 € (12.000 € the 5 kW chiller, 30.000 € the solar collectors and 8.000 the rest), but a 8 kW chiller with 30 square meters of solar collectors can be paid 40.000 € in Germany (mainly thanks to the lower price of German solar collectors).
If a simple economic analysis is conducted through a comparison with conventional cooling–heating systems (estimated cost equal to 15.000 € with similar performance), it is possible to evaluate the Payback Time.
The extra cost is (40000 – 15000) 25000 € while the saving is given by the value of the electric energy not used to produce chilling power: 9000 kWh/year x 0.12 € = 1100 €/year. Thus, the simple Payback Time (no maintenance, no energy cost increase and no inflation) is about 20 years, while diminishes to approximately 10 years if at least 50% of the investment is covered by incentives.

CONCLUSIONS

Six small size sorption machines have been recently introduced in the market to be employed in solar cooling or combi-plus system in residential applications. A recent European Research Project has fixed the main characteristics for such typology of plans witch are defined in a solar collector surface of 5 m^2 for kW of chilling power and a tank with 50-75 litres per square meter. Such parameters are usable for the different European Countries. Up to now solar combi-plus can have a payback time above 20 years without incentive but the decreasing of price of solar collectors and of absorption machine, along with State incentives, could help the payback time to reach value less than 6-8 years.

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Opportunity and Direction for Solar Cooling The Case in Australia

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Solar cooling technologies have existed for many years yet their market share is very low. This paper briefly examines the difficulties with conventional cooling technologies and the opportunity this provides for greater uptake of solar cooling systems. In particular, the cost of solar cooling seems to be the main barrier to market acceptance and so a comparative study is performed between a photovoltaic vapour-compression system, a solar thermal cooling with an absorption chiller and a grid-connected reference chiller. The study was performed with reference to conditions prevalent in Australia. It was found that a solar thermal cooling system has a lower lifetime cost than a PV-based system. However, both systems have higher lifetime costs than a grid-connected conventional system. A sensitivity analysis on electricity price showed that solar thermal cooling is more economic than PV-based cooling until the electricity price exceeds $AU 0.5/kWh$_{el}$. A PV-based system becomes the most economic cooling alternative if the electricity price exceeds $AU 0.55/ kWh$_{el}$. Greenhouse gas emissions were found to be lowest for the PV-based system due to the excess power being generated over the lifetime. The solar thermal system saves approx. 75% of the emissions of the conventional system.

INTRODUCTION

In solar cooling systems, energy from the sun replaces electricity as the source of energy to drive a cooling or refrigeration process. Solar cooling technology largely comprises 'off-the-shelf' heating, ventilation and air conditioning (HVAC) components which are generally mature technology. Combining these technologies into integrated systems has been proven feasible worldwide (mainly Europe) but the industry is still in its infancy, despite an apparent match between air-conditioning (AC) demand and solar irradiation availability.

There are a number of impending difficulties facing conventional electrically driven cooling systems. These are primarily the cost associated with peak electricity consumption and the cost associated with greenhouse gas emissions. These difficulties will be reflected in increased capital and operating costs for these systems.

In Australia, the increasing popularity of domestic vapour compression air conditioning has resulted in peak electricity demand growing much faster than baseload demand as noted by NEMMCO[1]. Transmission and distribution assets must be sized on the peak current transmission and that capacity is used for a small proportion of the time. Thus there is a poor return on a substantial investment is little incentive to upgrade the network in this way. This is leading to supply security issues also noted by NEMMCO. Solar cooling is a distributed form of peak electricity reduction and has the unique ability to offset loads at source, thus reducing transmission requirements and in particular, peak transmission requirements.

Greenhouse gas emissions from conventional electrically driven systems comprises emissions associated with electricity consumption during operation and potential emissions from greenhouse intensive refrigerant loss to atmosphere during the equipment lifecycle. Solar cooling systems typically consume an order of magnitude less electricity and often work with greenhouse neutral fluids.

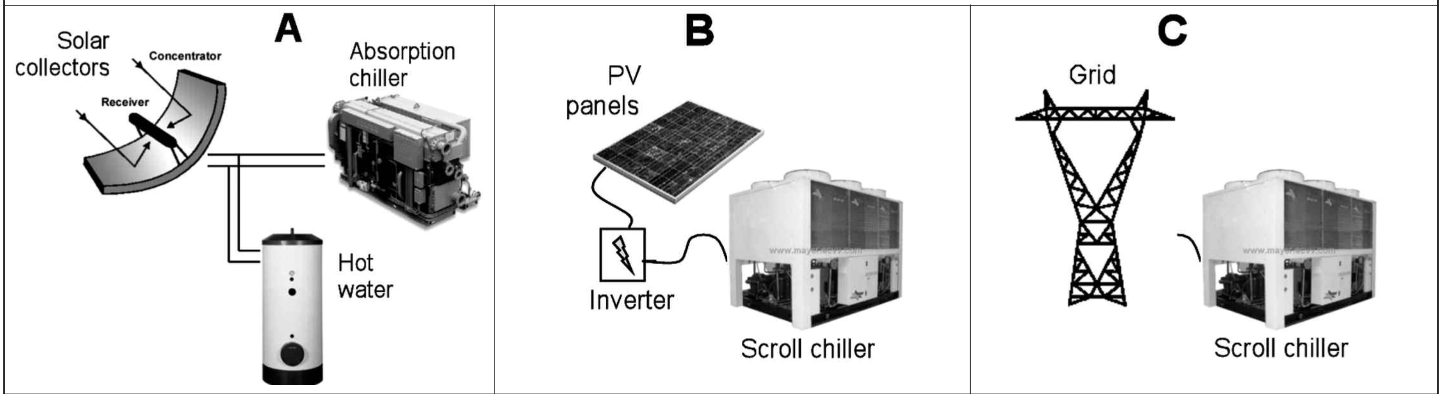
The large demand for AC in hot climates, combined with the economic problem of infrastructure support and threat of environmental degradation, provides a basis for consideration of alternative technologies.

CURRENT SITUATION

The combination of good solar resource and a large air-conditioning market seems like a perfect match for solar cooling and refrigeration applications. However, there are less than 1000 solar thermal cooling systems installed worldwide, concentrated primarily in central Europe.

The discrepancy between the great potential and the small number of installations is primarily due to the high cost of solar cooling, usually dominated by the cost of the solar collectors. Residential solar cooling systems of cooling capacities 5-15 kWr have high specific costs in the range of

Figure 1.
Scenarios for comparison of solar cooling technologies.[5-9]



Solar thermal collectors & absorption chiller (STAC)	Photovoltaic panels & scroll chiller (PVS)	Grid-connected scroll chiller (REF)

Table 1.
Financial assumptions for NPV calculations.

Financial assumptions	All Scenarios
Lifetime of scroll chiller	12 yrs
Lifetime of absorption chiller, collectors & PV modules	20 yrs
CPI (inflation rate)	2.5 %
Discount rate	8 %
Electricity cost	0.17 AU/kWh_{el}$
Annual escalation rate electricity cost	2 %
Natural gas cost	$AU6/GJ
Annual escalation rate natural gas cost	1 %

Table 2.
System specifications for NPV calculations.

System assumptions	STAC	PVS	REF
Total cooling power (kW$_r$)	230	230	230
Average annual COP chiller (-)	1.1	4.0	4.0
Heat required for cooling (kW$_{th}$)	209	-	-
Electrical power required for cooling (kW$_{el}$)	15	58	58
Solar thermal collector/PV area (m^2)	508	391	-
Backup system for heating/hot water	none	gas boiler[1]	gas boiler

1. Gas boiler efficiency was assumed at 85%.

approx. $AU 6,000-9,000/kW$_r$ installed. They are an order of magnitude more expensive than conventional split systems[2]. The situation is different for larger commercial or industrial applications with cooling capacities in the range 50-500 kW$_r$. Economies of scale make larger units more economic and the hours of operation are usually much greater in an industrial application compared to residential. However, other market barriers are also restraining the market in this segment.

Market barriers

The main market barriers for solar cooling have been identified as:[3, 4]

– Low electricity prices
– Low capital cost of conventional air-conditioning
– Cross subsidy of conventional air-conditioning system by all electricity customers who have to pay for network and generation infrastructure.
– Low number of installed systems
– System complexity
– Professionals involved lack training and experience with solar cooling

These are no major unsolvable technical issues for the implementation of solar cooling, however the main barrier for implementation is economic, not technical. There are sufficient installations in Europe where the technology has been proven feasible but the low electricity cost and cheap conventional AC units are hard to compete with. Nevertheless, economics for solar cooling can become much more favourable for a range of building and industrial applications as electricity prices rise and more experience is gained with solar cooling.

Market opportunities

In some countries, the situation for solar cooling has improved due to Government initiatives. Examples include:

– Time of use metering, thus encouraging peak power savings
– Mandated energy efficiency performance of buildings
– Implementation of a carbon pricing scheme to include for environmental externalities associated with electricity generation
– Funding and rebate schemes for solar cooling

A solar cooling system will most likely generate hot water during operation and can even generate space heat in cooler seasons. This additional functionality is yet to be realised in most marketed solar cooling systems and is likely to make the economics much more favourable.

ECONOMIC COMPARISON

Almost all existing solar cooling systems are driven by solar heat coupled to an absorption chiller. A competitive technology to solar thermal cooling is photovoltaic-based cooling using photovoltaic (PV) panels to generate electricity connected to a conventional air-conditioner. For some time, this technology has been too expensive due to the high cost of PV panels.
Recent price drops of PV panels to

around $AU2/W_p$ (~$AU4/W_p$ including installation) warrant investigation of whether a PV based system would be more economically attractive than a solar thermal cooling system. Thus, three scenarios have been compared to each other:

A. Solar thermal parabolic trough collectors and a double-effect absorption chiller

B. Photovoltaic panels and a scroll type vapour-compression chiller

C. Reference case: Grid-connected scroll type vapour-compression chiller

The comparison is made for a commercial system of 230 kW_r cooling capacity, this being a medium-sized industrial application for e.g. office buildings, shopping malls, art galleries, hotels and the like. The following general assumptions have been made:

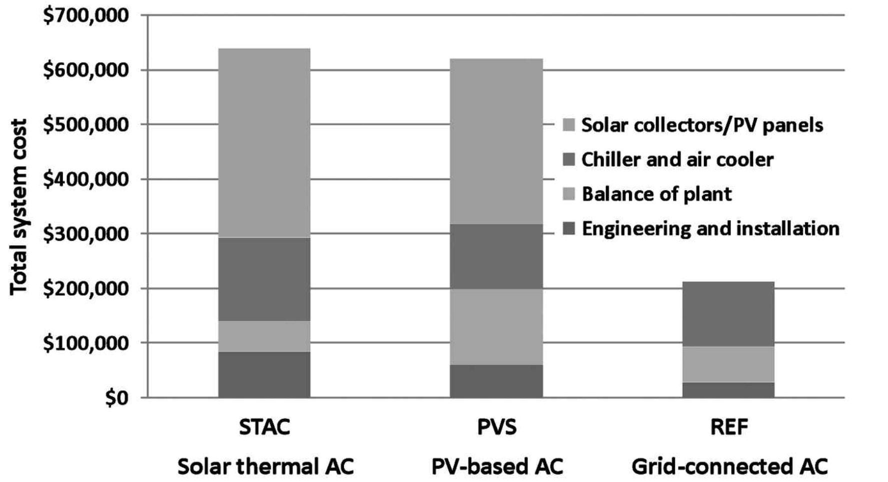
– All three scenarios have been investigated using representative hourly environmental data for Brisbane in Australia.
– Cooling is needed for 8 hours/day over 5 five months/year
– Heating/hot water is provided whenever cooling is not needed.
– No renewable energy subsidies have been assumed
– The price of carbon price has been set to $0/kg$CO_{2-e}$
– All three systems have been designed to provide 100% of the annual cooling load

Thus the comparison represents full costing for the solar cooling system, but subsidised costs for the conventional system since the true costs of peak electricity and greenhouse gas emissions are not taken into account.

The comparison was made by calculating investment and O&M cost and calculate the net present value (NPV) for a lifetime of 20 years. Table 1 shows the financial assumptions for NPV calculations. The system specifications are given in Table 2 and the costing in Table 3. Figure 2 shows the breakdown of system costs.

It can be seen in Table 3 and Figure 2 that the solar thermal cooling system (STAC) has the highest investment cost of all systems and is comparable to the PV-based system (PVS). The reference system (REF) is approx. 65% cheaper than both the STAC and PVS systems. The solar thermal system (STAC) uses parabolic trough collectors with an annual average efficiency of 55%. A hot water storage tank of 5,000 litres is used as a buffer tank. The absorption chiller is an air-cooled double-effect chiller with an annual average COP of 1.1.

Figure 2.
Breakdown of system equipment and installation costs.



The PV modules in the PVS system have been assumed with an annual average efficiency of 14%. A degradation of the module efficiency of 15% over the 20 year lifetime has been assumed. The PVS system yield has been calculated using an annual yield factor of 1.536 MWh/kW_p for Brisbane, including a 15% loss due to annual self-shading of the panels[11].

Excessive power generated by the PVS system is accounted for as net export to the grid. The scroll chiller is air-cooled and has an annual average COP of 4.0. For the reference (REF) system the same chiller as for the PVS system is assumed.

RESULTS AND DISCUSSION

Greenhouse gas emissions and the lifetime cost calculations over 20 years (replacement of scroll chiller in scenarios PVS and REF after 12 years) are given in Table 4.

It can be seen that the solar thermal cooling system (STAC) has significantly lower lifetime costs than the PV-based system (PVS) under the given assumptions. The cost difference between systems STAC and PVS is approx. $114k over 20 yrs. The reference case (REF) has the lowest lifetime cost of all three systems.

Greenhouse gas (GHG) emissions have been calculated over the lifetime using indirect emission factors for consumption of electricity from the Australian grid. The electrical emission factor for Brisbane is given as 0.89 kg$CO_{2\text{-}e}$/kWh_{el}, emissions for natural gas have been assumed as 0.2 kgCO_{2e}/kWhth[12]. Exported electricity into the grid from the PV system has been accounted for as emissions avoided using the same factors. It can be seen that the reference case (REF) has the highest GHG emissions of all three systems. The solar thermal cooling system (STAC) has approx. 78% less GHG emissions than the reference system (REF) under the given assumptions. The PVS system has no operational GHG emissions. This is due to the excess electricity generated over the lifetime which makes its GHG emissions negative.

It is obvious from the analysis that the lifetime cost difference between a solar cooling system (PVS and STAC) and a grid-connected cooling system (REF) is still quite large, despite the recent price drops in PV module price and collector cost. However, the cost difference between a solar thermal system and a PV-based system is significant under the current assumptions. Therefore it has been investigated which escalation in grid electricity price is required to make a PV-based cooling system competitive with a solar thermal cooling system. Also, it has been investigated at which electricity cost both solar driven cooling systems become competitive with the grid connected scroll chiller system.

Table 3.
Cost assumptions for NPV calculations.

Cost assumptions	STAC	PVS	REF
Solar collectors/PV panel cost[2]	$ 330,200	$ 301,440	-
230 kW_r Chiller and air cooler cost	$ 154,000	$ 119,600	$ 119,600
Balance of plant cost	$ 69,200	$ 137,650	$ 65,650
Total equipment cost	$ 553,400	$ 558,690	$ 185,250
Total engineering and installation cost[3]	$ 86,658	$ 60,882	$ 28,412
Total system cost	**$ 640,058**	**$ 619,572**	**$ 213,662**
Specific system cost	$/$kW_r$ 2,783	$/$kW_r$ 2,694	$/$kW_r$ 929
Annual average O&M cost	$ 6,893	$ 3,981	$ 17,163

2. Parabolic collectors have been assumed at $AU650/m², the PV panels at $AU4.20/Wp.
3. Cost estimates for installation and engineering have been taken from. [10]

Table 4.
Lifetime costs and greenhouse gas emissions.

Costs	STAC	PVS	REF
Lifetime cost (20 yrs)	$ 631,879	$ 745,959	$ 443,098
Comparison to reference case	143%	168%	100%
GHG emissions			
Lifetime GHG emissions (t CO_{2e})	317	-139	1410
Comparison to reference case	22%	-110%	100%

Figure 3.
Sensitivity analysis on electricity price to reach lifetime cost parity between reference and solar cooling systems.

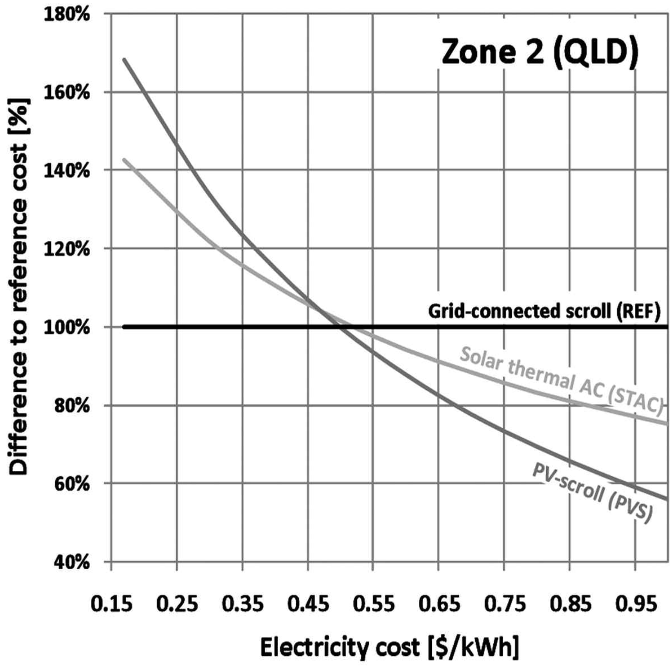


Figure 3 shows the results.

A few conclusions can be drawn from Figure 3. At current Australian electricity prices ($0.17/$kWh_{el}$), solar thermal cooling (STAC) has a lower lifetime cost than PV-based cooling (PVS). The STAC and PVS systems have an equal lifetime cost at an electricity price of $0.47 /$kWh_{el}$. The PVS system has lower lifetime costs than the REF system at electricity price higher than $0.50 /$kWh_{el}$ and the STAC system at electricity cost lower than $0.52 /$kWh_{el}$. The authors acknowledge that the results of this study are subject to the modelling assumptions and to some degree a snapshot in time. Continuing changes in the investment costs of PV panels, solar thermal collectors and absorption chillers will affect the outcomes of such a study. Influences of local electricity prices, local solar rebates and carbon pricing may also favour solar cooling. Furthermore, specific opportunities for solar cogeneration or utilisation of waste heat would improve the case for solar cooling.

SUMMARY AND OUTLOOK

Solar cooling still is a niche technology, despite a good match with solar resource availability and a large air-conditioning and refrigeration market. Barriers to increased market share are mostly economic rather than technical. This paper briefly summarizes the market barriers and opportunities for solar cooling. It further investigates the economics of a solar thermal, PV-based and a conventional cooling system over a 20 year lifetime.

It was found that at current economical conditions and under the given financial and technical assumptions, a solar thermal cooling system has a lower lifetime cost than a PV-based system. However, both systems have higher lifetime costs than a grid-connected conventional system. A sensitivity analysis on electricity price showed that solar thermal cooling is more economic than PV-based cooling until the electricity price reaches approx. $0.50/$kWh_{el}$. A PV-based system becomes the most economic cooling alternative if the electricity price exceeds $0.55/ kWh_{el}, beating the reference and solar thermal system in lifetime cost.

Greenhouse gas emissions were found to be lowest for the PV-based system due to the excess power being generated over the lifetime. The solar thermal system saves approx. 78% of the emissions of the conventional system.

The modelling represents a worst case scenario for solar cooling with low local electricity pricing and no recognition for the true costs of conventional electrical cooling systems.

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26 challenges for refrigerated trucks for sustainable development

Environmental challenges for refrigerated transport equipment

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UNEP EEC CENTRO STUDI GALILEO Policy Centre TERRE

This topic will be discussed in the next 14th EU Conference in UK and in Italy

Refrigerated Transport equipment have strongly developed during the last 60 years in line with the development of food exchange worldwide. Food safety can now be achieved throughout transport and logistics operations that for decades were the critical point of the cold chain. But at the crossroads of refrigeration and transport, these equipment are now facing the challenge of sustainability and environmental performance.
If many technical solutions have been tested during the last decades, there is still a lot of room for improvement. The challenge is high and relevant. This article presents 26 possible scientific and technical challenges for refrigerated transport equipment designers, manufacturers, users or experts.

Introduction

The fleet of refrigerated transport equipment has strongly increased over the last 60 years, in line with the development of food exchanges across the world. Food safety can now be achieved throughout transport and logistics operations that remained, for decades, the critical point of the cold chain. But at the crossroads of refrigeration and transport, these equipment are now facing the challenge of sustainability and environmental performance.
If many technical solutions have been explored during the last decades, a wide range of possible improvements are still open to prepare the future. The challenge is important and relevant. This article presents 26 possible scientific and technical challenges for refrigerated transport equipment designers, manufacturers, users and experts.

A few words of history and perspectives

After centuries of transporting ice all over the world to preserve food, the refrigerated transport of goods really began with refrigerated sea transports in 1850 followed at the end of the XIXth century with refrigerated trains. The first vehicle that can really be considered as a refrigerated truck appeared in the US as late as 1937. The development of these equipment only began after the Second World War. The real explosion of the number of refrigerated trucks begins then when their production reaches an industrial level in Europe and North America in the 70's. In parallel, the production of refrigerated rail cars began to slowly decline.
Some 4 millions terrestrial equipment are now in service around the world[1]. Their number is growing fast in some parts of the world such as Asia where the cold chain is under construction. A lot of innovations have been tested during the last 60 years, some have been widely developed but most of them stayed unused. During the last decades, the industry was not really driven by environmental issues. The refrigerated transport equipment were first dedicated to maintaining the temperature of perishable goods throughout their transport. They were not really optimized in terms of environmental impact or energy consumption.
To face the challenges of environmental performance and sustainability, refrigerated transport should go back to some ideas which were explored in the past but were then abandoned. It should also analyze the solutions developed in other fields of refrigeration or transport and study the possibilities of adapting them to transportation. Finally, the most recent scientific and technical progress should be explored in order to offer new technical possibilities.

Aerodynamics

If the first refrigerated trucks design were not so bad in terms of aerodynamics, the modern ones are not the best. There is a need to introduce a global conception of these equipment including trucks, bodies and refrigeration unit design, taking aerodynamics properties and performances into account. The reduction of the truck's air resistance should not reduce the air exchanges in the condensing unit for example. More than 15% of energy

Refrigerated truck in Cemafroid Antony ATP test station in the 50's and refrigerated trucks in Cemafroid Cestas ATP test station in 2008.

consumption of the truck can be caused by a lack of aerodynamics.

Bumpers

Ageing of the equipment is a major concern. Mechanical shocks on the rear end of trucks and trailers are degrading the structure of the body and consequently its insulation. Body manufacturers have developed specific bumpers for rear parts of the vehicles avoiding direct shocks on the body; they should be improved.

Color

Trucks and especially the large surface of their insulated bodies are attractive for marketing and advertisement but the color and the external surface of the body can impact up to 40 %[2] on the energy consumption of the refrigeration unit. The bright white equipment is of course far better than black mat ones. The feasibility of a field methodology to measure the surface performance has been demonstrated[3], the work should be completed and implemented.

Development of new refrigeration systems

Many solutions have been tested, on one hand for refrigeration technology such as adsorption, absorption, liquid-gas cryogenic systems, eutectics, on the other hand for energy production and transmission such as hydraulic, electric, indirect refrigeration, independent production or vehicle power use. Nevertheless, few solutions are really implemented on the market and there is a need to explore these solutions with an environmentally efficient approach. The number of solutions available on the market in the 10 next years will probably increase.

Electronic temperature recorders

Temperature recorders are a full part of the transport refrigerated equipment. In Europe they are regulated for all activities along the deep frozen goods cold chain since 2006. EU 37/2005 regulation requires a continuous recording of temperatures with approved and regularly checked

Thermal performance of cold stores equipped with different refrigeration systems

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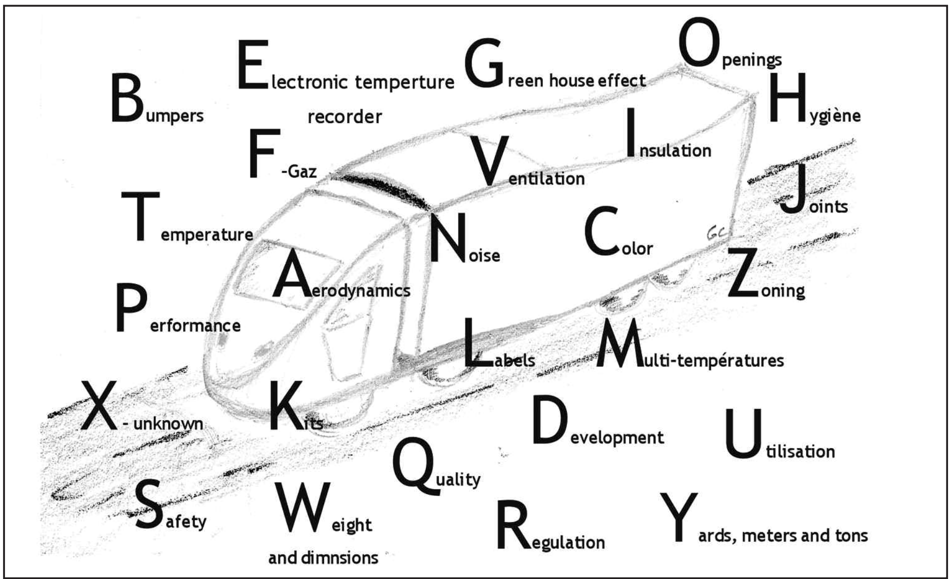
Introduction

During the past years, the food industry was forced to reduce the energy consumption of refrigeration units on board of delivery vehicles, due to the increasing use of refrigerated transport arising from the continuous increase in the variety of transported goods, of the demand of home delivery services, and greater quality expectations. However, any reduction in energy consumption cannot affect the temperature of the transported food products, which is governed by ATP regulations (Agreement on the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for Such Carriage). In the framework of energy saving policy, Cold Car SpA patented an innovative refrigeration system which uses as refrigeration unit eutectic beam elements named AL2 Aluminum Cold Beams®. This paper presents the results of an experimental investigation aiming at the assessment of the thermal performance of a cold store equipped with AL2 Aluminum Cold Beams, as compared with a conventional refrigeration system. The study was carried out in the framework of a research contract between Cold Car SpA and the Energy Department at Politecnico di Torino.

Refrigeration unit description

The refrigeration system installed in the cold store consists of aluminum beams, containing a eutectic mixture, fixed to the ceiling of the cold store. The eutectic beams refrigeration unit can be seen as a heat exchanger with finned ceiling containing the eutectic mixture, which is an aqueous solution of salts characterized by a freezing point lower than the freezing points of each component of the solution.



Refrigerated trucks should not stay the park!

recorders. The collected and stored records are a fantastic source of data for optimization energy consumption linked to transportation. The capacity of information systems allows for a better use of this information.

F Gases

For 30 years, refrigeration has greatly participated in the reduction of ODP and GWP in the world by banning CFC's and now HCFC's, including in refrigerated transport. The remaining HFCs still have a strong impact on the environment. Research and development should focus on the use of new refrigerants, for instance the replacement of banned gases by natural refrigerants such as CO_2, NH_3 or H_2O in traditional compression systems. New innovative solutions such as ad or absorption cycles are also under testing. In the meantime, the F-Gas charge can be reduced again in the refrigeration unit.

Green house effect

The energy consumption of refrigerated transport also contributes indirectly to greenhouse effect. This consumption has strongly been reduced over the last 20 years but it should be reduced again. There are still large differences between partial load and full load consumption for some units. Most of all, the global consumption must be reduced, that is to say the consumption in all operation mode of the unit, and not only the full load consumption. It is a great challenge for the designers of each refrigeration unit manufacturer.

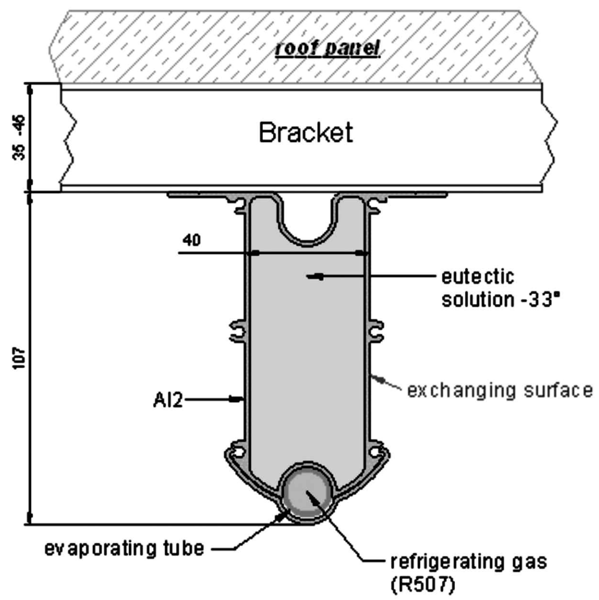
Hygiene

Even if most of the goods are packaged, the hygiene level of equipment is of growing importance.
The evolution of construction materials used for body ensure better hygiene, easier cleaning or even self-cleaning. It should be possible to reduce the environmental impact of

When the mixture temperature rises above the melting point, ice melts and salts are dissolved in the liquid. The process occurs with heat absorption so that the cold store temperature remains almost constant during the whole operation time of the delivery vehicle.
The main features of the innovative refrigeration system are:
- the refrigerant flows in a duct external to each eutectic beam, delaying the eutectic mixture freezing responsible of the heat transfer reduction between the cooling fluid and the eutectic mixture;
- the heat transfer surface of the eutectic beams is greater than the heat transfer surface of the standards eutectic plates.

The following figure shows the main characteristics of a eutectic beam and the installation arrangement.

Figure 1.
Eutectic beam cross section.



Experimental procedure and results

Two identical cold stores (Cold Car model 360) - one equipped with a standard eutectic plates system, and the other with the innovative eutectic beams system - were equipment cleaning, but also to reduce losses of goods due to a lack of hygiene.

Insulation

Strongly improved during the 50's and 60's, the insulation of the refrigerated body has then continuously deteriorated, mainly due to the changes in blowing agents for foams. New insulation materials appeared recently on the market such as new kind of foams, vacuum panels or aero-gels and materials including aero-gels. Their use in refrigerated transport should be tested. The search for better insulation focuses on thermal conductivity of materials; it should also be improved by the use of sophisticated composite structures where thermal radiations and reflection in a multi layers structure can improve the insulation characteristics.
The reduction of thermal bridges should also be researched particularly for the bulkheads.

Joints

The air losses of the body are known as a cause of energy losses. The joints used for insulated bodies have been improved but there is still room for improvement on the closing of lateral doors or the ageing of joints for example.

Kits

The industrialization of body manufacturing made it easier to build kits which can be transported and assembled only at the point of sale. The quality of the equipment is directly linked to the quality of assembly. These operations should be improved for kits to preserve the performances of the equipment. The international or national regulations should take into account this type of manufacturing especially by fixing the level of quality required from the companies which act as sub contractors of vehicle manufacturers.

Labels

Energy labels have been introduced for a lot of equipment in Europe. They have proved their efficiency. A European research project showed the value but also the difficulty of applying these labels to refrigerated transport equipment. This work should be completed and requires additional independent detailed technical research to build energy labels for the refrigerated transport equipment as a whole.

Multi temperatures

Multi-temperature equipment allow energy savings with the use of a single vehicle to deliver goods at different temperatures in the same operation to the same place. For 15 years their place on the market has been growing with 20% of in-use equipment in France and 30% of new ones in 2009. Their performance can still be improved and most importantly their tests and dimensioning should be harmonized across Europe.

Noise

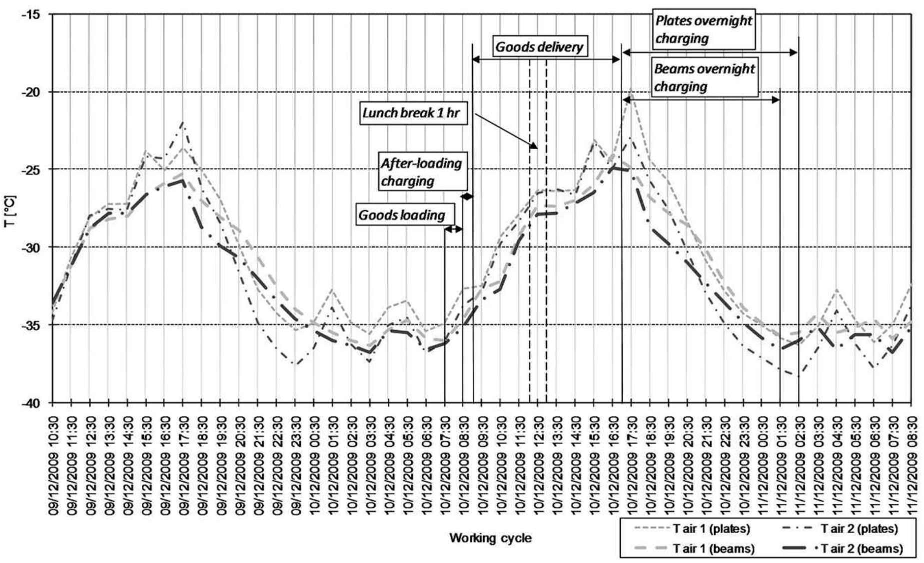
Noise of transport equipment, especially trailers and semi trailers during delivery is an important source of disturbance for urban populations. At the same time, night deliveries are an efficient solution to limit the environmental impact due to traffic jams and the consequent additional consumption of energy. The recent progress of the PIEK project can contribute to reducing the noise impact of refrigerated delivery in towns. Noise reduction has the advantage of delivering at night, thereby reducing the time of transport, the number of trucks and the energy consumption by up to 40%. This big challenge requires improved conception of all parts of the refrigerated trucks and of all the accessories necessary for refrigerated transport and logistics.

Openings

Doors openings are the major source of thermal losses in trucks, especially during delivery operations. In other refrig-

used to carry out a comparison in terms of energy performances. The cold stores were equipped with eight hinged doors (500 x 900 mm), and divided into compartments by aluminum divisional grids and slatted shelves, in order to reproduce the usual internal arrangement of cold stores during operation. Experimental tests were performed in a laboratory with constant temperature set at +30 °C. The system performance was assessed by simulating a real delivery process, with goods placed inside the cold store and with door opening/closing cycles representing typical goods loading and unloading. Transported goods were simulated by filling the cold stores with water bottles and buckets.

Figure 2.
Significant air temperature evolutions in the cold stores (see main text for details).



eration sectors such as display cabinets or cold rooms, systems of air flows or automatic doors are commonly used to reduce cold air losses. Experiments in transferring this experience to refrigerated trucks should be pursued.

Performance

The global performance of the equipment mainly depends on its use. There is no tool on the market to evaluate the global energy consumption and performance of the refrigerated transport equipments except the software developed by Transfrigoroute France in this field. Modelisation codes and available data allow developing such tools.

Quality

Even if a high level of performance can be achieved with a prototype, manufacturers should reach permanent performance. This can be done with adapted quality systems but also low cost methodology to check continuously the quality of the manufacturing: insulation, energy consumption, surface absorption, global performance, aerodynamics …

Regulation

International and local regulations on refrigerated transport equipment have been established for food safety purposes but they are also well adapted to environmental preoccupations. Nevertheless, they need time to be updated and it is necessary to adopt new approaches like the use of standards to established requisites.
This task represents a challenge for national and international standardization bodies and administrations.

Safety

To properly design equipment, the useful refrigeration capacity of the refrigeration unit in continuous operation should exceed the heat loss through the walls with a safety factor equal to 1.75. This consideration is based on technical limitations of equipment available in the 60's. For the future, it should be more efficient to optimize this safety coefficient, not only to avoid low refrigeration capacities, but also to prevent excessive energy consuming capacities. This safety coefficient should be reviewed and optimized in order to, not only avoid inferior refrigeration capacities but also excessive energy consumption.

Temperature

The legal temperature required in transport for the same categories of products varies from one country to another in the world. Deep frozen food should be preserved at -18°C in Europe and -17.8°C (0°F) in the USA, but European equipment are characterized for -20°C. It should be interesting to harmonize them on the basis of technical and scientific data. A change in the mandatory temperature classes of 2°C can impact energy consumption of more than 5% throughout the cold chain.

Usage

Even with the most efficient equipment on the market, an inadequate use can lead to very poor environmental performances.
Best practices should always be improved and disseminated to all the cold chain actors to take into account the conditions of use which maintain a high level of safety for the perishable foodstuffs without unnecessary energy consumption. Misunder-standings are still very common.

Ventilation

Air circulation in the trucks has long been an issue. But after the introduction of basic systems such as air ducts on the ceiling it has not been improved since 30 years.
New materials equipment and construction techniques allow for more efficient air distribution systems, for more homogeneity, a reduced opera-

The mass of water loaded in the cold store was equal to 515 kg equivalent to 800 kg standards goods.
A typical working cycle was simulated by the following stages:
- Overnight charging: the cold store, loaded to half of its capacity, was connected to the external cooling plant for refrigeration units recharging.
- Goods loading: the goods taken from the storage cell at an average temperature of -25°C were loaded in the cold store; the goods loading was performed by opening and closing the doors during a time span of 1 hour; the water bottles, simulating the actual load, were placed inside boxes to fill the upper compartment of the cold store; during the goods loading the energy supply was turned off.
- After-loading charging: the cold store was connected again to the energy source for about 30 minutes; successively, the compressor was turned off; it was assumed a standard travel time from the first delivery point of about 30 minutes.
- Goods delivery: the delivery of the goods was divided into two periods, a morning period and an afternoon period, with a stop at lunchtime.

The floor of both cold stores was covered with buckets and the refrigeration units were cooled until complete solidification of the eutectic solution before starting the test. The starting phase was carried out in order to simulate the condition of the cold store after one typical working day, i.e. when the vehicle goes back to the deposit after partial delivery of the products. The mean temperature inside the cold store equipped with the eutectic plates was -35.5 °C, whereas the mean temperature inside the cold store equipped with the eutectic beams was -36.1 °C. The remaining part of the load, consisting of 140 water bottles, was brought to a temperature of -25 ° C, which is the typical storage temperature of frozen food.
During the simulation of goods delivery, the bottles were removed from the cold stores in two stages. The first stage had duration of 3 hours and simulated the morning activity; the second step was 4 hours long and simulated the afternoon activity. Doors were opened every 15 minutes with 5 bottles being removed each time. The two stages were separated by a 1 hour interval to simulate the driver's lunch

tion time of the unit… and more efficiency. Inner air circulation can also be improved by optimizing external aerodynamics.

Waste

For years, old equipment were exported to other countries, reused for transport and finally, adapted for storage or dismantled, before disappearing... With the growing number of equipment and a higher level of quality expectation in most countries, old equipment should be recycled in appropriate system able to reduce environmental impact. Recycling solutions have not been developed and implemented.

X - like the unknown factor of the market

The market will be one of the main drivers of innovation. The economic crisis will certainly reinforce the interest of manufacturers for innovation, but economic growth is necessary to fund research and development. The evolution of the market in the next months is still uncertain.

Yards, meters and tons: weight and dimensions

Dimensions of semi-trailers have been harmonized at the European level at 16.5 m. Nevertheless, if a minor change on length up to 17.85 m were decided, it would allow 36 euro-palets (+10%) with better air circulation in temperature.
A weight of 44 tons would also allow more efficient transportation. These lengths and masses are already authorized for transporting other products in EU. Finally the reduction of the empty mass of the equipment is a real challenge for manufacturers which could reduce minimum consumption and allow heavier loads.

Zoning

The way of loading the contents of a trailer and the positioning of boxes have a great impact on the energy performance and quality of refrigerated transport.
A minimum air circulation should be maintained in the entire equipment to ensure homogeneity.
The definition of loading zones should be always clearly indicated for instance with maximum load lines and perhaps defined with more accurate technical rules.

Conclusion

The Cold chain will be more and more necessary to save food and will play a major role in the following years to feed the 9 billion inhabitants expected on earth in 2050! Refrigerated transportation will play a growing role. The number of refrigerated transport equipment will then necessarily increase strongly in the world.
At the same time, environmental performance and energy consumption has to be improved in order to preserve the resources of our planet for future generations.
The 26 challenges introduced in this paper can contribute to this improvement. More than in the past, their achievement will require coordination and a deep cooperation between the main actors of the sector, first of all manufacturers of trailers and isothermal bodies, refrigeration unit designers without forgetting final users. Finally, they will need an efficient and specialized scientific and technical support.
Energy efficiency and sustainability have been placed at the top of the agenda of the UNECE transport committee which is also in charge of ATP regulation. The overview of our future challenges can help this project.

●

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break. The break was called maintenance phase because during this interval the refrigeration units must keep the goods temperature below -20 °C as required by the ATP standard, in order to preserve the organoleptic properties of frozen products. Once all the bottles were removed from the upper shelves of both cold stores, the external cooling unit was reconnected in order to freeze the eutectic solution. Air temperature inside both cold stores was monitored using thermocouples NN-24-TT (type T) and the temperature values were recorded and processed by an ABC-Babuc data acquisition unit with a sampling time set at 1 hour. The figure 2 shows the air temperature evolution as measured in the centre of the upper and lower compartments of the two cold stores.

Conclusions

The comparison between the two different refrigeration systems shows that eutectic beam refrigeration units reduce the overnight charging time and keeps the air temperature inside cold stores below the ATP-temperature recommended limit.
The performance improvement obtained by the eutectic beam refrigeration units with respect to eutectic plate refrigeration units can be summarized as follows:

- the time required for overnight charging about 1 hour shorter, which implies a lower energy consumption;
- the surface temperature of eutectic beams after the overnight charging is about 7°C higher than the surface temperature of the eutectic plates, which allows one to use a smaller compressor for the external refrigeration unit;
- the geometric features of the eutectic beam refrigeration units improve heat transfer processes resulting into stored goods being kept at a temperature below -25 °C, in accordance to the ATP recommendations;
- the lower energy consumption of the eutectic beam refrigeration units results into a lower carbon dioxide emission, making this solution more environmentally sustainable.

Acknowledgements
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The new Ice Age for Cooling

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This topic will be discussed in the next 14th EU Conference in UK and in Italy

The ability to keep buildings, people, goods, food and beverages cold is a vital requirement for many sectors of our global economy. In the 20th we were able to rely on the miracle of cheap fossil fuel electricity to provide that cold but long before then the cold of the winter months was captured and transported across the seasons, and the oceans, to provide similar services using natural ice, that if well stored could last for months and years. The growing environmental imperatives in the 21st century are making building designers once more turn to this extraordinary substance in the drive for ever more sustainable buildings.

Humanity now faces major environmental challenges associated with having more people on the planet, fewer resources per person and a changing climate. These powerful trends are growing in scale, impacts and importance. This article is structured to begin with a brief review with four main environmental drivers on the way in which we currently design and service buildings and concludes that energy storage will be increasingly important in the future, and that ice can be used effectively as the medium for that storage.

21st CENTURY ENVIRONMENTAL DRIVERS ON BUILDING DESIGN

Climate Change – Mitigation. The 4th Report of the United Nations' International Panel on Climate Change(IPCC, 2007) states that there is now unequivocal evidence that the climate is warming as a result of man-made emissions of greenhouse gases, the chief of which is CO_2[1]. There is now a strong and growing imperative from International and national Governments to act to reduce the impact of climate change on the planet leading to emissions reduction targets introduced by governments, driving the move to Low Carbon Buildings with significant reductions in energy use and carbon emissions.

Climate Change – Adaptation. The increasing frequency and magnitude of extreme weather events across the world is covered daily in the Press. The need grows to sensibly locate buildings that are robust and resilient to resist events such as storms, floods, fires, droughts, heat waves or related collapses of communication and energy infra-structures. Buildings and cities need now to be designed to withstand a more extreme future[2].

Fossil Fuel depletion: Cost of Energy. Over the last century buildings have tended to use more energy year on year to provide indoor comfort conditions. However, as fossil fuels become scarcer as a result of the Peak Oil phenomenon[3], the issues of energy cost and security of power supply become more critical. Concerns over the rising cost of energy were amply born out in 2007 when oil prices doubled in a couple of months to over $147 a barrel. It is impossible to predict future prices but it is inevitable that as global supplies diminish, energy prices will rise significantly over time.

Security of energy supplies. The knock-on effects of both less abundant energy supplies and increasingly extreme energy events is the rise of systemic and catastrophic blackouts, brownouts and interruptions of energy supplies. These will require all organisations, and in particular large ones that are technology dependent such as offices, schools, hospitals, factories and universities, to invest more in building or site level micro-grid systems that are reinforced against grid fluctuations and failures to minimise the risk and impacts of energy failures on their operation. Security and stability of energy supply is easier to provide where the energy demands of premises are robust, defended, non-peaky and modest.

The Importance of Energy Storage. Central to providing solutions to all four of the above strong environmental drivers is the need to provide significant levels of energy storage in building to reduce the need for fossil fuel energy, to shift loads across time and to shave peak loads that can detrimentally produce energy spikes in the supply grid that cause local supply collapse, particularly when exacerbated by extreme hot and cold weather spells. A growing challenge, in an age of very 'peaky' glass buildings is to generate stable demand profiles demand and supply relationships between buildings and grids. This article deals with the rise and fall and rise again of the use of ice in the cooling systems in buildings.

ICE COOLING IN ANCIENT TIMES

From the dawn of recorded history, men have stored the cold of the winter months to re-use it in the heat of summer in the form of ice[4]. Our forefathers cooled their drinks, food, brows and rooms, by cutting the ice off ponds and rivers, or scraping it from mountain sides, in winter and storing it in underground ice-houses through the spring. Ice-houses have been opened in summer to provide ice for the kitchen and the table for thousands of years.

On a Cuneiform tablet sent by an Assyrian governor to his wife Iltani in 1800 BC was written:

"Let them unseal the ice of Qatara. The Goddess, you and [your sister] Belassunna drink regularly, and make sure the ice is guarded".

Ice was used thoughout Antiquity by the Greeks and Romans and throughout the Middle East[5], India and China.

THE ICE COOLED BUILDINGS OF THE 18th AND 19th CENTURIES

The Rocco-Baroque period of architecture is known for its ornate decoration, but it also resulted in some of the most sophisticated 'passive' buildings using natural energy flows for heating and cooling. One such building is the Villa Campolietto, in Herculaneum, by the sea, south of Naples[6]. It was laid out in 1775 by Van Vitelli, in a square, with the four corner blocks of apartments divided on the Piano Nobile where the family entertained on the first floor, by a huge cross axis of double-height rooms capped by a large raised rotunda in the centre with windows on four sides creating a venturi tower. Beneath the ground floor are two further basement levels including water cisterns and an ice storage room. Ice was brought down to it from the mountains to the north east. The walls are massive, providing inter-seasonal heat and cold storage capacity, with a plastered tufa construction. The genius of this building is its ventilation systems. In warm weather the whole building could be opened up to catch the wind. In very hot weather the external doors and windows could be shut and the venturi tower of the rotunda above the stairway would draw cooler air up from the basements through the transverse ventilation system. In extreme heat ice from the ice store could have been brought up in boxes to cool individual rooms. In conditions of dire heat basement living areas remained cool with temperatures kept constant by sea breezes blowing over the ice stores.

THE ICE TRADE

Ice was historically widely traded throughout history. The ice stores of the Sultans in Cairo were filled with ice brought by camel trains from the mountains of Lebanon. The ice stores of Granada were filled from mountains hundreds of miles away to the north. By the 18th century the ice trade was a major global economic force. The ice trade had spread to Chile in South America by 1800 where ice was cut from the Andes and lowered on ropes by Indians who then transported it some 90 miles on mule back at a brisk trot (where roads permitted) to Lima, a city that used between 50–55 cwt a day (a hundredweight being about 2.5 metric tonnes).

Tschudi, travelling in 1840 claimed that the trade was so important that its interruption might '*excite popular ferment*' and consequently '*in all revolutions*' care was taken to avoid commandeering the mules used in the transport of ice. Right up until the 1980s there are reports of natural ice being stored in winter for use in the 'salad days' of summer in ice-pits in the Kurdish mountains of Northern Iraq. It may be that adjacent mountain ice-stores could supply cooling ice to cities in the Gulf that suffer blackouts and can find no respite from summer temperatures that increasingly trend to soar over 50 °C, at which temperatures local populations do tend to take to the streets in demonstrations against discomfort.

The greatest of all Ice Trades was started in the United States In 1815 Frederic Tudor, the 'Ice King of Boston' sent his first shipment of ice from Boston to Martinique in the West Indies to relieve the Yellow Fever Epidemic that raged there[7] (Nagengast, 1999). While this could be considered as a medicinal use of ice to bring down temperatures by its direct application to the body, it was also considered as 'comfort cooling' of patients. In 1827 the ice-plough was invented by Nathaniel Wyeth on Lake Wenham near Boston, Massachusetts. The plough was drawn behind horses and enabled large quantities of blocks of clear, pure ice to be cut from the lakes, stored in huge above-ground ice-sheds and then transported by train to the coast where they were loaded onto wooden sailing ships and transported to Latin American, Europe, India and as far as China, where ice allegedly was sold for the price of its weight in silver.

Supposedly 50 000 people and thousands of horses worked in the American natural ice industry at it height but by the middle of the middle of the century European ice began to be largely imported from Norway. The first shipment of ice went out from Norway in 1849 when the first Fredrik Olsen took a cargo of ice for the Parr-brothers from Drøbak to Britain on the brig Oscar. Trade was necessarily a two way venture and in Europe the Norwegian trade flourished because the Steam Age had begun and engines needed coal and coal mines need pitprops from timber, and this came from Norway. Steam engines then also pumped water out of the dykes of Holland, and the dykes needed timber. The industrial towns of Europe grew rapidly driving demand for planking for housing. Norway supplied the timber and the planking because steam engines had augmented water driven sawmills. All of this produced saw dust necessary for the isolation of ice transport to Britain and the Continent.

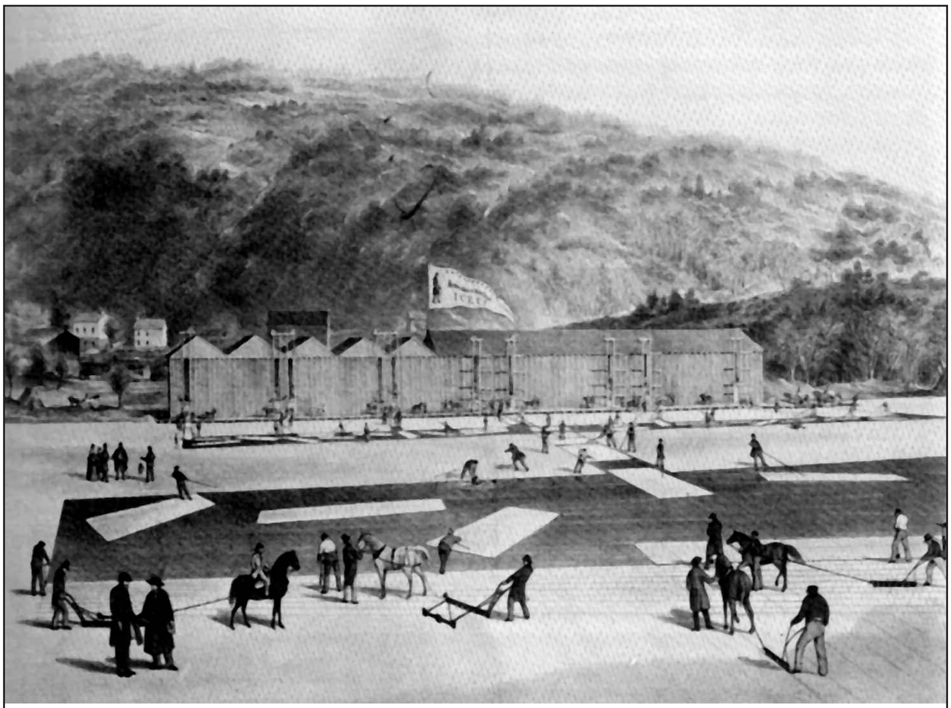

Figure 1. *Ice harvesting in 1845 at Rockland Lake, New York State, USA, by the Knickerboker Ice Co. (Source: Library of Congress, Washington)*

Dams were formed near the Norwegian fjords, and Europe was experiencing the little ice age, and therefore production of large 'crystal' clear cubes of ice was possible. Ice was often stored in large sheds to keep the ice for the end of season to secure for the highest prices. The sailing ships were tied up alongside the fjords and slides were made to facilitate the loading down into the ships. The ships had windmills on deck to pump out melt water from the ice on the voyages to the market[8]. The Ice trade was an integral part of the 19th century industrial revolution.

Imported American ice became most popular in Britain in the 1840s and the last delivery of imported ice to the Royal ice-houses was as late as 1936. Originally from Lake Wenham, this 'arctic crystal' was widely used in Britain where those selling it boasted that they could get a delivery of Wenham ice to any house in Britain within 24 hours. It was gradually replaced by 'Wenham' ice from Norway, from where over 300.000 tons a year were imported by the 1890s. The reason why it was preferred to British ice was that it was clear and clean whereas the British ice was often pellucid and polluted.

Three factors are cited as being responsible for end of the ice-houses, and the ice trade, in Europe:

1 World War I took the young men off the land, and made the seas dangerous for those shipping it.

2 The increasing use of the refrigeration.

3 The third reason for the demise of the ice-house was much less obvious. It was because the climate had changed. By the end of the nineteenth century the mean global temperature was rising steadily, heralding the end of the 'Little Ice Age'.

The significant thermal factor for the ice-house was that although the mean increase in global temperature was relatively small, getting on for c. 0.3°C between 1860 and 1920 (c.1.0 °C between 1860 and 2008), this increase in temperature meant that there were no longer, over time, sufficient cold winters in much of Europe to regularly stock its ice-houses. So the key factor here for a particular 'Ice' technology is not how much warmer it gets, but whether the increase in temperature experienced crosses a critical threshold of performance for this particular technology. The warmer the world gets the more energy it will require to make and store ice artificially and the more carefully we will have to harness this amazing resource.

ICE IN 20th CENTURY COMFORT COOLING

Air conditioning was first used on a large scale at the turn of the 20th century to cool food, but as early as 1748 William Cullen at Glasgow University experimented with evaporating ether under a partial vacuum. It was not until 1805 that Oliver Evans, an American, caused water to freeze using a similar process, and the possibility of cheap cold appeared. At that time many were also experimenting with freezing mixtures and the great natural ice trade was at its peak. In 1834 a closed cycle system was patented by Jacob Perkins, an American working in England, and in the mid-1840s the use of room coolers was pioneered independently in the USA by physician John Gorrie, who used ice to cool air in hospital wards in Florida and Charles Piazzi Smyth, a Scot.[9].

In 1862, at an International Exhibition in London, crowds were amazed to see hot-looking steam apparatus churning out miniature icebergs and one of these machines, made by Seibe (Ferdinand Carre produced the other ice making machine at the exhibition) was bought by the Indian government and sent to relieve the suffering of the troops in India. In the 1870s a few ice production factories were set up in cities and provincial towns but they were expensive and took time to become established. In 1877 a breakthrough was made when meat from England was first exported to America in refrigerated ships, and in the 1960s many cities around the world still got their main ice supply from cold storage plants from which one bought blocks of ice. Fridges were not designed into most European homes until the 1960s.

The first recorded proposal for the use of ice in comfort cooling in buildings was by George Knight of Cincinatti who in 1864 proposed a hospital cooling systems in Scientific American featuring a ventilations system in which the fan driven incoming air was cleaned and cooled with sprayed ice chilled water. In 1865 Nathaniel Shaler in next door Newport patented a system where air was blown across ice in holders in a 'tortuous passage'[10].

In 1880 New York's Maddison Square

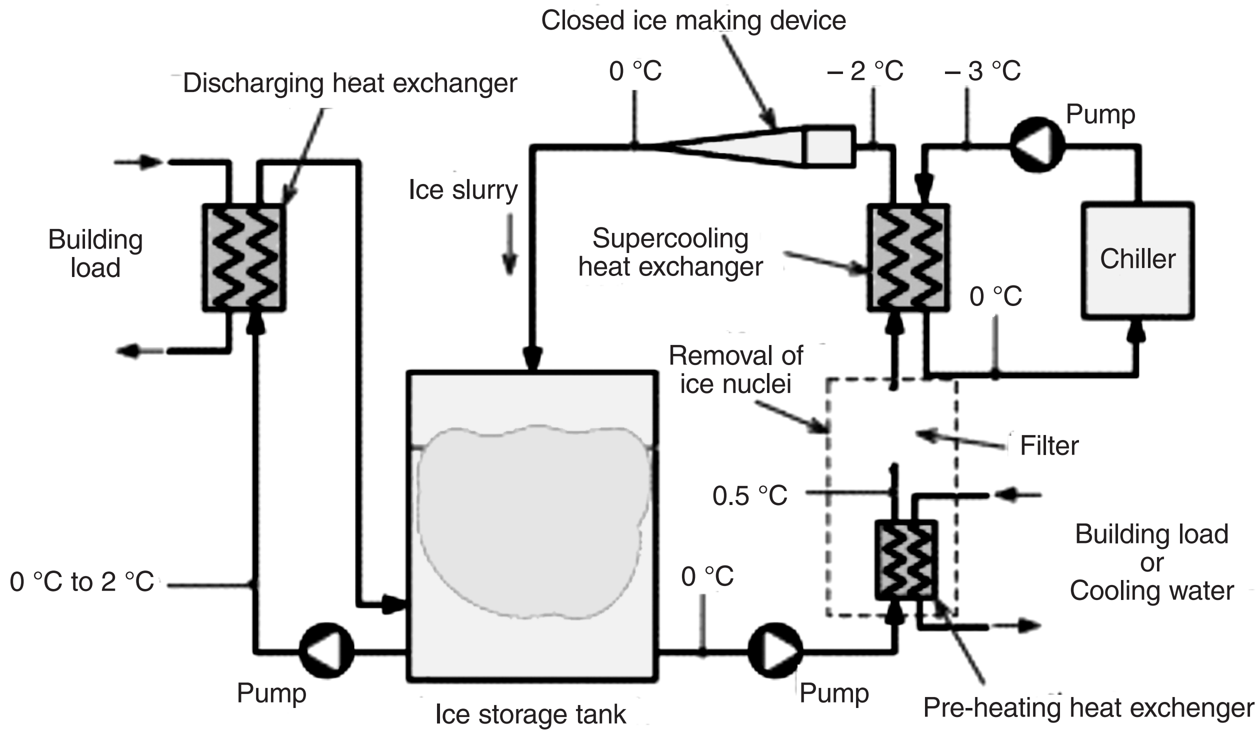

Figure 2. *Ice storage system "The Jiyu-Sekkei" from the Shinryo Corporation of Japan http://www.shinryo-international.com/thejiyusekkei.html*

Theatre was using about 4 tons (3630 kg) of ice to cool patrons at each summer evening performance . Fresh air was filtered thought 12m long cheesecloth bags passing over wooden included racks containing 2 tons of ice into ductwork to various openings through which cool air 'poured in the house to reduce the temperature and to furnish a supply for respiration'. By the 1920s and 1930s ice block cooling systems were used in the USA in Schools, Cinemas and Nagengasht also describes the inventive systems designed to cool the Carnegie Hall in 1889, and the New York Stock Exchange in 1901, both designed by engineer Alfred Wolff, the first great ice cooling system engineer. By this time the use of mechanical ice was beginning to prevail and for the first time 'enterprises were organised' to provide central cooling systems, particularly for brewing, printing, textiles, ice making and storage. Comfort cooling was still too expensive at that time and even ice was sparingly used due to its expense at a time when '...ice is not very cheap and cold cannot be produced as cheaply as heat'.

In large American buildings natural ice cooling systems saw a revival in the late 1920s and 1930s. Money was pumped into marketing the advantages of ice based systems in the States claiming that mechanical systems were still too expensive to make home cooling feasible.

The ice industry saw this as an opportunity to sell their cheaper ice but the continuation of the industry depended on persuading the air conditioning manufacturers to design systems that used their natural ice and also that the customers could be persuaded that ice systems were best. In the end none of these conditions were met, lakes were becoming more polluted and ice proved to be a messy, perishable and difficult medium, unlike electricity that was clean, reliable and increasingly cheap. Electrically chilled and humidified air conditioning systems, pioneered by the French[11] began to dominate the industry and it was not for over half a century that ice again was used in large systems.

ICE STORAGE IN 21st CENTURY BUILDINGS

The environmental concerns outlined above have significantly impacted on the way we now design buildings to drastically reduce energy use in them and carbon emissions from them. Architects can seldom be prevailed upon to design climatically intelligent buildings and a generation of 'glass buildings' are extremely difficult to heat, cool and manage. Their energy supply and demand profiles exhibit extreme peaks in very hot and very cold weather that in turn destabilize the ability of grid utilities to supply uninterrupted power.

We now are seeing the rise again of ice as an important medium in a growing number of HVAC systems. In the historic examples of harvesting, storing, using and transporting ice we saw what a economically valuable commodity it is, how robust and durable it is as a substance and that it has huge negative-energy storage potentials.

Today we are experiencing the advent of a new generation of ice cooled buildings with systems that combine the harvesting of natural cold sources in the environment, in the ground and night skies for example, and the efficient provision of top-up freezing mechanically.

The building-integrated ice reserves are used to shift energy demand loads across hours to use cheaper off-peak supplies for cooling, with low cost electricity bought when demand charges are low too, if applied at all. Such systems reduce the total energy demands of buildings by shaving the expensive peaks off demand profiles in hot weather.

Most modern ice storage systems are one of two types[12]:

- *Direct Ice Production* systems using heat exchangers with ice / water on one side and a sub-freezing fluid on the other where ice forms on the evaporator surface of the machine directly. Two such types are the *harvester systems*, where layers of ice are shed into an open slush tank, and the ice-on-coil systems with external melt. *Indirect Ice Production* systems where a secondary fluid is used and the refrigeration systems cools a brine solution (eg. glycol and water) to sub-freezing temperatures which in turn produces ice on the external surface of a heat exchanger over which the cooling air then passes.

A range of different control strategies are used including[13]:

- *Chiller-Priority* Controls are the simplest of this form of Thermal Energy Storage (TES) where the chiller runs continuously under conventional chiller control modes, possibly with demand limit, and the remaining cooling capacity is provided by the ice TES.
- *Adaptive Optimal Reinforcement Learning Control* using the ability of the machine to learn and evolve optimal algorithms to integrate-time dependent costs of electricity into the controls to reduce grid energy consumption and costs while maintaining required temperatures internally. Optimal control outcomes are defined as resulting in maximum operating costs savings in these controls.

Because of the growing need to use effective, low cost, thermal energy storage (TES) in buildings the growth of ice based systems in the last decade has been phenomenal. A growing number of large skyscrapers use ice TES systems to manage extreme electricity demand peaks and save energy[14].

The Bank of America HQ off Time Square in New York houses in the sub-basements in 44 cylindrical ice tanks, roughly 3 meters cubed enough ice to provide 25% of the annual cooling for the building, and 55% of the dirunal load on the hottest days. On hot summer afternoons, when power demand spikes, utilities typically fire up their least efficient and most polluting generators. During these peak periods, 90% of smog-forming particulates are emitted by just 50% of power plants. Since buildings with ice TES do not need to draw on this dirty power, the building's ice tanks will help to cut out a disproportionate share of pollution, a further benefit of the systems. The ice is produced at night, when excess electricity from the co-generation system is used to produce the ice that is then melted during the day to supplement the cooling system.

The Southern California Public Power Authority (SCPPA), working with Ice Energy, have planned distributed energy storage projects to demonstrate savings, such that if put into general use, would reduce fuel consumption by operating utilities by up to 30%, using TES and efficiency "negawatts", that in some cases cut energy demand by up to 90%. Over two years, the 11 small participating utilities will install 6,000 of the ice TES devices at a total of 1,500 locations, providing 53 megawatts of energy storage to relieve strain on the grid[15]. The units make cheap ice overnight using a high-efficiency compressor to freeze 450 gallons of water (1700 ltires). In the middle of the day, the device shuts off the regular air conditioner for the peak afternoon hours and instead pipes a stream of coolant from the slowly melting block of ice to an evaporator coil installed within the building's heating, ventilation, and air-conditioning blower system until the entire ice block has melted – which should be sized to take about 6 hours – to cover for the peak afternoon load on the grid.

Ice Energy is a leading provider of advanced ice energy storage and smart grid solutions to the electric utility industry in the USA[16]. Founded in 2003, the company is based in Colorado and has had particular success with its domestic and commercial systems like the 'Ice Bear' have been put into many homes and their systems into major national retailers, restaurants and fast-food outlets, convenience stores, data-centres, libraries, fire and police stations, schools, light commercial and manufacturing facilities, municipal buildings, an airport and even a motion picture studio.

CONCLUSIONS

We have seen in this article that ice has been used by man to preserve and cool since time immemorial. In the 21st Century the rising price of energy and the need to reduce greenhouse gas emissions, while at the same time withstanding extreme weather conditions and blackouts, will lead to the development of a new generation of ice storage systems for buildings, in machine-made and controlled systems, re-coupled to the ambient cold of the environments around them. The new Ice Age for building is here!

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Contractors: guiding you towards energy efficient refrigeration, air conditioning and heat pump systems

GRAEME FOX

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AREA (www.area-eur.be) is the European organisation of refrigeration, air-conditioning and heat pumps (RACHP) contractors. Established in 1988, AREA voices the interests of 22 national members from 19 European countries, representing more than 9,000 companies across Europe (mainly small to medium sized enterprises), employing some 125,000 people and with an annual turnover approaching € 20 billion. The associations, which are members of AREA, represent the enterprises responsible for the design, installation, maintenance, repair and dismantling of refrigeration, air conditioning and heat pump equipment. These companies are the indispensable competent intermediaries between component manufacturers and final users. In the recent years, energy efficiency has become a key priority for AREA and its members. Indeed, mindful of the fact that Europe wastes at least 20% of its energy due to inefficiency and that refrigeration and air conditioning (RAC) applications are responsible for a sizeable part of the energy consumed globally AREA is fully aware of the significant energy savings achievable through the raising of energy efficiency in the RAC sector.

This has led our association to get closely involved in a number of actions the aim of which is to address this issue, either directly or indirectly. AREA is thus working on a background paper on the contribution of the refrigeration, air conditioning and heat pump (RACHP) sector to energy efficiency, particularly in the context of several EU legislative initiatives, such as the F-Gas Regulation, the Energy Performance of Buildings Directive or the Directive on the promotion of the use of renewable energy sources (RES). Moreover, AREA is closely involved in the ongoing review of the F-Gas Regulation with the objective of increasing the latter's effectiveness and thereby the efficiency of the equipment which falls under its scope.

AREA core mission lies in the representation, defence and promotion of the industry and its high standards of quality, with the aim of ensuring the safe and uninterrupted usage of efficient refrigeration, air conditioning and heat pump equipment for users. To achieve its mission, AREA has thus been involved in a variety of initiatives in the fields of training & education (*Refrigeration Craftsman*[1] *project in the past, Real Skills Europe*[2] *and QualiCert*[3] *at present*) or standardisation (e.g. standard EN13313 on competence of personnel for refrigerating systems and heat pumps).

AREA also monitors regulatory developments at EU level and ensures the safeguard of its members' interests on issues that directly impact on their activities. Indeed, in view of their sphere of business, RACHP contractors are affected by a wide range of specific EU legislative acts: F-Gas Regulation, Energy Performance of Buildings Directive, Renewable Energy Sources Directive, Pressure Equipment Directive, Ozone Depleting Substances Regulation, Waste of Electrical and Electronic Equipment Directive, Restriction on Hazardous Substances Directive...). AREA is also involved in discussions on more general themes, such as energy efficiency and climate change from the point of view of RACHP systems.

To achieve its mission, AREA has adopted an adapted structure. Aside from the General Assembly and the Board, chaired by Mr. Graeme Fox (RACG/HVCA, United Kingdom), the Information Group is in charge of assessing any regulatory, legislative, vocational or technical issue relevant to the refrigeration, air-conditioning and heat pumps contracting sector, and devising strategies and work plans. The Task Group is then responsible for streamlining and coordinating the activities and priorities of ad hoc Task Forces, who deal with specific issues and formulate draft positions. X Task Forces are currently active to tackle various topics, such as energy efficiency, review of the F-Gas Regulation, heat pumps, CO_2 and other low GWP refrigerants.

As designers of RACHP installations, contractors have a thorough and unbiased expertise in the properties and manipulations of all refrigerants, be they fluorinated gases or natural refrigerants. On the basis of users' requirements, contractors choose among available solutions in the sole aim of ensuring the highest level of reliability, energy efficiency and cost-effectiveness. Over the years, this objectivity has given AREA a unique position in the "cold" sector and accrued legitimacy when address RACHP issues in the context of pressing needs for energy efficiency and fight against climate change and the role that green energies can play thereon.

ENERGY EFFICIENCY & RAC EQUIPMENT

Europe wastes at least 20% of its energy due to inefficiency[4]. According to the European Commission, "[r]*ealising the 20% potential 2020, equivalent to some 390 Mtoe, will result in large energy and environmental benefits. CO_2 emissions should be reduced by 780 Mt CO_2 with respect to the baseline scenario, more than twice the EU reductions needed under the Kyoto Protocol by 2012*".

Energy efficiency has thus become one of the highest political priorities, not only because of its financial impact but also because of its close connection with climate change. Mindful of the fact that RAC applications are responsible for a sizeable part of the energy consumed globally AREA is fully aware of the significant energy savings achievable through the raising of energy efficiency in the RAC sector. Some of these savings could be achieved without major investment in capital equipment and plant refurbishment but with education, good maintenance, implementation of good energy using practices and enforcement of relevant regulations. The other share of savings depends on the increased use of more efficient RAC systems, such as heat pumps.

For existing RAC systems, the vast majority of energy efficiency losses stem from a lack of regular and qualified maintenance. Frequent checking performed by properly qualified professionals is therefore a prerequisite to maximum efficiency of the system. In the EU, the F-Gas Regulation provides for such requirements for systems running on certain fluorinated gases. Although the original objective is to prevent leakages, the combination of enhanced qualification of professionals and regular checks positively impacts on the energy efficiency of the systems.

Refurbishment or new building projects give another opportunity of looking at the energy efficiency of the air conditioning system to be used. For instance, in large buildings, VRF[5] technology now offers substantial benefits, in particular when heat recovery[6] is possible. In addition, manufacturers of split air-conditioners have been producing reverse cycle heat pumps for many years based on a normal packaged air-conditioning system and incorporating a reverse cycle valve that reverses the flow of refrigerant to turn a cooling system into a heating one. Finally, RACHP systems use less and less refrigerant charge to achieve the same cooling duty. All these technological evolutions contribute to increasing energy efficiency.

In 2009, heat pumps were finally granted a well-deserved status of renewable energy technology in the EU, following the adoption of the Directive on the promotion of the use of energy from renewable sources[7]. Indeed, thanks to their high coefficient of performance, heat pumps enable energy production and recovery at a lower rate of CO_2 emissions. Although the heat pump market has been growing substantially for some years, the benefits of the legal framework will surely speed up this process, particularly in Member States with a low take-up.

Figures look promising. The European Heat Pumps Association, which represents the interests of the European heat pump industry, thus *"estimates the contribution of all heat pumps installed 2005-2009 and in operation at the moment at 27.2 TWh"*[8]. Despite a slow-down in 2009 because of the crisis, the European market shows a steady growth. In France, sales of heat pumps have thus increased from 25,000 units in 2005 to over 150,000 in 2008 and in Germany, from 25,000 to 80,000 in the same period. The potential is fantastic

Heat pumps, just like other air conditioning systems, use a refrigerant to achieve their potential. This refrigerant may be either natural or synthetic. Each type has its own merits and disadvantages. In any case, the choice of the right refrigerant plays a decisive role in the overall energy efficiency of the system.

CHOOSING THE RIGHT REFRIGERANT

Designing a RAC system involves a key element: the choice of the "right" refrigerant, i.e. the correct heat exchange media for the cooling or heating application. In the past few years there has been an increased interest in the promotion of non fluorinated refrigerants. Whilst AREA sees the development and promotion of new alternative refrigerants as a natural evolution, it must be pointed out that the energy efficiency level of the "new" refrigerant can only be assessed by comparing it to the existing HFC energy usage on a like for like basis.

When assessing the environmental performance of a RAC system, contractors tend to refer to the Total Equivalent Warming Impact (TEWI) rather than the sole Global Warming Potential (GWP) of the refrigerant used. The reason is very simple. The GWP of a refrigerant can only be achieved when the gas is released into the atmosphere through leakage. By limiting themselves to GWP, contractors would only take for granted that the system will leak. Moreover, GWP does not take into account that certain RAC systems are reach their highest energy efficiency levels with fluorinated gases rather than natural refrigerants. Finally, the impact of the F-Gas Regulation in Europe should not be ignored. F-Gas aims at reducing leakages through more regular and qualified maintenance. The experience of some AREA members (e.g. Netherlands, Sweden, Austria) has shown that thanks to high training and certification standards for RAC contractors combined with regular leak checking requirements, leakage was decreased up to fivefold. TEWI, on the other hand, takes into account the CO_2 emissions from fossil fuels to generate power to run the refrigeration and air-conditioning systems. In other words, TEWI incorporates the energy efficiency of the system in which the refrigerant is contained. GWP does not.

Daily experience of European contractors shows very clearly that when it comes to refrigerants, there is no panacea. Each refrigerant has its own merits depending on the characteristics of the RACHP system. In small systems, such as domestic refrigerators and freezers and point of sale display fridges, it has been demonstrated that hydrocarbon refrigerants (HCs) are very good in terms of energy efficiency compared with the old HCFCs, according to reports by the hydrocarbon industry. On large systems, such as central plant systems serving an office block or a shopping mall, it is normal practice to have a remote plant area either on the roof or besides the building. In these cases again the flammability or toxicological issues are less of a risk to the occupants of the building. However, it is generally accepted that in these cases it is preferable to use either CO_2 or ammonia as the primary heat exchange refrigerant. There are also, however, certain applications where it is beneficial to retain the use of fluorinated gases. In small to medium cooling duty applications, such as room air conditioners and localised process or comfort cooling applications, it has been demonstrated that HFCs are often the most energy efficient refrigerants to use compared with the alternatives[9].

These aspects are extremely important for heat pumps. Whereas their use is being promoted, it must be stressed that many heat pumps are reliant on HFCs to achieve their low carbon potential. This is what one could call the *duality of HFCs*. Whereas they intrinsically show a high GWP, when leakages are limited their TEWI is unequalled on the aforementioned applications.

So each refrigerant has its downsides. HFCs have a high GWP. Alternatives show toxicity, flammability or very high working pressure depending on which refrigerant you are looking at. In addition, each RACHP system will show different levels of energy efficiency depending on its characteristics and the refrigerant it runs with. This is where contractors' added value lies: in guiding users to make the most efficient choice.

CONTRACTORS: YOUR GUIDE TO ENERGY EFFICIENT SYSTEMS

Energy efficiency is a key element included in each facet of the contractor's work:

- *Proper system design* for new installations enables to maximize the overall energy efficiency level of all the installation's components put together. Design involves key elements, such as the choice of the refrigerant or capacity control;
- *Professional installation* guarantees the efficiency and the reliability of the system;
- *Regular maintenance* and servicing prevents refrigerant's leaks or enables early detection.

Contractors therefore play an essential role in advising and guiding users towards the most energy efficient system. The choice is made on the basis of many different requirements: intended use, cooling duty, location... and of course budget. Contractors are present throughout most of the system lifecycle from design, installation, maintenance, repair, dismantling (including decommissioning).

Such close presence combined with the fact that the RACHP sector is generally highly innovative requires the highest level of professionalism from contractors. In Europe, the F-Gas Regulation has enabled a general upgrade of a professional standard that varies from one Member State to another. The RES Directive is expected to have a similar effect on the installation of heat pumps.

AREA did not wait for legislative initiatives to act. Harmonisation of education & training / certification and promotion of professional techniques & high-level standards are among key basic objectives of the association. A few years ago, in the framework of a Leonardo da Vinci Project, AREA thus developed a portfolio of qualifications and skills needed to work in the field of refrigeration and air conditioning with excellent craftsmanship. The AREA Refrigeration Craftsman Project[10] was a first concrete step into ensuring a uniform minimum standard at EU level, at the initiative of the industry itself.

AREA continues on this path and recently got involved in 2 projects aimed at harmonising and increasing the general standard of the sector. Real Skills Europe is based on the successful British project Real Zero. It aims at achieving reductions in refrigerant leakage through improved awareness, education and training. AREA practical and technical expertise will hopefully help to ensure that the new material will provide the level of depth and practical skills needed in the sector to achieve reductions in leakage. QualiCert is a 30-month project that started in July 2009. It aims at developing a common approach to accreditation and certification of installers of small-scale renewable energy systems, in line with the obligation arising from Directive 28/2009 on the promotion of the use of renewable energy sources (RES). QualiCert has a broad scope, since it will address all types of RES (including heat pumps) from a general point of view.

In addition to these 2 projects, AREA has collaborated to an upcoming handbook on hydrocarbon refrigerants and related safety issues, which is put together for developing countries under the patronage of the German Ministry for Environment. The handbook will refer to the findings of the AREA Refrigeration Craftsman project for the part covering training and competences of technicians for the safe handling of HCs.

Through all these initiatives AREA and the entire European contractors community contribute to fostering the energy efficiency of RACHP equipment installed in Europe, thereby decreasing its environmental impact. Whereas forecasts anticipate steady growth of cooling needs in the coming years, contractors' role is therefore essential.

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Refrigerants: Making the Smart Choices

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Summary

Refrigerants are vital to the health, comfort, and well-being of hundreds of millions of the world's population. Today, industry leaders, government officials, and non-governmental organizations are being called upon to make decisions regarding which refrigerants best meet our air-conditioning, heating, and refrigeration needs while at the same time addressing the challenges of climate change and energy use. Industry's responsibility is three-fold:

- *to take a very active part in that discussion,*
- *to make all parties aware of the benefits and costs of the many refrigerants available for use today, and*
- *to provide funding for, and participate in, research into the next generation of refrigerants.*

Choosing a refrigerant for a specific application is not a zero-sum choice – it involves identifying and deciding which trade-offs – in safety, energy efficiency, availability, and cost – one can live with. Only when all of those aspects are fully discussed is an informed decision possible. Industry must be clear about one thing: The most widely used refrigerant today, hydrofluorocarbons(HFCs), which are the successor to HCFCs, have a high GWP but are also safe, widely available, economical, and have a zero ozone depletion characteristic. Equally important, there currently is no obvious successor that possesses all or even most of HFCs' positive characteristics. There are alternatives, sometimes called natural refrigerants, but they are typically limited to specific applications and present varying levels of safety and energy efficiency challenges.

Accordingly, HFCs will be part of the global refrigerant mix for some time to come. During that time, AHRI and the industry are committed to handling these refrigerants responsibly, to contain them and if a phase-down becomes reality, to ensure the phase down is not disruptive to the marketplace. We also will use this time to develop alternatives, in cooperation with government and non-governmental organizations. In fact, AHRI is actively engaged in discussions with its members, its colleagues in associations around the world, and with government officials on this matter.

AHRI is promoting research on the subject by others and is conducting research itself. For example, ne recently completed AHRI project summarizes issues and regulatory barriers on a region-by-region basis regarding which ones currently limit the use of carbon dioxide, ammonia, hydrocarbons, and other newly developed, low-GWP fluids (such as HFO-1234yf) in many applications in the United States, Japan, and the EU. This report makes it clear that alternative refrigerants not only can present technical issues but legislative and regulatory ones as well.

Another project, still ongoing, involves research into the Life Cycle Climate Performance (LCCP) Model for HVACR Systems. This project will establish a standardized methodology to calculate the LCCP of HVACR products. LCCP is a concept that identifies all the global warming impacts due to the use of a certain product through its lifetime, including both the direct effect of refrigerants and possible blowing agents' emissions from the product as well as the indirect effect of carbon dioxide emissions related to the energy consumption of the product. The research is a multi-phase project; the current effort focuses on residential heat pumps. The outcome of this research will be a simulation tool which can perform calculations to compare products' LCCP with different types of equipment and refrigerant choices, all while considering regional effects. Results of this research will provide policy makers and HVACR systems manufacturers with a great opportunity to evaluate the overall environmental impact of specific products and refrigerants.

What underpins all that we do on the air conditioning and refrigeration side of our industry is our core mission to provide comfort cooling and commercial refrigeration, in an economical and environmentally responsible way, to every person in every country in the world that can obtain it. It doesn't hurt for us to be reminded now and then how important our mission is, not just to the comfort of the world's citizens, but also to their economic productivity, their health, and indeed their very survival. Our products have enabled people to live in areas that were previously uninhabitable. They have enabled a more comfortable – and therefore far more productive – workforce. The farmers

(picture above) The last European Conference (Yurek second from the left): the 14th Conference will see two sessions taking place. The first session on the 21st January 2011 in Edinburgh will be about renewable energy in heating and cooling, the second session will take place on 10th-11th June 2011 in Milan and it will cover the latest technologies in refrigeration and air conditioning with a focus on energy efficiency.

that grow food here in Europe, but also in the breadbasket of America and in other nations around the world, are far more productive and efficient now than they were before mobile air conditioning. The food they grow is available to more people – the whole year round – thanks not only to the mobile refrigeration that enables the safe transport of foods, but also to the commercial refrigeration that stores it at the proper temperature in the markets where it is sold. Similarly, the air conditioning that keeps a family comfortable in the hottest days of summer also allows for efficient use of space in cities by enabling workers to be productive in high-rise buildings that would otherwise be uninhabitable. It has been de rigueur this summer in the United States to discuss life without air conditioning, as though that were possible in this day and age…or desirable. But air conditioning and commercial refrigeration – classes of products manufactured by members of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI), the association I lead – require refrigerants. I suppose it might make life easier if all refrigerants had the same characteristics – wide availability, efficiency, economy, safety – but they do not. Choosing a refrigerant for a specific application is not a zero-sum choice – it involves identifying and deciding which trade-offs – in safety, energy efficiency, availability, and cost – one can live with. Only when all of those aspects are fully discussed is an informed decision possible. Industry must be clear about one thing: The most widely used refrigerant today, hydrofluorocarbons (HFCs), which are the successor to HCFCs, have a high GWP but are also safe, widely available, economical, and have a low ozone depletion characteristic. Equally important, there currently is no obvious successor that possesses all or even most of HFCs' positive characteristics. HFCs are safe, containable, reclaimable, and recyclable gases which – and this is an important point – are highly energy efficient. While all other green house gases are byproducts of some process, HFCs are intentionally produced as energy efficient refrigerants for use in, among other things, air conditioning and refrigeration applications.

While HFCs are a very important part of the global refrigerant mix, AHRI believes that manufacturers must, at least for the foreseeable future, have access to a variety of refrigerants and that they should be free to use the proper refrigerant for the appropriate application. There are many other available refrigerants but each, like HFCs, has its advantages and its drawbacks even if they may have a low GWP.

There are those in the environmental community who suggest that industry is too reliant on HFCs and should move to other – sometimes referred to as "natural" – refrigerants. But let's take a look at some of those refrigerants and others that are available today and examine some of their advantages and drawbacks:

Ammonia is an economical refrigerant with a very low global warming potential. It is efficient and available and technicians are generally familiar with its use and characteristics. It is, however, both flammable and highly toxic, in addition to being incompatible with copper and copper alloys.

Hydrocarbons, on the other hand, are efficient, have very low toxicity, and are quite economical, but they are highly flammable. In fact, in the U.S., some building codes prohibit their use.

CO_2 would seem to be a good choice, as it has a very low global warming potential, is economical and non-flammable. This refrigerant operates under higher pressures than most, however, which makes the systems that use it more expensive and prone to leaks. In addition, technicians are not as familiar with its use.

My point here, obviously, is that while alternatives to HFCs are available and indeed are in use in some applications, refrigerant choice must be maintained if we are to have an appropriate mix of available refrigerants for the number of applications for which they are needed. Furthermore, many different criteria must be taken into account when deciding which refrigerant is best for each application. Factors such as equipment size and location, operating pressures, capital and operating costs, and operating temperatures all must be considered for each application. In addition, national, regional, and local laws and regulations must be considered as well.

Research

But, even though our firm position is the maintenance of refrigerant choice, we must ensure that in the likely event HFCs are to be phased down, the transition is orderly and incentives are provided for the development of new refrigerants that have both a low GWP and high energy efficiency – not an easy task! AHRI is promoting research on the subject by others and we are conducting research ourselves. For example, a recently completed AHRI project, completed by our research arm, the Air-Conditioning, Heating, and Refrigera-tion Technology Institute (AHRTI) summarizes issues and regulatory barriers on a region-by-region basis to determine which regions currently limit the use of carbon dioxide, ammonia, hydrocarbons, and other newly developed, low-GWP fluids (such as HFO-1234yf). The conclusion is that use of those refrigerants would currently be restricted in many applications in the United States, Japan, and the EU. This report makes it clear that alternative refrigerants not only can present technical issues but legislative and regulatory ones as well.

Another AHRTI project, still ongoing, involves research into the *Life Cycle Climate Performance (LCCP) Model for HVACR Systems.* This project will establish a standardized methodology to calculate the LCCP of HVACR products. LCCP is a concept that identifies all the global warming impacts due to the use of a certain product through its lifetime, including both the direct effect of refrigerants and possible blowing agents' emissions from the product as well as the indirect effect of carbon dioxide emissions related to the energy consumption of the product.

The LCCP concept has been well recognized and utilized in mobil air-conditioning industries across the world, but there has been no standardized methodology and tool for stationary HVACR equipment worldwide. AHRI is leading the initiative to develop the tool for the product classes or applications of interest to the industry. The research is a multi-phase project; the current effort focuses on residential heat pumps. The follow-on efforts on other types of equipment will be continued upon industry's requests.

The outcome of this research will be a simulation tool which can perform calculations to compare products' LCCP with different types of equipment and refrigerant choices, all while considering regional effects in the United States initially, and eventually around the world upon the implementation of local data inputs. Specifically, for a particular application such as residential air conditioning, a standardized LCCP model will be able to demonstrate the life cycle energy consumption and related CO_2-equivalent emissions associated with different systems. The model will enable the comparison of LCCP values in different regions for systems having the minimum SEER of 13 but different variations, e.g., fixed-capacity compressors, variable capacity compressors, and other variations. Evaluations of the LCCP values of systems with SEER values above 13 in regions with differing climates will reveal whether there are regions where higher SEER systems provide only marginal LCCP benefits. The effect on LCCP on a refrigerant's GWP and emissions during a system's operating life can be calculated for several refrigerants and assumed emission histories in different regions/climates will show the relative significance of refrigerant choice on direct global warming vs. indirect global warming. The results will provide policy makers and HVACR system manufacturers with a great opportunity to use a standardized approach to evaluate the overall environmental impact of specific products and refrigerants, and establish a basis for engineers and policy makers to make decisions on alternative competing technologies.

Law of Unintended Consequences

Aside from the issues discussed above, policy makers need to be careful that their policies do not reduce emissions in one sector, while increasing them in another. While low direct emissions are a desirable outcome, they should not occur at the expense of overall efficiency. After all, indirect emissions account for more than 90 percent of the total emissions due to the operation of air conditioning systems. Therefore, it is important that efficiency be maximized in all possible situations, in summer and winter, and during high- and low-demand periods.

Limiting or eliminating energy efficient refrigerants like the current HFCs might reduce the potential for leaks of greenhouse gases from the air conditioning sector of the economy, while at the same time increasing them in the power generation sector because of the loss in efficiency from the air conditioning sector. This is known as the law of unintended consequences. The point is, most economic sectors are interconnected, and policy changes in one sector usually affect other sectors, and not always in a good way.

What will happen if we don't get it right:

With regard to HFCs, we are quite simply in a better situation than we were when the HCFC to HFC transition began. While policy makers in Europe and in America have made noises about phasing down HFCs, there are to date no concrete proposals to do so. By planning for that eventuality, however, we are essentially giving ourselves a head start. We are able to get started developing suitable alternative refrigerants so that if – and probably when – legislation and directives mandating a phase-down are enacted, we will be able to maximize the amount of time available to develop and test equipment using those refrigerants.

But if we do not expend the resources commensurate with the challenge here; that is, if we do not take this seriously enough, we could very well end up with an untenable situation for all involved: Manufacturers unable to make products that use the safest and most efficient refrigerant available; contractors unable to sell the products that have been the most economical and efficient; and consumers unable to buy the products that are right for their needs. We have a good record as an industry in researching, developing, and producing goods in a variety of efficiency levels and a multitude of price points. We must make the extra effort to work with policy makers to ensure we can continue to do that. And that work with policy makers needs to recognize the global nature of our industry. The industry has an opportunity to approach what are truly global issues in a unified fashion and it should not lose sight of that opportunity.

I am proud that our industry has begun to develop more foresight on these important regulatory matters. We've talked in the past, many times, about the importance of self-regulation and being proactive, but this is a situation where we are actually moving forward on our own, for the benefit of our industry AND the environment. And that is something we can all be proud of.

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Performance assessment of air conditioners with propane

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This topic will be discussed in the next 14th EU Conference in UK and in Italy

The research group is mainly working in the field of alternative refrigerants to HCFCs. Dr. Devotta and Dr. Padalkar are technical consultants on the project 'Demonstration Project, Conversion of the Production Facilities for the Manufacturing of Split and Window-Type Air-conditioning Equipment from Halogenated Chemicals to Natural, Climate-Friendly Cooling Agents' funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. This research mainly focuses on the development of unitary air conditioning systems with propane, a natural refrigerant. All tests have been carried out in M/s Godrej & Boyce Mfg. Co. Ltd. The test facility is equipped with quality instrumentation and software. Advanced simulation tools were used for the design and development of new and optimized systems.

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HCFC-22, widely used in room air conditioners, has to be phased out in Article 5 countries by 2030 under Montreal Protocol. HC-290 is considered as an attractive alternative to HCFC-22.
A 5.13 kW capacity split air conditioner designed for HCFC-22 was considered. After establishing the baseline performance data with HCFC-22, the unit was retrofitted with HC-290. Under the drop-in test, the cooling capacity with HC-290 was lower by 6% and COP higher by 14%. The optimized charge of HC-290 was about 50% of HCFC-22 by weight. A 30% larger condenser gave 1.6% lower capacity and 10% higher COP. With a 10% higher capacity compressor, the cooling capacity was improved by 2.8% and COP was lower by 1.1%. In the case of a new condenser with 5 mm tube OD, the cooling capacity was nearly equivalent to HCFC-22, with 16.6% higher COP. In this case, HC-290 charge used was only 30% of HCFC-22 charge.
ORNL Heat Pump Design Model was used for simulation and optimization the system with HC-290.

INTRODUCTION

HCFC-22 is widely used refrigerant in air-conditioning (AC) all over the world. The growing global demand for room air conditioners increases the usage of HCFC-22. Due to its environmental concerns of Ozone Depletion, it is a controlled substance under the Montreal Protocol. As per the accelerated phase out schedule, HCFC-22 has to be phased out before 2020 in Non-Article 5 and by 2030 in Article 5 countries. In Europe, it is already phased out in new equipment and the total phase out is scheduled for 2014. The accelerated phase out schedule poses a major challenge for developing countries. At present, HFC alternatives to HCFC-22 for ACs are R-407C and R-410A. However, with relatively high GWP of HFCs and the uncertainties on the future of such HFCs, they are not preferred as long term alternatives. Some developing countries, including India and China, are searching for long term alternatives instead of opting for intermediate solution of HFCs. Therefore, there is a lot of interest in natural fluids like hydrocarbons. Propane (HC-290) is considered as an energy-efficient replacement due to its similarity to HCFC-22 except for its flammability.
Many studies have revealed the advantage of HC-290 in air conditioner and heat pumps. Park and Jung (2008) showed that HC-290 when used in air conditioner, the refrigeration capacity and coefficient of performance were 8.2% lower and 11.5% higher respectively than that of HCFC-22. Granyrd (2001) concluded that the energy demand with HC-290 for a given cooling load is slightly lower than HCFC-22. Fernando et al. (2007) showed that HC-290 in the heating mode works without loss of performance. Devotta et al. (2005) experimentally assessed HC-290 for air conditioners under drop-in conditions and

found 7.9% improvements in COP. Poggi et al. (2008) showed that the charge reduction is possible with reduction in the internal volume of the system components. Many studies emphasise the charge reduction technique to minimise the risk due to flammability. It has been concluded by many researchers that HC-290 performances equal or better than existing system with HCFCs or HFCs.

This article presents the simulated and experimental performance of a room air conditioner with HC-290. The air conditioner was tested as per the Indian Standard 1391 (1992) Part II, for unitary air conditioners. These test conditions are close to the Air Conditioning & Refrigeration Institute (ARI) Standard 210/240 (1989) for unitary air conditioning and air source heat pump for cooling mode. All safety measures for using HC-290 were duly considered and implemented for the experiments.

STANDARDS FOR FLAMMABLE REFRIGERANTS

Important issue of HC-290 is its flammability. As per ASHRAE Standard 34, HC-290 is classified as Class 3 (high flammability fluid). The lower flammable limit (LFL) and upper flammable limit (UFL) of HC-290 are 2.1 % and 9.5 % respectively by volume in air.

There are some standards for air conditioning and heat pump applications when operating with HC-290. These standards prescribe the norms for design, constructional features and equipment, including refrigerant charge, room size limit, use of non-sparking and sealed electrical components, use of safety valves, refrigerant detector, etc. In order to reduce the risk of fire, the charge reduction strategy is one of the most important issues.

The safety precautions to be taken are based on the refrigerant charge quantity and physical location of the unit or the separation of components containing HC-290. Charge size limitations are set considering that flammable concentration should be far below the LFL, if the whole charge leaks and diffuses into the given space. The European standard EN378 allows HC-290 in a broad range of applications, if safety requirements are fulfilled. The international standard for the safety of air conditioners, IEC 60335-2-40, contains requirements comparable to those in EN 378.

Table 1.
Capacity rating test (CRT) conditions as per IS 1391 part 1 (1992).

Test	Indoor Room Conditions		Outdoor Room Conditions	
	DBT (^oC)	WBT (^oC)	DBT (^oC)	WBT (^oC)
Capacity Rating Test	27	19	35	24

Corberan et al. (2008) have reviewed the various existing standards for air conditioning applications. According to DIS ISO 5149, EN 378 and EN/IEC 60335-2-40, the maximum refrigerant charge could be 1 kg for human comfort applications.

TEST CONDITIONS

Indian Standard 1391 (1992) Part II prescribes various tests to assess the performance of room air conditioners. The important tests for energy efficiency are Capacity Rating Test (CRT) and Power Consumption Test (PCT). The purpose of CRT is to determine the magnitude of the net cooling effect. The conditions for PCT are the same as CRT. The conditions of air on both sides of room air conditioners are presented in Table 1.

EXPERIMENTATION

In this study, a typical 5.13 kW capacity room air conditioner-split unit designed for HCFC-22 was selected for performance evaluation with HC-290. Initially the baseline performance was established with HCFC-22. Then, the performance was measured under drop-in and retrofitted conditions. Further during optimization study, the area of condenser and capacity of compressor were varied to achieve the best possible performance. Higher condenser area and higher capacity compressor were considered to compensate the capacity loss under retrofit conditions. In order to reduce the charge inside the system, the condenser tube OD was reduced to 5 mm. This approach also has secondary benefits for HC-290 since the same pressure drop as HCFC-22 is maintained but refrigerant-side heat transfer coefficient is increased considerably.

The following different cases were considered.

- Test 1: HCFC-22 for baseline performance
- Test 2: Drop-in test with HC-290 with optimized charge
- Test 3: HC-290 with 30% higher condenser area
- Test 4: HC-290 with 10% higher capacity compressor
- Test 5: HC-290 with condenser of 5 mm tube OD

For all the above tests, refrigerant charges were optimized. Only optimized results are presented. Table 2 presents the details of the hardware data of the air conditioner. Two identical air conditioners were used for tests. For tests 1 to 4, first air conditioner was used and test 5 was conducted with another air conditioner (of otherwise identical characteristics).

Experimental test facility

The air conditioner was tested in psychrometric chamber as per IS 1391 part 1, as shown in Figure 1. The cooling capacity was calculated from measured dry bulb and wet bulb temperatures of entering and leaving air and the associated flow rates. The air temperatures were recorded using thermocouples with an accuracy of ±0.1 °C. Nozzle type air flow measuring device was used to measure the volumetric flow rate of air. Air pressure difference across the nozzle was measured using manometer. An electronic panel recorded all the pressures, temperatures, air flow rates, and power consumed by test unit.

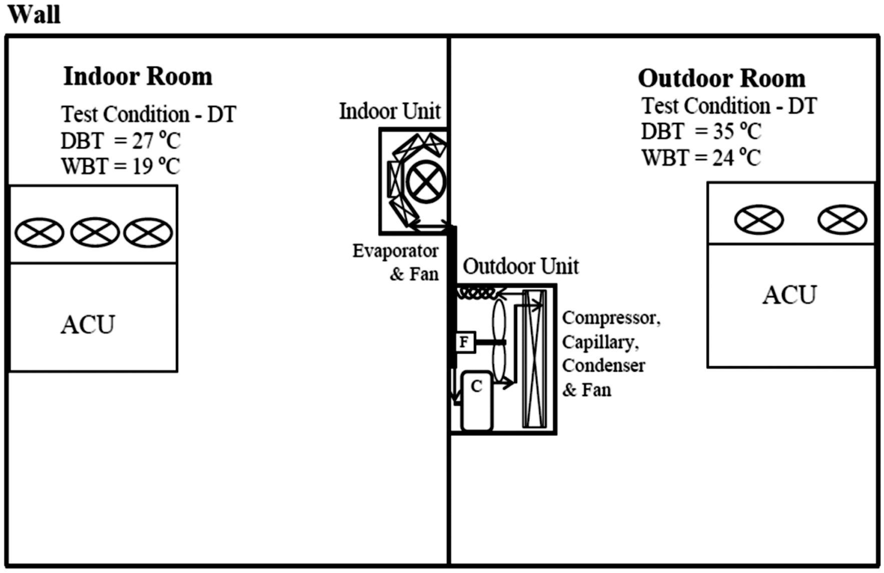
After running the unit under steady state for about 1½ hr, all data were recorded for 1 hr at an interval of 10

min. The performance data for HCFC-22 were used as the baseline data. After completion of HCFC-22 test, HCFC-22 was recovered from the unit and the unit was then charged with HC-290 following standard procedures.
HC-290 charge was varied in the range 30 to 60% of the original HCFC-22 charge during various tests.

Safety considerations using HC-290 in selected system

All safety precautions were taken while testing the air conditioner. All tubing joints were brazed. The electrical components like capacitor, thermostat switch, on/off switch were properly sealed. Both the chambers consisting indoor and outdoor unit were well ventilated before starting the system. The test chambers were also fitted with HC detectors and exhaust fans.

Figure 1.
Schematic diagram of the test facility.



SIMULATION

The simulation was done using the Heat Pump Model Mark VI (Rice, 1997) developed by Oak Ridge National Laboratory (ORNL). This model was used to predict the steady-state performance of air-to-air-heat pump in cooling or heating mode. Morrison (2004) found that the model simulated the performance within accuracy of ±5% compared to measured data.
The input data required for system simulation were collected from the original equipment and compressor manufacturers. The component specifications used for simulation are presented in Table 2.

RESULTS AND DISCUSSION

Cooling capacity
Figure 2 shows the variation of cooling capacity for HCFC-22 and HC-290. HCFC-22 gave a cooling capacity of 4.82 kW. For HC-290, under different tests through Test 2 to Test 5, the cooling capacities were in the range 4.54 kW to 4.96 kW. Under the drop-in condition (Test 2), the capacity for HC-290 was lower by 6% and optimized charge was 50% of that of HCFC-22. In case of a larger compressor with an EER of 3.0, as against the original compressor with an EER of 3.05 (Test 4), the cooling capacity increased by 2.8% over the base line test. However, with increase in condenser area only (Test 3), HC-290 gave lower capacity by 1.6%. The cooling capacity obtained in Test 5, i.e. smaller size tubing with condenser is nearly equivalent to HCFC-22. The highest cooling capacity obtained was 4.96 kW in Test 4.

Table 2.
Component Specifications and refrigerant charge for various tests.

		Test 1	Test 2	Test 3	Test 4	Test 5
Compressor		Compressor 1	Compressor 1	Compressor 1	Compressor 2	Compressor 1
	Cooling capacity (kW)	5.10	5.10	5.10	5.62	5.10
	EER (W/W)	3.05	3.05	3.05	3.00	3.05
Condenser; air side area (m^2)		13.0	13.0	17.3	13.0	7.04
Evaporator; air side area (m^2)		8.7	8.7	8.7	8.7	8.7
Capillary length (mm)		610	610	610	610	610
Refrigerant Charge (g)		1130	565	665	678	340

Figure 2.
Cooling capacites of HCFC-22 and HC-290 for various tests.

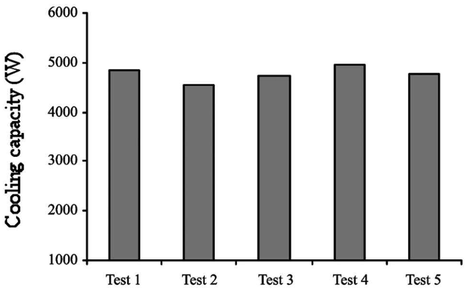


Figure 3.
Coefficient of performance of HCFC-22 and HC-290 for various tests.

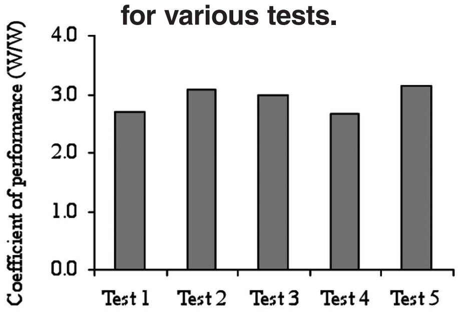


Figure 4.
Power consumption of HCFC-22 and HC-290 for various tests.

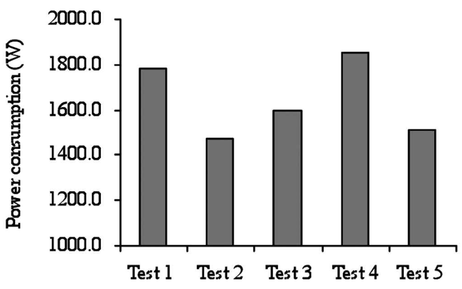
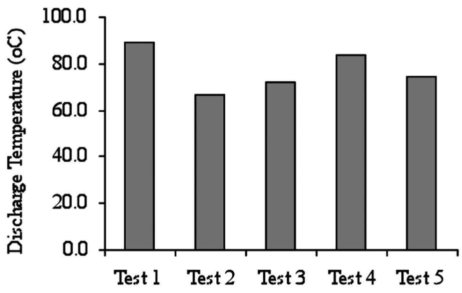


Figure 5.
Discharge temperature of HCFC-22 and HC-290 for various tests.



Coefficient of performance

Figure 3 shows the variation in COP for HCFC-22 and HC-290 under various tests. COP for the base line test (Test 1) with HCFC-22 was 2.70. Under the drop-in test (Test 2) with HC-290, COP was 3.08, higher by 14%. For Tests 3 and 4, HC-290 gave COPs similar to HCFC-22 even though the larger compressor has marginally lower EER. The air conditioner with 5 mm tube condenser gave the highest COP of 3.15, 16.6% higher than that of base line test.

Power consumption

Figure 4 shows the variation in power consumption by the air conditioner for various tests. The power consumed by the base line system (Test 1) was 1.79 kW. Under HC-290 drop-in test (Test 2), the power consumption was 17.8% lower than that of base line.

The power consumed in test with larger condenser area (Test 3) was 13.5% lower than HCFC-22. In case of the tests with higher capacity compressor, Test 4, the power consumed was higher by 3.6% as the EER of the larger compressor is also slightly lower. Under Test 5, the power consumption was 15.6% lower than HCFC-22.

Discharge temperature

Figure 5 shows the discharge temperature of HCFC-22 and HC-290 for various tests. The discharge temperature of HC-290 for all other tests was lower in the range 5.1 °C to 17 °C than that of 89°C for HCFC-22. The lowest discharge temperature of 66.3°C was observed for the drop-in test. Lower discharge temperature helps in reducing the degradation of oil and leads to increase in compressor life.

CONCLUSIONS

HC-290, a natural refrigerant with negligible GWP, is a potential long term alternative to HCFC-22. Based on the experimental investigation of a typical 5.13 kW split AC unit, the following conclusions could be drawn.

For HC-290, under the drop-in test, although the cooling capacity was lower by 6%, COP was 14% higher. The charge of HC-290 was about 50% of that of HCFC-22 by weight. For HC-290, the power consumption was lower by 17.8% and the discharge temperature was significantly lower by 22.7 °C.

In the case of HC-290, due consideration should be given to the flammability. Therefore, charge minimisation is a very critical step. This was achieved by reducing the tube diameter of condenser. The air condenser with 5 mm condenser tube diameter gave equivalent capacity and 16.6% higher COP as compared with HCFC-22. For equivalent cooling capacity, the charge of HC-290 was reduced to 30% of HCFC-22.

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Petter Nekså

CO_2 - A refrigerant with potential in several applications[1]

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Carbon dioxide was among the widely used refrigerants in the infancy of refrigeration around year 1900. Unlike ammonia, however, it more or less disappeared when the (Hydro)ChloroFluoroCarbons ((H)CFCs) were launched. After being re-introduced as a refrigerant around 1990, CO_2 has become an important alternative in replacing environmentally harmful refrigerants such as CFCs, HCFCs and HFCs. The development has shown potential in several applications both in terms of system efficiency and system cost, thus making it a viable alternative for applications not considered feasible earlier. This has been made possible through an enormous effort from industry, research institutes and universities. Currently, CO_2 is the refrigerant of preference for many companies, and commercial products are already available. For some applications there are still challenges to be overcome if introduction of CO_2 should become successful. The paper gives an overview of the far and near historic development of CO_2 as refrigerant and discusses future potential and challenges.

1. Based on extracts from: Nekså, P., Walnum, H.T. and Hafner, A. (2010): *CO_2 - A refrigerant from the past with prospects of being one of the main refrigerants in the future*, 9th IIR Gustav Lorentzen Conference 2010, Sydney, April 12-14, ISBN 978-2-913149-74-8, ISSN 0151-1637

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HISTORICAL DEVELOPMENT

Carbon dioxide was one of the first substances used as a refrigerant. Alexander Twining proposed its use as refrigerant in a British patent from 1850. It became the refrigerant of choice for several applications. Among these were marine refrigeration and air-conditioning. However, unlike ammonia, it did not survive the introduction of the CFCs and HCFCs. Registration of marine refrigeration systems from Lloyds register in London shows a gradual phase-out of CO_2 systems in use from 1950 until 1960.

Around 1990, when focus was put on the CFC and HCFC refrigerants' ozone depleting ability, and consequently, the Montreal Protocol was implemented to phase them out, CO_2 was introduced as one of the alternatives (Lorentzen, 1989). In competition with the HFCs, CO_2 again managed to be a refrigerant of choice.

Now, when the high GWP HFCs seems to be at the verge of being phased out as well, partly due to the focus put on greenhouse gas emissions by the Kyoto Agreement, CO_2 may become the preferred refrigerant in several new applications. Together with other natural refrigerants, most importantly hydrocarbons and ammonia, CO_2 should be able to cover most applications of refrigeration, air conditioning and heat pumps, and also being an alternative working fluid for Rankine cycles for power production from surplus heat.

The paper will through examples from different applications discuss future potential and challenges. An important challenge in many potential applications is to obtain competitive energy efficiency for operation when the heat sink temperature is high. This will most often mean heat rejection to high ambient temperature air. Different measures to overcome this challenge will be discussed and needs for research and development pointed out.

FUNDAMENTAL ASPECTS

Fundamental aspects of CO_2 used as refrigerant have been discussed in several publications, for instance Nekså (2002) and Kim et al. (2004). Compared to conventional refrigerants, the most remarkable property of CO_2 is the low critical temperature of 31.1°C. Vapour compression systems with CO_2 operating at normal ambient temperatures thus work close to and even above the critical pressure of 73.8 bar. The operation close to the critical point leads to three distinct features of CO_2 systems when used as the only refrigerant:

– **Heat is rejected at supercritical pressure when the heat sink temperature is high.** The system will then use a transcritical cycle that operates partly below and partly above the critical pressure. The high-side pressure in a transcritical system is determined by refrigerant charge and not by saturation pressure. The system design thus must consider the need for controlling the high-side pressure to ensure a high COP and capacity. A refrigerant buffer volume is needed in order to enable charge variations, but since no liquid can be stored at the supercritical pressure, other options must be found. The most common is to buffer liquid on the low pressure side of the system or at intermediate pressure.

– The pressure level in the systems will be relatively high, often between 30 and 120 bar. The high operating pressure results in a high volumetric capacity. This is leading to smaller required cross sectional flow areas in the system and thus also smaller inner volume of the system. As a consequence, components should be redesigned to fit the properties of CO_2. The advantage is that components most often can be designed more compact since e.g. the compressor displacement needed for a given capacity compared with HFC-134a is 80-90% smaller. Further, compressor pressure ratios are low, thus giving favourable conditions for achieving high compressor efficiency. The relatively high operating pressures in evaporators and condensers/gascoolers also lead to very efficient heat transfer compared with HFCs, further enabling heat exchangers to be of a more compact design. Higher pressures are often associated with a higher hazard, but due to smaller volumes of piping and components, the stored explosion energy in a CO_2 system is not much different from that of a conventional system.

– Large glide in temperature of the refrigerant during heat rejection. At supercritical or near-critical pressure, all or most of the heat transfer from the refrigerant takes place by cooling dense single phase gas. The heat rejecting heat exchanger is therefore called a gascooler instead of a condenser. Since heat is transferred as sensible heat, the temperature will be gliding according to the actual high pressure. Gliding temperature can be an advantage in heat pumps for heating water or air. For other applications care must be taken in order to achieve as low refrigerant temperature as possible out of the gascooler. With proper heat exchanger design the refrigerant can be cooled to less than or a few degrees above the entering coolant (air, water) temperature, and this improves the COP of the systems compared to if typical temperature approach assumptions from simple cycle comparison approaches are used. It should be noted that provided the gas cooler outlet temperature can be cooled to a sufficiently low temperature, the COP will be higher than in a typical HFC system. Internal heat exchange to subcool high pressure gas with the compressor suction gas may also improve efficiency, especially at high ambient temperatures.

When CO_2 is used as a low temperature fluid in cascade systems, for example in combination with ammonia, pressure levels in the CO_2 stage can be kept to a more conventional level, for example below 25 or 40 bar. Then components and tubing commonly used for other refrigerants can be used, often without adjustment. CO_2 is also commonly used as a heat transfer fluid (HTF) in combination with other refrigerants. This results in considerably lower pumping power requirement than for brine systems, especially at low temperatures.

Due to the difference in CO_2 thermophysical properties and cycle characteristics compared to HFC refrigerants, typical system efficiency curves (e.g. cooling COP) shows different trends with the heat sink temperature, see Figure 1. CO_2 tends to be more efficient at lower ambient temperatures, while HFC systems may be slightly more efficient at the highest ambient temperatures. When comparing energy efficiency for CO_2 systems and alternative technologies, it is therefore essential to make a seasonal comparison based on the operating conditions the systems will experience during the year. A comparison only at typical rating conditions, e.g. 32 or 40 °C, will not give a fair comparison with respect to energy consumption over the year. Usually the rating point is given for the most severe condition the equipment is likely to experience. The system only will experience temperatures around the design point for shorter periods of the year, see Figure 2 (red vertical line represents 35 °C). It is important to ensure that the required cooling or heating capacity is achieved at these conditions. However, this is merely a matter of design. Operation at the rating point condition will usually not be important for the annual energy consumption of the equipment. Life cycle climate performance evaluations (LCCP), is one way to address comparison to other alternatives, taking into account indirect emissions due to power consumed of the system at varying operating conditions during a year, direct emissions related to refrigerant emissions, and emissions related to system production and demolition/scrapping.

For some applications, however, efficiency at high heat sink temperatures needs to be addressed more carefully. This may be due to limitations in power supply or due to continuous or long-term operation at these conditions. Cycle improvements of different kinds may then be required, such as alternative cycle modifications, e.g. parallel compression, or including work recovery during expansion. Different options will be discussed in connection with various applications in the following section.

APPLICATIONS

Technology for CO_2 as refrigerant has been developed for a range of applications. Concentrating on systems with CO_2 as the only refrigerant one may range the readiness of technology in the order:

■ Already developed and commercialised
- Heat pump water heaters – domestic, commercial and industrial sized
- Commercial refrigeration systems, supermarkets
- Beverage coolers
- Ice cream chest freezers
- Water chillers for moderate climates, air conditioning and industrial
- Transport refrigeration (bus, train)

■ Already developed – not yet commercialized
- Mobile air conditioning systems

■ Under development
- Mobile heat pumps
- Transport refrigeration systems (containers, truck, marine)
- Residential heat pumps (space heating and reversible)
- Vending machines for combined hot and cold beverages
- Combined heating and cooling of

non-residential and residential buildings
– Heat pumps for space heating and combined space and water heating
– Heat pump dryers of residential and commercial size, e.g. laundry applications
– Rankine power cycles for utilisation of low temperature surplus heat

■ Early development
– Residential air-conditioning systems
– Water chillers for hot climates, air conditioning and industrial
– Industrial refrigeration and heat pumps

The list is not meant to give a complete picture, but illustrates that CO_2 technology already now has become an important alternative. Component availability in different capacity ranges have been developed, even though production numbers for some of them still is an issue in order to obtain competitive cost with HFC components. Another important barrier for some applications is energy efficiency at high heat sink temperatures. The most important barrier may however be the scepticism to new technology among both manufacturers and end-users. In the following sub-sections status and challenges for some important applications are discussed.

Figure 1.
Typical COP vs condenser/gascooler inlet temperature of heat sink.

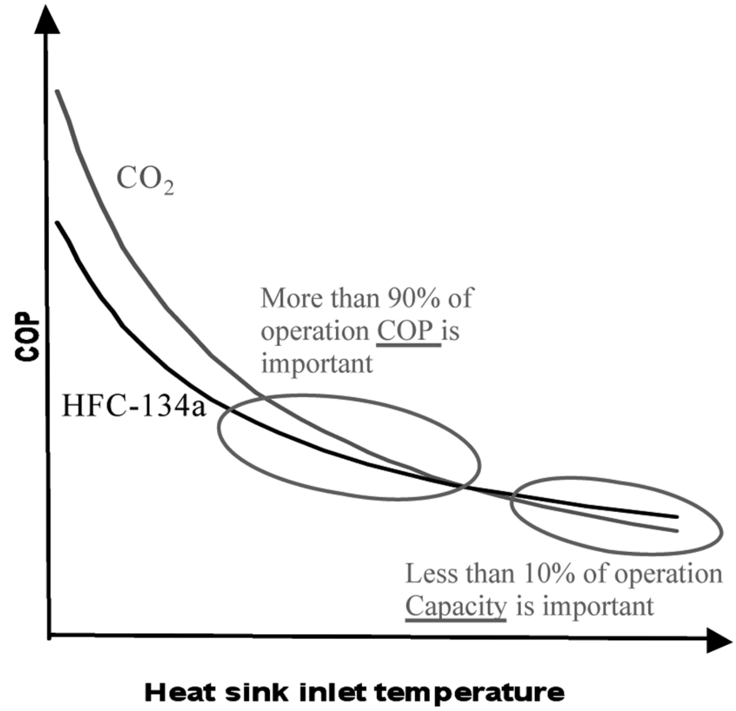
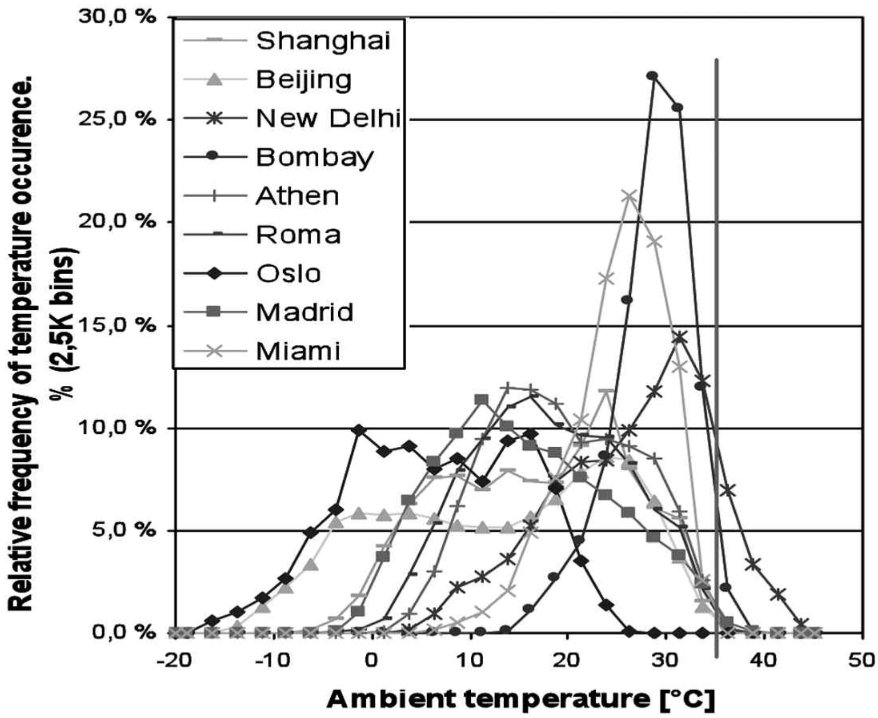


Figure 2.
Temperature bin curves for a variety of hot and moderate temperate cities world-wide.



Heat pump water heaters

Heat pump water heaters, used for heating tap water typically from 10 ºC to 65 ºC, is an application very well suited for the transcritical CO_2 cycle (Nekså, 1998a). After the initial development phase in the period 1990-98, successful commercialisation was made in Japan from 2001 with help of governmental incentives aiming to move water heating from fossil fuel heating to heat pumps. About 1.7 million units were installed between 2001 and 2008. The aim is to install 5.2 million units within 2010, which would reduce CO_2 emissions in Japan with about 2.9 Mt-CO_2/year, corresponding to about 5% of Norway's CO_2 emissions. A significant improvement of the systems has taken place since market introduction in 2001, to make the efficiency even higher (Hashimoto, 2006). The improvements have been done both on components, such as compressors and heat exchangers, as well as introducing ejectors for energy recovery. Currently, seasonal performance factors are above 4. Systems both for residential, commercial and industrial use are now also introduced in Europe by several manufacturers. With the increasing importance of tap water heating due to less heating demand in low energy buildings, this technology should have great prospects.

Mobile air conditioning and heat pumps

Mobile air conditioning was among the first applications addressed when CO_2 was reintroduced. Systems using CO_2 as refrigerant have readily been developed by several OEMs. Equal or superior performance compared to HFC-134a systems has been demonstrated, even for small cars operating in hot climates (Hafner and Nekså, 2007). The constrained nature of the application both regarding system weight and volume makes it possible to utilise the good thermophysical properties of CO_2 to make compact and light-weight systems with high energy efficiency.

The phase-out of HFC-134a in EU in this application for all new car models from 2011 will require a shift of refrigerant. CO_2 and HFC-1234yf seems to be the most realistic alternatives. The hydrofluorocarbon HFC-1234yf has a low GWP, but is a new and unknown chemical. Unavoidable emissions will cause known and potentially unknown negative impacts to the local and global environment due to the decomposition products formed, see e.g. Kajihara et al. (2010). Technically, CO_2 technology is already developed; it is now more a policy decision to decide on a technological shift to CO_2 or to choose a third generation halocarbon with unknown future consequences. What also makes it complicated is that a common world-wide refrigerant choice would be preferable.

CO_2 is also a very good alternative refrigerant for future vehicle heat pumps. This will be an important application for fuel efficient cars with less excess heat available and hybrid or electrical cars with little or no waste heat available for heating during the cold season, especially for moderate and colder climates. CO_2 systems perform very well for such heat pumps as demonstrated e.g. by Mager et al. (2002).

Commercial refrigeration

Now, several system manufacturers and supermarket chains have decided to make all-CO_2 systems their preferred choice for future installations. CO_2 is an important refrigerant alternative to HCFCs and HFCs in commercial refrigeration systems since it is the application area within the refrigeration sector with the largest refrigerant greenhouse gas (GHG) emissions. Developments for using CO_2 as HTF, in cascade systems or for all-CO_2 systems took place in parallel, starting in the 1990s.

Some of the major commercial refrigeration manufacturers and contractors have introduced direct expansion systems using CO_2 as the only refrigerant with a transcritical/subcritical cycle depending on ambient temperature, supplying both low- and medium-temperature refrigeration. More than 200 supermarkets have been built in Europe with this kind of system design, from Italy in the south to Norway in the north, with a cooling capacity range of 50 to 1200 kW. Energy consumption and cost are reported to be within the range of today's direct expansion (DX) R-404A systems and indirect system designs. A recent review article by Tassou et al. (2010) also points to CO_2 based systems, as the only refrigerant or in cascade, as a probable dominant technology in the future.

Berg (2009) reports initial cost on parity for larger systems, while systems for smaller supermarkets tend to be 10-20% more expensive. Comparison of energy consumption for six different supermarkets in Norway (about 1500m^2 each) with heat recovery (three with R-404A systems and three with CO_2 systems) showed all lower energy consumption for the CO_2 based systems. A life-time assessment was therefore always lower in cost for the CO_2 option.

In moderate climates, the possibility to do heat recovery will always be important. Due to the refrigeration load from the display cabinets in the supermarket, the period for heat demand is considerable. CO_2 systems have important advantages since it is possible to supply large parts of the heat required very efficiently. It will also be possible to make direct heat exchange between CO_2 and the air heating system, enabling a cost efficient concept. High ambient temperature operation is the most challenging. Girotto et al. (2004) and Girotto (2007) showed that low temperature refrigeration systems compete well with R-404A DX, but at medium temperature, the CO_2 system suffered in efficiency.

Results show that the efficiency gap observed at higher ambient temperatures for a medium temperature application may be closed. Parallel compression is possible to implement already with existing components. Another possibility is to utilise evaporative cooling at heat rejection. This would of course benefit both CO_2 and R-404A, but the relative gain would be higher for CO_2. Further results on these options and other cycle options are reported in Girotto and Minetto (2008).

Also in the light commercial sector, including stand-alone equipment such as bottle coolers and vending machines, some of the major companies have introduced CO_2 technology. Several thousands of units have been installed in pre-commercial deployment tests, with an expected number of 85,000 by the end of 2009 (Azar, 2009). In the application of hot and cold vending machines, being important especially in Japan, CO_2 also give important advantages when both the hot and cold side of the cycle can be utilised (Jakobsen, 2006 and Tsuchiya, 2006).

Residential air conditioning and heating

Reversible air-to-air heat pumps with CO_2 as refrigerant have been investigated by industry and research institutions. Since this is the application with the highest production numbers, alternatives to HFCs in this application would be of great interest. Jacobsen et al. (2006 and 2007) made experimental and theoretical evaluation of a prototype CO_2 reversible split type system at conditions representative for Athens and Oslo and comparing it with highly efficient HFC 410A systems on the market. The CO_2 system competed very well in heat pump mode for both hot and moderate climates. The seasonal cooling performance was competitive in air conditioning mode, but COP at the highest ambient temperatures, above 30 ºC, were poorer. Results show that it should be possible to reach the same efficiency level as high efficiency HFC-410A units even at the highest ambient temperatures. However, component and cycle improvements are required, and perhaps equally challenging, within an acceptable cost level.

Transport refrigeration

CO_2 HVAC systems are viable alternatives to HFC-systems in the public and goods transport sector. Sonnekalb et al. (2009) show an innovative roof concept for bus air conditioning with flexible and time saving mounting in order to reduce life cycle costs. The CO_2 prototype has proved its high efficiency for more than 6,000 operating hours since 1996. In addition to the unit for AC operations, an air-to-air heat pump for a concept-bus was presented. Rindsfüsser (2008) shows similar concepts for both city buses and coaches.

Hafner and Christensen (2010) describe the opportunity for use of CO_2 as refrigerant in air conditioning systems for public trains. Today, 75% of the air conditioning systems in trains use HFC-134a as refrigerant. The CO_2 system shall provide cooling in the summer and heating in the winter. Radial piston compressors, which are extremely compact solutions for applying CO_2, have been trialed in the first trains and are certified for use on railways.

Container and transport refrigeration is a demanding application field; however, CO_2 is a sustainable alternative to HFC refrigerants in this area, where compactness and reliability is extremely important.

Industrial refrigeration, air conditioning and heat pumps

CO_2 has become an important refrigerant within industrial refrigeration for use in a low temperature stage of cascade systems, with ammonia in the upper stage. For low temperature refrigeration this combination can both increase efficiency and also reduce the investment cost. It is also an important option in order to reduce ammonia charges, where this may be an issue. Cold storage and ice rink systems are example applications.

Transcritical CO_2 systems have also been proposed by Visser (2007) for applications where there is a combined high demand for hot water and cooling, e.g. in meat processing plants, and for office air conditioning primarily. Concepts for district heating systems have also been proposed by several. These are large capacity systems. Heat pump systems with capacity up to 4 MW are now offered in the market utilising screw compressors.

CONCLUSION

A tremendous development of CO_2 technology has taken place since the revival of the refrigerant around 1990. The development has led to efficient CO_2 systems that have been introduced in the market, but also inspired developments for other technologies. Ongoing development in several applications and in development of components and novel system designs are expected to enable commercialisation in several applications in the near future. Challenges exists in achieving energy efficiency and competitive system cost in some application areas. However, looking at the results achieved in the development so far and the considerable research and development effort ongoing, it is expected that the challenges may be overcome for many new applications. The focus on reducing GHG emissions and environmental aspects as such is also expected to further encourage increased use of natural refrigerants in general and CO_2 in particular.

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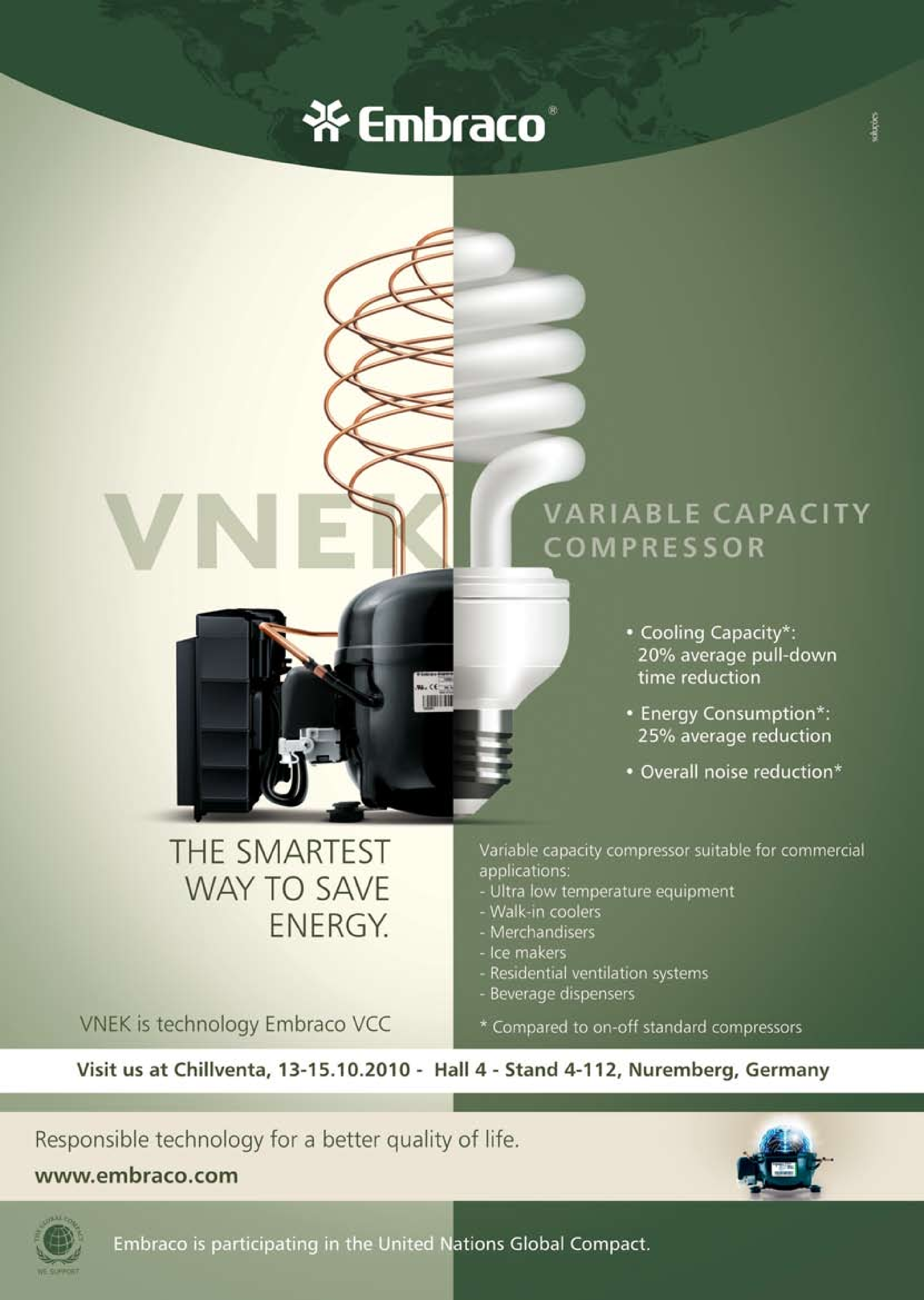
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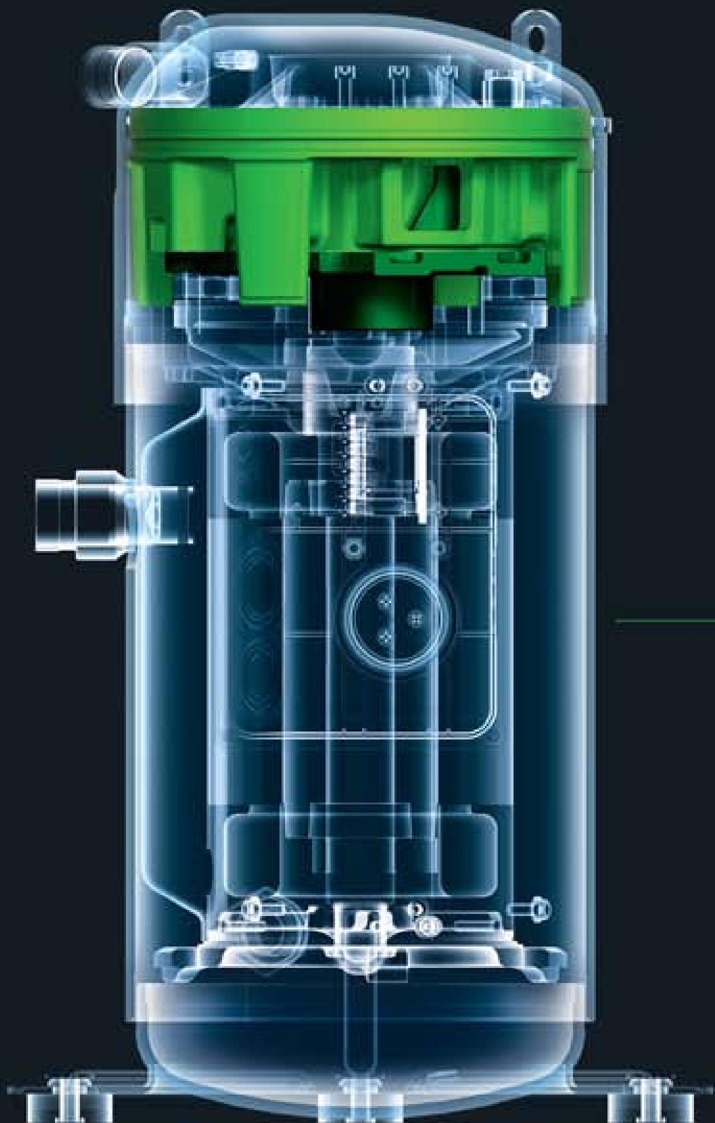

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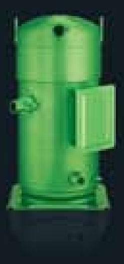

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