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refrigeration and air conditioning

THE ROAD FOR NEW GENERATION TECHNOLOGIES

ENVIRONMENT • ENERGY
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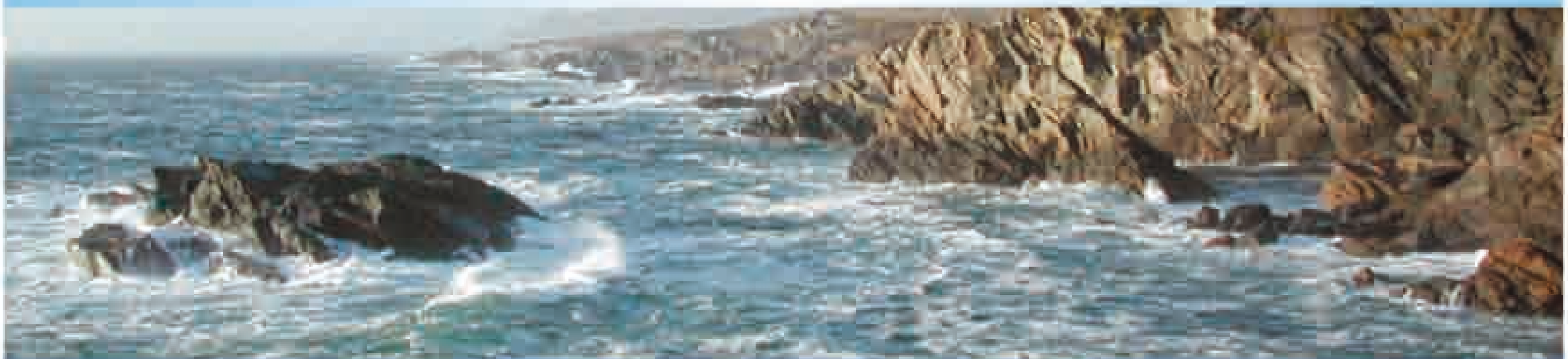

UNDER THE AUSPICES OF THE ITALIAN MINISTRY OF THE ENVIRONMENT

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From the left picture ISI2006, ISI2008, ISI2010 and the last ISI2012

About the pictures on the cover: as ISI2006, ISI2008, ISI2010, ISI2012 **bottom part** the image of Achill Island of the most North-Westerly point of Ireland, **top part**, one of the most magnificent mountain panoramas of the world, the image of Monte Rosa mountains (see also Mont Blanc mountains at page 22 in the article of Mr. Shende) which illustrates:

- **Ozone protection** the blue sky contains our Earth's ozone shield
- **Climate Change** the Global Glacier retreat due to global warming is a global threat
- **Energy Efficiency and Renewable Energy** glaciers and the water are a primary font of energy for our hydroelectric plants.

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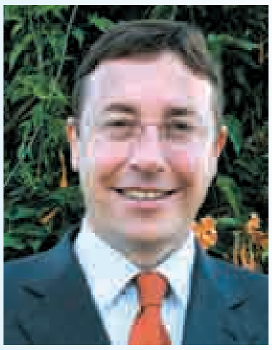
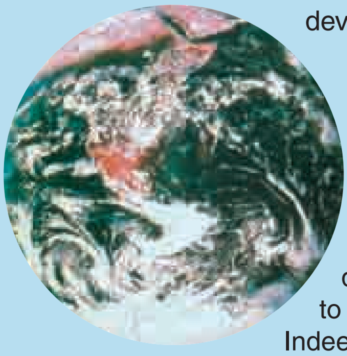
FOREWORDS



During the first 25 years of its existence, the Montreal Protocol on Substances that Deplete the Ozone Layer has achieved universal ratification by 197 Parties which committed to phase-out the consumption and production of nearly 100 ozone-depleting substances. If all phase-out provisions of the Protocol are complied with, scientists expect the recovery of the Ozone Layer to regain its historical levels in the second half of this century.
It is estimated that without the Montreal Protocol, the level of harmful ultraviolet radiation (UV-B) could have led to millions more cases of skin cancer and eye cataracts, not to speak of damage to human immune systems, wildlife and agriculture. Given that most ozone-depleting substances are also potent greenhouse gases, the Montreal Protocol has also significantly contributed to climate protection.
The remaining challenges are the phase-out of methyl bromide used for soil fumigation and pest treatment, and the phase-out of hydrochlorofluorocarbons (HCFCs), which are widely used in the refrigeration and air-conditioning, foam and fire-protection sectors.
It is in the refrigeration and air-conditioning sector, where manufacturers and wholesalers, service technicians and end-users, building planners and investors, industry associations and standardization bodies can make a tremendous contribution by promoting energy efficient, ozone- and climate-friendly technologies, and to the extent possible avoid new installations using high global warming gases such as hydrofluorocarbons.The introduction of superior alternatives – in particular in developing countries - requires overcoming country-specific barriers for example through (safety) training and certification of technicians, incentive schemes to ensure commercial availability at competitive prices, conducive legislation and standards, and awareness of investors and building owners.
Each of you can contribute to ozone layer and climate protection in your field of expertise for example though purchasing decisions, participation in expert training, transformation of your business, and investment decisions.
The story of protecting the ozone layer has not yet turned its final chapter. Governments to industry need to maintain their ambition. But investing in healing the damaged ozone layer has already proven that investing in the environment can have high returns in terms of prevented economic losses, sustainable development and human progress.



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

The Kyoto Protocol and the Montreal Protocol are two separate environmental agreements, but the phase out of the ozone depletion substances (ODS) helped the CO_2 reduction and the fight to climate change.
Indeed substances like Chlorofluorocarbons (CFCs), Halon, Carbon tetrachloride are ODS and powerful greenhouse gases, so the activities through the ozone Multilateral Fund have in addition resulted in greenhouse gas reductions equivalent to 25 billion tonnes of CO_2-equivalent.
The ongoing challenge is the transition from the production and consumption of the HCFCs, substances used in different industrial and civil sectors like: air conditioning, refrigeration, heat pump and foam, to alternatives which do not deplete the ozone layer and which do not harm the climate. Indeed depending on the alternatives selected, through the phasing out of HCFCs we can either significantly contribute to climate change mitigation.
So far the Montreal Protocol has been recognized as a global success and model for its capacity to bridge consensus among the relevant stakeholders. In particular involving the industries, the Academia, the policy makers and the civil society.
The same approach is going to be used by the industry, who are the engine of the innovation, which are already developing new substances and process with better performance with the aim to minimize the impact for the environment in view of a low carbon society goal.
Italy will play its role first within the EU and in the contest of the International negotiation for support the low carbon innovation.

Corrado Clini - Italian Minister of the Environment

FOREWORDS (2)

The aim of the International Institute of Refrigeration (IIR), an intergovernmental organization comprising 60 member countries (developed and developing countries) in all continents, is to disseminate scientific and technical information on all refrigeration technologies and uses, thanks to conferences, databases and publications.
We are used to work with United Nations agencies and programmes in order to better disseminate this information, which is vital. Refrigeration is necessary for life, however refrigerating equipment has an impact on the environment, on the stratospheric ozone layer as well as on global warming, due to currently used refrigerants and to huge energy consumption. We need sustainable development. Partnership with UNEP in promoting climate friendly technologies via such a publication is necessary.
Italy is an active IIR member country and its help as well as the publication work handled by Centro Studi Galileo for promoting climate friendly technologies are both very welcome. We must thank them for giving us such an opportunity to deliver crucial messages.

IIR experts and correspondents have written articles on various issues which can not reflect the diversity of cases but can offer you an overview of what can be done in the refrigeration sector. And all refrigeration stakeholders must make an effort in order to address environmental challenges, as in other sectors, but probably more so, because of the growing importance of our sector.
We hope that after having read these articles, you will have some answers but also more questions: achieving sustainable development in each country is a long-term issue and technical improvements will continue to be developed in the short and the long term. We are at your disposal to help you.

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

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

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

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.

From the left M. Buoni-ATF, D. Coulomb-IIR, E. Buoni-CSG

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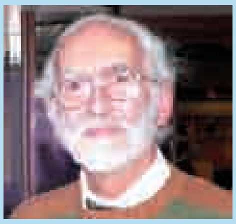
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Refrigeration Main Challenges

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DIDIER COULOMB

International Institute of Refrigeration - IIR

IIR offices: on the left D. Coulomb showing ISI2006, on the right M. Buoni ATF.

This topic will be discussed in the next 15th EU Conference

REFRIGERATION IS INCREASINGLY NECESSARY

Refrigeration is necessary to mankind

- Temperature is a magnitude and a key variable in physics, chemistry and biology.
- It characterizes the states of matter in liquid, solid and gaseous phases and is therefore essential in material applications.
- It is vital to all living beings and each living being (bacteria, plant, animal) has a temperature range within which it can live.

Temperature governs whether pathogens can develop, survive or not. Foodstuffs and health products are thus often chilled or frozen.

Refrigeration is everywhere, in:
- Cryogenics (petrochemical refining, the steel industry, the space industry, nuclear fusion…)
- Medicine and health products (cryosurgery, anaesthesia, scanners, vaccines…)
- Air conditioning (buildings, data centres…)
- The food industry and the cold chain
- The energy sector (including heat pumps, LNG, hydrogen…)
- Environment protection (including carbon capture and storage), public works, leisure activities…

The Needs are increasing, particularly in developing countries

We need to keep a few facts in mind:
- 1600 deaths/year in the USA[1], at least partly associated with temperature control, are due to pathogens. According to the World Health Organization[2], refrigeration and improved hygiene have reduced stomach cancer by 89% in men and 92% in women, since 1930 in the USA. Figures would certainly be much higher in less developed countries where there is huge leeway for progress.
- There is an increase in global population, particularly in Africa and South Asia (9,3 billion in 2050, 8 billion in developing countries).[3]
- 70% (50% now) will be in urban areas (doubled figures in developing countries)[3] and this will increase the need for cold chains, because of longer distances between production and commercialization sites and because of increasingly westernized models (meat,…)
- 1 billion people are undernourished[4]; 23% of food losses are caused by a lack of refrigeration in developing countries (vs. 9% in developed countries)[5]. The refrigerated storage capacity in developed countries is tenfold the refrigerated storage capacity per inhabitant in developing countries[5].
- There are needs for better health everywhere (good cold chains, air conditioning), particularly because of an ageing population.

This increase in emerging and developing countries will increase the impact on the environment.

ENERGY AND THE ENVIRONMENT ARE INCREASING CHALLENGES FOR THE FUTURE

Refrigeration is a major energy consumer

Refrigeration, including air conditioning, represents 15% of global electricity consumption. And this figure will increase (The Netherlands: already 18%...). Refrigeration issues are clearly linked with electricity issues, which are:
- Global warming because of CO_2 emissions (electricity production depending on fossil fuels): we need to take into account the TEWI (Total Equivalent Warming Impact), and the LCCP (Life Cycle Climate Performance) of the refrigerating equipment (the IIR recently built a Working Party to measure it)
- The price of electricity will increase (new sources of energy have higher costs)
- There is a lack of power infrastructures, particularly in developing countries Overall system solutions (district cooling, trigeneration…) should certainly be developed and we need to review the coefficients of performance of the systems. For instance, heat pumps are considered as a renewable energy in the European Union, provided that they have a sufficient Coefficient of Performance because of their electricity consumption. There are and there will be new regulations on

energy and on buildings in Europe, the USA or Japan with new constraints on energy and thus new constraints on refrigeration systems.
New sources of energy can be used, such as solar energy. Even if the coefficient of performance of solar equipment is still relatively low and if investment costs can be high, some systems are already in place and many experiments and research programmes are ongoing.
Refrigeration can also drive new sources of energy, like liquefied gases (Liquefied National Gas, Liquefied Hydrogen…).
In any case, changing a system because of refrigerant issues must take into account potential reductions in energy consumption: both issues are linked.

The impact of refrigerants on the environment

Vapour-compression systems will remain predominant in the short and medium term and thus we will require more refrigerants in the future.
Because of their impact on the stratospheric ozone layer, Chlorofluorocarbons (CFCs) and Hydrochlorofluorocarbons (HCFCs) are included in the Montreal Protocol and each country (whether developed or developing) had to build phase-out plans.
That issue will thus hopefully soon be behind us, apart from the bank issue (refrigerants in existing equipment to be destroyed in the future). However, the main issue of phase-out plans is the kind of refrigerating equipment which is used to replace old equipment.
There are alternative refrigerants:

– Hydrofluorocarbons (HFCs), including Hydrofluoroolefins (HFOs) have no impact on the ozone layer but they have an impact on global warming (they are included in the Rio Convention and the Kyoto Protocol)
– Natural refrigerants (ammonia, CO_2, hydrocarbons, water, air) have a very low impact on global warming.
– Mixtures, combinations (cascades, secondary fluids) are being developed in order to meet the various requirements.

HFCs currently represent less than 1% of CO_2 eq emissions. In 2050, they will represent 7-45% (more likely 7%) of CO_2 equivalent emissions.
HFCs emissions in 2050 could offset the achievements of the Montreal Protocol related to the phase-out of CFCs.
Hence, discussions are held at an international level (Montreal Protocol and Kyoto Protocol meetings) on the future of HFCs: replacing HCFCs with HFCs could be a real threat to the climate.

The following table summarizes the impact of the main refrigerants on the ozone layer (Ozone Depleting Potential = ODP) and on climate change (Global Warming Potential = GWP). Even if CFCs have a very high ODP and GWP, HCFCs and HFCs have similar impacts.

Family of refrigerants	Main refrigerants	ODP	GWP
CFCs	CFC 11	1	4 750
	CFC 12	1	10 900
	Others	0.4 -> 1	6 000 -> 15 000
HCFCs	HCFC 22	0,05	1 810
	Others	0.020 -> 0.070	70 -> 2 400
HFCs	HFC 134a	0	1 430
	HFC 404A	0	3 900
	HFC 407C	0	1 800
	HFC 410A	0	2 100
	HFC 32	0	720
	HFC 1234yf	0	4
	Others	0	4 -> 4 500 (except HFC 23 = 14 800)
Natural Refrigerants	HC 290	0	20
	HC 600a	0	20
	HC 1270	0	20
	R717 (ammonia)	0	~0
	R744 (Carbon dioxide)	0	1
	Air, water	0	~0

HOW TO REDUCE THE IMPACT OF REFRIGERATING EQUIPMENT ON ENVIRONMENT?

Various solutions

a – ***There are other technologies:*** ab-sorption, adsorption, solar refrigeration, magnetic refrigeration, thermoelectric cooling, cryogenics (nitrogen, CO_2) but they still require technological improvements (in terms of cost, energy efficiency, capacity). Thus, they are currently only niche technologies.
However, many technical developments take place. IIR Conferences on adsorption-absorption technologies, on magnetic refrigeration and on cryogenics are increasingly successful and people in universities and industries from America, Europe, Asia attend them. Prototypes of magnetic refrigeration are developed in all these regions. Solar cooling is experimented in Africa as well as Southern Asia and Australia.
New solutions will be found on a mid-term perspective.

b – ***We can reduce leakage***

Refrigerant emissions are due to leakage and poor recovery at the end of life of the equipment. Both issues can be handled and it would certainly be part of the solution on a short-term perspective.
Because of important variability within similar equipment working in similar conditions, there are margins for progress. For instance, leakage rates in the European Union which were at 30% in the 1980s are now at 5% and less.
This is part of the solution the European Union decided to implement in order to reduce fluorinated gases emissions. The F-gas regulation was adopted in 2006. It is too early to assess the impacts of this regulation on refrigerant emissions and the regulation is currently under revision. However, some advantages and backwards of such a regulation can already be seen. The aim was to strengthen the

CFCs and HCFCs are mainly replaced by HFCs, which generally have a high GWP

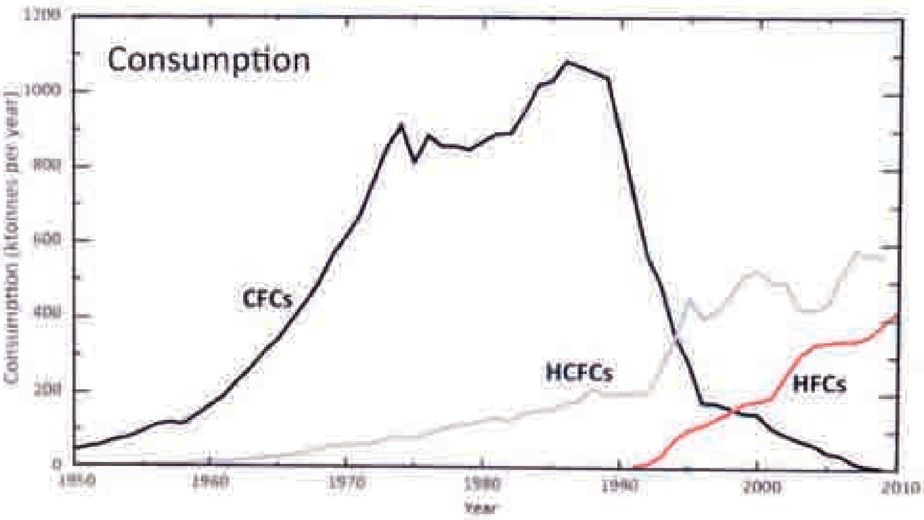

Figure ES 1. *Global consumption (in kilotonnes per year) of ozone depleting CFCs and HCFCs. The phasing in of HFCs as replacements for CFCs is evident fram the decrease in CFC usage concomitant with the increasing usage of HFCs. Use of HCFCs also increased with the decreasing use of CFCs. HCFCs are being replaced in part by HFCs as the 2007 Adjustment to the Montreal Pratocol on HCFCs continues to be implemented. Thus, HFCs are increasing primarily because they are replacing CFCs and HCFCs.* Source UNEP

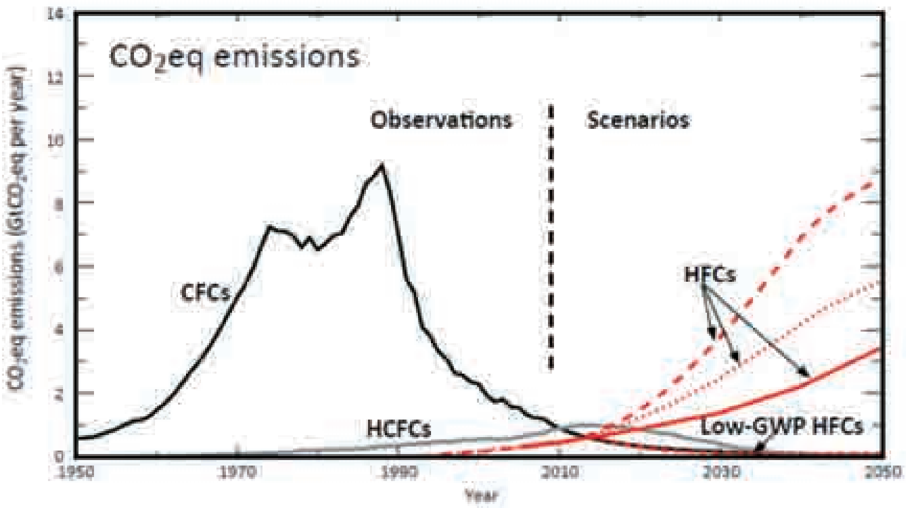

Figure ES 2. *Trends in CO_2eq emissions of CFCs, HCFCs, and HFCs since 1950 and prajected to 2050. The HFC emissions scenarios are trom Velders et al. (2009) and Gschrey et al. (2011). The low-GWP ~ HFC line represents the equivalent HFC emissions for a scenario where the current mix of emissions . (with an average lifetime of HFCs of 15 years and an average GWP of 1600) was replaced bya mix of low GWP HFCs (with an average lifetime of less than 2 months or GWPs less than 20).* Source UNEP

control on leakage thanks to staff training, and the certification of staff and companies handling refrigerants in stationary equipment.

Training is necessary but it is the most important difficulty and it takes time. However, reducing leakage has clear advantages in terms of savings and on safety. For instance, a draft European proposal for the review of the F-Gas regulation proposes to extend training and certification to non-fluorinated gases which could be toxic and flammable. In any case, more training of staff handling refrigerants will be necessary in the future.

c – ***We can reduce the refrigerant charge***

The aim is the same: reducing the refrigerant charge without changing the refrigeration equipment capacity and its efficiency would reduce leakage rates. Several technologies can be used and are currently developed: secondary refrigerants, micro-channel technologies… It is also both a Greenhouse-gas emission reduction issue and a question of safety.

d - ***Choosing a low-GWP refrigerant***

There can be several definitions of a “low-GWP” refrigerant. People generally consider refrigerants as low GWP fluids when their GWP is lower than 20: natural refrigerants (ammonia, CO_2, hydrocarbons, water, air) or some HFCs called HFOs (hydrofluoroolefins).

However «moderate» GWP refrigerants (for instance R32) are also chosen by companies, since their impact would be much lower in cases of leakage than some higher GWP refrigerants. (1/2 to 1/7…). In any case, several issues should be considered:

- Most low GWP refrigerants have safety drawbacks: flammability, toxicity. Some of them require very different equipment than that used with HCFCs or HFCs, because of corrosion or pressure issues. They all require adaptations of the equipment.
- Equipment energy efficiency depends on the kind of equipment, the working fluid as well as working conditions, such as climate conditions. However, solutions with natural refrigerants exist all over the world for many applications with similar energy efficiency than in most common equipment.
- Investment costs can be higher for low GWP refrigerants especially because of safety reasons. However, the cost of the fluid and the maintenance must also be taken into account.
- Numerous current technical developments on low GWP refrigerants and on new technologies are underway and constantly updated information is required.

HFCs are mainly used in refrigeration and air conditioning

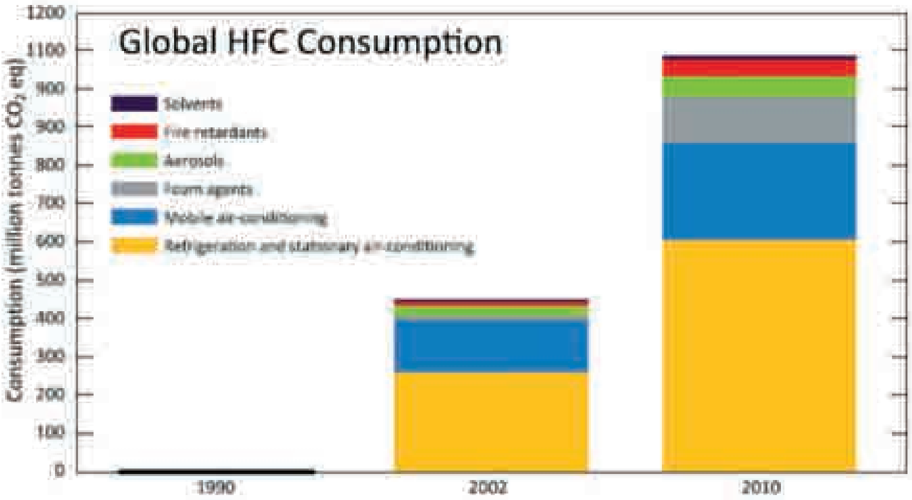

Figure 1.4. *Estimated global consumption of HFCs by various sectors, expressed in CO_2equivalent, for 1990, 2002 and 2010 (TEAP 2005, EPA 2010a). HFCs are predominantly used for the same industriai uses as the CFCs and HCFCs which are subject to phase-out under the Montreal Protocol. The rapid growth in HFCs after 1990 is also clearly evident.* Source UNEP

CONCLUSION AND PRESENTATION OF THE ISI 2012 REPORT

And this is precisely the aim of this publication: to present various issues related to refrigerating equipment, various technologies, whether currently used or still under development.
The articles presented deal with:
– General phase-down or phase out of HFCs policies: three articles, representing different opinions, from the industry as well as non-governmental organizations. AREA represents refrigeration, air conditioning and heat pump contractors (installers…) in Europe. EPPE represents manufacturers of refrigeration equipment components, systems, refrigerants as well as various European industrial associations. They agree on the need to better control F-gases and to phase down their consumption, in the European context: with the F-gas regulation (under revision) and the MAC Directive, the European Union is the region of the world which currently has the most ambitious objectives in terms of major production and consumption of HFCs. Greenpeace, a well-known worldwide non governmental organization, has a more ambitious objective involving full and rapid phase-out of HFCs.
These general policy texts are completed by an interview of Rajendra Shende, former head of OzonAction within UNEP and currently manager of an Indian association Terre Policy Centre.
– More specific policies are needed concerning refrigerants: Business Edge proposes training and qualification of people handling refrigerants in the United Kingdom, in order to reduce leakage, because of the impact of the latter on the environment (application of the current European F-gas regulation) as well as safety issues in the case of natural refrigerants. Centres of expertise and control of refrigerating equipment (Cemafroid and CRT) involved in the International Institute of Refrigeration (IIR) present the IIR Informatory Note on counterfeit refrigerants. A stricter policy on fluorinated gases is needed, provided that we pay attention to that issue. The reduction of the refrigerant charge and thus refrigerant leakage can be obtained by technologies like minichannels as explained in the article of the Padova university (Italy).
– Natural refrigerants: SINTEF, a Norwegian Scientific and Technical Research Centre presents the latest technologies using CO_2 as a refrigerant: CO_2 has been a reference refrigerant for about 20 years, especially in Northern and central Europe and improvements are still underway.
The IIAR, based in the USA, presents the current and possible uses of ammonia, which has been a widely used refrigerant in the refrigeration industry for more than 100 years (since the outset) and is still recognized as a very efficient refrigerant.
– Other technologies that avoid the use of refrigerants are presented: the case of a ground-source absorption heat pump in China is presented by the Chinese Association of Refrigeration. A solar thermal driven absorption chiller under Algerian climate is presented by our Algerian colleagues. The use of solar collectors for heat pumps by universities in Chile and in the United Kingdom is also mentioned.
The use of renewable energies, such as solar energy, such as heat pumps and heat pumps driven by solar energy in particular, must also be considered: indirect emissions of refrigeration equipment due to its energy consumption are much higher than direct emissions. Magnetic heating, refrigeration and energy conversion are also presented by a Swiss team working within an International institute of Refrigeration (IIR) Working Party on Magnetic cooling: even if it is still a niche technology, it might be a promising technology for the future.
Finally, an article of Politecnico di Torino mentions how to better monitor the energy consumption of refrigerating systems: as explained before, reducing the energy consumption is a major objective, which shall not be forgotten when designing a new system or when changing components such as refrigerants.
The aim of the publication of such articles is of course not to be exhaustive but to give you new ideas regarding more environmentally friendly technologies in the refrigeration and air-conditioning sector. The IIR is at your disposal to give you additional information. Please consult our Web site: www.iifiir.org

●

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Working together with the major experts towards "the future of refrigeration" XV European Conference

MARCO BUONI

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

Introduction

We have arrived now to the fourth edition of the International Special Issue (ISI) which take the cue from the various previous editions that have been a good success and which have been delivered and launched in several UN Summit Meetings of Montreal Protocol to Head of States and Ministers with the purpose to show the environmental problems linked to refrigeration and air conditioning.
ISI2006 was launched in MOP18 in New Delhi (India) by Mr Rajendra Shende former UNEP director together with the Italian Foreign Affair Ministry, ISI2008 in MOP20 in Doha (Qatar) in the presence of the Environment Ministry of Qatar and Kuwait, ISI2010 in MOP22 in Bangkok (Thailand) in the presence of IIR Director Didier Coulomb, Mr Shende, Italian Environment Ministry Alessandro Peru and the Nepal Minister of the Environment.
The present ISI2012 will be launched in Geneve (Switzerland) in MOP24.
The previous International Special Issues have been also delivered to various other UN summits among which Nairobi's (2006), Bali's (2007), Poznan's (2008), Copenhagen's (2009), Cancùn's (2010), Durban's (2011) Conferences of Kyoto Protocol and to all the previous XII (2007) – XIII (2009) – XIV (2011) European Conference of Centro Studi Galileo.
As ISI2012 will be distributed also to the worldwide operators of refrigeration and air conditioning connected with United Nations and International Institute of Refrigeration and the 15th European Conference of Centro Studi Galileo and of Associazione dei Tecnici del Freddo in which all the major associations and World Organizations will also participate.

Latest technologies in relation to the environment

The International Special Issue is born in its first edition in 2006, with the purpose to show in a general way the environmental problems connected with refrigeration and air conditioning.
Refrigeration and Air conditioning are nowadays fundamental elements in the everyday life of human being, technologies of which we cannot do without and rather have been very important for the economic expansion that we have seen in the last century.
This edition is created as natural evolution and it is realized by UNEP, IIR and CSG underlining which are the alternative technologies to avoid environmental problems in the future.
On this magazine the bigger associations, institutes and worldwide organizations describe the above subjects in a complete manner, explaining the advantages of the technologies and how those, in the different regions of the world, could be helpful to improve the environment and to solve the problems connected to it.

XV European Conference UNEP-IIR-CSG

In the matter of the latest technologies in refrigeration and air conditioning Centro Studi Galileo, editor of ISI 2012, organize every 2 years a European conference.
The next, 15th European Conference, will be hold in Politecnico of Milano and it will see the participation,

besides the authors of the various editions of ISI, also of all the major international experts in HVACR sector.
Among the international Associations that cooperate with Centro Studi Galileo and the Associazione dei Tecnici Italiani del Freddo (Association of Italian Technicians of Refrigeration) there are the:
- AREA (Air Conditioning and Refrigeration European Association),
- AFF (French Association of Refrigeration),
- ASHRAE (American Society Heating Refrigeration Air conditioning Engineers)
- AICVF (the French Association of Engineers of the Air conditioning, Ventilation and Refrigeration), and many more which write on this issue.

These associations / institutes are the

UNEP office in Paris: from the left Marco Buoni, Secretary Italian Association of Refrigeration, Enrico Buoni, Director Centro Studi Galileo, Jim Curlin, Acting Head OzonAction Programme UNEP.

most important in the refrigeration and air conditioning field and most of them have contributed to this International Special Issue.

Importance of Training

Beyond the conference, in which the latest knowledge about the most modern technologies in Energy Saving and Environment Safeguard are disseminated both to experts of the sector both to the companies involved in the market and to operators in the production and in the design process, even more important, are the operators which manage the plants and should install and repair, as they should have the relative competence.

An adequate training and information about the latest technological innovations, so that a positive effect on the Environment is achieved, should arrive to them as they are the persons responsible for an efficient running of the plants and the handler and verifier of the correct use of the refrigerants in those contained.

Centro Studi Galileo with the moral support of the United Nations Environment Programme, promote technical meetings of training and information dedicated to explain the procedures, equipments and regulations act to reduce the environmental danger. Every year in fact Centro Studi Galileo organizes about 200 technical seminaries for training the Refrigeration and Air Conditioning Technicians in all Italy in the different training sites and in the main Italian Universities, teaching every year to more than 3.000 attendants the procedure to have a perfect maintenance, installation and design, in order to optimize their work and consequentially to reduce energy efficiency and environmental dangers.

UNEP'OzonAction Programme in cooperation with AREA / Centro Studi Galileo have also invited several Presidents and Experts of the ECA network in a training session on strengthening National Refrigeration &Air Conditioning (RAC) Associations on a session of training. The objective of the meetings are to share experience on all aspects of the management of a national RAC association including recruitment of members, fund raising and providing services.

Also the meeting is dedicated on the establishment of training & certification schemes, curriculum development, certification & assessment as well as related to regulations and networking with international stakeholders. The assessment session in Europe is part of the F-gas regulation and certification of the companies and the relevant personnel involved in installation, maintenance or servicing of the equipment containing Fluorinated gases strong Greenhouse gases.

Acknowledgments

We thank the Under-Secretary-General Executive Director of United Nations Environment Programme Achim Stainer and the Italian Minister of the Environment Corrado Clini for the support and for the auspice to this initiative.

BRIEF OVERVIEW OF CSG-ATF

1. Over more than 36 years, CSG and ATF have trained three generations of technicians and professionals in refrigeration, air conditioning and energy, including more than 45,000 individuals. This training and education is carried out through the organisation of courses and conferences in Italy and abroad – the next conference will be the XV European Conference - in major universities and regional centres with specialised training facilities, with more than 3,000 participants every year for the last decade.

2. CSG publishes the internationally renowned Industria & Formazione, with periodical international editions in English, in collaboration with the United Nations. These editions are distributed at some of the most important summits in the world - New Delhi, Nairobi, Doha in Qatar, Bangkok and soon in Geneva.

3. For more than ten years, the United Nations (UNEP and UNIDO) and major global organisations have been working closely with CSG and ATF in training and education, and these events are always held with the support of of the Presidency of the Council of Ministers, as well as numerous Ministries (Ministry of Environment, Foreign Affairs, Economic Development, etc.)

4. Centro Studi Galileo has collaborated in the creation of the Associazione italiana dei Tecnici del Freddo ATF (see www.associazioneATF.org). Thanks to the journal, training courses and conferences, we have been able to gather 1000 members from the refrigeration industry in a short time. The ATF was quickly appointed as vice-president of the European Association AREA (Air Conditioning and Refrigeration European Association), which has 21 members, coming from all European nations, and represents 125,000 technicians.

5. CSG and ATF organise major conferences in close collaboration with international organisations, representing countries such as the US, China, India and the Middle East, with the International Institute of Refrigeration, Paris (an intergovernmental refrigeration organisation covering more than 80% of the world population). CSG also founded the UK European Energy Centre (see www.EUenergycentre.org), which organises courses and conferences in renewable energy related subjects, based at various universities in Britain.

ATF Secretary, CSG Technical Director and Vice President of AREA, Mr. Marco Buoni, was asked to represent the refrigeration sector in Europe at a conference on new technolgies organized by the Turkish government, having been re-elected Vice President of AREA and also becoming responsible for AREA task force on low-GWP refrigerants.

Under the auspices of Italian Government

UNITED NATIONS ENVIRONMENT PROGRAMME
INTERNATIONAL INSTITUTE OF REFRIGERATION
ASSOCIAZIONE DEI TECNICI DEL FREDDO
CENTRO STUDI GALILEO
EUROPEAN ENERGY CENTRE

XV EUROPEAN CONFERENCE ON

THE LATEST TECHNOLOGY IN AIR CONDITIONING AND REFRIGERATION INDUSTRY

WITH PARTICULAR REFERENCE TO ENERGY ISSUES
new refrigerants, new European regulation, certification new plants, mobile air conditioning

7th - 8th June 2013 – Politecnico di Milano

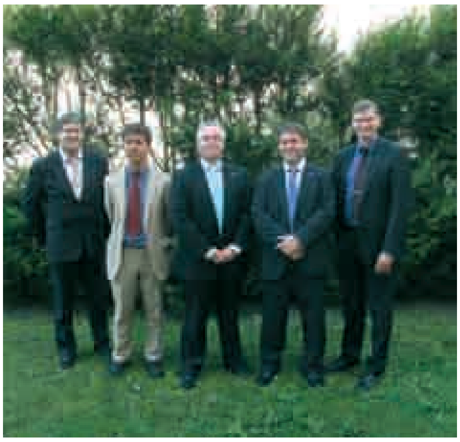
First Session: NEW REFRIGERANTS AND PERSPECTIVES. ENERGY SAVING
Second Session: NEW COMPONENTS AND EQUIPMENT IN RELATION TO NEW REFRIGERANTS, ENERGY SAVING AND ENVIRONMENTAL ISSUES. RESULTS AND UPDATES IN NEW SYSTEMS
Third Session: OPEN DISCUSSION ON ENERGY AND ENVIRONMENTAL ISSUES, NEW FLUIDS, NEW COMPONENTS AND NEW PLANTS IN REFRIGERATION AND AIR CONDITIONING: REVIEW EUROPEAN REGULATION ON F-GASES
Fourth Session: F-GAS REGULATION REVIEW, EUROPEAN AND INTERNATIONAL LAWS, CERTIFICATIONS AND LICENCES
Fifth Session: MOBILE AIR CONDITIONING

GENERAL CHAIRMEN

JIM CURLIN - United Nations OzonAction - UNEP; **DEAN COOPER** United Nations Energy Branch - UNEP; **PHILIP OWEN** Head European Commission, Action Clima; **ALESSANDRO PERU** Ministero dell'Ambiente e della Tutela del Territorio e del Mare; **SABRINA DI NICOLA** Ministero degli Affari Esteri; **DIDIER COULOMB** Director, **ALBERTO CAVALLINI** Honorary President International Institute of Refrigeration (I.I.R.); **ENNIO MACCHI** - **GIOVANNI LOZZA** - **C. M. JOPPOLO** Politecnico of Milano; **RAJENDRA SHENDE** President TERRE Policy Centre; **SUSAN ROAF** Director Low Carbon Cities Initiative, Heriot-Watt University; **LOUIS LUCAS** Former President Conseil National du Froid, Past President Association Française du Froid (A.F.F.); **PATRICK ANTOINE** President Association Française du Froid (A.F.F.); **W. CHAKROUN** Director American Society Heating Refrigeration and Air conditioning Engineers (ASHRAE); **STEPHEN YUREK** President Air-conditioning, Heating and Refrigeration Institute (AHRI); **ANDREA VOIGT** Director European Partnership for Energy and the Environment (E.P.E.E.); **GRAEME FOX** President Air conditioning and Refrigeration European Association (AREA); **ANDY PEARSON** President Institute of Refrigeration (IOR); **GERALD CAVALIER** Director CEMAFROID; **ALFREDO SACCHI** President Associazione dei Tecnici del Freddo (ATF); **LAMBERT KUIJPERS** Technology an Economic Assessment Panel (TEAP); **DENIS CLODIC** Deputy Director Ecole des Mines; **HERMANN HALOZAN** Graz University of Technology, Austria; **MARCO MASOERO** Politecnico of Torino; **ANDREA DE LIETO VOLLARO** - **FRANCO GUGLIERMETTI** University La Sapienza of Roma; **PAOLO AMIRANTE** - University of Bari; **FRANCESCO ASDRUBALI** - University of Perugia; **SERGIO BOBBO** - **ROBERTO CAMPORESE** - **GIROLAMO PANOZZO** I.T.C. CNR Padova; **FILIPPO DE ROSSI** - Sannio University; **CIRO APREA** - Napoli University; **GIUSEPPE PANNO** - University of Palermo; **FABIO POLONARA** - University of Ancona; **LUCA TAGLIAFICO** - University of Genova

(INVITED) **PRESIDENTS AND EXPERTS OF THE EUROPEAN ASSOCIATIONS**: Gerhard NEUHAUSER (ÖKKV - **Austria**), Linda BUDDAERT(UBF-ACA - **Belgium**), Jiri BROZ(S CHKT - **Czech Republic**), Kim VALBUM (AKB – **Denmark**), Petri HANNULA (FREA - **Finland**), Philippe ROY(SNEFCCA - **France**), Wolfgang ZAREMSKI (VDKF - **Germany**), Peter BACHMANN (BIV - **Germany**), Seamus KERR (IRI - **Ireland**), Marco BUONI (ATF - Italy), Valentino VERZOTTO (Assofrigoristi - **Italy**), Coen VAN DER SANDE (NVKL - **Netherlands**), Stig RATH (VKE - **Norway**), Grzegorz MICHALSKI (KFCh, NRF - **Poland**), Fernando BRITO (APIRAC - **Portugal**), Peter TOMLEIN (SZ CHKT - **Slovakia**), Blanca GOMEZ (CNI - **Spain**), Per JONASSON (KVF - **Sweden**), Cedric SLOAN (FETA, BRA - **United Kingdom**), Graeme FOX (B&ES/RACG - **United Kingdom**),

Presidents of the XIV European Conference: From the bottom left W. Chakroun, G. Cavalier, L. Lucas, L. Antonini, M. Buoni, R. Shende, S. Roaf, P. Buoni. From the top right D. Coulomb, E. Buoni, A. Cavallini.



Contractors: training the craftsman in the safe use of low GWP energy efficient refrigeration, air conditioning and heat pump systems

GRAEME FOX

President AREA Air conditioning and Refrigeration European Association

Picture: from left to right Phillipe Roy (SNEFCCA - France), Marco Buoni (ATF - Italy), Peter Bachmann (BIV - Germany), Graeme Fox (B&ES - United Kingdom), Per Jonasson (KYL - Sweden).

This topic will be discussed in the next 15th EU Conference

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 21 national members from 17 European countries, representing more than 9,000 companies across Europe (mainly small to medium sized enterprises), employing around 125,000 people and with an annual turnover in the region of € 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 end users.

AREA's 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 (RACHP Group/B&ES, 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. Task Forces are currently active to tackle various topics, such as the review of the F-Gas Regulation, heat pumps, CO_2 and other low GWP refrigerants, and training requirements for 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 so called "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 ad-dressing 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

Meeting with European Commission on Low GWP refrigerants, on the left Olivier Janin AREA Secretary General.

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 preventative 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.

Choosing the right refrigerant

Designing a RACHP 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 RACHP systems are at their most efficient 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 depending on geographical location and ambient conditions. 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[7].

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.

Low GWP Refrigerant handling issues

The AREA position paper "Low GWP Refrigerants"[8] sets out a general guidance in identifying which refrigerant is best for which application. The work that went into producing this guidance paper raised concerns about the lack of field technicians properly trained in the safe handling of low GWP refrigerants. In particular, there was a general concern about the safety aspects of non specifically trained technicians when handling highly flammable hydrocarbons and high pressure CO_2 gases.

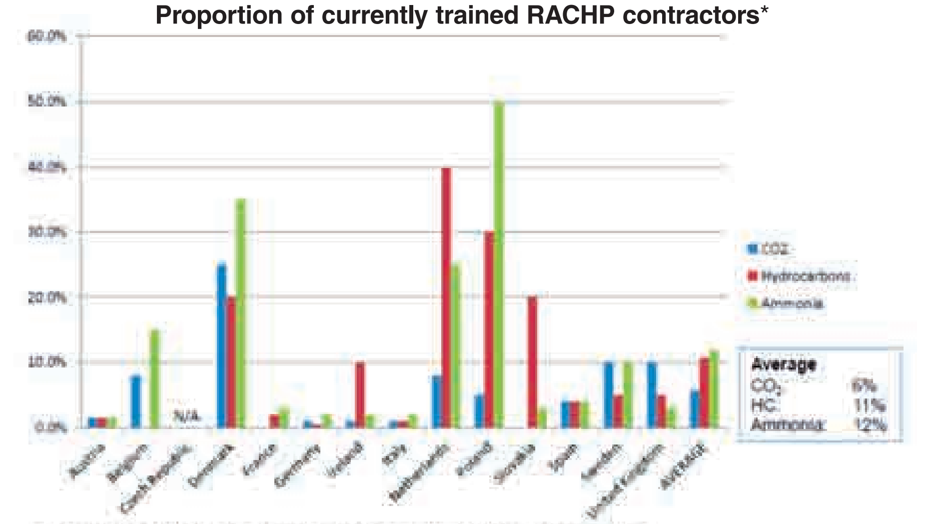
A survey carried out internally amongst AREA members highlighted some major differences across the European Community:

The real danger in the current political moves to rapidly phase down HFC use, or indeed the sometimes suggested phase out, is that there is clearly a large shortfall in technicians properly and safely trained in the use of low GWP alternatives. A sectoral phase out or product ban has been proposed by some NGOs as a means of rapidly cutting HFC use. These calls do not seem to take into account the real dangers in promoting a rapid widespread use of hydrocarbons, ammonia or CO_2.

It is generally accepted that poorly installed and maintained systems lead inevitably to increased leakage rates. Where the refrigerant in use is an HFC there are few safety concerns for people in the surrounding area other than through the displacement of oxygen causing respitory problems or, in the worst case, asphyxiation. Where the refrigerant is a hydrocarbon, however, the hazard this poses could quite clearly result in catastrophic explosion. Similarly, CO_2 works at very high pressure and the potential for human injury or damage to property is high as was demonstrated in 2011 when a series of incidents on CO_2 systems caused a rethink of refrigerant policy by a large supermarket chain in the UK.

A rapid roll out of training schemes is starting throughout the EU to try and address this anomaly but it will clearly take some time before a significant percentage of the workforce is anywhere near competent enough to cope with the inherent dangers in using the current crop of low GWP refrigerants. At a cost per craftsman of between € 700 and € 3000 it is difficult for contracting businesses to afford sending their craftsmen away on training courses. Especially so during a time of economic turmoil across most of the continent. A lack of training centres is also a major issue in many countries. At a cost of setting up a training centre to deal with low GWP refrigerants in the region of € 300,000 – an example of the cost of setting up an ammonia centre in the Netherlands – there are few organisations with the spare capital to invest in such a thing.

Proportion of currently trained RACHP contractors*



* Percentage of all RACHP contractors trained with low GWP refrigerant systems

An increased use of online and so called "e-learning" training has enabled many existing technicians to cover the necessary theoretical aspects of new and refresher training requirements in a way that does not impact on the daily workload as it can be carried out during evenings and weekends. Many aspects of the training, however, must be carried out in practical environs due to the nature of the qualification.

This necessitates quality training centres where practical abilities can be assessed and improved upon prior to demonstration testing for certification. Much of the current training at present consists of written or online examination of theoretical, environmental and regulatory knowledge followed by a practical test consisting of demonstration of a candidate's ability to properly and safely cut, prepare and join by brazing of sections of a refrigeration circuit, followed by correct leak tightness and strength pressure testing, evacuation, charging and putting into work a small refrigeration system; their ability to correctly identify and repair faults in a working system; and their ability to identify refrigerants by using comparator charts, etc.

It is essential that sufficient quantity and quality of training centres are open and available across Europe, and indeed globally, if the growth in use of lower GWP refrigerants is to be realised without detriment to the industry sector as a whole and the technology in general, in terms of poor image of RACHP systems. It is also essential in terms of preventing safety concerns being realised and to ensure the high efficiency potential of the technology is not only realised at the time of installation but is maintained throughout the life cycle of the systems.

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 and a widespread use of commercial and residential heat pumps in the coming years, the contractors' role is therefore essential.

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1. More info on the project's results available on AREA website: www.area-eur.be
2. www.realskillseurope.eu
3. www.qualicert-project.eu
4. European Commission's Communication Action Plan for Energy Efficiency: Realising the Potential COM(2006)545 final
5. Variable Refrigerant Flow: type of air conditioning system where the indoor units all connect to the outdoor unit through a common set of pipes rather than each indoor unit having a set running back to the outdoor unit
6. System enabling to recover the heat being extracted in a building area needing cooling and to transfer this heat to the indoor units serving those areas needing heating
7. See AREA Input Paper "HFCs vs. alternatives in refrigeration & air conditioning equipment", June 2009
8. See AREA Guidance Paper "Low GWP Refrigerants" , June 2011

A cap and phase-down of F-Gases is the most cost-effective measure to reduce direct emissions from heating and cooling

ANDREA VOIGT

President EPEE European Partnership for Energy and the Environment

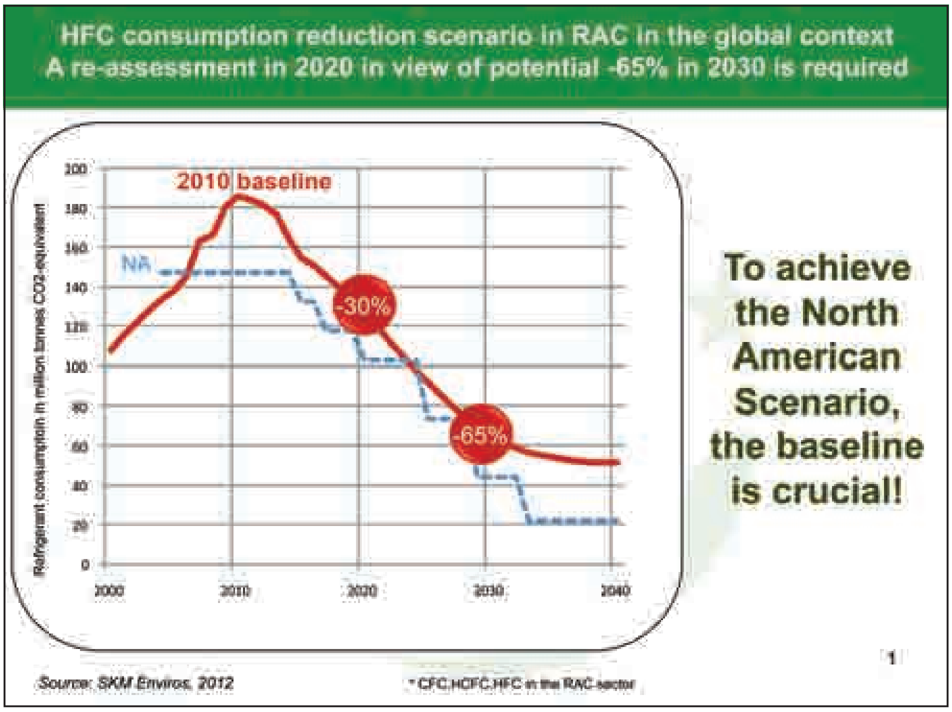
This topic will be discussed in the next 15th EU Conference

Fluorinated gases currently contribute 1.1% to global greenhouse gas emissions, and in the EU the current provisions of the F-Gas Regulation and the Directive on Mobile Air-Conditioning (MAC) are expected to reduce direct F-Gas emissions by more than 40% in 2030.
Nevertheless, along with the requirements of the roadmap for a low carbon economy, the EU Commission identified potential additional F-Gas emission savings of 70 million tonnes of CO2-equivalent in 2030. EPEE estimates that the heating and cooling industry can make a substantial contribution to achieve this goal provided that the complexity of the sector and the strong interconnection between refrigerants, energy consumption, uptake of renewable energy technologies and safety are respected.
A realistic and technically achievable cap and phase-down mechanism for F-gas refrigerants supports the existing F-Gas Regulation by limiting the quantities of HFCs (hydrofluorocarbons) available and hence stimulating the containment and recovery of these gases. It is also unique in providing both regulatory certainty to achieve the required emission savings, and flexibility for a complex sector.
As an example, recent studies have identified more than 40 heating and cooling applications, all requiring different technologies and covering a very wide range from refrigerated trucks to food processing, heating and cooling of buildings, refrigeration in supermarkets, etc.
Andrea Voigt, EPEE's Director General explains: *"There is no perfect refrigerant. Refrigerant choice is complex and often a compromise between many different factors. Two of these are non-negotiable: the safety and the energy efficiency of the installations. Safety is essential for the installers and the users of the equipment. Energy Efficiency has a major impact on running cost and our environment, as most of the emissions are due to energy consumption."*

Yes to a realistic and achievable HFC phase-down

According to the latest evidence based on two studies funded by EPEE, one from the French research institutes ARMINES/ERIE and the other from British SKM Enviros, a phase-down could achieve a reduction in HFC consumption by 30% in 2020 (vs. 2010) and by up to 65% in 2030, provided a re-assessment takes place in 2020 to evaluate feasibility and progress made. Such a phase-down scheme could achieve fluorocarbon emission savings of approximately 74 million tonnes of CO_2-equivalent in the refrigeration, air-conditioning and heat pump (RAC) sector alone – well in line with the requirements of the low carbon roadmap.

Andrea Voigt President of the Conference-Introduction to the XV European Conference (under the auspices of Italian Government) in MCE Milan organized by CSG-ATF-United Nations UNEP-IIR in March 2012.



About the phase-down study conducted by SKM Enviros: In 2012 EPEE commissioned the British consultancy SKM Enviros to research the cost and emission reduction potential of different phase-down mechanisms for the consumption of HFCs in the European Union. The study – published on 4 October 2012- looked at the whole HFC-using sector, but focused in detail on the heating, cooling and refrigeration sector (RAC sector and represented by EPEE). The consultants researched 4 different scenarios – from lowest impact on the climate to highest impact on the climate - and also assessed the feasibility of other proposed phase-down scenarios, such as the "North American Proposal".

The study found that a 30% HFC consumption reduction in 2020 and 65% reduction in 2030 would:

- Achieve emission savings of over 70 million tons of CO_2 equivalent versus 2010.
- Cost between 15€ to 25€ per ton of CO_2 equivalent abated, although this cost varies significantly depending on the application sector and is very sensitive to assumptions such as additional capital costs related to using alternative refrigerants, maintenance cost, and the difference in energy efficiency.

Finally the study assessed the substantial environmental benefits of heat pumps (which use mainly f-gases for safe and efficient operation), which can reduce net GHG emissions by 155 million tons of CO_2 equivalent in 2030 when compared to fossil fuel boilers.

An over-ambitious phase-down schedule, however, would be counter-productive. It would for example put at risk the growth of heat pump technologies, which predominantly use HFCs for their safe and efficient operation. Heat pumps are absolutely essential for the EU's 20-20-20 targets and are expected to reduce total CO_2 emissions by as much as 155 million tonnes of CO_2-equivalent in 2030 compared to fossil fuel based heating systems.

No to HFC bans

The Commission's own research as well as the SKM Enviros study have also shown that a phase-down is the most cost-effective way of reducing emissions. Whilst it is important to take into account that the cost per ton of CO_2-equivalent abated varies significantly depending on the application, findings from SKM Enviros indicate an average cost of € 15 to € 25 per ton of CO_2-equivalent abated.

Adding bans on top of a phase-down, however, would increase the cost of emission reduction very significantly. For example, by adding HFC bans in commercial refrigeration and certain HFC maintenance bans, the total cost could potentially increase by as much as € 25 billion by 2030 compared to the cost of a phase-down only. EPEE therefore questions the usefulness and the effectiveness of adding bans on top of a phase-down.

Clearly, future F-Gas rules need to strike the right balance between the aim they are trying to achieve and the economic impact on industry and society that they will bring about.

Banning HFCs in certain applications does also not guarantee that an alternative can perform as well and as safely in all applications and climate zones. In an industry sector where indirect emissions due to energy consumption account for 70 to 80% of total CO_2 emissions, it would be detrimental to the EU climate and energy targets to sacrifice energy efficiency. For example, refrigerant solutions such as carbon dioxide are known to be less efficient in hot ambient climate zones; and in small air-conditioning applications, there is no safe and energy efficient alternative which fulfils the future minimum energy efficiency requirements set under the European ecodesign rules.

About EPEE:

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 of promoting a better understanding of the sector in the EU and contributing to the development of effective European policies. For more information, please visit www.epeeglobal.org .

Nexus of survival

JANOS MATÉ

Senior Consultant Greenpeace International Political Business Unit

This topic will be discussed in the next 15th EU Conference

Human survival, in fact the survival of life as we know it, requires a nexus between the reality of climate change, preventative policies and sustainable technological development.

Climate chaos is already here

Our home is on fire. The rapidly growing litany of record breaking extreme weather events around the world signals that global warming induced climate chaos is already upon us. As the June 6, 2011 cover of Newsweek Magazine proclaimed “weather panic is the new normal”.

Nine of the 10 warmest years in the modern meteorological record have occurred since the year 2000[1]. Correspondingly, CO_2 emissions in 2010 reached a record high of 30.6 Gt.[2] and global greenhouse gas emissions have increased 36 per cent since the 1992 Rio Convention, despite the treaties in place to stabilize and to cut emissions.[3]

In 2010, 2011 and 2012 the world suffered unparalleled devastation from record floods, fires, droughts, more frequent and intense tornadoes and hurricanes. In some countries, millions of acres of agricultural land were lost due to flooding, while other countries report massive declines in crop harvests due to heat and drought.

In 2010, there were an estimated 38 million “climate refugees” in the world.[4] The same year hundreds of millions of drought starved trees died in the Amazon, raising fears that the Amazon, the so called lungs of the planet, “is on the verge of a tipping point, where it will stop absorbing greenhouse gas emissions and instead increase them”.[5] In 2011, millions of people in China faced shortages of drinking water due to a drought along the Yangtze River, and portions of the river were closed to navigation. And in September 2012 the size of the Arctic sea ice, which has been referred to as the air-conditioner of the planet, had shrunk by 49% compared to average ice conditions between 1979 to 2000, with the loss being more than one million square kilometers greater than in any previous year.[6]

Tipping the Climate

A tipping point in the climate system implies abrupt, non-linear changes. It is reaching thresholds of no return, where human intervention has little or no capacity to restore nature’s balance. Human activity is steadily pushing the climate ever closer to self-accelerating turning points, whereby due to positive feedback, a change in one system triggers a cascade of changes in others. Alarmingly, climate “tipping points” could be reached within a few decades.

There is now scientific and political agreement that 21st Century temperature rises must be kept between 1.5° to 2 °C in order to avert full-scale climate catastrophes.[7] The average temperature around the globe in 2011 was 0.92 degrees F (0.51 °C) warmer than the mid-20th century baseline.[8]

According to UNEP Executive Director, Achim Steiner, to ensure that by 2020 temperature levels do not exceed the 1.5° to 2° centigrade threshold, global greenhouse gas emissions must be limited to around 44 gigatonnes (Gt) of CO_2 equivalent. However, under a business as usual scenario, emissions are projected to rise to around 56 gigatonnes, and even if all the highest climate protection ambitions of all countries are implemented the global emissions are still expected to reach 49 gigatonnes of CO_2 equivalent by 2020.[9]

We must therefore think both long and short term, and take immediate measures that will reduce greenhouse gas emissions and have significant climate benefits over the next several decades. The question then becomes: What are the most available and effective steps to reduce the flow of greenhouse gas emissions in the short term while we tackle the overall challenge of weaning the world from dependence on fossil fuels?

Need to phase out HFCs

HFCs are “short term climate forcing substances”. Their global warming potential (GWP) is thousands of times greater than that of carbon dioxide and their impact on the climate is most

concentrated in the near term following their release into the atmosphere.
The "CO_2 equivalent emissions of HFCs increased by approximately 8% per year from 2004 to 2008".[10] By 2050 their annual emissions are projected to rise to about 3.5 to 8.8 Gt CO_2eq, or to between 18 to 45% of global CO_2 emissions.[11]
Therefore, the rapid phase out of HFCs is one of the immediate preventative measures that can be taken today to try to avoid near term climate tipping points. Their elimination by 2020 could help buy back some needed time to further tackle the challenges of reducing CO_2 emissions from fossil fuels.
Moreover, the short term climate benefits of a rapid global HFC phase-out is even more profound when viewed through the 20 year GWP metric than the conventional 100 year GWP metric.

Using the 20 Year GWP metric to accurately measure the short term global warming potential of HFCs

The average lifetime of HFCs is 21.7 years. Consequently their global warming potential (GWP) is much higher when measured over a metric of 20 years than over a metric of 100 years. In fact, the conventionally used GWP_{100} metric dilutes the short-term climate impact of HFCs. The $GWP_2$0 metric better reflects the true potency of HFCs during their actual time in the atmosphere.
The absolute annual HFC emissions weighted by GWP_{20} are roughly twice as high as the absolute annual HFC emissions weighted by GWP_{100}.
Adopting the GWP_{20} metric for HFCs for policy formulation would have several ramifications. Most pronouncedly, it would present governments a more accurate accounting of the short term climate benefits of a vigorous HFC phase-out regime. It would also define more accurately the definition of "low GWP refrigerants". For example, HFC-32, with a GWP_{100} 675 and GWP_{20} of 2330 could not be marketed as a "low GWP" refrigerant.

COOL TECHNOLOGIES: WORKING WITHOUT HFCs

Since the 1990's, the Greenpeace report "Cool Technologies: Working Without HFCs" has routinely surveyed the availability of HFC-free, low GWP, alternatives to replace HCFCs.
The extensive (100 page) 2012 edition documents the wide variety of technologies in the market today that use natural refrigerants and foaming agents. For the most part these technologies use CO_2, hydrocarbons, ammonia, water and air.
Natural refrigerants and foaming agents, in contrast to fluorocarbons, abundantly occur in the biosphere, maintain a steady state, and are easily absorbed by nature.
HFC-free technologies exist in nearly the full spectrum of applications, such as: (a) domestic refrigeration and air-conditioning, (b) commercial refrigeration and air-conditioning, (c) mobile air-conditioning, (d) industrial processing and (e) insulation foam blowing.
The Greenpeace report lists the names of companies manufacturing and/or using equipment with natural refrigerants, and describes the equipment. The report documents, based on data released by the companies, the efficiency advantage of equipment using natural refrigerants compared to those using HFCs.

Table 1.
Projections for global HFC consumption (Mt CO_2-eq) expressed in GWP_{100} and GWP_{20} metrics[12]

100 GVP	**2010**	**2020**	**2030**	**2040**	**2050**
Industrialized	637	909	1,047	1,137	1,253
Developing	163	1,179	2,570	3,802	5,008
Global	800	2,088	3,617	4,939	6,261
20 GVP	**2010**	**2020**	**2030**	**2040**	**2050**
Industrialized	1,395	1,992	2,323	2,537	2,807
Developing	379	2,546	5,539	8,209	10,875
Global	1,558	4,538	7,862	10,746	13,182

GreenFreeze: hydrocarbon domestic refrigeration

The GreenFreeze, hydrocarbon domestic refrigerator technology was developed by Greenpeace in 1992. There are over 650 million GreenFreeze refrigerators in the world today. 100 million domestic refrigerators and freezers are produced in the world each year, and GreenFreeze technology represents between 35% and 40% of the total. It is projected that at least 75 to 80% of global new refrigerator production will use hydrocarbon refrigerants by 2020.[13]
The "Cool Technology" report lists nearly 50 companies around the world that manufacture Greenfreeze refrigerators.
95% of the European and 75% of the Chinese new domestic refrigerators use hydrocarbons.[14] GreenFreeze is also produced in South America with countries such as Argentina and Brazil in the forefront. In 2010, Brazilian power companies initiated a refrigerator exchange program, replacing older fluorocarbon models with new hydrocarbon based refrigerators.[15]
GreenFreeze entered the Mexican market in 2009. In 2011 the US EPA approved the use of hydrocarbons in domestic refrigeration in the United States. In 2012 GE introduced the first hydrocarbon refrigerator into the US market.[16]

Natural refrigerants in commercial cooling equipment

Today, commercial refrigeration represents 40% of total annual refrigerant emissions, and it is expected to represent 47% by 2015.[17] It is the refrigeration subsector with the largest CFC, HCFC, and HFC CO_2-equivalent refrigerant emissions.[18]
There are three main types of commercial and industrial refrigeration equipment: (a) stand alone plug-in equipment, (b) condensing units, (c) centralized systems. "Cool Technologies: Working Without HFCs" documents the market penetration of natural refrigerants in all of these applications.
Refrigerants, Naturally! is a global initiative of multinational corporations that aims to replace the use of HCFCs and HFCs in their point-of-sale cooling

Speech of Janos Maté: the XII European Conference about the latest technology in refrigeration and airconditioning with particular reference to the energy issues will be organized by CSG-ATF and by the United Nations Environmental Programme-UNEP and International Institute of Refrigeration on the 8th-9th June 2007 in the Politecnico of Milan.

applications. Current partners include Coca-Cola, Unilever, McDonald's, PepsiCo and Red Bull. The partners are proceeding. For example, by 2015 both Coca Cola and Unilever will be 100% free of HFCs in new cooling equipment and freezers.
Many other large companies use equipment with natural refrigerants, including Carlsberg, Danone, Heineken, and Nestlé. And in 2010, the Consumer Goods Forum (CGF) a body comprising of over 650 companies from 70 countries, pledged to begin phasing-out HFCs as of 2015 and replace them with non-HFC refrigerants.
Numerous supermarkets around the world are using natural refrigerants in a variety of stand alone equipment and centralized systems. There is, for example, an exponential growth in the installation of transcritical CO_2 systems in supermarkets. In Europe alone the total number of installed systems in 2011 was approximately 2000.[19]
The Greenpeace report names nearly 50 supermarkets from around the world that have installed natural refrigerants based cooling equipment and refrigeration systems. Many of these supermarket chains have plans to only use natural refrigerants in new stores, as well as to convert existing facilities to natural refrigerants. Combined they operate thousands of outlets.
The "Cool Technologies Report" also documents up to 50 manufactures and distributors of cooling equipment using natural refrigerants. Examples of equipment include: plug-in-type supermarket cabinets; variety of display coolers; commercial fridges and freezers; ice cream freezers; water coolers; ice maker units; vending machines; cold rooms; transcritical-cascade CO_2 refrigeration systems; integrated systems for air-conditioning, heating and refrigeration functions.

Industrial use of ammonia in cooling applications

Ammonia is widely used in a variety of industrial cooling applications.
Specifically in the foods industry, ammonia is used in various processes for cooling purposes. Europe is in the forefront of using ammonia in industrial processes. Many facilities using ammonia for both industrial processes as well as space cooling.
Ammonia based systems are used in a wide variety of industrial processes including: ice cream production; beverage production; dairy products production; fresh fruit and food preservation; meat processing; poultry production; production of chocolates and fruit gums; beer production; manufacturing of pharmaceuticals; oil refinery. The Greenpeace report lists companies that install advanced ammonia cooling systems, and provides descriptions of installations in industrial plants and distribution centers.

Domestic and Commercial Air-Conditioning

As we experience ever-increasing temperatures around the world due to global warming the demand for domestic and commercial air-conditioning is exponentially growing in both industrialized and developing countries.
The global inventory of stationary air-conditioners is approximately 790 million units. This includes window and portable air-conditioners, single split type air-conditioners, multi-split type air-conditioners, ducted systems, small chillers, large chillers and centrifugal chillers. The global annual production of new stationary air-conditioning units, including all of the above A/C subtypes, is approximately 87.5 million.[20]
There are natural refrigerant alternatives to HFCs for each of these A/C subtypes. Major breakthroughs are currently occurring. For example, Gree company in China, and Godrej company in India, are introducing hydrocarbon split air-conditioning for domestic use. And China's HCFC Phase-out Management Plan, under the Montreal Protocol, plans for 18 HCFC-22 air-conditioner production lines, with an annual output of 4.5 million units, to be converted to R290 by the end of 2015.[21]
According to one study, a comparison of hydrocarbon charge sizes with the standard flammability limits indicates that hydrocarbons in split air-conditioners can be used in about 65% of the cases where HCFC/HFCs are currently used.[22]
The "Cool Technologies: Working Without HFCs" report details numerous supermarkets, office buildings, department stores, public buildings, hospitals, universities, airports, convention centers, and other commercial enterprises in various countries that are cooled by air-conditioning systems using natural refrigerants.

Conversions from HCFC-22 to hydrocarbons in air-conditioning

It is widely accepted that propane and other hydrocarbons are the optimal alternative, nearly drop-in replacements for HCFC-22 in air-conditioning systems. The Greenpeace Report documents the conversion of up to 160 public and commercial buildings from HCFC-22 to hydrocarbons in Malaysia, Singapore, Indonesia, Thailand, Jamaica and the Philippines. These conversions report 10 to 30% energy savings.

District cooling

A district cooling system (DCS) distributes thermal energy in the form of chilled water or other media from a central source to multiple buildings through a network of underground pipes for use in space and process cooling. The cooling or heat rejection is usually provided from a central cooling plant, thus eliminating the need for separate systems in individual buildings."[23] DCSs today rely on a variety of cooling agents, including HFCs, ammonia, water, or the use of absorption chillers. However, the use of HFCs for DCSs is unnecessary because natural refrigerants are available and can be safely applied in large chillers. DCSs exist in many parts of the world. There are about 100 DCSs in Europe[24]. In the United States, there are approximately 2,000 DCSs, which cool 33,000 commercial buildings, plus numerous schools, institutions, and residences.[25] They have also been installed in the Middle East and in Singapore.

Mobile Air-Conditioning

Global passenger-car production in 2010 was approximately 66 million, of which 75%, or 49.5 million, were equipped with air conditioners. In 2010, there were an estimated 600 million cars in the world with approximately 70% of them equipped with A/C, each with an average charge of 0.6 -0.8 kg of refrigerant. The total stock of refrigerant charge from the global fleet of passenger-cars was 70,100 tons in 2006, with an average leakage rate of approximately 17%.[26] Currently, all new mobile air-conditioning (MAC) units use HFC-134a refrigerant.

Hydrocarbons offer reliable and more efficient alternatives to HFCs in mobile air-conditioning (MACs). Though at the present time there are no hydrocarbon mobile air-conditioners sold on the world market, HFC MACs are routinely converted to hydrocarbons in many countries including China, United States, Australia and elsewhere.

Greenpeace estimates that globally up to 50 million cars may have been converted, outside of regulatory framework, from CFCs and HFCs to hydrocarbons.[27] From a technical perspective CO_2 based MACs can also provide better alternatives to HFCs. Extensive measurements carried out in 1999 at the University of Illinois showed that CO_2 MACs have at least 30% lower TEWI than HFC systems.[28] The Cool Technologies Report lists several companies that are using natural refrigerants for air-conditioning in trucks, buses and commercial vehicles, as well as for shipping of goods.

HFOs

Because of concerns regarding the high GWP of HFCs currently on the market, the chemical industry is now rolling out a new generation of low GWP unsaturated HFCs, branded as HFOs, or "hydrofluoro-olefins."

HFC-1234yf is slated to replace HFC-134a in mobile air-conditioning. Other HFO refrigerants are in the pipeline for various cooling applications. HFOs do not deplete the ozone layer and have low global warming potential, but there are significant environmental and human safety risks associated with these new substances. The "Cool Technologies Report" summarizes these concerns, and cautions against their uptake. The Report notes that on "September 25, 2012 Mercedes-Benz/Daimler announced that the company will not be using HFC-1234yf in its products".

Summary

"Cool Technologies: Working Without HFCs" documents the "possible." It demonstrates that the necessary nexus between climate protection policies and technological development is achievable in the refrigeration and cooling sectors. ●

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Montreal Protocol: Ozone Treaty? No, climate treaty!

RAJENDRA SHENDE

President TERRE Policy Centre
Former Director UNEP

This topic will be discussed in the next 15th EU Conference

Rajendra Shende, who retired from UNEP as Head of OzonAction of DTIE at the level of Director, is better known as ' man in hurry with action-agenda '. After 20 years of experience in the private sector he brought the corporate culture of management-by-results and the target-oriented-goals to build the OzonAction Programme of United Nations from scratch. He was awarded with Climate Protection Award of USEPA in 2009 for his achievement in Climate Mitigation through OzonAction. His programme also became first ever Programme of United Nations to get USA award for the Ozone Layer Protection. Here he talks to Marco Buoni Vice President of AREA and Technical Director of CSG:

INTERVIEW

It was 5 years back that the world community decided under the Montreal Protocol to accelerate the phase out of HCFCs. That time you were leading the United Nations programme to assist the developing countries to enable them to implement that decision. As some one who is not in UN system now, and one who has opportunity to observe the phase out scenario from 'outside' the system, do you think that historic decision of accelerated HCFC phase out is getting implemented effectively?

I completed my assignment in United Nations Environment Programme in 2011. As a chief of the OzonAction Programme I had assisted 146 developing countries to enable them to implement the Montreal Protocol. Having assisted the countries in phase out of CFCs and other Ozone Depleting Substances, before leaving UNEP I assisted more than 100 countries between year 2007 and 2011 to prepare the HCFC Phase out Management Plan (HPMP). Other implementing agencies i.e. World Bank, UNDP and UNIDO have assisted other developing countries. Positioning the phase out strategies for HCFC phase out in such HPMPs, itself has been remarkable achievement for the developing countries. HPMP is the first small but critical step towards long march of the developing countries to phase out the production and consumption of HCFCs.

National Ozone Units (NOUs) have demonstrated extraordinary commitment and creativity in developing their HPMPs. NOUs understood very well that HCFCs is the last ODS under the Montreal Protocol and that accelerating the HCFC phase-out would guarantee a faster recovery of the ozone layer. As Head of OzonAction it was not easy task for me to convey and convince NOUs that HCFC phase out would also significantly reduce greenhouse gas (GHG) emissions and help delay further climate change. UNEP team deployed various strategies to convey this message. Each and every HPMP now has mainstreamed the concept of 'getting maximum Climate-benefit' under the Montreal Protocol. The implementation so far has been very effective.

Considering that the Montreal Protocol is aiming to get 'Ozone Benefits', can you explain how the developing countries can effectively get 'climate benefit' from HCFC phase out?

The Technology and Economic Assessment Panel (TEAP) estimates that HCFC production without any controls could exceed 700,000-800,000 tonnes by 2015 – roughly five times more than its 1998 projection of just 163,000 tonnes by 2015. The future is difficult to predict, of course, and the HCFCs growth predictions could be higher still. The actual HCFC production in year 2010 (the last year for which full figures are reported to UNEP) was about 38500 ODP tonnes i.e. about the same as what was projected by TEAP for 2015. The growth rate of HCFC-22 was considerably higher than what was predicted. For the last decade the growth rates particularly in the developing countries varied between 15-20 percent. As per UNEP Scientific Assessment Panel, an accelerated HCFC phase-out would contribute to a faster recovery of the ozone layer to pre-1980 levels, possibly advancing recovery to as early as 2035.

These are the 'Ozone Benefits'.

Given that many substances like CFCs and HCFCs that deplete the ozone layer are also potent greenhouse gases, the Montreal Protocol by phasing out CFCs has "provided substantial co-benefits by reducing climate change." Already, the phase-out of CFCs and other ODSs reduced GHG emissions by 11 $GtCO_2$-eq. yr^{-1} [or ~ 110 $GtCO_2$-eq. in aggregate, between 1990 and 2010, and delayed climate forcing by up to 12 years. Thus annual GHG emission reductions were five times larger than those targeted by the first commitment period (2008-2012) of the Kyoto Protocol, the greenhouse emissions reduction treaty.
HCFC who's Global Warming Potential (GWP) is nearly 1600-2000 times that of CO_2, phasing them out will provide 'climate benefit'. To be specific, accelerating the HCFC phase-out could reduce GHG emissions by an estimated 20-30 gigatons of carbon dioxide-equivalence (22 $GtCO_2$-eq.) between 2010 and 2050, according to calculations by TEAP
Additional emissions reductions of an estimated 3.5 $GtCO_2$-eq. would occur from 2010 to 2040, according to TEAP, from the elimination of the HFC-23 by-product emissions, which otherwise would result from HCFC-22 production. Further emissions reductions, which in reality would be significant as compared to the direct emissions of HCFCs, will also result from improvements in energy efficiency expected to accompany the transition out of HCFCs. As a result, maximizing the climate benefits of an accelerated HCFC phase-out could reduce GHG emissions up to 40 $GtCO_2$-eq. between 2010 and 2050, assuming the substitution pathway is managed carefully to avoid substitutes with high Global Warming Potentials (GWPs) and to promote the use of low GWP substitutes and alternatives as well as more energy efficient equipment and products. Maximizing the climate benefits of the HCFC phase-out to reduce more than 30 $GtCO_2$-eq. between 2010 and 2050, will further delay climate change.

It seems that there are many 'ifs and buts' to get these climate benefits. Do you think that these benefits would finally remain in the sort of ' cloud'?
The progress of HCFC phase out in the developed countries where more than 80% of the phase out has occurred, does give dismal picture of the reality about the 'climate benefit'. More than 60% of the HCFC phased out in the developed countries has taken place with HFCs, another powerful GHGs. For example, the GWP of HFC 134a, which is major replacement of HCFCs in the refrigeration and AC application, is 1300 and that of HFC 410A, which has replaced most of HCFCs in the Air conditioning and heating sector in the developed countries, is 1800. It is also not at all clear if the replacement of HCFCs in the developed countries has resulted in the better energy efficiency and how much better or worse.
Replacing HCFCs with HFCs of high GWP is certainly not a way to avail the opportunity of climate benefits. Developing countries who have just embarked on the HCFC phase out have lot to learn from the adverse lessons from HCFC phase out in the developed countries so far. There is no doubt that the technology development for replacing HCFCs has been identified by the industry and research and development institutes as one of the major potential area for action within the overall climate change challenge.
An international group of modelers working with UNEP have 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. HCFC phase out with low GWP or zero GWP gases, therefore, provide hopes to bridge this gap. The industry is definitely moving towards such alternatives. Hence I am optimist that climate benefit would not remain in the 'cloud' but will precipitate into action.
The high projected HCFC growth is driven by economic development in A5 Parties and the "perverse incentive" under the Kyoto Protocol's Clean Development Mechanism (CDM), which awards carbon credits for the capture and destruction of HFC-23 emissions produced as a by-product from HCFC-22 production. HFC-23 is a super greenhouse gas with a global warming potential (GWP) of 11,700, meaning it is 11,700 times more powerful at warming the planet than carbon dioxide. HCFC-22 producers can earn a multiplier of the profits by capturing and destroying HFC-23 for CDM credits as they can from selling HCFC-22 itself.


The last visit of Mr. Rajendra Shende (in the middle of the picture) in Centro Studi Galileo's headquaters in Palazzo Anna D'Alençon in Casale Monferrato, Italy.

Is there evidence for your optimism?
Yes. My organization TERRE Policy Centre is engaged in the regular Review of Refrigerants development in Dubai, where every six months number of technological development to replace HCFCs is announced. It is done in partnership with CPI-Industry of Dubai. We decided to hold the review every two months due to accelerated development of the technologies. Such review takes place with direct interaction with the technology developers.
Several new substitute chemicals have been identified for use in automobile air conditioning systems (to replace HFCs) that have low GWPs and have

the potential to be adapted to other applications to replace HCFCs, including in room air conditioning and commercial applications. The replacement of HCFCs by near- zero GWP alternatives in insulating foams has been commercial reality now.
Many of developing countries have prioritized their phase out in the foam sector, because low GWP alternatives are proven. Natural replacements like Cyclopentane and other hydrocarbons are being deployed to replace HCFCs in the foam sector. Vacuum insulation is also being employed to get more energy and climate advantage.
Refrigeration and AC is challenging sector as far as low GWP and energy efficient replacement is concerned. However the technology development is progressing faster than one could imagine. The assessment criteria like toxicity, safety as well as LCCP (Life Cycle Climate Performance) are being increasingly used for the decision making.
International Institute of Refrigeration (IIR) has been advocating environmentally friendly, safe, energy-efficient and cost-effective design, operation and end-of-life management of refrigeration and air-conditioning systems. As part of these efforts, the IIR formed a Working Party (WP) to assess the merits of different methods of LCCP for evaluating the environmental impact of direct emissions refrigerants and indirect emissions of GHGs. In Dubai in September 2012, IIR provided the work plan with target dates for the Working Party to produce implementation protocols for these methods. IIR also presented the results of LCCP analysis by more than one methods carried out by experts for Mobile Air Conditioning (MAC) technologies . It showed that Hydrocarbon HC 290 has the lowest LCCP among the alternatives including HFCs. Hydrocarbons as refrigerants in smaller room ACs are already commercialized. I am the proud owner of Hydrocarbon based room ACs –first of its kind in India. Multilateral Fund of the Montreal Protocol has financially supported the conversion of HCFCs to Hydrocarbons in China . My optimism is based on such initiatives .

Can you give specific examples that demonstrate the Industry's stewardship in latest technology development?

During the Refrigerants Review in September 2012 in Dubai, DuPont announced that it continues to explore the compound class of Hydro-Fluoro-Olefins (HFOs) as working fluids with no ODP and very low GWP for cooling, heating and power generation. DuPont presented two new HFO-based developmental refrigerants, DR-2 and DR-12 the blends based on HFOs. DR-12 was presented publically for the first time.
What is interesting is that technology development is crossing the traditional technical barriers. Earlier HFO-based fluids have been subject to an apparently inescapable trade-off between GWP and flammability. In contrast, DR-2 and DR-12 offer both very low GWPs of 9 and 32, respectively, and non-flammability (according to ASHRAE Standard 34). Moreover, DR-2 and DR-12 remain chemically stable up to 250 dig C, the highest temperature tested thus far (according to ASHRAE-ANSI Standard 97). Clearly, the remarkable thermal stability of DR-2 and DR-12 solidifies the paradigm shift away from the conventional wisdom that unsaturated fluorocarbons would necessarily be inadequately stable as working fluids. DR-2 and DR-12 could enable energy efficient chillers, high temperature heat pumps and Organic Rankin Cycles and contribute to meeting sustainability objectives (e.g. reducing non-renewable energy consumption and greenhouse gas emissions) with attractive economics.
Similarly, Daikin of Japan, the only manufacturer involved in all phases from refrigerant development to development of air conditioning equipment, has announced in Dubai's September Refrigerant Review that it will adopt in its air conditioners the refrigerant HFC32, a refrigerant having only one-third*2 of the global warming potential (GWP) of the conventional refrigerant R410A. In addition to having a lower global warming impact than that of R410A, HFC32 can help curtail greenhouse gas emissions originating from energy sources when equipment is in use by its better energy efficiency compared to R410A.
Daikin also gave free access to its "Basic Patent Essential to Manufacture and Sale of Air Conditioners Using HFC32 for most developing countries in order to prepare an environment in which each country could begin to easily promote the widespread use of HFC32 air conditioners. Carrier, the leading Refrigeration and AC equipment manufacturers anno-unced that apart from its initiatives off use of CO_2 in the Supermarket and transport refrigeration, it also has achieved the emission reductions in its own manufacturing facilities across the world. Its Mexico Factory building was the first in the World to be LEED Gold certified.

Do you see the challenges in HCFC phase out in short and long term amidst the hopes and optimism you express?

Replacing HCFCs with low or zero GWP substitutes and alternatives and

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

In the middle Rajendra Shende (white dress) chairman of the EEC-CSG-UNEP Conference in Heriot Watt University in Edinburgh. On the podium Paolo Buoni director of EEC - UK.

Improving energy efficiency of equipment that use such refrigerants is obviously the key challenge.

The 2007 G8 Summit Declaration that affirms: "We will also endeavor under the Montreal Protocol to ensure the recovery of the ozone layer by accelerating the phase-out of HCFCs in a way that supports energy efficiency and climate change objectives." The statement further adds, "Improving energy efficiency worldwide is the fastest, the most sustainable and the cheapest way to reduce greenhouse gas emissions and enhance energy security.

Improvements in energy efficiency are expected to accompany a transition out of HCFCs, as HCFC-based equipment is replaced with superior designs. The accelerated HCFC phase-out could spur improvements in energy efficiency of about 20% within a decade, which is double the business-as-usual" rate of improvement. The global potential for saving energy is huge. According to the International Energy Agency, successfully implemented energy efficiency policies could contribute to 80% of avoided greenhouse gases while substantially increasing security of supply. The TEAP has found that when energy efficiency is improved, the reduction in GHG emissions from decreased energy use can far outweigh the direct emissions over the life of the product or equipment. However, such energy efficiency improvement would need system wide technology development going beyond the simple refrigerant replacement. This would be challenge for any industry.

The high ambient temperatures that generally exist in the developing countries further complicate the improvement in energy efficiency. Higher the ambient temperature, lower is the energy efficiency of the system for the given refrigerants. There is critical need to develop a refrigerant as well as the RAC system to face the challenge.

Yet another challenge will be to deal with the ODS Banks. Banks are defined as ODSs contained in existing equipment (air conditioners and refrigerators), products (e.g. foam insulation), and stockpiles (e.g. the military stockpiles various chemicals for specialized uses). These exist in both developed and developing countries. Since developed countries phased-out of CFCs well ahead of developing countries, most of the CFC banks in the present and the future will be in developing countries. Approximately 7.4 $GtCO_2$-eq. of CFCs currently contained in banks of existing equipment and products are expected to be released into the atmosphere between 2002 and 2015. There will be additional significant emissions beyond 2015 from as more CFC and HCFC-based equipment reaches end-of-life. A portion of these emissions can be avoided as part of the accelerated HCFC phase-out. Destroying ODS banks ensures a "bonus" for ozone and sets an important precedent for future efforts to address the growing problem of banks. However the destruction of ODS is huge challenge considering the logistics and facilities needed for such operation.

Unlike CFCs, HCFCs are used as feedstock to manufacture high engineering polymers. The production and consumption of HCFCs for such feedstock purposes is not covered under the Montreal Protocol. In other words, significant quantities of production and consumption HCFCs will never be phased out. This is multi dimensional challenge. Firstly, HFC 23, super GHG with GWP of more than 10,000 and by product of manufacture of HCFC 22 will continue. The emitted HFC 23 needs to be destroyed. Second, the continued production of HCFCs may give rise to illegal trade of HCFCs for the use in RAC applications. Capacity building to understand the extent of these challenges and to resolve them would be herculean task.

What is the scenario in your own country – India? Is there any unique feature of phase out of HCFCs in India?

Like many developing countries India faces all the challenges that are described above. It appears that the market and the unique feature would lead India would be 'democratic choices of technology' keeping the energy efficiency and HCFC phase out targets as priority. Company like Godrej is leading the Hydrocarbon based energy efficient room AC manufacture where as Daikin will start mass production of HFC 32 based room AC products in 2012, having produced sample models already and having kept in view superior energy efficiency as compared to HFC 410A. India does not have very large base for the manufacture of RAC equipment as in case of China However the energy efficiency would be the driving criteria for the HCFC phase out in India. It will keep close watch on Chinese technology development and its own energy star rating for the room AC would lead the transformation.

What will be the priority of TERRE in the context of HCFC phase out?

TERRE considers that HCFC phase out is mainly the climate issue and less of Ozone protection issue. The recent massive electricity power grid failure in north India has part of its roots in the growing energy consumption for AC in residential and commercial buildings. Hence raising awareness on the opportunity of energy efficiency during the transition away from HCFCs will be the priority of TERRE. Not in kind technologies like vapor absorption systems that avoid the use of refrigerants and use of renewable and waste energy for such system would be promoted by TERRE. As a partner with Centro Studi Galileo, it will engage itself in the training and capacity building of the technicians and work with industry to continue reviewing the technology development.

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F Gas Training and Assessment in the UK and the Introduction of Qualifications for Natural Refrigerants

KELVIN KELLY

Business Edge

This topic will be discussed in the next 15th EU Conference

The Training and Assessment programme to allow competent persons in the UK to comply with the F Gas Regulations (EC Regulation 842, 303 etc), has now been available for the approximately 3 1/2 years.
The publication of the review of the F Gas Regulations indicate that as of July 2011 (when all personnel were required to be assessed to the new qualifications) the number of personnel subject to certification requirements were 19,500 and out of that number 15,584 have become fully certified; this equates to 79.9%.
In real terms we feel that this is rather optimistic. We at Business Edge have been in contact with many organisations that have multiple members of staff who are yet to attend a certification course. Indeed many organisations have only seen 50-60% of their staff gaining the required level of certification. This is due to many factors including, reluctance/lack of confidence on the part of the individual and/or the company, Cost (both financial and time) and the perceived lack of policing.
This position has been further confused by a recent report from UK Governmental department, the Department for Farming and Rural Affairs (DEFRA). They are now saying that over 26,000 individuals have achieved certification, this however exceeds their previous estimate of 20,000 which show some inconsistency with their calculations.
Certain sectors of the Industry have had even less success with regard to the adoption of the scheme, particularly in the Domestic and Small Commercial Refrigeration sector, some of this being due to a large number of these systems utilising non Fluorinated Refrigerants, I will return to these areas later within this text.

Has the F Gas Training and Assessment Qualification been a success within the UK?
To a degree. On a positive note many Training Centres have seen a large number of candidates successfully complete the assessment process and gain their qualification to comply with the regulation. From the outset Business Edge Ltd was inundated by customers wanting to know when the new qualification would be made available by the awarding bodies and requesting a place on a course as soon as possible. I am sure that other Training Centres across the UK experienced a similar response. However, to a degree, we have been "preaching to the converted", as the majority of the engineers attending the courses over the last 3.5 years have been "upgrading" from the previous UK voluntary Refrigerant Safe Handling qualification, therefore most of those who attended were familiar with the assessment process and prepared for what was required of them.
The feedback from the attendees of these courses has always been positive; many have stated that they felt that the Training and Assessment process was very worthwhile and that they now understand the obligations under the F Gas Regulations and what needs to be implemented on their part to ensure that their customers are compliant.
It would appear that the number of installations and equipment that have been worked on in accordance with the F Gas Regulations over the last four years are few and far between, leaving Operators open to prosecution. This will obviously improve as time goes on and more engineers are made aware of the legislation and their obligations.

Mr. Kelly in a recent certification session of CSG.

What has been well publicised is the overall lack of uptake with regard to the opportunity to undertake the Assessment prior to the 4 July 2011 deadline and this may be down to several reasons:
- The economic downturn within the UK.
- Leaving it to the last moment.
- Simply not wanting to undertake the

training and assessment.
- Not believing that the regulations would be "Policed".
- Difficulty in booking a place on a course.
- Fear of failure.

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

This has in turn led to an increase in organisations offering F Gas training and Assessment courses. It appears however that the multitude of these centres have had relatively few candidates attend and complete the process. I would imagine that this is due to the fact that although the centre may have the facilities, equipment and infrastructure to carry out F Gas courses, they are finding it difficult to find suitably qualified, experienced instructors and assessors to carry them out. Certainly, we at Business Edge have been approached by several of these centres asking for assistance in this matter. Unfortunately in most cases we have been unable to oblige due to our own work commitments as well the organisational and logistical problems. Business Edge had to increase availability of spaces on F gas courses for potential candidates as much as we could by increasing the number of courses, as well as the number of venues.

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

What should be done regarding the enforcing of the Regulations?

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

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

Business Edge feels that if the F Gas Regulations are to be taken seriously they should be fully implemented. This has been on-going as DEFRA are targeting organisations on a "risk basis" i.e. the major users of Fluorinated Greenhouse gases, to ensure compliance. With regard to the Individual and Company Certification requirement, DEFRA have contacted all approved Training and Assessment Centres in the UK to request details of Individuals and Companies that have successfully attended a suitable Assessment Course. It is therefore important that companies and individuals are encouraged to undertake the Training and Assessment process, even though it is after the deadline date. The F gas Regulations are not going to go away.

As previously mentioned some of the individuals and organisations that have not yet complied with the F Gas Regulations have not done so due to misconception and the fact that they predominantly work on "Natural" or low GWP Refrigerants such as Hydrocarbons and CO_2. However not all small systems utilise these low GWP Refrigerants many use HFC's such as R134a and R404A.

The main confusion that has resulted in non-compliance is the "3kg rule". A great many people have either been misinformed or wrongly interpreted the F Gas Regulations and believe that if they work on systems with less than 3kg then they are exempt. This is obviously not correct as the Category 2 Qualification is specifically aimed at engineers who work on systems with less than 3kg of refrigerant (6kg if the system is hermetically sealed).

Therefore more needs to be done to ensure compliance by this sector, however, with DEFRA operating on a "risk basis" these organisations will not show up on the radar for some time.

The UK is seeing an increased use of low GWP Refrigerants in a wide range of applications from Supermarket Refrigeration, Chilled Water and Variable Refrigerant Flow Systems, therefore, with this increased use comes an increase in risk to operatives working with refrigerants that are better for the environment but potentially more hazardous to them. This has led to the introduction of competency certification schemes for the handling of these refrigerants.

Training in Natural Refrigerants

One of the F Gas Certification Bodies, City and Guilds, has recently launched additional Training and Assessment Modules in the UK aimed at personnel who Install and Maintain Refrigeration, Air Conditioning and Heat Pump Systems with particular emphasis on Natural Refrigerants.

The Modules include:

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

sioning techniques.

- Install and Commission Ammonia Refrigeration Systems.
- Service and Maintain Ammonia Refrigeration Systems.

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

The principle running through all modules is Health and Safety, i.e. ensuring that all operators of equipment using these refrigerants can do so with minimum risk. For example the Hydrocarbon element requires attendees to enable them to prove:

- An understanding of the hazards of HC Refrigerants.
  - Flammability
  - Low boiling point
  - Asphyxiation
  - Lower and upper flammability levels
  - Sources of ignition
  - Practical limits
  - etc
- Standards and regulations covering HC usage and the impact they have for example on charge size.
- How system design varies when using flammable refrigerants.
- How to safely service and maintain HC systems, including a calculation for the safe fill weight of recovery cylinders.

Practical elements covered within the module include:

- Preparation of a Risk Assessment.
- Selection and use of appropriate safety equipment.
- Recovery of Hydrocarbon Refrigerants.
- De-Brazing and component replacement.
- Pressure Strength and Tightness Testing.
- Evacuation.
- Charging HC Refrigerants.
- Sealing of the systems.
- Leak testing.
- Checking the systems performance and efficiency.

Practically speaking the main requirement is that personnel undertaking reworks on Hydrocarbon systems can prove competency with regard to being able to remove/replace system components by safely un-brazing them. Obviously the "hot works" on a system that has contained a flammable gas has the greatest risk associated, particularly when these activities may have to take place in an occupied space, possibly with members of the public in the vicinity. Therefore, ensuring that the lower flammability level is not present whilst the repairs are taking place is paramount. This is achieved by initially recovering the bulk of the refrigerant from the systems using a specially designed EX rated recovery machine into a suitable recovery cylinder. In most cases this will not remove all of the refrigerant as it is entrained in the Compressor oil (Oil crankcase heater should be on to minimise this).

Once the refrigerant has been recovered, the system should be filled with a suitable inert case (Oxygen Free Nitrogen). This gas should be vented to a safe well-ventilated area, preferably outside and clear of any source of ignition. The system should be then connected to a suitable vacuum pump (exhausted outside) and a partial vacuum should be achieved. The operation should then be repeated. Finally the system will be again filled with OFN which will then be vented outside. The refrigeration system should then have a trickle of OFN flowing through whilst the un-brazing of the components is carried out. As it is best practice to always fit a new filter drier to the systems whenever this kind of work is carried out, the drier should be pierced before the de-brazing is undertaken (thereby ensuring that the system does not become over pressurised due to any trapped refrigerant within the system). Once the system has been repaired it can then be tightness tested, evacuated and dehydrated prior to charging with the correct amount of Refrigerant.

Another potentially hazardous but important skill to develop is resealing the system after repairs have been carried out. On Domestic and small Commercial refrigeration systems the unit should be left hermetically sealed (no service or schraeder valves fitted). This is achieved by running the system to ensure that the correct storage temperature is achieved prior to crimping the charging line twice and then removing the valve, turning over the pipe and brazing over the end of the pipe whilst the system is running to ensure a very low pressure behind the pipework.

In Italy with the UK inspector Kelvin Kelly has been certified over 600 technicians. In a UNEP joint meeting in Casale Monferrato - Centro Studi Galileo headquaters - will be also certified the Presidents of EAST-Europe and Asia Associations.

The other "Natural Refrigerant" modules follow similar routes for proving competency in the handling of refrigerants. As well as obtaining a nationally recognised certificate, successful candidates are able to register for the voluntary skills passport. This a joint venture between one of the certification bodies, Construction Skills and the Air Conditioning and Refrigeration Industry Board (ACRIB). It allows individuals to provide independent proof of their qualifications held. Not only does the skill card show that the individual has an understanding of Health and Safety at work and their level of F Gas Qualification (i.e. Category 1, 2, 3 or 4) but it will also show level of competency with regard to Natural Refrigerants.

Business Edge was the first independently owned training company offering courses in Refrigeration, Air Conditioning and Heat Pumps in the UK and we continue to be at the forefront of training in our industry as one of the first training and assessment centres to offer this range of training courses on natural refrigerants.

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Risks Inherent in the Use of Counterfeit Refrigerants

23rd Informatory Note on Refrigeration Technologies

GÉRALD CAVALIER

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President of transport commission of International Institute of Refrigeration (IIR)

This topic will be discussed in the next 15th EU Conference

Introduction

Several cases of explosions occurring in marine refrigerated containers (reefers) have been reported in various parts of the world in recent months. Besides causing major material damage, these accidents have resulted in the deaths of several operators. The assessments performed following these accidents have established that these explosions were due to the use, for maintenance of refrigeration equipment, of counterfeit refrigerants containing R40 mixed with R134a, the refrigerant initially used in these units. A report published by the Container Owners Association[1] describes the global situation concerning contamination of R134a by a refrigerant mixture composed primarily of R22, R30, R40 and R142b. There are no external signs indicating that counterfeit refrigerants have been used during maintenance operations.

Over 1.3 million reefers are in use worldwide,[2] and counterfeit refrigerants represent a potential risk for all operators servicing this equipment or handling it in ports, on ships, during land transport and loading and unloading at hubs, or in warehouses or factories. It is estimated that around 5000 containers have been tested for contamination so far and around 10-15% of the world fleet may be contaminated.[3]

Moreover, similar cases involving automobile or bus air-conditioning systems have been reported in the Far East, the Middle East and Greece.[4] Replacement refrigerants with unknown composition are known to be available on the black market. In particular, cases of contamination with hydrocarbon refrigerants have been reported. The goals of this Note are to raise the awareness of operators concerning this new risk, to propose a detection method designed to detect systems containing counterfeit refrigerants that thus constitute a risk, and to examine ways of decontaminating contaminated systems. The aim is also to attract the attention of public authorities and decision-makers regarding the impact of counterfeit refrigerants on the refrigeration sector, with respect to safety and also in economic terms.

The current situation and risks associated with R40

- *Reasons underlying the use of counterfeit products and the consequences of such use:* the addition of other refrigerants to R134a in order to intentionally make the mixtures obtained resemble pure R134a markedly reduces the cost of the counterfeit product with respect to that of R134a, and an opportunity for financial gain for counterfeiters. The counterfeit market is encouraged by the recent price spikes in the worldwide cost of R134a as a result of the phase-out of HCFCs, and this is stimulating the market for counterfeit R134a. This results in safety issues for operators of course, and also gives rise to costs for the refrigeration industry: certain refrigeration stakeholders consider that counterfeit refrigerants cost several million US dollars per year.[5]
- *Known causes of accidents:* several containers have exploded in Vietnam, South America, North America and Asia. Analyses of material have demonstrated that these explosions resulted from the presence of trimethyl aluminium ($Al_2(CH_3)$[6]), which is liquid at room temperature. This substance is produced by the reaction of the refrigerant used to replace R134a, i.e. methyl chloride (chloromethane or CH_3Cl), R40, when it enters into contact with the aluminium contained in the compressor or the refrigeration circuit.

- *Risks:* it is likely that other systems that have undergone maintenance operations during which counterfeit refrigerants have been used are circulating in various parts of the world, including Europe. On contact with aluminium in the equipment, these refrigerants gradually react, and can cause an explosion at any time during use, or during maintenance operations, and can even cause fires. The use of steel piping is the best way of preventing such risks.

Methyl chloride

Methyl chloride, also known as chloromethane (CH_3Cl) or R40, was used as a refrigerant prior to the advent of chlorofluorocarbons (CFCs). Because of its impact on ozone-depleting mechanisms, it is no longer used as a refrigerant. It is colourless, and has a mild ethereal odour which is not transmitted to foodstuffs accidentally exposed to it in vapour form. At temperatures below 100 °C, it is not corrosive with respect to metals commonly used in the refrigeration sector, but it reacts with zinc, aluminium and light alloys.

- *Risks associated with R40:* R40 is flammable under certain conditions; a mixture of methyl chloride vapour and air can explode when the concentration reaches 9-15% in the presence of a source of heat.

If a major leak of this refrigerant occurs, care must be taken to ventilate before detecting the leak using a halide lamp.

The reaction of R40 with aluminium also forms highly flammable gases which become self-igniting and explosive when in contact with air. Aluminium is gradually dissolved by R40. Lubricating oil does not prevent this dangerous reaction. R40 also reacts with the aluminium compressors used in mobile refrigeration systems, and plastic components can also react on exposure to R40. The refrigerant lines can also be seriously damaged by R40.

POE oil used to lubricate refrigeration system is highly saponified on reaction with R40, and its initial components separate out. These reactions form acids and alcohols.

Prevention of risks associated with R40

All operators must be informed regarding risks and must implement measures designed to prevent risks.

- *How to detect counterfeit refrigerants:* R40 is readily detected by using a halide lamp that does not detect R134a. Counterfeit refrigerants can be mixed with R40, R22 or R142b, but these components can also be detected by using a halide lamp. Such detection must be performed in a well-ventilated area.

In order to test a cylinder or a system, it is unfortunately necessary to trigger a small refrigerant leak then to analyse the gas using a halide lamp. The system must be stopped in order to perform this operation safely. No marine-shipping-container refrigerant test procedures have been developed to date. New models of refrigerant analyzers for use with R134a systems are announced to detect R40 in concentrations as low as 2%.5

- *Isolate and clean systems containing counterfeit refrigerants:* in order to prevent risks, at-risk systems must be isolated, stopped then decontaminated if possible. For operators involved only in the transport, loading or unloading of containers, it is advisable to ask the operator to specify whether or not the system has been checked and provided with a compliance certificate indicating that no counterfeit refrigerants are present.
- *Avoid the use of counterfeit refrigerants:* in order to prevent risks, it is above all essential to avoid the use of counterfeit refrigerants by monitoring maintenance operators and their refrigerant supplies. Maintenance of the systems concerned by explosions had been conducted in Asia. Compliance certificates may be needed for cylinders: methyl chloride can be detected in cylinders.

How to decontaminate systems contamined with R40

Several methods have been proposed in order to decontaminate systems, but to date none of them have been validated or widely used. Methyl chloride can be recovered in the gaseous form; however, the trimethyl aluminium formed when methyl chloride reacts with aluminium is liquid at room temperature. Trimethyl aluminium accumulates at the lowest point in the refrigerant circuit, in particular in the compressor housing, where it can be recovered.

IIR Recommendations

There is a significant risk associated with the use of counterfeit refrgerants containing R40 in marine containers. Operators need to be made aware of such risks, and must implement preventive measures and set up:

- a certification scheme governing the refrigerants used in maintenance,
- certification of marine containers for logistics interfaces,
- a method of decontaminating contaminated systems.

Beyond the use in marine containers, vigilance must be strengthened with respect to other applications and refrigerants used in these domains, in particular automobile and bus air conditioning and on-board refrigeration.

Finally, another important aspect: at the level of public authorities, control measures and deterrence need to be strengthened in order to prevent the use of counterfeit refrigerants.

This Informatory Note was prepared by Gérald Cavalier, (Executive Director of Cemafroid, Head of the IIR's Section D, Storage and transport) and Richard Lawton (Technical Director, Cambridge Refrigeration Technology, President of the IIR's Commission D2, Refrigerated transport). It was reviewed by several of the IIR's international experts.

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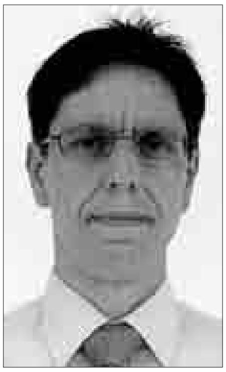
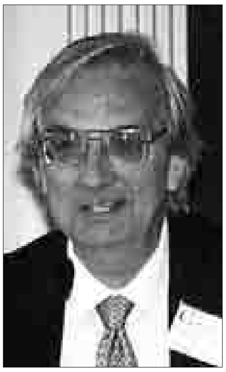
Minichannel devices for low charge refrigerating systems





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This topic will be discussed in the next 15th EU Conference

The worldwide alert about global warming has led to an increasing interest in new HVAC (heating, ventilation and air conditioning) technologies with low environmental impact. When considering this impact, both an indirect effect due to the energy consumption, and the consequent carbon dioxide emissions caused by the electricity production process, and a direct effect due to leakages of refrigerant must be taken into account. A way to achieve high heat transfer rates in compact heat exchangers is using minichannel technology. In addition to high heat flux applications, minichannels are viewed as appropriate options to reduce the charge of refrigerant, minimize the problems of release of potentially hazardous fluids in the atmosphere and allow to use natural fluids such as hydrocarbons and carbon dioxide.

Keywords: minichannels, charge reduction, void fraction, heat exchangers.

INTRODUCTION

A significant and still growing part of the engineering research community has been devoted in the last few decades to scaling down devices, while keeping or even increasing their functionality. The introduction of minichannels in the field of enhanced heat transfer and in the refrigeration and air conditioning sectors is surely one of those attempts (Fig. 1). Minichannels allow to develop compact elements which work with reduced refrigerant charge and can withstand extremely high system pressures. Both for HFC and for natural refrigerants, such as hydrocarbons and ammonia, the minimization of the charge is a key point to reduce global warming impact or even solve safety problems.

HEAT TRANSFER IN MINICHANNELS

Proper understanding of microscale transport phenomena is fundamental for the designer of microscale heat exchangers. The transition between micro- and macro-scale has been a recurring theme in the literature; however so far there is no established criterion to properly define the transition between conventional ducts to minichannels, particularly in the case of boiling and condensation heat transfer.

With regard to condensation, some researchers observed flow regimes with R134a in minichannels, but no general flow regime map is available. Matkovic *et al.* (2009) presented heat transfer data taken inside a 0.96 mm diameter single circular channel. They measured the heat transfer coefficient during condensation of R134a at 40 °C saturation temperature, and found an experimental trend of the heat transfer coefficient as one would

Del Col second from the right in a hydrocarbon training course for United Nations-UNDP for the Ghana delegation of the Ministry of the Environment inside Centro Studi Galileo headquaters.

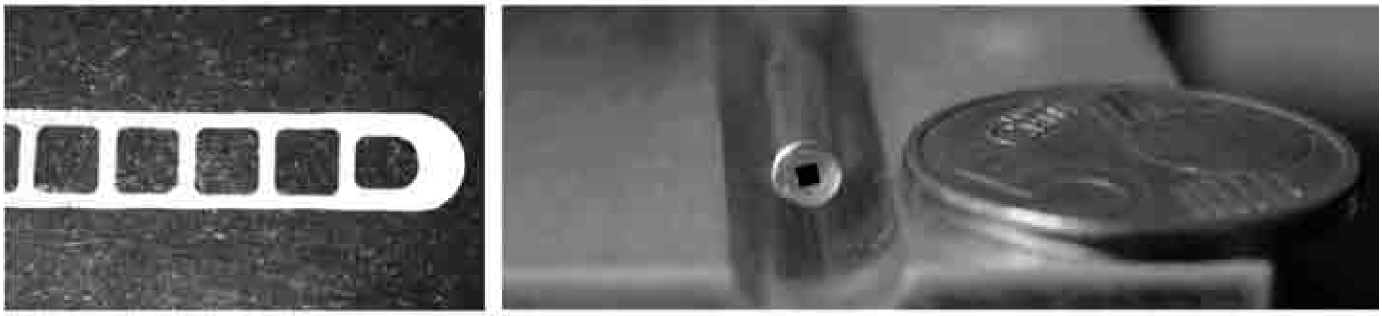

Fig. 1. *Right side: enlarged image of a 1.4 mm hydraulic diameter multiport minichannels test tube. Left side: square channel cross section with 1.23 mm hydraulic diameter.*

expect from macroscale condensation, at least at mass velocity equal or higher than 200 kg m^{-2} s^{-1}.
Some numerical studies have been presented in the literature reporting that the channel shape may have great influence on the heat transfer coefficient during condensation inside minichannels. In fact, the surface tension is supposed to enhance the heat transfer in the presence of corners as compared to the case of circular channels. The effect of the minichannel shape is particularly interesting since most of the minichannels used in practical applications have non circular cross sections. Del Col *et al.* (2011) compared the heat transfer coefficients measured inside a 1.23 mm square section channel against data by Matkovic et al. (2009) taken inside a circular channel. The heat transfer is found to be enhanced in the square channel at 200 kg m^{-2} s^{-1} and this must be due to the effect of surface tension, whereas this enhancement is null at higher mass flux.
A validated experimental technique has been employed by Del Col *et al.* (2012) to assess the effect of channel orientation on heat transfer coefficients during the condensation inside a square cross section minichannel, with a hydraulic diameter of 1.23 mm. No differences have been noticed with mass velocities down to 200 kg m^{-2} s^{-1}, whereas the condensation heat transfer is controlled by the shear stress. Some effect of inclination was found at lower mass fluxes.
A criterion to identify the transition between micro- and macro-scale has been proposed for flow boiling: the transition occurs when, reducing the channel dimension, the tube diameter reaches a value which is of the same order of magnitude of the bubble size. Several recent studies have been reported on vaporization in minichannels. Some experiments show that the heat transfer coefficients obtained during vaporization in minichannels are not a function of vapor quality nor mass velocity (in contrast with the macro-channel trend), but are a function of heat flux and saturation pressure. Other experimental studies demonstrate that the heat transfer coefficient also depends on vapor quality and mass velocity. Some experimentalists conclude that flow in small channels is dominated by nucleate boiling while forced convection evaporation is less important.
A phenomenon that must also be accounted for in evaporators design is the onset of dryout in flow boiling that causes a sharp decrease of the heat transfer coefficient due to a change in the heat transfer mechanism. Liquid film dryout is the result of the gradual disappearance of the liquid film adjacent to the wall. Much recent activity has been carried out in order to investigate the behaviour of flow boiling heat transfer and critical heat flux in minichannels, but there is still a lack of information and reliable data, if compared to the wide range of engineering design and possible applications.

SYSTEMS USING MINICHANNELS WITH LOW SPECIFIC CHARGE

If the aim is to maintain high performance and to reduce the refrigerant charge, it can be useful to have a parameter to compare the performance of different systems. The comparison is done by using the specific charge which is the ratio of the refrigerant charge to the heating/cooling capacity.
A 100 kW water-to-water heat pump working with 30 g/kW of propane is installed at the University of Padua and presented in Cavallini *et al.* (2010). The unit is devoted to testing applications and two prototypes heat exchangers using minichannels can be used as a condenser and as an internal heat exchanger. Minichannels are used in order reduce the internal volume of the heat exchangers and then to minimize the refrigerant charge of the system. The prototypes are segmentally baffled shell-and-tube heat exchangers using copper minitubes with an internal diameter of 2 mm (Fig. 2).

As in the previous conferences, in the last XIV European Conference, Alberto Cavallini (on the right of italian flag) was President and general chairman.

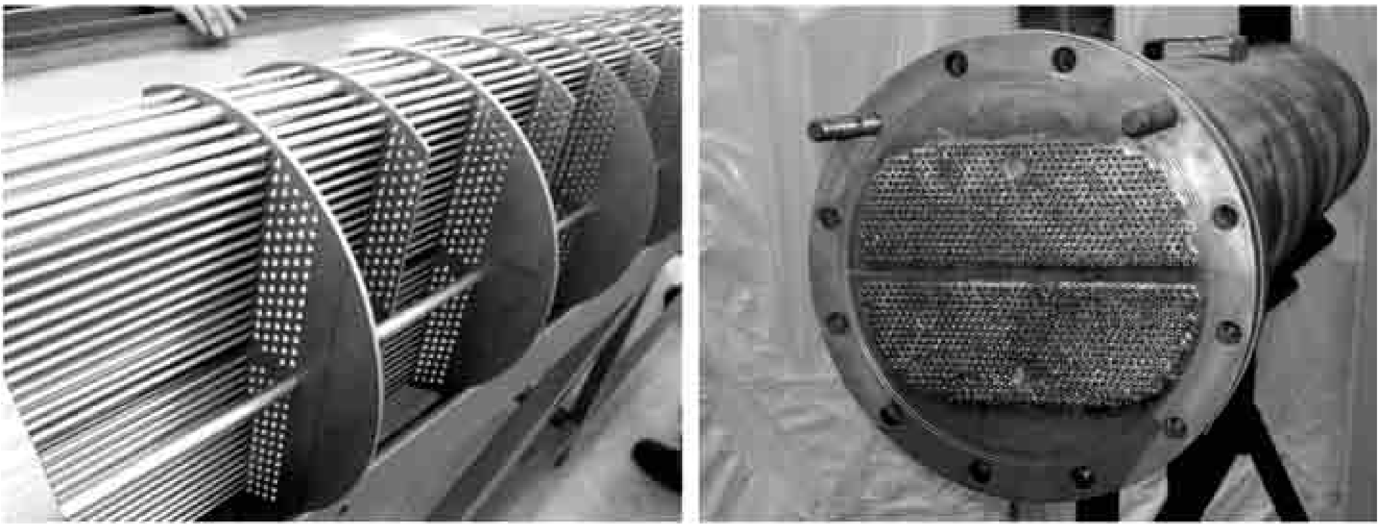

Fig. 2. *Left side: tube bundle of the minichannel condenser. Right side: front view of a minichannel evaporator without header.*

The authors reported that the experimental specific charge measured in the heat pump without a liquid receiver was about 30 g/kW using a plate condenser and a plate evaporator and a 0.8 kg reduction could be achieved using the minichannel condenser with a negligible COP performance variation, around 2%.

Fernando *et al.* (2004) reported the experimental measurements of the charge in a minichannel condenser and in a minichannel evaporator simulating a water to water heat pump working with propane. The two heat exchangers, designed with the priority of the minimization of the refrigerant charge, are composed of 30 and 36 multiport aluminum tubes in two parallel rows, respectively. Every tube had six channels of about 1.42 mm internal hydraulic diameter and a length of 651 mm. Tests were conducted at different conditions and run to find the maximum COP. In the evaporator and in the condenser the optimum measured refrigerant charge resulting in the highest COP vary respectively between 23 and 27 g and between 69 and 93 g. The minimum specific charge that could be achieved is about 37 g/kW considering 7.23 kW of heating capacity.

An ammonia chiller has been experimentally investigated in Hrnjak and Litch (2008). They tested one plate evaporator and two air cooled condensers, one with parallel tube arrangement between headers and multiport microchannel tubes with an hydraulic diameter of 0.7 mm, and the other with a single serpentine microchannel tube with a hydraulic diameter of 4.06 mm. The condenser had louvered fins, each tube had triangular minichannels with a length of 698.5 mm. This system could work with a very low specific charge of 20 g/kW.

In order to make an accurate estimation of the refrigerant charge in a minichannel heat exchanger a model that uses void fraction correlations must be developed. Void fraction is a dimensionless quantity defined as the ratio of the cross sectional area occupied by the vapor compared to the total cross sectional area. To calculate the void fraction it is necessary to use proper correlations (Da Riva *et al.*, 2010).

SUMMARY

The refrigerant charge reduction in refrigerating systems, along with the substitution of HCFCs and high-GWP HFCs, is a goal for the urgent need to reduce their contribution to the greenhouse effect and to reduce atmospheric emission. In this paper minichannels technology and various applications are presented. Minichannels are used in order to reduce the internal volume of the heat exchangers without decreasing performance. The understanding of dominant mechanisms during boiling and condensation in minichannels is the fundamental basis for the development of accurate design methods. Systems using minichannels heat exchangers that could work with a specific charge of 30 g/kW with propane, and 20 g/kW with ammonia have already been developed. For the evaluation of the refrigerant charge in the heat exchangers there is need to calculate the volume that is occupied by the liquid and by the vapour and this can be achieved by using void fraction correlations available in the literature.

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Latest energy efficiency achievement's within R744 refrigeration



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This topic will be discussed in the next 15th EU Conference

CO_2 (R-744) is increasingly being used as refrigerant in various applications. Recent developments in component and system development will contribute in further deployment. Competing or better energy efficiency and lower environmental impact than the alternatives is an important criterion for further expansion.
This paper cover some of the lately developments.
Restrictions on the use of synthetic refrigerants are coming into force in several countries. There is a need for natural refrigerant alternatives which allows for a safe investment in efficient refrigeration systems, not forced to be retrofitted by legislation in the future. Systems applying R744 as the only refrigerant have been developed and more than 1331 supermarkets existed in the beginning of 2012 in Europe (Shecco, 2012), mainly in northern and mid-European countries.
However, the currently installed R744 systems still have a large development potential with respect to energy efficiency, heat recovery and cost efficiency.
Supermarkets are the most energy intensive building category within commercial sector; their technical installations require a large amount of primary energy. Every effort which improves the energy efficiency of these systems reduces the expanses of the shop owners and helps to reduce peak power issues for the electricity providers. Beside their major energy consumption the equipment contributes also to relatively large direct emission of greenhouse gasses (GHG) through emissions of refrigerants from the refrigeration plants and the air conditioning system installed. The huge majority of these systems, which are installed in European supermarkets, are applying HFC-404A as working fluid. Average annual leakage rates in Europe are in the range of 15-20 % of the total charge. Worldwide the figure is about 30 % and HCFC-22 being the main refrigerant in use.
This paper will focus on two recent developments; a single stage R744 compressors with variable volume flow rates in the range of 18 to 90 m^3/h, developed with focus on high efficiency. Secondly, an ejector integrated R744 system architecture will be described, which improves the system COP of R744 systems by up to 20% at high ambient temperature operation.

INTRODUCTION

Since the re-introduction of carbon dioxide (R744) as a working fluid *by Lorentzen et al. (1992/1994/1995)*, many advantages of this natural substance are realized in various mobile and stationary applications ranging from heat pumps, air conditioning to refrigeration. During the last 20 years the availability of components for stationary R744 applications improved drastically, however, there is still a need for further developments to reach the same range in variety for components as designed for low pressure refrigerants. *Neksa et al. (2010)* reviews some of the fundamentals, developments and applications where R-744 are becoming an alternative.
In last 30 years supermarkets are usually built as a part of shopping malls. There are over 111 million m2 of shopping malls over the EU. The amount and sizes of supermarkets and shopping malls will increase in the future, due the increase in population and higher living standard across Europe.
Consequently, if significant energy efficiency measures would not be undertaken, this increase in the supermarket area equipped with chilling or freezing equipment will result in tremendous increase in the total energy use. For example, a 25 % decrease in total energy use for shopping malls will result in about 14 000 GWh saved energy. Therefore, energy efficiency measures in the supermarket sector will give a substantial contribution to EU's 2020 goal.

Table 1. **Main Compressor data.**

	Value / Range
Height x Width x Length [mm]	500 x 440 x 830
Weight [kg]	286
Volume flow rate [m^3/h]	12-90
Displacement [cm^3]	380
Max power consumption [kW]	100
Revolutions per minute [rpm]	500 - 4000
Frequency range [Hz]	33 - 267

Figure 1.
R744 compressor.

Figure 2A.
Measured overall efficiencies.

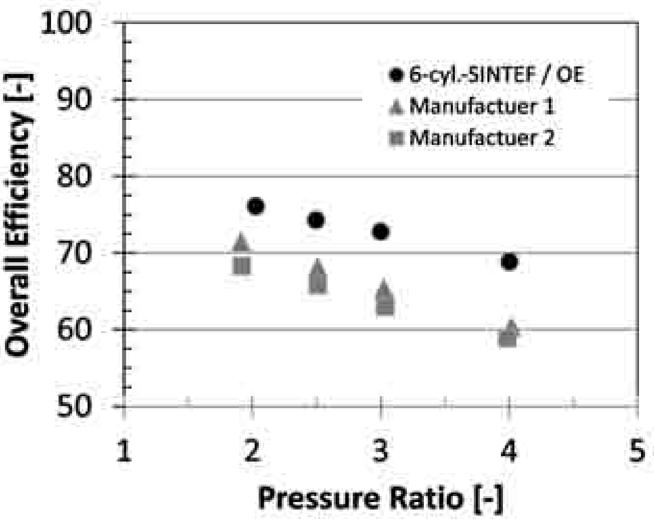
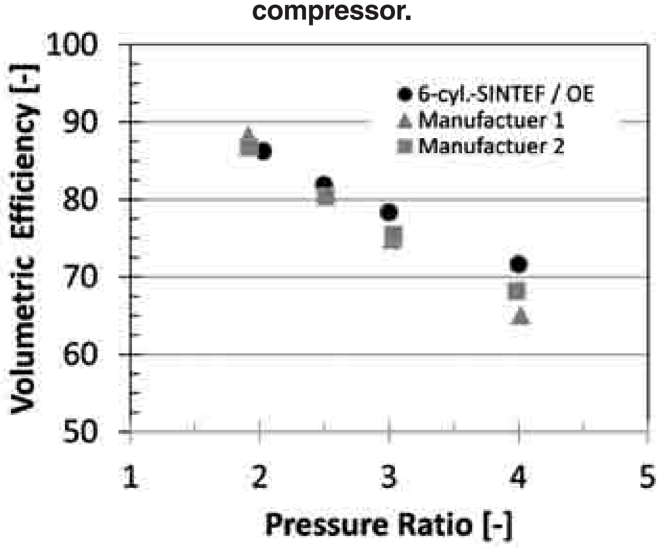


Figure 2B.
Measured volumetric efficiencies of the R744 compressor.



During the last decade, there has been a tremendous deployment of R-744 transcritical refrigeration systems for supermarkets in Europe, with a documented number of installations to 1331 in early 2012. A dominant part of these are installed in Germany and northern Europe. The technology is now, however, spreading around the world, e.g. to Australia and USA. An important feature for R-744, is that it well suites for integration with heat recovery, air conditioning and ventilation. Further, it is well suited for concepts with ground energy storage. All of these may contribute to high energy efficiency of the total supermarket energy system.

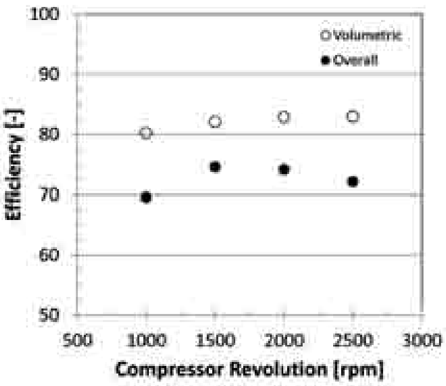
NOMENCLATURE

COP	Coefficient of Performance (-)
$eta_{overall}$	Overall compressor efficiency (-)
eta_{vol}	Volumetric compressor efficiency (-)
$\dot{m}_{total}$	mass flow rate (kgs-1)
n	Frequency of compressor (Hz)
P_{elec}	Measured compressor power consumption, excluding converter losses (W)
P_{is}	Isentropic power consumption (W)
R744	CO_2
V_H	Swept volume / compressor displacement (m^3)
Δh_{is}	isentropic enthalpy difference; enthalpy compressor outlet (at equal entropy as inlet) - enthalpy compressor inlet ($kJkg^{-1}$)
ρ_1	refrigerant density at compressor inlet (kgm^{-3})

High efficient compressor development

In order to perform R&D on novel energy efficient R-744 systems, a flexible compressor and heat exchanger test facility has been built and installed in the laboratories of SINTEF and NTNU in Trondheim. It enables a thorough investigation of higher capacity R744 components like compressors, heat exchangers, expansion- and work recovery devices. The maximum electrical power input to the compressor is in the range of 100 kW. Various plate heat exchangers are applied as a baseline equipment to be able to

Figure 3.
Measured efficiencies at various compressor revolution speeds.



$$eta_{overall} = \frac{P_{is}}{P_{elec}} \cdot 100 = \frac{\dot{m}_{total} \cdot \Delta h_{is}}{P_{elec}} \cdot 100 \quad \text{eq(1)}$$

The volumetric efficiency shown in Figure 2B is defined as shown in equation 2. The density is calculated based on temperature and pressure measurement at the suction side of the compressor.

$$eta_{vol} = \frac{\dot{m}_{total}}{\dot{m}_{theoretical}} \cdot 100 = \frac{\dot{m}_{total}}{\rho_1 \cdot V_H \cdot n} \cdot 100 \quad \text{eq(2)}$$

investigate real system operations in the pressure range from triple point pressure to maximum discharge pressures of 130 bar for R-744.

A new high-efficiency compressor concept is now being tested. The main improvements and efforts made in the compressor development are related to:

- Thorough oil separation inside the electric motor on the suction side of the compressor.
- Integration of a permanent magnet motor.
- Smart heat management in order to avoid unintended transfer of heat from the hot to colder parts of the compressor
- Advanced valve design to be able to operate at a large rpm range.
- Improved cylinder sealing concept to reduce piston blow by.
- Sophisticated internal pressure equalisation concept between the suction and the crank-case volumes.

The main compressor data are shown in Table 1, while Figure 1 is a photo of the high performance 6-cylinder R744 compressor.

Experimental set up & results:

The first experimental results obtained at 1500 rpm, a discharge pressure of 80 bar and a 10 K superheat at the compressor inlet are shown in Figures 2A and 2B. As a reference, measured values of two different R744 compressors from renowned manufactures are The benchmark compressors were off the shelf, however, their displacement was only around 33% compared to the newly developed 6-cylinder unit.The overall efficiency shown in Figure 4A is defined as shown in equation 1. The total mass flow rate is the sum of the refrigerant + lubricant mass flow rate not trapped by the novel internal oil separator concept applied. The isentropic enthalpy difference is calculated as the difference of the isentropic enthalpy at the discharge pressure (entropy of the compressor inlet) minus enthalpy at compressor inlet. The electric power consumption is measured, while the losses insides the frequency converter are not included.

The initial measurements indicate a significant efficiency improvement obtained with the new 6-cylinder R744 compressor.

In these first results the improvement is mainly due to the permanent magnetic motor and possible compressor size effects, since an ordinary valve arrangement and ordinary piston ring concepts are applied.

Therefore a further improvement of both the overall and volumetric efficiency can be expected when the concepts under development are applied.

Another important feature is that the overall efficiency decrease with higher pressure ratios is relatively much less than for the state-of-the-art off-shelf compressors,, as shown in Figure 2. This shows that the new concept has a large potential when applied in heat pumps, where due to large temperature lifts elevated pressure ratios might be the case.

Figure 5 shows the variation in overall efficiency with the pressure ratio. The optimum, i.e. the highest overall efficiency values with the current valve arrangement are obtained between 1200 and 2000 rpm. When analysing load profiles of ordinary refrigeration systems as applied in commercial refrigeration, 80 % of the compressor operation could take place at these conditions, i.e. a high system COP can be achieved which results in a high energy efficiency of total system.

This compressor concept can help the industry and the end user to achieve the next level on the way to further improve the energy efficiency of energy intensive installations which contain heat pumping equipment. High temperature heat pumps and large commercial refrigeration plants are potential applications for this high efficient compressor concept.

How to integrate non-controlled ejectors to improve the energy efficiency of R744 systems at elevated ambient temperatures?

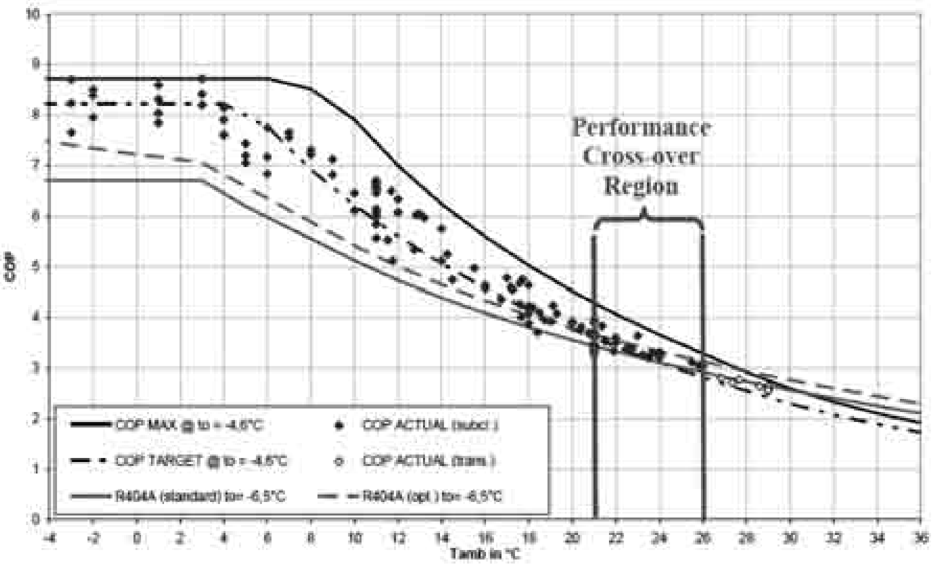
Energy efficiency and reliability of R744 systems are the key factors to success on its way to become a global solution for supermarket applications as well as for refrigeration units in mobile applications (trucks and containers) and heat pumps in general. Figure 4 shows the system COP of HFC and R744 commercial systems as a function of ambient temperature provided by a leading supermarket equipment manufacture.

At elevated ambient temperatures HFC system solutions require slightly less energy compared to current R744 Booster systems to provide the required cooling capacity. Therefore, a so called "*CO_2 equator*" exists across Southern Europe, where the annual average temperature are around 20 °C, i.e. south of the *CO_2 equator* current R744 Booster systems still have lower energy efficiencies compared to HFC systems.

How can the system efficiency of R744 systems be improved at high ambient temperature conditions? I.e. is it possible to move the *CO_2 equator* to Africa?

Applying transcritical R744 ejectors in the refrigeration system is one of the most promising methods to increase the system efficiency and reduce the throttling loss (Elbel and Hrnjak (2008) and Elbel (2011)). In addition, the ejector's simplicity (no moving parts) of construction compared to

Figure 4.
COP comparison between different systems with respect to ambient temperature.
Finckh et al. (2011)

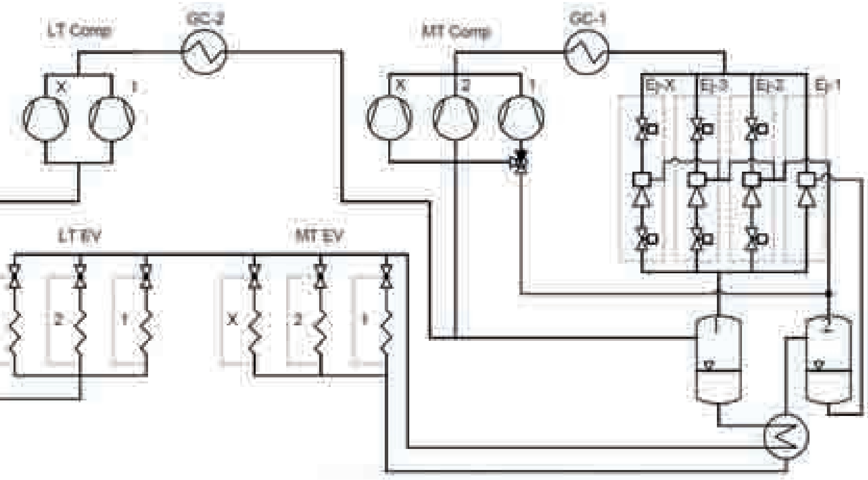


expanders, low cost and reasonable efficiency may result in a fast market introduction.
Two-phase ejectors utilise partly the expansion work available when high-pressure refrigerant is throttled in a motive nozzle inside an ejector. The ejector pumps the low-pressure mass flow rate of the evaporators to a higher pressure level, into a separator. The kinetic energy of the motive flow rate is applied to accelerate the refrigerant flow downstream of the evaporators. In the mixing chamber of the ejector both fluid flows equalize their velocities, which is transferred into a higher pressure level, compared to the suction pressure, inside the diffuser of the ejector.
Pressure lifts of more than 5 bars can be achieved at reasonable entrainment ratios. This means that the compressor suction pressure is higher compared to a system without ejectors, which again reduces the pressure ratio and the required work. Consequently a higher system COP of an ejector R744 system can be achieved compared to an ordinary R744 booster system.
Figure 5 shows one possible circuiting of a novel commercial refrigeration system design, including non-controlled ejectors with different ejector geometries, which allows applying standardized ejectors. The different motive nozzles, controlled on/off by shut off valves, are controlling the high side pressure according to ambient temperature or load requirements, i.e. to operate the refrigeration system at optimum COP.
The MT-Compressors are connected to the separator (1) downstream of the ejectors, the suction pressure is therefore much higher compared to an ordinary R744 Booster system, where the compressors are connected to the exit of the evaporators.
The ejectors are applied to maintain a certain pressure difference between the medium pressure receiver (2) downstream of the MT evaporators and the separator (1). A reliable liquid supply pressure to feed the evaporators is maintained. This represents a direct work recovery from the expansion work, which is normally not utilized = lost. The higher the ambient temperature, i.e. the refrigerant return temperature to the expansion devices, the higher the available work which can be recovered during expansion with an ejector.
At low and moderate ambient temperatures the optimum high side pressure is low, i.e. a subcritical mode of the R744 Booster systems is chosen. In this case the pressure lift capability of the ejectors is reduced, since less work can be recovered from expansion. Therefore one (or more, depending on the system size) of the MT-compressors (rpm-controlled, called auxiliary compressor, 'MT Comp. 1' in Figure 5) can be connected/switched to the vapour outlet of the medium pressure receiver (2) to compress some of the vapour directly to the high pressure side. This reduces the entrainment ratio of the ejectors, which supports the ejectors in operation to maintain the necessary pressure lift of the refrigerant via the ejector into the separator (1).
Proper oil management can be done inside the separator downstream of the ejectors. This solution secures a constant pressure difference between the separator and receiver, i.e. the proposed system can be applied in any climate zone.
Intensive system simulations and experimental results showed that the performance (COP) of supermarkets equipped with an ejector R744 system increases significantly by up to 20%, at high ambient temperatures, as validated by Girotto 2012. The excellent performance of R744 systems at low ambient temperatures, as shown in Figure 4, can also be maintained with the ejector system.
No patent applications could be found which protect the use of the control principle applying an auxiliary compressor, which allows a high performance of the vapour compressing ejectors during all boundary conditions.
This concept can also be applied for other R744 vapour compression system which do have efficiency challenges at high ambient (refrigerant return) temperatures like: heat pumps for space conditioning and high water temperatures, mobile applications (truck & containers) and chillers.

Next generation R744 evaporators

The energy efficiency of all kind of R744 commercial refrigeration systems could be significantly further improved if the MT-evaporators are redesigned for higher evaporation pressures and lower superheat values. An adaptation of the heat transfer surfaces should be considered.

Figure 5.
Ejector R744 System with non-controllable ejectors.
Hafner et al. (2012)



Most of the current R744 commercial refrigeration systems are designed to maintain a certain superheat inside the evaporators. Traditionally this has be common practice to protect the compressors from liquid slugs. However, when applying R744, every additional degree of superheat in the MT-evaporator requires a one bar lower suction pressure for the compressor.

Compared to traditional HCFCs and HFC systems where 1 K of superheat is equal to 0,1 to 0,2 bar. i.e. the penalty of superheat does not only reduce the system efficiency because of the inefficient heat transfer when reserving large heat exchanger surfaces to provide superheat, it lowers also the refrigerant density upstream of the compressor and increases the pressure ratio of the compressor.

This results in a significant reduced total efficiency and an increased power demand. If the heat exchangers are adapted the evaporation temperature will be much higher compared to current designs, i.e. evaporator outlet pressures above 30 bars (-5 °C) at medium temperatures are possible.

The ejector R744 system shown in Figure 5 can be equipped with non-sophisticated expansion devices, which may slightly overfeed the evaporators with refrigerant. The liquid refrigerant downstream of the evaporators is collected inside the medium pressure receiver.

SUMMARY

Important energy efficiency improvement possibilities for R744 refrigeration and heat pumping systems have been evaluated and quantified by experimental investigations. R744 is increasingly being used as refrigerant in various applications. Recent developments in component and system development will contribute in further deployment.

A 100 kWel power and 400 kW cooling capacity test rig with multi-functional testing possibilities is presented. It allows measurements on R744 heat exchangers and compressors with detailed analysis possibilities. First test results are shown with test rig and the new developed 6 cylinder R744 compressor.

Currently compressor racks contain several compressors to be able to maintain low and high capacities, this concept with the wide capacity range allows replacing several ordinary compressors with a single compressor, i.e. the cost of installed cooling capacity is in the same range or even lower.

Initial results indicate that the performance of the 6 cylinder R744 compressor driven by a permanent magnet motor is close to the expected efficiencies as indicated by thorough simulations. Overall efficiencies of 76 % are measured. The compressor also shows favourable efficiency at a wide range of compressor revolution speeds.

Applying an ejector R744 system will improve the system performance of supermarkets significantly by up to 20% at high ambient temperatures.

This concept can also be applied for R744 heat pumps, chillers and other equipment which faces high heat rejection temperatures.

MT-Evaporators should be re-designed for higher evaporation pressures and lower superheat values to improve the energy efficiency of all kind of R744 commercial refrigeration systems.

When applying the mentioned system improvements like the high efficient R744 compressor and the ejector concepts for supermarket systems may enable energy efficient operations also at hot ambient temperatures, the 'CO_2 equator' can be moved to Africa.

●

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Ammonia: The Refrigerant of the Future

BRUCE BADGER

President IIAR International Institute Ammonia Refrigeration

This topic will be discussed in the next 15th EU Conference

It may seem odd to call ammonia – a refrigerant first used for refrigeration in the 1800's – the refrigerant of the future. However, a drastic evolution in equipment, controls and other technologies in recent years is ensuring that ammonia will be at the center of the new safer, greener and more efficient industrial refrigeration systems to come. It is true that the basic ammonia refrigeration cycle hasn't changed much since it was first used in 1859, but several developments have made ammonia more relevant than ever before – taking it from the mechanical workhorse of the industry to the efficiency-boosting, cost-saving powerhouse it is today.

This evolution is evident at every level of engineering, beginning with the dramatic changes to the equipment and controls that make up the nuts and bolts of modern refrigeration systems. It takes only one picture of a vertical, single acting compressor produced in the early 1900's to notice the amazing difference between that machine and the modern day compressor. The same is true of evaporators, condensers, valves and controls. In fact, almost every aspect of today's refrigeration system is different.

Beyond the basic changes, advances have been made in four important areas. First: variable frequency drives are much more affordable and applicable to motor driven equipment. Second: computer-based control systems now permit remote monitoring and control, taking safety to a new level while giving operators the precision that ultimately boosts efficiency. Third: new water treatment technology has also improved overall system efficiency. Fourth: equipment as basic as hand and control valves have improved so significantly that their operation is far easier and more reliable.

So what is it about these advances that are making ammonia refrigeration a game changing system? All of these changes lower operating costs and improve safety, naturally supplying environmental gains and infusing a new level of efficiency into the operations of refrigerated warehouses and processes.

Nevertheless, the application of ammonia refrigeration technology beyond the food and beverage industry provides the most telling evidence of how completely the technology has evolved. In recent years, ammonia technology was on display when images of NASA astronauts were televised attaching a 1700 lb, double-chamber tank which contained a 600 lb ammonia charge to the International Space Station.

The International Space Station could not exist without its cooling system. Cooling is not just for keeping the astronauts comfortable, but also insures that computers and other delicate electronic systems are protected from being alternately frozen and overheated. "Without thermal controls," a NASA publication says, "the temperature of the orbiting Space Station's sun-facing side would soar to 250 °F (121 °C), while thermometers on the dark side would plunge to -250°F (-157°C)." Given this volatile environment, it is no wonder that ammonia, with its high thermal capacity and wide range of operating temperatures, was selected as the refrigerant for key components of the Space Station's thermal control system.

But ammonia's advantages don't stop there. Ammonia is also readily available and inexpensive. Even in outer space where ammonia's environmentally friendly characteristics do not matter; its advantages still exceed those of synthetic refrigerants. Because ammonia refrigeration is a relatively mature industry, there is a knowledge base on how to handle it safely—even in deep space.

Ammonia was selected as the refrigerant for the Space Station's external cooling system because, in the words of Boeing Active Thermal Control System Analysis and Integration engineer, Thang Mai, it is simply "the best…it's more efficient and has great viscosity which means liquid ammonia can travel through piping with minimum pumping power. This translates into lower energy use."

Mr. Mai continued that ammonia also has enormous thermal capacity. It can collect, store and transport heat without using high pumping power. It also has a low freezing point of -108°F at standard atmospheric pressure. "No other fluid can go that low and still be pumpable." Ammonia, moreover, is lighter than water by 30% which means that an ammonia system has less launch weight — another huge plus in an application where every bit of weight in the payload has to be justified.

From the first, the ISS was designed and built with thermal balance in mind. The electronic devices aboard the Space Station generate excess heat which must be removed and either distributed to cooler parts of the station or ejected into outer space. When the heat aboard the Space Station exceeds the capabilities of the Passive Thermal Control System, the Active Thermal Control System comes into play. The Active Thermal Control System is comprised of 3 cooling subsystems: the External Active Thermal Control System, which uses anhydrous ammonia as a coolant; the Photovoltaic Thermal Control System, which also uses anhydrous ammonia coolant; and the Internal Active Thermal Control System, which uses water as a coolant.

The ATCS cools the astronauts' living quarters and working areas, electronic equipment and laboratories by means of a pumped liquid ammonia heat transfer system. Mechanically pumped fluids in closed-loop circuits perform three functions: heat collection, heat transportation, and heat rejection. It is a dual system: the internal, inhabited areas are cooled through a closed loop system that utilizes water as a refrigerant, while the external areas utilize a closed loop ammonia system. A compact, plate-fin, liquid-to-liquid heat exchanger is used to interface the internal thermal loops that use water as a refrigerant and the external thermal loops that use ammonia refrigerant. Waste heat is removed in two ways: through cold plates and heat exchangers, both of which are cooled by circulating ammonia loops on the outside of the station. On the space station, the internal cooling system uses water as a medium to cool the inhabited areas of the spacecraft. The heat is rejected to a liquid-to-liquid heat exchanger that interfaces between the water and ammonia. The water collects all the waste heat from the internal module and transfers it into the ammonia system. The heated ammonia is then pumped to a radiator where the heat is rejected into outer space. The external system consists of a pump, a tank which contains a 600 lb ammonia charge in two separate chambers, and the heat exchangers.

The External Active Thermal Control System is comprised of two independent loops that were designed so that a failure in one would not take down the entire external thermal control system. Both loops are physically segregated from one another to achieve redundancy and the fluid transport lines are buried within the truss structure to protect them from orbiting debris.

If a loop fails to function, the EATCS continues to operate, but at a reduced capacity. Each loop collects heat from up to five Interface Heat Exchangers. The EATCS also provides ammonia resupply capability to the Photovoltaic Thermal Control Systems. All EATCS components are located outside the pressurized areas to prevent crew contact with ammonia.

There are five interface heat exchangers for each EATCS loop. The IFHX units transfer heat from the IATCS water coolant loops to the external ammonia coolant loops. Each IFHX core is a counter-flow design with 45 alternating layers. IATCS water flows through 23 of the layers, while EATCS ammonia flows through the 22 alternate layers in the opposite direction. These alternating layers of relatively warm water and relatively cold ammonia help to maximize the heat transfer between the two fluids via conduction and convection. The heat exchanger core is a simple flow through device with no control capability.

The Photovoltaic Thermal Control System consists of ammonia loops that collect excess heat from the Electrical Power System components in the Integrated Equipment Assembly and transport this heat to the four PV radiators where it is rejected to space. The Photovoltaic Thermal Control System consists of ammonia coolant, 11 cold plates, two pump flow control subassemblies, and one photovoltaic radiator. The Photovoltaic Thermal Control System can dissipate 6,000 watts of heat per orbit.

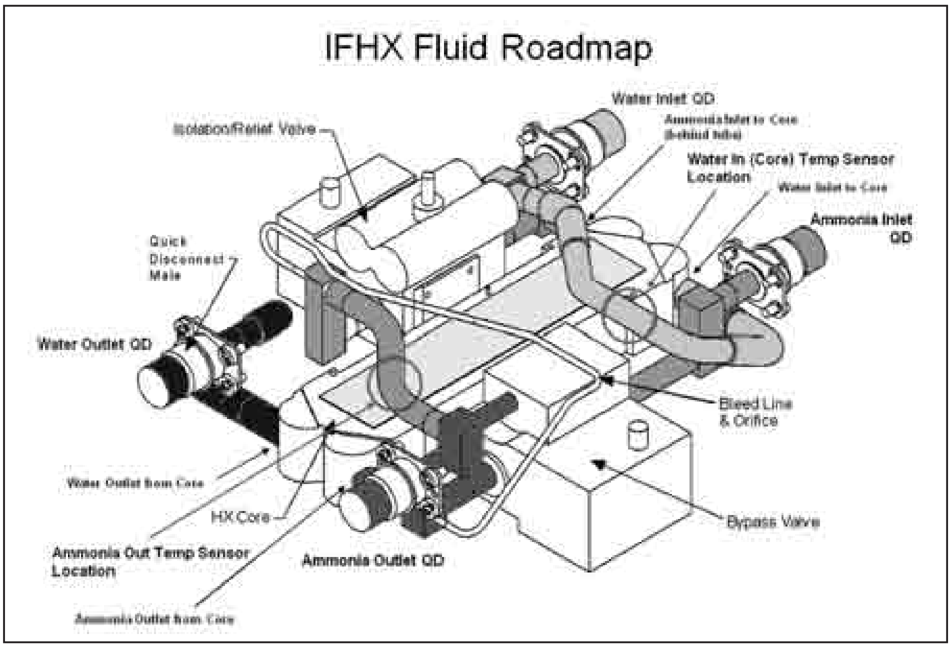
Each loop provides cooling to externally-mounted cold plates. The cold plates contain electrical equipment that converts and distributes power to downstream ISS loads. Each ammonia loop contains four cold plates, two attached to Current-to-Direct Current Converter Units and two attached to Main Bus Switching Units. Each cold plate Orbital Replacement Unit is connected to the EATCS ammonia loop by self-sealing quick disconnect couplings and contains a finned cold plate, two or three strip heaters and a temperature sensor.

The cold plates are installed such that the fins of the cold plate are positioned adjacent to corresponding fins on either the DDCU or the MBSU to facilitate heat transfer by radiation between the cooled equipment and the cold plate. Each DDCU cold plate measures 35 inches (88.9 cm) by 28 inches (71.12 cm) by 31 inches (78.74 cm) inches and weighs about 96 pounds (43.54 kilograms).

Circulation, loop pressurization, and temperature control of the ammonia is provided by the Pump Module. Each ammonia loop contains a Pump Module Assembly ORU to provide flow and accumulator functions, and to maintain proper temperature control at the pump outlet. Each Pump Module consists of a single pump, a fixed charge accumulator, a Pump and Control Valve Package containing a firmware controller, startup heaters, isolation valves, and various sensors for monitoring performance.

The accumulator within the Pump Module works in concert with the Ammonia Tank Assembly tanks to compensate for expansion and contraction of ammonia caused by temperature changes and keeps the ammonia in the liquid phase through a fixed charge of pressurized nitrogen gas.

The Pump Module provides fluid pumping, fluid temperature control and system pressure control. The Pump and Control Valve Package provides flow control. A single pump in the PCVP circulates the ammonia. The Flow Control Valve located within the PCVP regulates the temperature of the ammonia. The Flow Control Valve mixes "cool" ammonia exiting the radiators with "warm" ammonia that has bypassed the radiators. Loop



A typically operates at 8,200 lb/hr and loop B at 8,900 lb/hr with the pumps turning at 14,000 and 14,700 revolutions per minute, respectively.

The accumulator located in the Pump Module provides auxiliary pressure control. The accumulator keeps the ammonia in the liquid phase by maintaining the pressure above the vapor pressure of ammonia and provides makeup ammonia in case of a leak. The accumulator works in conjunction with the Ammonia Tank Assembly to absorb fluctuations in the fluid volume due to varying heat loads through the expansion and contraction of its internal bellows. Nominal operating pressure for the loops is 300 psia at the pump inlet. The maximum system design pressure is 500 psia. Each Pump Module measures 69 inches (175.26 cm) by 50 inches (127 cm) by 36 inches (.91 cm) inches and weighs about 780 pounds (353.8 kilograms).

Flow Control Monitoring Failure Detection, Isolation and Recovery for high and low pressure conditions are monitored by Multiplexer / Demultiplexers. For an over pressure, gaseous nitrogen pressure is relieved down to 360 psia when pump inlet pressure reaches 415 psia (active control). The Pump and Control Valve Package Inlet pressure, Radiator return pressure, and Bypass return pressure sensors are part of this system and two of three pressure readings are used to determine if an overpressure condition exists. The pump will shut down when the pump outlet pressure reaches 480 psia.

Low pressure (the current limit is set at 170 psia) is monitored by two methods to determine a low pressure condition, the higher of the two values determine the limit. Low pressure conditions are monitored using the PVCP inlet pressure, radiator return pressure, and bypass return pressure sensors.

The Pump and Control Valve Package also maintains temperature set point control of the ammonia supplied to the Heat Acquisition Subsystem. The PCVP has a temperature control capability of 36 °F (2.2 °C) to 43 °F (6.1 °C) and it is set at 37 °F ± 2 °F (2.8 °C). The temperature control method is by a three-way mixing valve that mixes flow from the radiators and the Heat Rejection System Bypass. Heaters on the HRS Bypass leg provide an additional level of control. Total heater power of 1.8 kW is split across two heater strips mounted on the HRS bypass lines at 900 watts each. Pump outlet over temperature protection is provided by a Firmware Controller in the PCVP that uses three PCVP outlet sensors to determine an over temperature condition and issues zero pump speed. Multiplexer/ Demultiplexers use the Pump Module outlet sensor to determine an over temperature condition and pull power from the Solenoid Driver Output card providing power to the Pump Module. The current limit is set at 65 °F (18.33 °C). The pump is also shut down when the PCVP firmware detects potential freezing in the IFHX.

Each ammonia loop contains an Ammonia Tank Assembly Orbital Replacement Unit to contain the heat transfer fluid, in this case, liquid ammonia, used by the EATCS loops. There is one Ammonia Tank Assembly per loop. The ATA ORU is used to supply makeup fluid to the system, to act as an accumulator in concert with the Pump Module accumulator and provide the capability to vent the ammonia loops by way of a connection to an external non-propulsive vent. Each ATA primarily consists of two bellows ammonia tanks pressurized by an external nitrogen source, two internal survival heaters and two sets of quantity, differential pressure, absolute pressure and temperature sensors. The ATAs can be isolated and replaced during orbit.

The ATA in combination with the Nitrogen Tank Assembly provides fluid supply and primary system pressure control. The ATA acts as the primary accumulator for the EATCS in concert with the NTA. If required, it can also be used to replenish the PVTCS fluid lines. Each ammonia loop contains a Nitrogen Tank Assembly ORU to provide storage for the high pressure nitrogen used for controlled pressurization of the ATA.

The NTA is connected to the ATA by self-sealing Quick Disconnects. Each NTA ORU primarily consists of a nitrogen tank, a gas pressure regulating valve, isolation valves and survival heaters. The nitrogen tank provides a storage volume for the high-pressure gaseous nitrogen, while the GPRV provides a pressure control function as well as nitrogen isolation and over pressure protection of downstream components. The NTA provides the necessary pressure to move the ammonia out of the ATA. The single high-pressure tank contains nitrogen at 2,500 psia (@70 °F, ground fill) and uses the GPRV to supply continuous pressure up to 390 psia in one psia increments. A back-up mechanical valve limits the maximum nitrogen pressure to 416 psia. The GPRV provides pressure control as well as high-pressure nitrogen isolation and over-pressure protection of downstream components. The NTA has venting capabilities and over pressure controls. Each NTA measures 64 inches (162.56 cm) by 36 inches (91.44) by 30 inches (76.2 cm) inches and weighs about 460 pounds (208.65 kilograms). Fluid Lines and external Quick Disconnects provide the transportation path from the truss segments to the IFHXs. Connections between segments are made with flex hoses and QDs.

Heat collected by the EATCS ammonia loops is radiated to space by two sets of rotating radiator wings—each composed of three separate radiator ORUs. Each radiator ORU is composed of eight panels, squib units, squib unit firmware controller, Integrated Motor Controller Assemblies, instrumentation, and QDs. Each Radiator ORU measures 76.4 feet (23.3 meters) by 11.2 feet (3.4 meters) and weighs 2,475 pounds (1,122.64 kilograms). Each ammonia loop contains one radiator wing comprised of three Radiator ORUs mounted on the Radiator Beam and six Radiator Beam Valve Modules as well as one Thermal Radiator Rotary Joint.

Each Radiator ORU contains a deployment mechanism and eight radiator panels. The deployment mechanism allows the Radiator ORU to be launched in a stowed configuration and deployed on orbit. Each radiator ORU can be remotely deployed and retracted. Each individual radiator has two separate coolant flow paths which flow through all eight radiator panels. Each panel's flow path has eleven flow tubes for a total of 22 Inconel flow tubes or passages, 11 passages per flow path, per radiator panel; flow tubes are freeze tolerant.

Flow tubes are connected along the edge of each panel by manifolds. Flex hoses connect the manifold tubes between panels. Each panel has a white (Z-93) coating which provides optimum thermo-optical properties to maximize heat rejection. The flow tube arrangement is designed to minimize ammonia freezing in the radiator. Each radiator path contains one Radiator Beam Valve Module as a part of the radiator wing. Six RBVMs are mounted on the radiator beams and truss segments. Two RBVMs service each radiator ORU. Each RBVM consists of an isolation relief valve, an isolation valve, an Integrated Motor Controller Assembly, QDs, and pressure and temperature sensors. The RBVM controls the transfer of ammonia between the Radiator Assembly ORU and the rest of the EATCS loop. Each RBVM contains sensors to monitor absolute pressure, temperature and valve position within the ORU. Remote control venting of the radiator fluid loop is also available through the RBVM to facilitate radiator replacement and prevent freezing of the ATCS coolant during contingency operations. The RBVM provides flow path isolation in the event that a panel suffers micro-meteoroid damage and also provides automatic pressure relief when the EATCS is over pressurized. Each RBVM weighs about 50 pounds (22.68 kilograms) and measures 24 inches (60.96 cm) by 20 inches (50.8 cm) x 5.4 inches (13.72 cm).

The rotation capability for each radiator assembly is provided through a Thermal Radiator Rotary Joint. The TRRJ provides power, data, and liquid ammonia transfer to the rotating radiator beam while providing structural support for the radiator panels. Rotation angles are determined via the Radiator Goal Angle Calculation algorithm which commands the Radiator Beam to put the radiators either "edge to the sun" during isolation phase of the orbit or "face to the Earth" during the eclipse phase.

The RGAC ensures the radiators stay cold enough so the heat can be rejected but warm enough so that the ammonia does not freeze. There is a temperature goal of –40 °C at the radiator outlet. The FHRC provides the transfer of liquid ammonia across the rotary joint and is capable of rotating 230 degrees, at ±115 degrees from its neutral position, the software command limit is ±105°; with a variable rotation speed of 0 to 45 degrees-per-minute. Each TRRJ measures approximately 5.6 feet (1.7 meters) by 4.6 feet (1.4 meters) by 4.3 feet (1.3 meters) and weighs 927 pounds (420.5 kilograms).

Software Thermal Control System software is used to control and monitor the system. The TCS software executes actions such as system startup, loop reconfiguration, and valve positioning for flow and temperature control automatically or via commands from crew laptops or ground workstations. Telemetry from the various temperature, pressure, flow, and quantity sensors is monitored by TCS software and displayed on crew laptops or ground workstations. In addition, Fault Detection, Isolation, and Recovery software is used to monitor the performance of the TCS and, if there is a problem, alert the crew and flight controllers. In some cases, FDIR software initiates recovery actions.

Examining the mechanics of the ammonia system on the International Space Station is a great way to see how far the technology of our industry has evolved. However, the best place to look for evidence of the growing sophistication of our technology may not be in the outer space, but rather on the corporate balance sheet.

Thanks to efficiency increases, ammonia systems are delivering more cost savings than ever before and generating an industry-leading return on investment. The issue is a relevant one, as the industrial producers in every sector of our global economy struggle to cut costs more than ever before and race to meet their customer's new demand for a green supply chain.

While ammonia refrigeration may not be the same industry that it was fifty years ago, technology improvements do not replace the need to properly design, install and service these systems, either here or in space. This will require an ongoing emphasis on educating the next generation of knowledgeable engineers, contractors and equipment manufacturers.

These days, the potential for ammonia-based systems – to deliver measurable financial and environmental gains – is getting the attention of the industry. Ammonia refrigeration continues to expand, with new partnerships between industry leaders, end users and government agencies, answering the demands of a global supply chain with a highly effective and efficient technology.

●

Bruce Badger has served as president of the International Institute of Ammonia Refrigeration since 2008. He has 40 years of industrial refrigeration experience as an engineer, contractor and manufacturer.

Hu Wangyang

Research on A New District Heating Method Combined with Hot Water Driven Ground Source Absorption Heat Pump

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A new district heating method combined with hot water driven ground source absorption heat pump to extract shallow geothermal was put forward, and the district heating system provides hot water for the driven heat source of the absorption heat pump. By the first energy efficiency and economical analysis method, research results show that compared with the conventional district heating system, the heating capacity of the new district heating system with absorption heat pump can be greatly improved and the heating costs can be largely reduced without expanding the capacity of district heating system and increasing other energy consumption. Also, compared with electric-driven ground source heat pump heating system, the new district heating system utilized high temperature water as the driven heating resource to replace the high grade electricity, which can improve significantly the energy utilization efficiency and decrease sharply the power consumption. Compared with electric-driven ground source heat pump heating system on the same heat quantity condition, the new district heating system has the advantage of lower first energy consumption and smaller size of underground heat exchanger and the smaller heat extraction during winter period which was conducive to achieve winter and summer heat balance.

Keyword: District heating system; shallow Geothermal; Absorption Heat Pump.

INTRODUCTION

The electric-driven ground source heat pump was widely researched and applied to extract shallow geothermal resource for building cooling or heating [1-5]. It relied on electricity for driven resource of heat pump to extract heat from soil for heating in winter and releasing the chiller condenser heat for cooling in summer.

If the electric-driven ground source heat pump fails to maintain seasonal heat balance between winter and summer period, its coefficient of performance will gradually decrease with the increase of its running time. So the seasonal heat balance of the ground source heat pump is the key point. In addition, electric-driven ground source heat pump in the heating condition consumes much electricity, and the heating cost will depend on the electricity price. So the higher electricity price will be the disadvantage of the electric-driven ground source heat pump system for heating.

A new district heating system combined with ground resource absorption heat pump to extract shallow geothermal resource was presented. The ground resource absorption heat pump is placed in the heat substation to extract heat from the soil or ground water, the district heating system provides hot water with primary heating network for the driven heat resource of the ground resource absorption heat pump. Also, such absorption heat pump can be converted to be absorption chiller for building cooling in summer driven by hot water with district heating system.

Heat exchange facility is applied in heat exchange station in conventional district heating system. Heat exchange equipment only transfers the quantity of heat of the high temperature water of the primary heating network to the secondary heating network, and heat exchange equipment only make use of the thermal of the high temperature water and fails to fully develop the work ability of the high temperature water. Compared with conventional heat exchange equipment in heating substation of district heating system, the absorption heat pump not only makes use of the thermal of the high temperature water but also develops the work ability of the high temperature water, because the absorption heat pump uses the hot water supplied with primary heating network as its driven heating resource to extract the shallow ground resource.

The primary energy efficiency and economic analysis mode of the new district heating method combined with ground source absorption heat pump was set to analyze the difference of the energy efficiency and economy feasibility with conventional system and electric heat pump system. Comparative analysis of district heating system combined with ground source absorption heat pump with electric-drive means for ground source heat pump shows that compared with conventional district heating system, the heating capacity of the new district heating system can be greatly increased and the heating costs can be largely reduced without expanding the capacity of the heat resource and other power consumption of district heating system.

Unlike electric-driven ground source heat pump makes use of high-quality electrical to drive, the ground source absorption heat pump system takes advantage of the high temperature water as the driven source, thus the power consumption of the absorption heat pump system will be significantly reduced and then the incremental investment of the new district heating system combined with ground source absorption system can be recovered in four years.

Also the ground absorption heat pump system not only combines shallow geothermal with conventional district heating system, but also optimizes the configuration and energy efficiency of district heat system. Consequently, compared with conventional district heating system or electric-driven ground source heat pump, the new district heating system combined with ground source absorption heat pump system makes significant energy efficient, economic benefits.

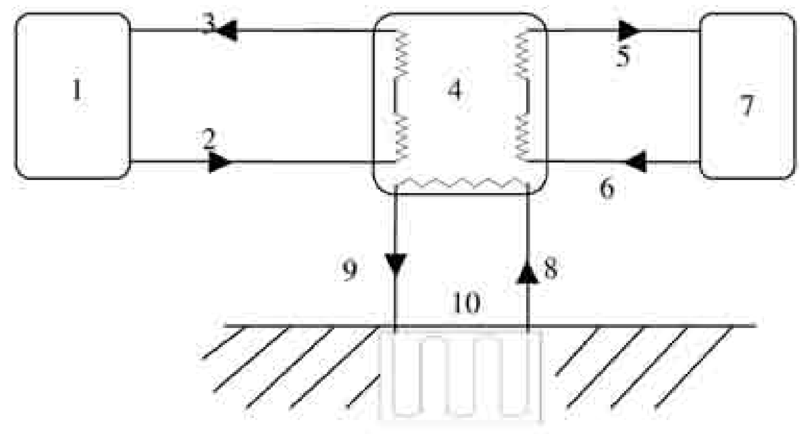
DISTRICT HEATING SYSTEM COMBINED WITH GROUND SOURCE ABSORPTION HEAT PUMP

System Description

The new district heating mode mainly makes use of ground source or water source absorption heat pump to replace heat exchanger of heat substation in conventional district heating system, and uses high temperature hot water provided by primary heating network as driven heating source for absorption heat pump to extract heat from low-grade heat sources such as the shallow soil or water, and then both the heat of driving heat source and low-grade heat of ground source are supplied for heating building users by the secondary heating network.

The new district heating system is mainly constituted with district heat source (usually a combined heat and power plant, coal or gas heating boiler, etc.), primary heating network, secondary heating network, distributed ground source absorption heat pump,

Figure 1.
Schematic of district heating system combined with ground source absorption heat pump.



1. district heat source 2. primary heating supplying water network 3. primary heating returning water pipe 4. ground source absorption heat pump 5. secondary heating supplying water network 6. secondary heating returning water network 7. heating users 8. ground supplying water pipe 9. ground returning water pipe 10. Underground pipe

Figure 2.
Conventional district heating system.

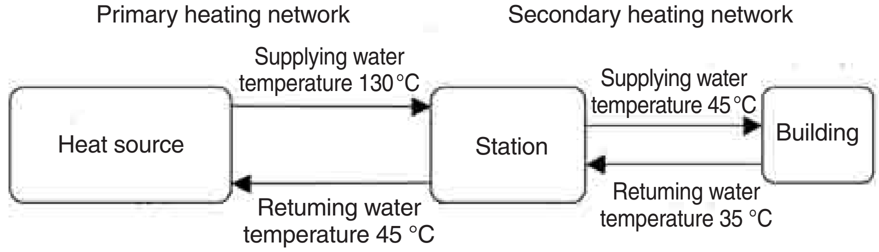
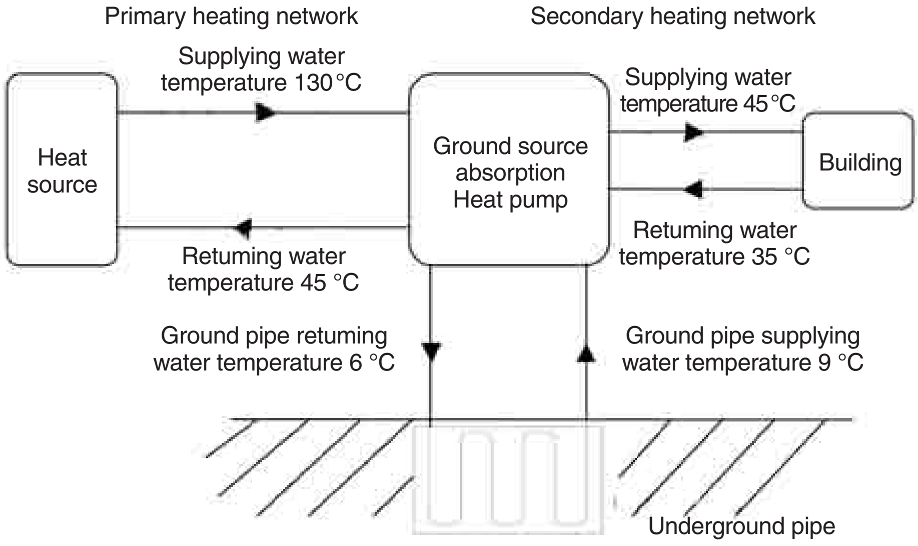


Figure 3.
District heating system combined with ground source absorption heat pump.



underground pipes(water taken wells and recharge wells), heating users and their connection accessories.

Features of the new district heating system

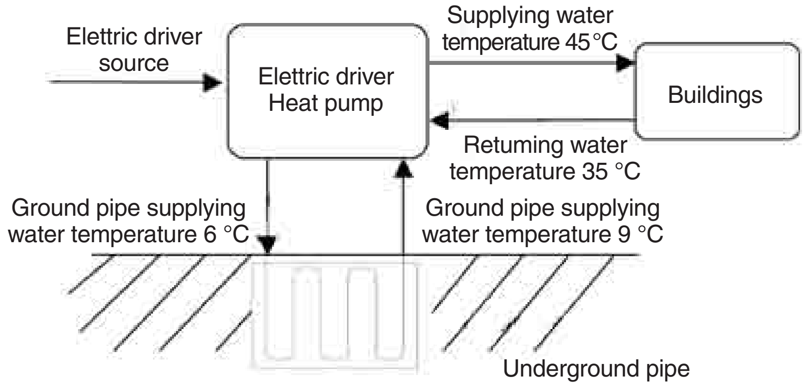
Compared to conventional heating method, the new district heating system combined with ground source absorption heat pump system can increase the heating capacity of the system, reducing heating costs without increasing the capacity of the district heating source. On the other hand, compared with electric-driven ground source heat pump heating method, it is not used high grade electricity as the driven source of heat pump, but made use of the high temperature water supplied by district heating source. Thus it can significantly reduce power consumption and increase the primary energy efficiency of the district heating system. Also, such new district heating approach can more easily achieve the summer and winter seasonal heat balance.

ANALYSIS MODEL OF PRIMARY ENERGY EFFICIENCY

Comparison condition setting

To analyze the energy efficiency and economy feasibility of the new district heating method, the conventional district heating system and the electric-driven heat pump heating system are selected as reference system. In the condition of the same heating parameter of secondary heating network for building heating users, it is assumed that the buildings for heating users are all energy-saving buildings with low temperature heating parameters and the supplying and returning heating water parameters of secondary heating network is 45/35?. Schematic diagram of different heating systems and its working parameters are shown as below.

Figure 4.
Electric-driven ground source heat pump system.



Primary energy efficiency evaluation

Primary heating efficiency of different heating system is calculated by equation 1.

$$\eta_h = Q_h/(Q_s/(\eta_{net\ 1}\eta_{net2}\eta_{CHP}\eta_b) + W_{net\ 1} + W_{net\ 2} + W_{ground} - W_e/(\eta_e\eta_b) \quad (1)$$

Which η_h —Primary heating efficiency
Q_h —Heating amount of building users, GJ
Q_s —Heating amount of heat source, GJ
$\eta_{net\ 1}$ —Heating transport efficiency of primary heating network, %
$\eta_{net\ 2}$ —Heating transport efficiency of secondary heating network, %
η_{CHP} —Heating efficiency of cogeneration heat and power system, %
η_b —Heating efficiency of boiler, %
$W_{net\ 1}$ —The power consumption of primary heating network pump, GJ
$W_{net\ 2}$ —The power consumption of secondary heating network pump, GJ
W_{ground} —The power consumption of underground water pump, GJ
W_e —Electricity generation, GJ
η_e —The average efficiency of power generation of coal power plant
$\eta_{e,net}$ —The transport efficiency of power network

The flow charts of primary energy utilization process for different heating systems in the design condition are shown as figure 5 to figure 7, and all units in the charts are GJ

Figure 5.
Energy flow chart of electric driven ground source heat pump heating system.

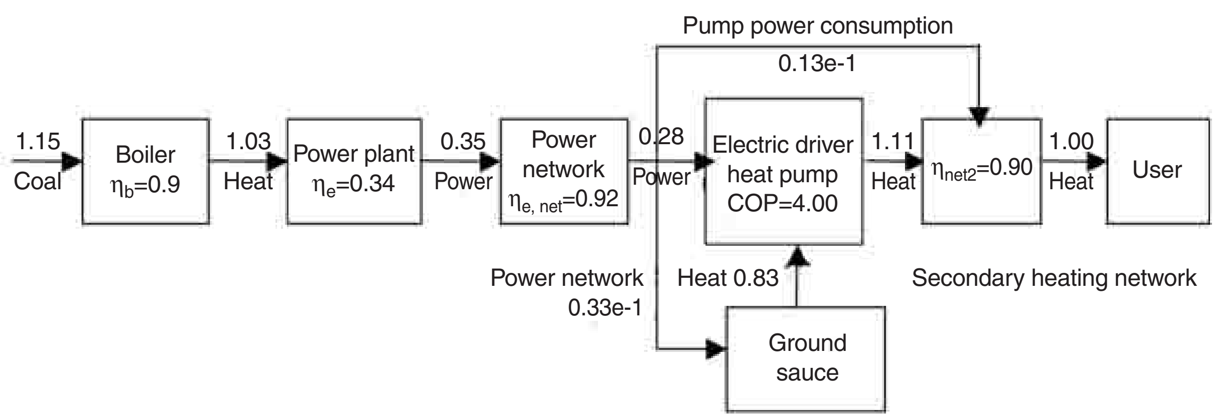


Figure 6.

Energy flow chart of conventional district heating system with CHP.

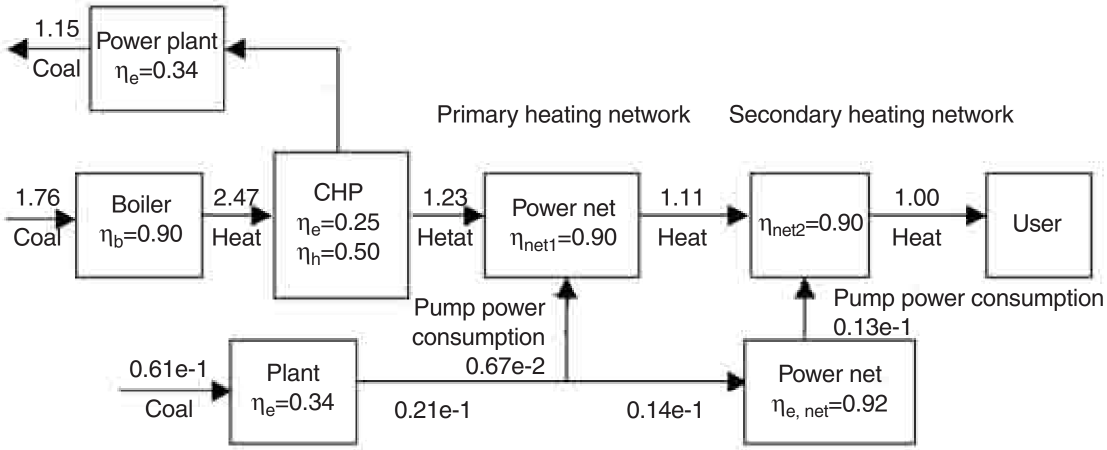
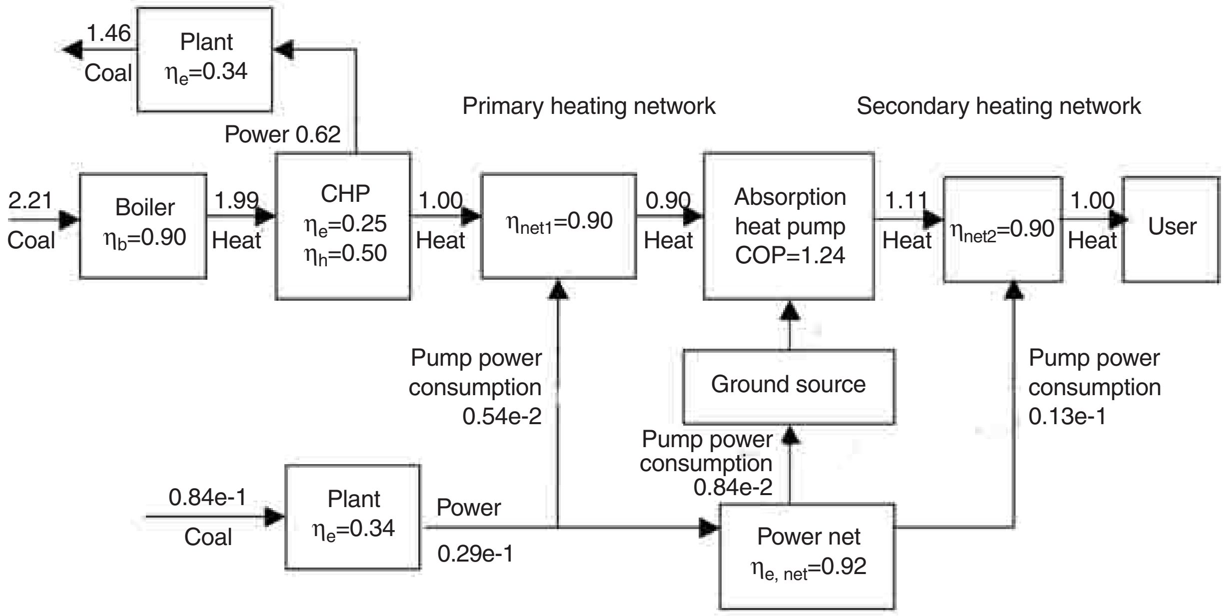


Figure 7.

Energy flow chart of the new district heating system combined with ground source absorption heat pump.



Evaluation results

The primary energy efficiency of different heating systems is shown in figure 8. The figure shows that the primary energy efficiency of the new district heating system combined with ground source absorption heat pump is highest among three heating systems.

Compared with the conventional district heating system with combined heat and power heating system, the primary energy efficiency of the new district heating system combined with ground source absorption heat pump can be increased about 20%.

ECONOMIC ANALYSIS

4.1 Economic model

The initial investment of the new district heating system combined with ground source absorption heat pump is calculated by equation (2).

$$C = C_{\text{heatng source}} + C_{\text{primary network}} + C_{\text{absorption heat pump}} + C_{\text{ground pipe}} + C_{\text{secondary heatting network}} + C_{\text{indoor heating network}} + C_{\text{heat end}} \quad (2)$$

The initial investment of electric-driven ground source heat pump heating system is calculated by equation (3).

$$C = C_{\text{eletric heat pump}} + C_{\text{ground network}} + C_{\text{secondary heating network}} + C_{\text{indoor heating network}} + C_{\text{heat end}} \quad (3)$$

For cogeneration heating system, the initial investment is calculated as follows. The initial investment of district heating system with CHP system is calculated by equation (4).

$$C = C_{\text{heating source}} + C_{\text{primary heating network}} + C_{\text{heat substation}} + C_{\text{secondary heating network}} + C_{\text{indoor heating network}} + C_{\text{heat end}} \quad (4)$$

Figure 8.
Primary energy efficiency of different heating systems in the design condition.

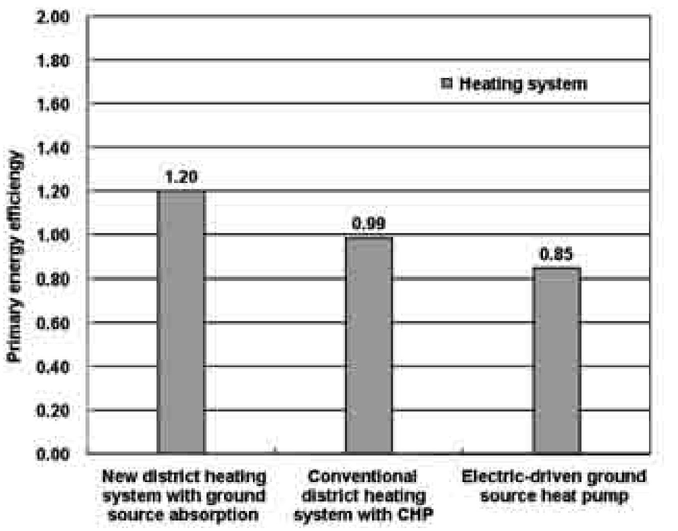


Figure 9.
Ground source absorption heat pump delay heating load curve.

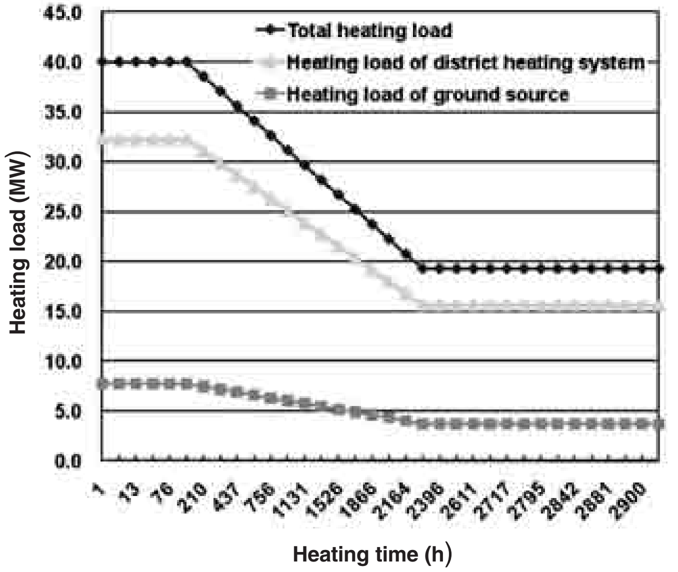


Table 1.
Primary energy consumption of different heating systems in all heating period.

	Units	District heating system with ground source absorption heat pump	District heating system with CHP	Electric-driven ground heat pump heating mode
Total heat amount	Ten thousand GJ	28.2	28.2	25.4
Supplying heat amount from geothermal	Ten thousand GJ	5.5	0.0	19.0
Supplying heat from district heating system	Ten thousand GJ	22.7	28.2	0.0
Primary heating network pump consumption	Ten thousand kWh	34.6	42.8	0.0
Secondary heating network pump consumption	Ten thousand kWh	101.8	101.8	91.6
Heat Pump consumption	Ten thousand kWh	0.0	0.0	1762.9
Underground pump consumption	Ten thousand kWh	59.2	0.0	206.3
Total power consumption	Ten thousand kWh	195.5	144.6	2060.8
Equivalent primary energy consumption	Ton standard coal	5303.0	6192.9	7515.2
Primary energy consumption per unit heating area	kgce/m^2	5.3	6.2	7.5

The initial investment of the second network, indoor heating pipe network and the end of heating is the same in the above economic model.
The investment base prices of different components are shown in table 3. The cogeneration system is the heat source of district heating system and its investment price can be calculated as 4.5 million RMB / MW (electrical load).
Its power generation efficiency is 25% and its heating efficiency is 50%, and then the ratio of thermal to power is 2.0, thus the initial investment of heating system can also calculated as 2.25 million RMB / MW.

Table 2.
Fuel prices (in Chinese YUAN RMB)**.**

	Unit	Price
Standard coal price	RMB/tce	500.0
Electricity generation price	RMB/kWh	0.4
Business electricity price	RMB/kWh	0.7
Heat price	RMB/GJ	33.0

The initial investment price of primary heating network can be calculated as 30 RMB per heating square meter.
The initial investment price of absorption heat pump can be calculated as 0.6 RMB/W (heating load), and the underground pipe can be calculated as 2.5 RMB/W (heat load from underground). The plate heat exchanger and other equipment in conventional substation can be calculated as 0.2 RMB/W. The electric-driven heat

Table 3. **Installation capacity of different heating systems.**					
	Basic price	Unit	District heating system with ground source absorption heat pump	District heating system with CHP	Electric- driven ground heat pump heating mode
Heat source	2.25 million RMB/MW	MW	32.3	40.0	0
Increased capacity of power	1,800.0 RMB /kW	MW	1.0	0.7	10.5
Primary heating network	30.0 RMB /m^2	Ten thousand m^2	80.6	100.0	0.0
Increased thermal type units	0.6 RMB /W	MW	32.3	-	-
Thermal Power Station	0.2 RMB /W	MW	-	40.0	-
Electric Heat Pump	1.0 Yuan/W	MW	-	-	9.0
Underground pipe	2.0 RMB /W	MW	7.7	0.0	27.0
Secondary heating network	15.0 RMB /m^2	Ten thousand m^2	100.0	100.0	100.0
Indoor pipe	30.0 RMB /m^2	Ten thousand m^2	100.0	100.0	100.0
End of heating	40.0 RMB /m^2	Ten thousand m^2	100.0	100.0	100.0

pump can be calculated as 1.0 RMB/W and the investment of increasing electricity capacity can be calculated as 1,800 RMB/kW.

The construction and installation costs of the heating system can be calculated as 20% of the equipment initial investment. The construction costs of plant building can be calculated as 30% of the equipment initial investment. The prices of different fuels are shown in Table 2.

Analysis results

As shown in table 3, the installation capacity of the electric-driven ground source heat pump heating system is the smallest because it has no heat loss of primary heating network. Also, as shown in table 4, the investment of the electrically driven heat pump heating system is lowest because of none primary heating network.

The primary energy efficiency of the new district heating system combined with ground source absorption heat pump is highest among them, because it can utilize the work capability of the hot water from the district heating system with CHP to extract the shallow geothermal. Also, its annual operating cost is lowest. While, the annual operating cost of the electric-driven heat pump heating system is highest, as shown in table 5.

According to the economics comparative analysis of different heating system, some results can be found as follows. Compared with conventional district heating system with CHP system, the investment of the new district heating system combined with ground source absorption heat pump will increase, but its annual operating cost will decrease because its high primary energy efficiency. So its investment recovery period is about 6.9 year.

Compared with the electrical-driven ground heat pump heating system, the investment of the new district heating system combined with ground source absorption heat pump will increase, but its annual operating cost will decrease, because it can utilize the cheap heat

Figure 10.
Initial investment of different heating systems.

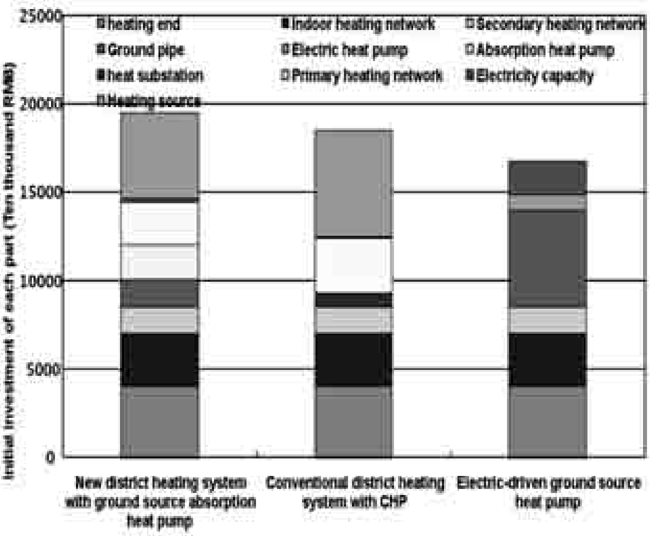


Figure 11.
Annual operation costs of different heating systems.

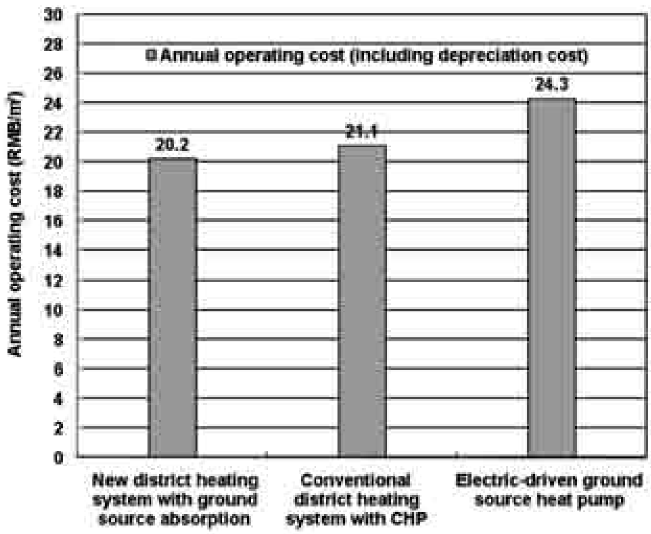


Table 4.
Operation costs of different heating methods (The unit is ten thousand RMB).

Item		Unit	District heating system with ground source absorption heat pump	District heating system with CHP	Electric- driven ground heat pump heating mode
Heat cost	Heat cost of district heat system	Ten thousand RMB	749.1	930.6	0.0
Pump power cost	Primary heating network	Ten thousand RMB	13.8	17.1	0.0
	Secondary heating network	Ten thousand RMB	71.3	71.3	64.1
	Heat pump system	Ten thousand RMB	0.0	0.0	1234.0
	Underground water pump	Ten thousand RMB	41.4	0.0	144.4
Total heat and electricity cost		Ten thousand RMB	875.6	1019.0	1442.6
Operating costs per heating area		RMB /m^2	8.8	10.2	14.4
Annual operating costs (including investment depreciation)		RMB /m^2	20.2	21.1	24.3

Table 5.
Initial investment, operating cost and payback period.

			Case 1 Reference object	Case 2 Reference object
Item	Unit	District heating system with ground source absorption heat pump	District heating system with CHP	Electric-driven ground heat pump heating mode
The initial investment of unit area	RMB/m^2	231.7	221.9	209.2
Operating cost per unit area	RMB/m^2	8.8	10.2	14.4
Payback period	Year	-	6.9	4.0

supplied with district heating system with CHP system as its main heat source and also take advantage of the shallow geothermal energy as its auxiliary heat source. So its investment payback period is 4.0 year.

CONCLUSIONS

(1) The new district heating system combined with ground source absorption heat pump to extract shallow geothermal was presented. And it is driven by high temperature water supplied with district heating system.

(2) Compared with conventional cogeneration district heating system in the same heating capability and heating parameters condition, the primary energy efficiency of the new district heating system combined with ground source absorption heat pump can increase about 22% in the design condition. Also its heating energy consumption can decrease about 15% in the whole heating period.

(3) Compared with electric-driven ground source heat pump heating system in the same heating capability and heating parameters condition, the primary energy efficiency of the new district heating system combined with ground source absorption heat pump can increase about 42% in the design condition. And the its heating energy consumption can decrease about 30% throughout the heating period.

(4) Compared with electric-driven ground source heat pump heating system in the same heating amount condition, the new district heating system combined with ground source absorption heat pump extract less heat from ground in winter, so the installation capacity and the initial investment of underground pipes are smaller.

Acknowledgment

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Simulation of solar thermal driven absorption chiller under Algerian climate

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This paper presents a simulation of 17.5 kW solar-driven LiBr/H_2O single-effect absorption cooling machine (ACM) under Algerian climate. The system consists of a solar collectors and a LiBr–water absorption chiller. A rated coefficient of performance (COP) of 0.6 was considered and the amount of heat which must be provided to the generator was calculated on this basis. For the solar thermal system we have chosen flat plate collectors (brand REGULUS, model KPA1-ALP) whose datasheets are provided by the manufacturer and we have calculated the number of collectors to be installed which is 22 collectors of 2 m^2 each. And for the ACM we have used the data sheet of chillii WFC18 provided by the manufacturer called SOLARNEXT to implement its parameters in our simulation. In order to see the performance of the whole system we have established a simulation model under TRNSYS simulation environment. For the ACM model we have used Type 107 which is supplied as a standard component in the TRNSYS components library. The meteorological data used for the simulation are that of Bechar city and the simulation period was two months (July and August) on hourly time step basis. The simulation results allowed us to see the performance of such facility under actual meteorological data.

Keywords: Absorption chiller, Solar energy, TRNSYS Simulation

INTRODUCTION

Global climate change, the depletion of non-renewable fuels and awareness of the impact of harmful emissions on health and the environment has led to an increased interest in renewable energy and energy efficiency applied to every major energy sector. Due to the climate change and the global warming effect the weather is becoming warmer and warmer and the need of air conditioning will increase in the future. Since most air conditioning systems, today, use electric energy as primary source, the demand of electric energy will increase and as a result Carbon Dioxide (CO_2) emission will increase too. CO_2 is a major Green House Gas that is impacting negatively on the global environment. Also, the use of CFC and HCFC refrigerants which have a bad impact on the ozone layer will be forbidden to use in the near future.

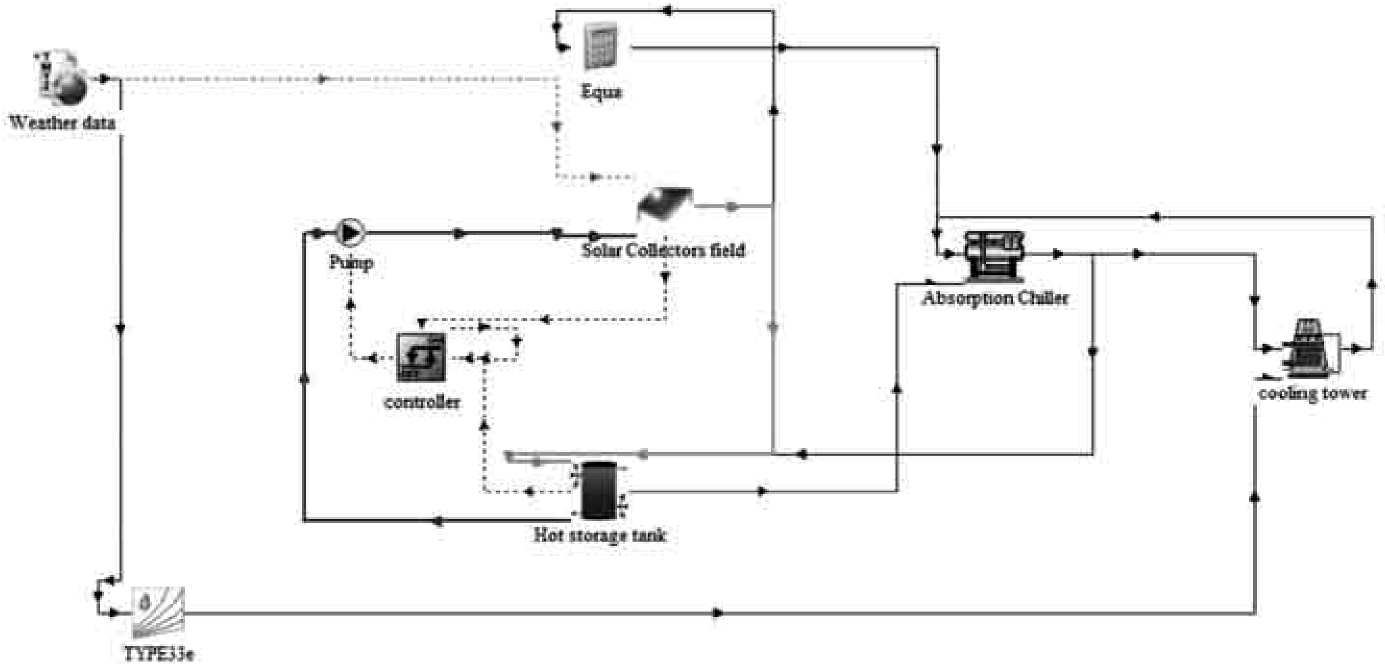
Absorption chillers are the most distributed thermally driven chillers worldwide[1]. A thermal compression of the refrigerant is achieved by using a liquid refrigerant/sorbent solution and a heat source, which is replacing the electric power consumption of a mechanical compressor. For chilled water above 0 °C, as it is used in air conditioning, typically a liquid H_2O/LiBr solution is applied with water as refrigerant. Nevertheless, other liquid solutions can be used like H_2O/LiCl or NH_3/H_2O which permits to produce chilled water at temperatures below 0 °C. Many of these products are available in the market; however typical chilling capacities of absorption chillers are several hundred kW. The required heat source temperature is usually equal or greater than 80 °C for single-effect machines and the coefficient of performance (COP) is in the range from 0.6 to 0.8. Double-effect machines with two generator stages require driving temperature of above 140 °C, but the COP's may achieve values up to 1.2[1].

The generator temperature range of single effect LiBr-water absorption chiller operate at 70 to 95 °C and the coefficient of performance (COP) of these systems are between 0.6 to 0.8, which are higher than NH_3-H_2O absorption cooling systems[2].

Till 2007 Sparber et al. reported that there were 81 installed large scale solar cooling systems, eventually including systems which are currently not in operation. 73 installations are located in Europe, 7 in Asia, China in particular, and 1 in America (Mexico). 60% of these installations are dedicated to office buildings, 10% to factories, 15% to laboratories and education centers, 6% to hotels and the left percentage to buildings with different final use (hospitals, canteen, sport center, etc). They also cited that 56 installations are belong to absorption systems and the overall cooling capacity of the thermally driven chillers amounts to 9 MW 31% of it is installed in Spain, 18% in Germany and 12 % in Greece[3].

Bong et al. designed and installed solar absorption chiller in Singapore. The system included 7KW absorption chiller, heat pipe collectors with a total

Figure 1.
TRNSYS solar cooling system interface.



area of 32 m , a hot water storage tank, an auxiliary heater and a 17.5 KW cooling tower. They cited that the overall average cooling capacity provided was 4KW, solar fraction of 39% and COP of 0.58[3].

Balghouthi et al. accomplished a simulation using TRNSYS program in order to select and size different components of solar absorption chiller. They reported that solar absorption cooling systems were suitable for Tunisian's condition[3].

Alizadeh et al. simulated and optimized a solar LiBr-water absorption cooling system that has been design for Malaysia using evacuated tube solar collectors. The modeling of the solar absorption chiller was accomplished with TRNSYS program[3]. Yeung et al. designed and installed a solar driven absorption chiller at the University of Hong Kong. Yeung et al. designed and installed a solar driven absorption chiller at the University of Hong Kong. This system included 4.7KW absorption chiller, flat plate collectors with a total area of 38.2 m^2.water storage tank and the other equipments. They reported that the collector efficiency was estimated at 37.5%, the annual system efficiency at 7.8% and an average solar fraction at 55%, respectively[3].

The objective of this work is to evaluate the performances of a small capacity solar cooling system using LiBr-water absorption chiller under real meteorological data of Bechar city. For the simulation of this plant the simulation software TRNSYS 16[4] is used.

Figure 2.
Monthly average total solar radiation on horizontal surface (W/m^2)

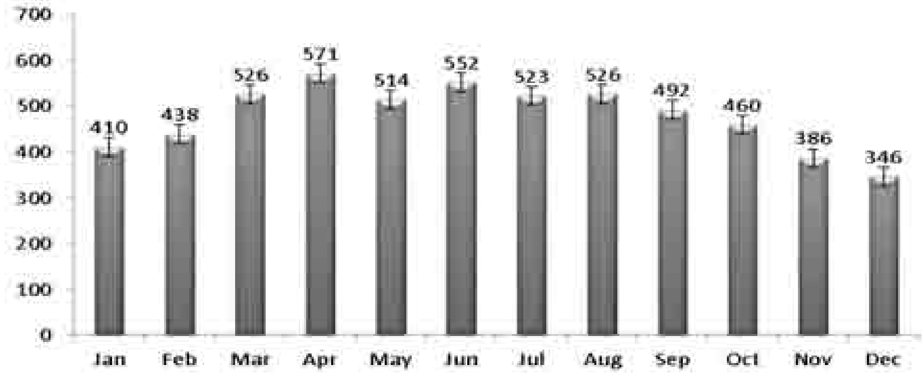


Figure 3.
Monthly average ambient temperature (C).

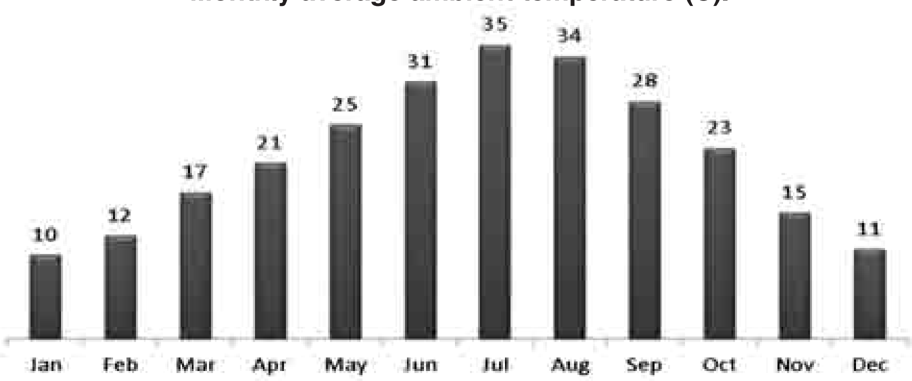


Figure 4.
Basic single effect LiBr-H_2O absorption cycle.

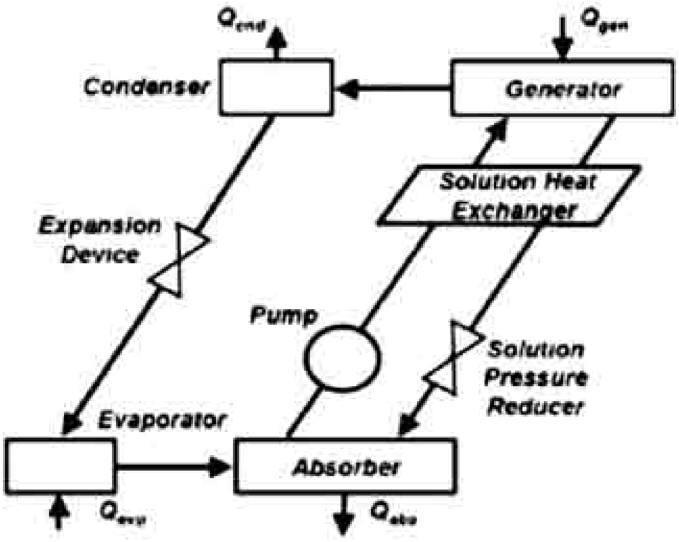
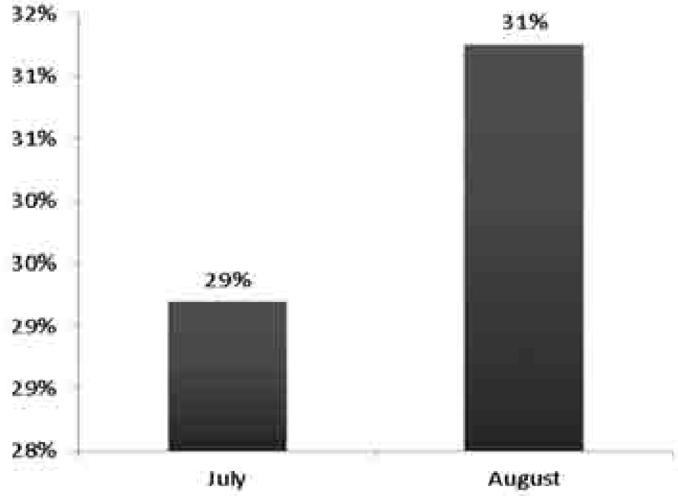


Figure 5.
Monthly average efficiency of the solar field.



SYSTEM DESCRIPTION

The Figure 1 shows the interface of the solar cooling system under the TRNSYS simulation software. The major components of the plant are solar flat plat collectors, a 17.5 kW cooling single-effect LiBr–H_2O absorption chiller, a hot water storage tank, a cooling tower, a pump, a controller, and some other auxiliary components.

Meteorological data

The link between the cooling system and the meteorological data is established by Type 109 from the standard library of TRNSYS software. The meteorological data of Bechar city are generated by METEONORM 6[5] software and the common format "Typical Meteorological Year" (TMY2) is used. It includes dry bulb temperature, relative humidity, solar diffuse and global radiation, etc. Bechar climate is warm temperate. The monthly mean ambient temperature and total solar radiation on horizontal are illustrated on figure 2 and 3.

Solar collector fields

The solar collector field is composed of a 76 m^2 apparent area for an array of 38 flat plat collectors field which work in the range of 97/120 C and a capacity of 1,389 kW (for I = 1000 W/m^2), where I is the solar insolation at the collector plane[6]. Type1 has been used, and manufacturer data of the solar collector (REGULUS, Type KPA1-ALP) including collector yield, incidence angle modifier and mass flow rate were implemented in the model. The solar field is designed on the basis of the hot water cycle data of the absorption chiller manufacturer [7] i.e: capacity: 25.1kw, Tin-out: 88/83, flow rate: 4300 kg/hr.

Storage

The hot water storage tank with a capacity of 1.5 m^3 is used as buffer storage. This tank acts as a storing and buffers that supplies hot water which enters the chiller generator at constant value. The stored heat in the tank comes from the solar collectors. Type 4 a component from the standard library of TRNSYS is used to model the storage tank.

Absorption chiller

The basic principle of a lithium bromide water absorption chiller is depicted in Figure 4, which is the simplest and most commonly used design. In the absorption cycle, compressing refrigerant vapor is achieved by the absorber, the solution pump and the generator, in combination. Water evaporated from evaporator (which outputs a cooling effect) is absorbed into a strong lithium bromide solution in the absorber, and the absorption process need to release heat of absorption to the ambient. After absorbing the water vapor, the lithium bromide solution becomes a weak solution, which is then pumped to the generator to be heated. As heat is added to the generator, water will be desorbed from the solution in a vapor form. The vapor then flows to the condenser, where it is condensed and condensing heat is rejected to the ambient. The condensed water flows through an expansion device, where the pressure is reduced. The strong solution from the generator flows back to the absorber to absorb water vapor again, a heat recovery heat exchanger could be used between the strong solution and weak solution lines. The entire cycle operates below atmospheric pressure, since water is used as the refrigerant.

The advantages of absorption chillers over conventional electric chillers are that they consume little electricity, they can be used for waste heat recovery applications, they have very few moving parts leading to low noise and vibration levels, and they do not emit ozone depleting substances.

A Water Fired Chiller with a rated capacity of 17.5 kW cooling power when it is operating at a driving hot water temperature of 88 C, coolant water temperature of 31 C and output chilled at 7 C with coefficient of performance (COP) of 0.7 as reported by the manufacturer[7] were simulated by Type 107 from the standard library . For Type 107 based models care has to be taken when creating the performance data file[8].

Figure 6.
Hourly variation of the inlet and outlet water temperature in the cooling tower.

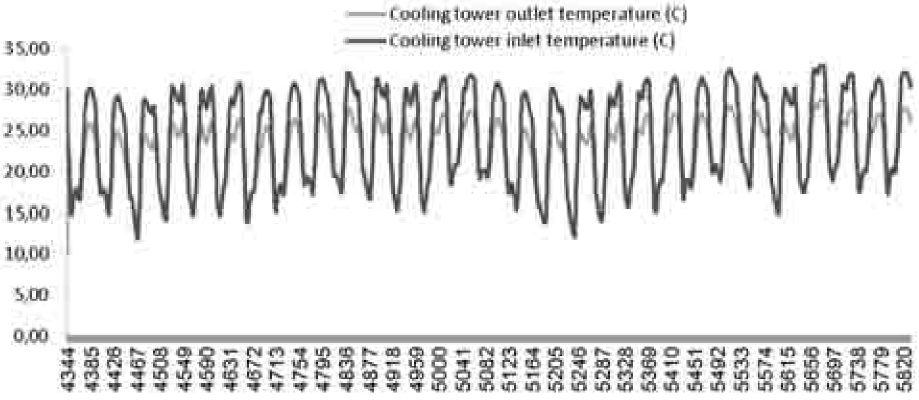
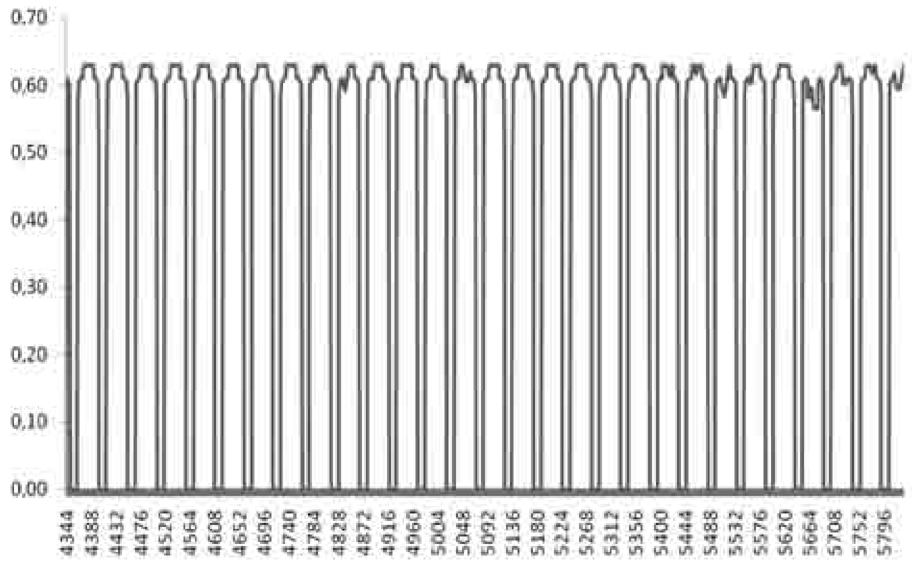


Figure 7.
Hourly Variation of the coefficient of performance.



Cooling tower
The cooling tower is serving to reject the heat from the chiller coolant water to the ambient as well as a source of free cooling in the plant. The cooling tower has a capacity of 41.5 kW at the design conditions[7]. Type 510 from the Thermal Energy System Specialists (TESS)[9] component library is used to model the closed circuit cooling tower. According to literature[10] it is able to find accurately the power rejected based on only one design point.

RESULTS

Once the whole model was finished, it was simulated in TRNSYS with the following parameters:
- Simulation start step: 1st of July
- Simulation end step: 31st of August
- Simulation step time: 1hr
- Tolerance integration: 0.001
- Tolerance convergence: 0.001

The monthly average efficiency of the solar field is presented on figure 5. The maximum field efficiency of the solar field for July and June are 41% and 47%, respectively.
The inlet and the outlet temperature for the cooling tower are presented on figure 6. The maximum inlet and outlet temperature are 32.94 and 28.69, respectively. The design conditions for the cooling tower from the manufacturer are 31 as outlet temperature and 35 C as inlet temperature. These design conditions have not been reached.
The Coefficient of performance is a useful performance indicator to evaluate the key air-conditioning equipment of the solar cooling systems[11].
For solar absorption refrigeration,

$$COP = \frac{Q_e}{Q_{gen}} \quad (1)$$

Where:
Q_e = refrigeration effect (kW)
Q_{gen} = heat input to generator (kW).
The evolution of the coefficient of performance of the absorption chiller is illustrated on figure 7. The maximum COP reached of the chiller is 0.63 which is slightly higher than the rated COP 0.6.

CONCLUSION

A solar cooling system model consisting of a flat-plate collector array, absorption machine, cooling tower and hot water storage tank was developed and simulated under real time meteorological conditions of Bechar city. The system worked entirely with solar energy without any auxiliary heating element and thus the solar fraction is 100%. A controller turns off the heating system when the outlet temperature from the storage tank to load is less than 5 °C from the outlet temperature of the solar collector field. The results obtained from the simulation need to be validated by experimental results of such plant.

●

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ASHRAE activity in refrigeration technology

THOMAS WATSON

P.E., Fellow ASHRAE, Life Member
2012-13 ASHRAE President - ***Broadening Our Horizons***

UNEP EEC CENTRO STUDI GALILEO TERRE

This topic will be discussed in the next 15th EU Conference

This year, ASHRAE is emphasizing that engineers and those who install and maintain new technologies are the leaders in sustainable practices in our communities. I am concentrating on how the three focal points of technology, applications and people combine to develop stronger, more sustainable communities.
Our technology needs to consider many issues: climate, culture, how people think about air conditioning, how dependent a society is on refrigeration and economics. In my community, and in every one of your communities, there are economic issues. We need to consider our resources, the technical education of the labor force and the infrastructure available. These are the challenges we face in balancing what our technology offers with what people want and what people can afford. In many cases, we have not yet achieved the balance needed to meet the needs of all of the communities throughout the world that we serve.
My personal professional interest is refrigerants. And during my years of involvement in ASHRAE one of my focal points has been how to reduce the impact of refrigerants on the environment.
I am pleased to announce that ASHRAE is creating a voluntary refrigerant management plan, which is initially for the United States. Proper cradle to grave management is necessary to minimize the environmental impact and to ensure that suitable refrigerants are used by the HVAC &R industry to meet growing demand.
Our goals for this project are many: to track and report refrigerant use and refrigerant life cycle; to minimize environmental impact of refrigerant use; and to raise public awareness of the environmental issues and the economic impact of refrigerant use.
Another activity sponsored by ASHRAE is a joint conference held in October with the United States National Institute of Standards and Technology. With a theme of Moving Towards Sustainability, the conference will present information on alternative low global warming potential refrigerants. Included will be hydrocarbons, R-717, R-744, HFC and HFO technologies. ASHRAE also is working on standards that allow a wider use of A2L refrigerants which have low flammability characteristics.
However, as important as new technological development is we need to keep the users in mind. We need to keep it simple. Do we really need those latest technologies in all cases? Do we need super-sophisticated solutions? Do we need complicated buildings? We need to focus on impact, making sure the advanced technology is used throughout the life of the building, not just installed as showpiece to win an award, then not be used. We need to have buildings that remain viable for years to come. We need to use innovation that works. An important issue for our industry is providing simple, affordable solutions. We need to use global expertise to meet local needs.
We all understand that we have to advance the technology to improve the built environment. However, the operation and maintenance of these advanced systems must be simple and easy to use in order to be successful. We are a team when it comes to applying technology for the greatest good.
So what can we, as an industry, do? We need to focus on our greatest impact. We need to match the technology to the need. We need affordable regional technologies based on global expertise, and we need to benefit our communities and ourselves.

Marco Buoni VicePresident AREA, Technical Director of CSG, meets in New York in one of the periodic ASHRAE winter meetings the past President Kent Peterson.

Tariq Muneer delivers Napier University cup of friendship to CSG director Enrico Buoni in Centro Studi Galileo headquaters.

Heat Pump performance boost with the use of solar collectors

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The need for an energy performance improvement in Ground-Source Heat Pumps (GSHP) for the residential and commercial sectors has historically been identified as a result of regular project work undertaken by European Energy Centre. It is clear that there is a dearth of in-situ measured data that is available on COP of GSHP and their equivalent performance. In order to achieve higher heat pump COP through the use of roof-top thermal solar collectors, the Edinburgh Napier University team has been commissioned to undertake research and investigate the performance of such systems. Heretofore such systems shall be called as 'Solar-assisted Ground-Source Heat Pumps (SGSHP)'. Figure 1 provides an illustration of a SGSHP system.

This article presents an investigation on the use of solar collectors to improve the performance of Heat Pumps (HP). The work has been developed following four main development areas; a review of the on-site solar and ground energy resource, an analysis on the influence of the solar collector in achieving better performance, a development of a simulation tool for the performance of the solar-assisted ground source heat pump and conclusions.

This study shows that the use of solar collector in northern latitude country has little impact on the heat pump performance improvement in winter. However, the system works slightly better in spring/autumn. The system is more suitable for cold countries with high irradiance. Table 1 presents a summary of the findings.

Figure 1. **Schematic of a Solar-assisted Ground Source Heat Pump (SGSHP).**

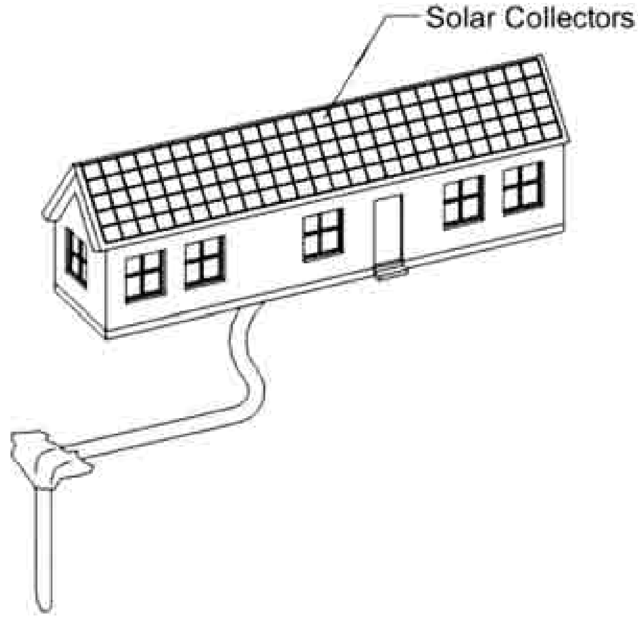
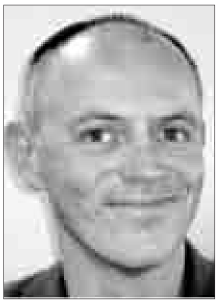
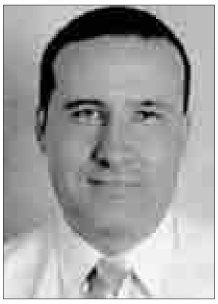


Table 1. **Comparison between the 3 sources of heating.**

	GSHP (0m² of solar)	SGSHP (63m² of solar)	Conventional gas boiler
W compressor, kWh	1760	1662	–
W pumps, kWh	28	37.5	–
Energy space heating, kWh	8,632	8,632	8,632
Average yearly COP (efficiency for gas boiler)	4.9	5.2	0.9
Total electricity, kWh	1,788	1,699.5	–
Total gas used, kWh	–	–	9,495
Cost of energy, £/year	217	206	345.62
Overall cost, £/year Fuel usage + fuel standing charge + maintenance cost + equipment replacement cost	1,517	In view of the quoted solar collector prices this option is uneconomical on a monetary basis.	1,055
CO_2 emission, kg	971	923	1747

Nanotechnology in new magnetic heating, refrigeration and energy conversion devices

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This topic will be discussed in the next 15th EU Conference

Research on magnetic heating and energy conversion is still very rare, but starts to develop more and more. Substantial efforts are occurring in the domain of domestic magnetic refrigeration, with devices having power consumptions from 50 up to 100 Watt. Up-to-present there have been built approximately forty such prototypes and first specialized industrial companies start to discuss production lines for their magnetic refrigerators, which are predicted to show higher performance than their conventional counterparts. Nonetheless of such first important progress, magnetic heat pumps, refrigerators and energy conversion prototypes, with an operation based on the magnetocaloric effect, usually show a restriction in their frequency of operation to a few Hertz. Related to this permanent magnets with high masses are demanded, which show a high cost and lead to an economic drawback.

Therefore, in 2010 Kitanovski and Egolf proposed to apply a new technology – based on (nanotechnology) thermal switches – to overcome this barrier. In this article the new thermal switch refrigerator is presented in detail.

MAGNETIC HEATING, REFRIGERATION AND ENERGY CONVERSION

The magnetocaloric technology has been presented in numerous articles, review articles and books and shall only briefly be described in the next section of this article. A very brief overview of only eight pages is given in an Informatory Note of the International Institute of Refrigeration (IIF/IIR) (see Egolf and Rosensweig (2007)). One can find a longer and more comprehensive description of this technology, for example, in a journal of the Italian Industria & Formazione, which was produced in collaboration with the International Institute of Refrigeration and the United Environmental Programme, UNEP, (see Egolf and Rosensweig, 2008). Extensive and good explanations of the magnetocaloric effect and its applications are given in a standard text book published by Tishin and Spichkin (2003). This and other sources, as e.g. the review articles of Gschneidner et al. (2005) and Brück (2005), allow a deeper understanding of the magnetocaloric phenomenon and specialities of the magnetocaloric effect in different kinds of materials in which maybe some rare earths are present. On the other hand, Yu et al. (2010a) have reviewed on all the built magnetic heat pump and refrigerator prototypes built before 2010. This publication and the one of Kitanovski and Egolf (2006) contain much knowledge on thermodynamic cycles and machine building.

The operation principle of a magnetic heat pump or/and refrigerator is shown in Fig. 1 on the left-hand side to the top and the one of a conventional heat pump/refrigerator just beneath it. In a conventional device a compressor heats up a gas (process No. I), which then is cooled (process No. II) and expanded (process No. III) where it becomes cold and takes up heat from a heat source (process No. IV), which needs to be refrigerated. If these four processes are repeated in a cyclic manner, one obtains a thermodynamic process of a heat pump/refrigerator. In a magnetic heat pump or/and refrigerator exactly the same four-stage process occurs, but instead of compressing a gas, a solid is magnetized. The magnetization of a magnetocaloric material (process No. I) leads to a heating effect. Then also heat is released (process No. II) and just after that the material is cooled by demagnetization (process No. III). You have probably realized that demagnetization is the analogue process to the expansion in a conventional thermodynamic machine! The cold solid now also acts as absorber for heat of a heat source (process No. III), which usually is the interior part of e.g. a refrigerator. The operation of a heat

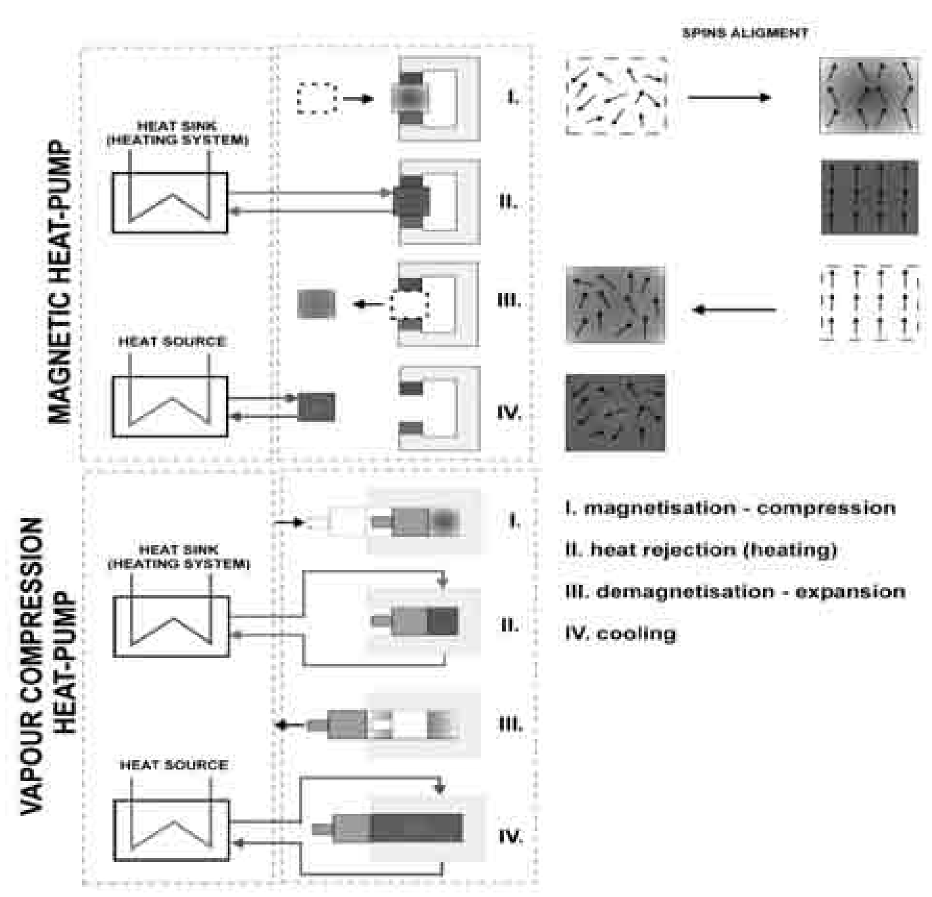

Figure 1: The four magneto-thermodynamic process stages each of a magnetic heat pump or/and refrigerator shown at the top and of a conventional gas heat pump or/and refrigerator in the lower part. Heating by magnetization and cooling by demagnetization is explained by spin orientation shown in two times three small pictures on the right-hand side.

pump and refrigerator are practically identical, in the first case the ejected heat at high temperature and in the second case the absorbed heat at cold temperature are of main interest. The operation of a magnetic energy conversion machine works inversely. In this case, from injected heat, mechanical energy and furthermore electric energy can be produced.

The cooling effect in magnetocaloric materials can be explained with some pictures on spin alignement shown on the right-hand side of figure 1.

Because a high frequency of the four just explained processes is required, the magnetization and demagnetization processes are fast and there is no time for a heat exchange. Scientists name such a process an adiabatic or isentropic process. Isentropic means that the total entropy does not change. In many magnetocaloric materials the total entropy is the sum of thermal and magnetic entropy.

The thermal entropy describes mainly the movement (vibrations, phonons) of the crystalís lattice. The higher the amplitude of the vibration is, the higher the thermal entropy is.

The magnetic entropy is related to the order of the electronic spins. If the spins are aligned, the order is high and the magnetic entropy low. Now if a magnetocaloric material is exposed to a magnetic field, the spins align, and the magnetic entropy reduces (see upper three small pictures on the right-hand side). Because the thermal entropy is the total entropy minus the magnetic entropy, now a smaller quantity is subtracted from the constant total entropy value.

Therefore, the thermal entropy, and with it the temperature, increases. By moving magnetocaloric material out of a magnetic field demagnetization and the inverse disordering process of the spins occurs (see lower three small pictures on the right-hand side). Finally this results in a cooling of the material.

The periodically occurring four stages of such a process can ideally be realized in a linear reciprocating or a rotational machine (see e.g. Fig. 2). The advantage of a rotational machine is that no acceleration and deceleration work has to be performed, so that it is expected that this version is slightly more efficient. Here a machine is shown that has four sectors of 90° each, in which alternatively the magnetocaloric wheel is magnetized by magnetic fields created by permanent magnets and in which, because of a lack of nearby magnets, there is no magnetic field. By a rotation of the magnetocaloric wheel through these different sectors, a periodic magnetization and demagnetization of double frequency compared to the frequency of the basic rotation of the cylindrical wheel is obtained. Because the wheel is performed by a porous matrix of magnetocaloric material, it can be transversed by heat exchanging fluids. There are separated heat transfer fluids in the hot magnetized and the cold demagnetized part, which extract heat from and export heat into the magnetocaloric material of the wheel. By this, in the most economic manner, the four stages of the overall thermodynamic process are realized.

In a numerical study for the Swiss Federal Office of Energy Kitanovski et al., 2008a have shown that magnetic refrigeration reaches higher coefficient of performance and exergy efficiency than conventional refrigeration. Applying conservative methods, taking all the energy losses into consideration, depending on the frequency of the magnetic refrigerator up to a doubling of the values (improvement of 100%) have been obtained. Economic realistic values will correspond to improvements of 30%-50%. The final conclusion is that with this technology instead of the conventional one, high amounts of electrical energy doesn't need to be utilized and can be saved for future generations. Furthermore, the environmental benign and noiseless operation of magnetic refrigeration are convincing arguments to concentrate more means into final development steps of this technology.

The already promising prospect for

magnetic refrigeration is even topped by a new development, named the thermal switch technology (see Chapt. 3). This technology shows the same level of efficiency of the machines, but allows higher frequencies of operation and by this a lower mass of the permanent magnets assembly, which is related to a smaller weight and cost of the machines under consideration. This is a key issue for wider/deeper market penetrations.

THE STATE-OF-THE-ART MAGNETIC REFRIGERATOR AND ITS LIMITS

In magnetic heat pumps or/and refrigerators heat must be transported into and out of the solid refrigerant – which is the magnetocaloric material – by diffusion. Diffusion is known to be a slow physical process. Egolf et al. (2007) presented in their article a well-known criterion for the frequency of diffusion, based on the Fourier number criteria: Fo=1. These results are adapted to plates of Gadolinium (Gd), which is taken as characteristic material for these considerations (see Fig. 3). In symmetric plates it is the half thickness which defines the maximal characteristic diffusion length. One can see, for example, that with a plate thickness of 0.25 mm, one can build a machine operating up to 100 Hz.
If heat has to be transferred from the magnetocaloric material to a fluid, then also a contact resistance occurs leading to a tailback effect. But this doesnít influence the frequency.
Another physical phenomenon leads to an even more restrictive condition for the frequency of operation of a machine. It is the carry-over leakage. In numerous types of machine designs two different fluids flow through parts of the magnetocaloric porous matrix. If this matrix moves or rotates to fast, captured fluid in the matrix is transported from the cold part without a magnetic field to the hot part with a magnetic field and vice versa. This leads to undesired mixing of the different fluids and a related loss of exergy. This phenomenon is also described in Egolf et al. (2007), but is nothing else than a summary of long-known knowledge of rotary heat exchangers applied in the field of air conditioning. This effect restricts the practical operation frequency to a few Hertz. The criterion here is also defined by a non-dimensional number, which in this case is the Strouhal number. It relates the time of flight of a fluid lump through the heat exchanger to its rotation frequency. To limit the carry-over leakage, it is necessary to demand an order of magnitude higher time period for the rotation compared to the time of flight of a fluid lump through the rotor. Results of this criterion are presented in Fig. 4.
The second of the two discussed criteria is usually the more restrictive and in the end demands low frequencies of magnetocaloric machines. Because the power of a machine is approximately direct proportional to the frequency of a machine, high frequencies are essential for the competitiveness of the magnetocaloric technology in comparison with the conventional gas compression heating and cooling technology.
It now has also become clear that higher frequencies lead to smaller magnetís assemblies and, therefore, also to smaller overall machines. Smaller machines are more economic in their production and of lower cost. Furthermore, to get the magnetocaloric machines to be an alternative for automobile refrigeration, small magnet’s masses are essential and, therefore, new solutions to allow them are required.

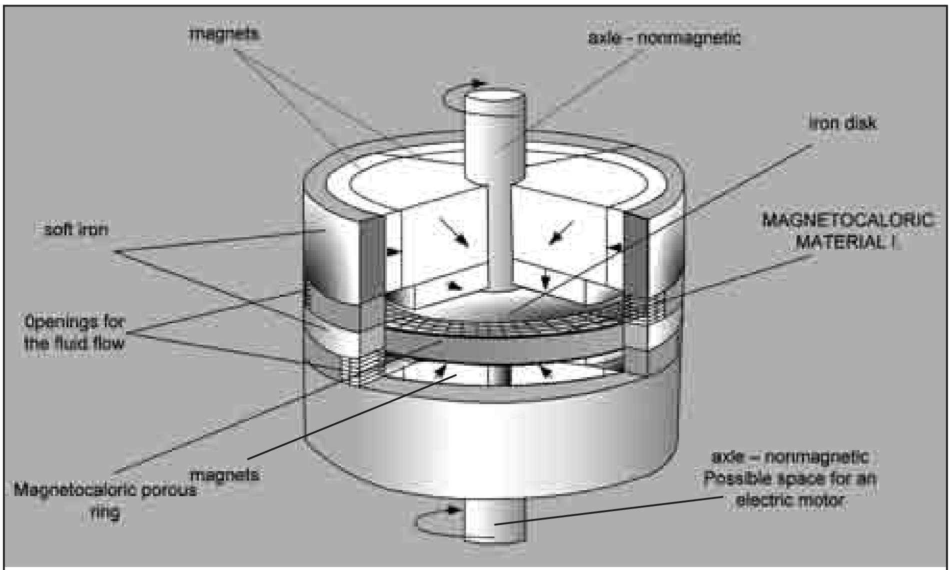

Figure 2: A cut through a magnetic device with a porous rotor (design: Andrej Kitanovski).

HIGH-FREQUENCY MODULES

Kitanovski and Egolf (2010) made a proposal how higher frequencies than in up-to-present realized prototypes can be obtained. In their solution a thin magnetocaloric material layer is built in a sandwich structure between two thermomagnetic layers (see Fig.'s. 5-7). Furthermore, these three components are layered between two microchannels occurring on each side of the now complete module. A stack of such modules yields the core of an alternative magnetic heat pump, refrigerator or energy conversion machine.
In such a new machine the operation principle is completely different than in prototypes described, for example, in Yu et al. (2010a). The magnetocaloric material is layered and does not need to be porous. Porosity would even be a disadvantage, because the thermal conductivity is usually reduced by the occurring voids containing fluid. Furthermore, the material is not rotating from one fluid domain to the other. In the new device the material is located statically between two fluid channels, one with cold and the other with hot fluid. A schematic drawing of such a device is shown in Fig. 5 and a cylindrical practical realization in Fig. 6.
In the magnetized state the magnetocaloric material heats up and the thermal switch to the left is closed and avoids any heat to flow away into the channel containing the cold fluid (see

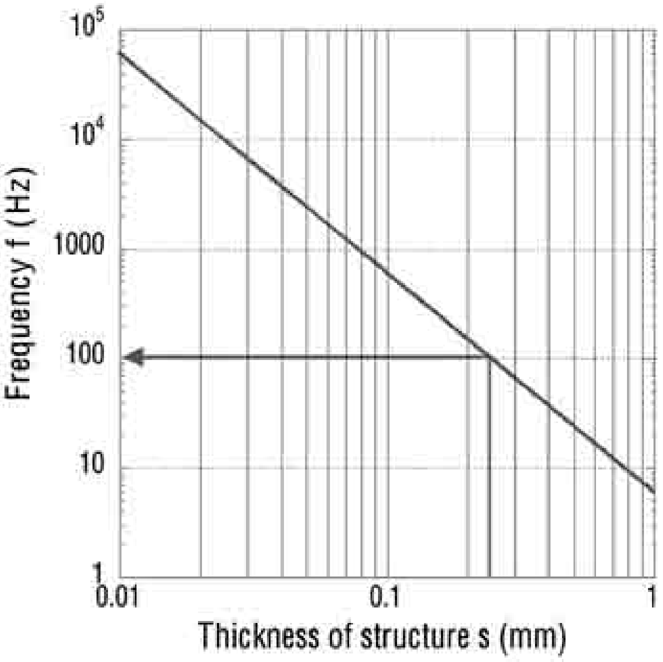

Figure 3: The frequency that can be obtained to transport heat out of a magnetocaloric structure of thickness s is presented in this figure. It is assumed that a symmetric situation occurs, where the heat flows away from the centre of a plate to its two sides. The characteristic physical properties are given by the following listing:
Density: ρ=7900 kg m^{-3},
Thermal conductivity: k = 10.5 W m^{-1} K^{-1},
Heat capacity: c_H = 886 J $kg^{-1}K^{-1}$,
FThermal diffusivity: α = 1.5 10^{-6} m^2 s^{-1}.

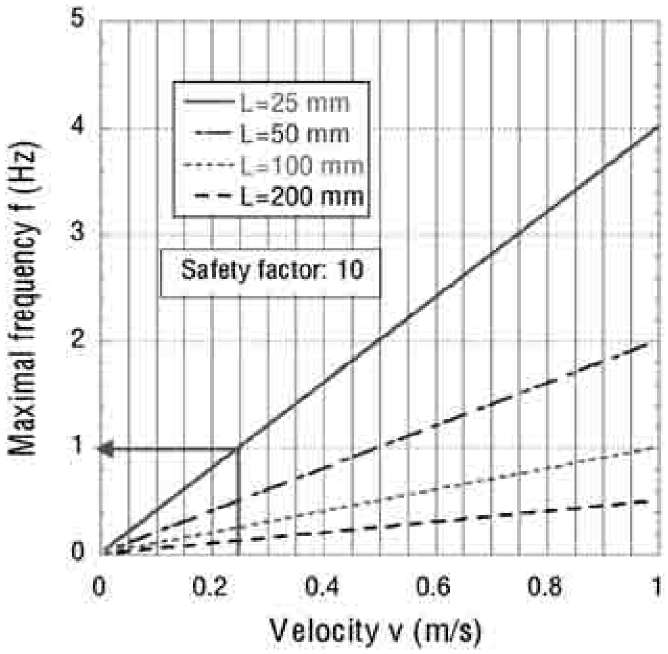

Figure 4: The limit to avoid a substantial carry-over leakage in a rotary machine. Different than in Egolf et al. (2007) here the factor of safety is taken ten instead of five. The figure shows, for example, that in a wheel of 25 mm length and a fluid velocity of 0.25 m/s the frequency should not be higher than 1 Hz, if a remarkable carry-over leakage shall be avoided. One notes that usually the carry-over leakage criterion is the stricter criterion than the one of heat diffusion in the magnetocaloric matrix.

Fig. 5 on the left-hand side). The thermal switch on the right is open and on this side lets heat flow into the channel with hot fluid. The occurring processes are just contrary in the demagnetized state shown in Fig. 5 on the right-hand side. Here the thermal switch on the left-hand side is open and heat can flow from the cold fluid to the even colder magnetocaloric material layer that has just left the magnetic field. The demagnetization process is the actual cooling process. Now in this time period, the thermal switch on the right-hand side does not permit any heat to flow from the hot fluid into the magnetocaloric material domain. If a machine contains such sandwich structures, the switching gates allow the cold and hot fluid to constantly flow in the same direction through their channels. The flows in the two channels are preferably designed to be counter current flows. With such elements there are no limits to the frequency of the system given by the fluids. Restrictions only occur by the diffusion of the heat into and out of the magnetocaloric material, the switching frequency of the thermal gates or the magnetocaloric effect itself.

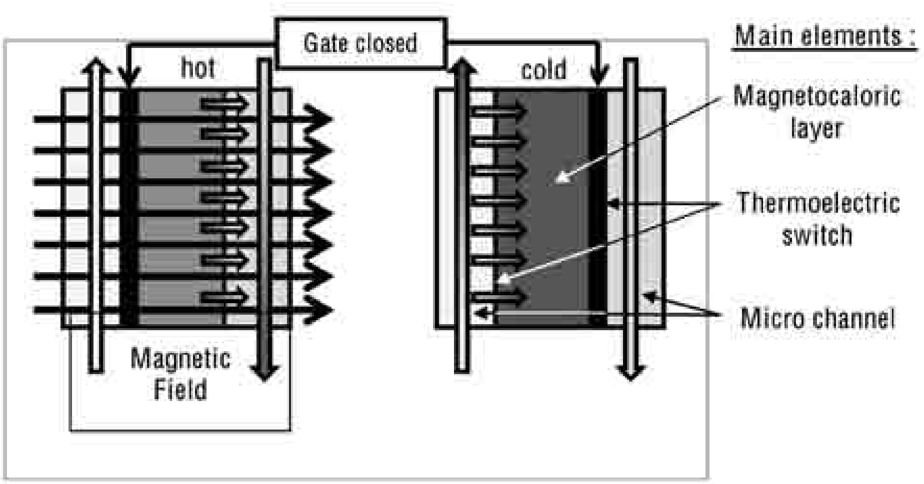

Figure 5: The proposed sandwich structure contains a magnetocaloric material layer between two thermoelectric switches and two microchannels. The small arrows represent heat flows from hot to cold areas.

Magnetocaloric materials with a second-order phase transition perform much better than those with a first-order transition. The transition time of a second-order phase transition can reach

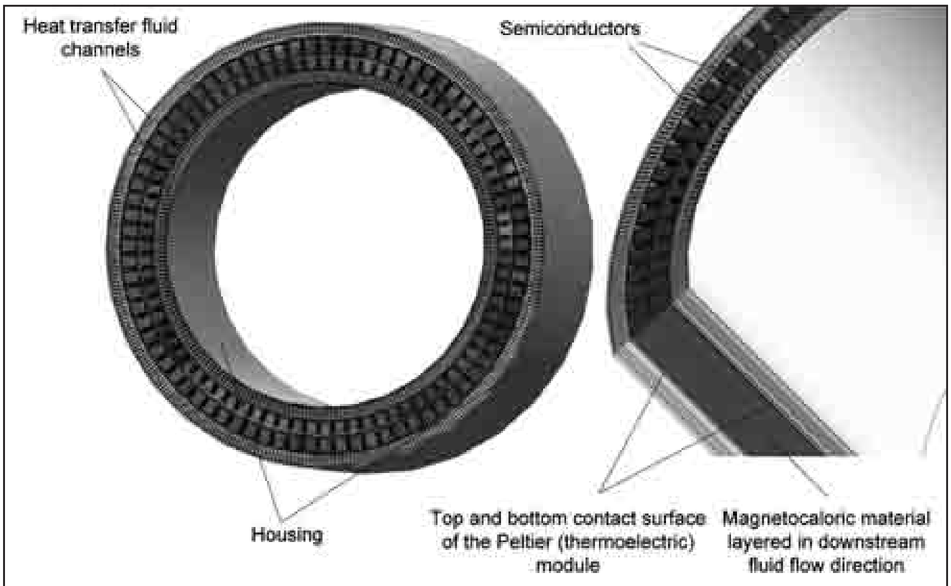

Figure 6: A full single cylindrical layer of a new magnetic heating device, refrigerator or energy conversion apparatus is shown in this perspective view on the left and a zoomed part of it on the right-hand side (from Kitanovski and Egolf, 2010).

the order of a millisecond corresponding to a frequency of 1000 Hz (Brück, 2009). Therefore, this should not be the limiting factor in the proposed new magnetocaloric device! Eventually the magnets themselves could be the limiting factor (see Chapt. 8).

CLASSICAL AND NANO-SCALE PELTIER ELEMENTS

Thermoelectric devices are applied in the Péltier mode to heat or/and to cool and in the Seebeck mode for energy conversion (see e.g. in CRC Handbook of Thermoelectrics (Rowe, 1995). The devices must be designed and optimized for each of these applications and usually cannot be used for both processes, because also the temperature levels are very different and that demands elements designed with different materials.
Nanotechnology now opens the door for new developments of efficient small Péltier element layers or films. Such developments were performed by Kumar et al. (2010) in ultrathin films, quantum wires and carbon nanotubes. Dillner (2008) studied the effect of thermotunneling on the performance (figure of merit) of such devices. Three dimensional nano pattern films were produced and studied recently by Yu et. al. (2010b). Furthermore, Gravier et al. (2006) performed physical modelling and numerical simulations of nano pillars and compared numerical results with experimental data, showing that in certain applications the thermal inertia shows an influence on the performance and must be taken into consideration. Nanowires performed from Ni are shown in Fig. 7.
The thermal switch used and presented in the present article is a flexible ultra-thin Péltier module made up of 20 micrometer thick nanostructured composite films. The thin films make them particularly suitable to coat practically any surface.

AN EXPLANATION OF THE THERMOELECTRIC SWITCH

Thermoelectricity denotes the effect of interrelations between electricity and thermodynamics. One distinguishes three such main effects, namely the Péltier effect, the thermoelectric effect (Seebeck effect), and the Thomson effect. They are all physically related. For the present work actually only the first one is relevant.
The Péltier effect is the effect where an electric current leads to a cold and hot part in a device, which is usually located at the two different boarder sides of a plate-like structure. It is the inverse effect, of the Seebeck effect, which produces from a source and a sink at different temperatures a current. It now becomes clear that with a Péltier device one can heat and cool and with a device applying the Seebeck effect one can produce electricity from a thermal source and sink. The Thomson effect, discovered in 1856 by William Thomson, who was later named Lord Kelvin, describes the change in heat transport in a circuit showing a temperature gradient and a current. This effect is overlapped by the resistance heating, and because it is a very small effect, it is not so easy observable.
The full and detailed theory, briefly described in this chapter, is presented in Egolf et al. (2012). For a more popular-scientific explanation of the phenomena, we observe Fig. 8, where a metal is heated at its left-hand side and cooled at the right-hand side.
The electrons in the heated region contain more energy and have greater velocities than the ones at the cold end. This leads to electron diffusion to the cold end and the electron density increases at the right-hand side. Because of this, on the left-hand side more positive ions are found. After some time, an equilibrium situation is reached, where the created electric field prevents a further increase of this electron diffusion.
This explains the potential difference as shown in the drawing of the positive and negative sides of the metal or n-type semiconductor slab. In the case of a p-type semiconductor, it is the holes that are more energetic on the left-hand side. In this case they diffuse horizontally to the right. Therefore, now the negative overall charge is located on the left-hand side and the positive on the right-hand side, just opposite to the situation in a n-type semiconductor.
The nanowire n and p elements are connected to create a thin film Péltier thermal switch. By adapting the temperature on the outer part of these switches contacted by the fluid to the fluid's temperature, a heat flux can be avoided.
On the other hand, in the other mode by increasing the temperature between the switches and the fluid even more an even higher heat flux is obtained. This leads to a kind of electronic pumping of heat.

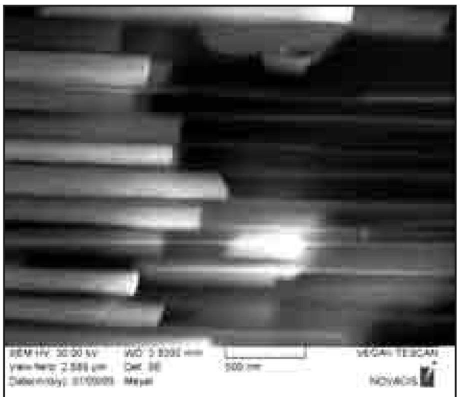

Figure 7: Nanowires performed with Ni with a characteristic diameter of *d*=200 nm. Thermoelectric materials integrated in the composites can be of several kind: conventional thermoelectric materials like Bismuth, Tellurium are advantageous, but we also explore the potential of metallic alloys, like NiCu and NiCr, which exhibit interesting figures of merit Z at nanoscale. Picture: *Anne-Gabrielle Pawlowski.*

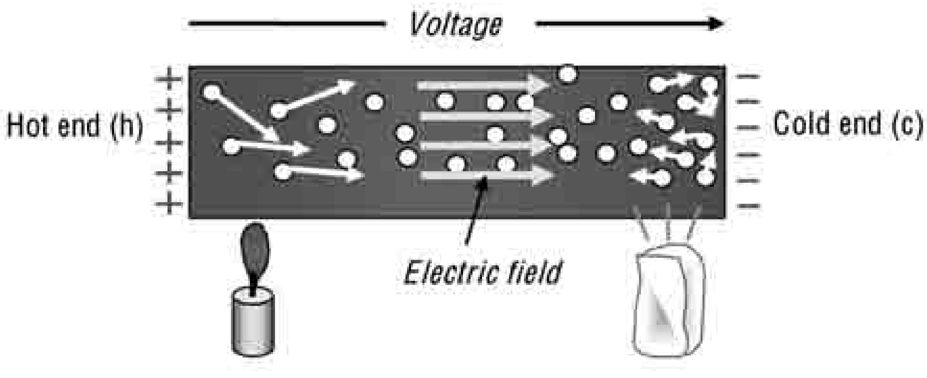

Figure 8: A horizontal temperature directional derivative gives rise to an electric potential (after Kasap, 1997). The situation describes a metal or a n-type semiconductor. The white little spherical objects represent electrons. Their mean velocity is higher at the hot end.

THE COEFFICIENT OF PERFORMANCE

The quality of thermodynamic devices is described by their coefficient of performance, *COP*. The highest obtainable value in nature or technics is the *COP* of a Carnot machine. If one divides the *COP* of a real device by the *COP* of the ideal Carnot device, COP_{Carnot}, one obtains a value between zero and one, because the second value (denominator) is equal or larger than the first number (nominator). This measure is named exergy efficiency and is very often given in percentage.
The coefficient of performance *COP* of the thermal switches must be distinguished from the *COP* of the overall magnetic heat pump or/and refrigerator. The *COP* of the thermal switches takes into account how much electrical energy is demanded to produce a cold and hot side each. The utilization of hot and cold leads to an improvement of the *COP* compared to applications where only one part is of importance.
The full theory of the determination of the *COP* of the thermal switches is outlined in a scientific-technical article, which was frequently published (see Egolf et al., 2012). Its results are graphically presented in Fig. 9.

To have a good interpretation of this figure, one needs to have knowledge on the two dimensionless numbers given as abscissa and as a free parameter. There are three powers, respecttively energy fluxes of importance.
The first is the electrical power to drive the thermal switch. The second is the electrical heating by the electric resistance of the device and the third the internal heat flux from the hot to the cold side. The two last energy fluxes are energy losses and must be as good as possible minimized.
The first dimensionless number θ_1 is the ratio of the internal heat flux to the driving electric power of the device. Therefore, it is clear that a low value of θ_1 is favorable. The second dimensionless number θ_2 is the ratio of the electric energy loss divided by the electric energy consumption. Also here a high loss in the nominator leads correctly to a smaller coefficient of performance as can be seen in the figure.
Generally one can see that high values of the *COP* are actually possible to be obtained. But it is expected that the power to drive the thermal switches is of minor importance compared to the energy per unit of time which the magnetic refrigerator demands, so that its influence on the overall *COP* of the machines will show practically no impact.
An interesting idea is that the electric power to operate the thermal switches is directly taken from the sweeping magnetic field, which leads to an electric induction in well-positioned coils. Such can only be performed with accurate electronics to obtain a good synchronization of the involved processes. On the other hand, this new idea simplifies the system substantially.

FIRST EXPERIMENTAL RESULTS

The experimental data listed in Table 1 are first results obtained with specimens of thermal switches performed with Ni nanowires. The Seebeck coefficient and the electrical resistance were measured in an experimental set-up configuration transverse to the film.
At the present stage of development, we demonstrate a temperature difference of up to 5 K across a film of a Ni-based composite film in a free-standing configuration, i.e. without any load. The obtained elevated temperature gradient of 2.5 10^5 K/m corresponds to a fictious temperature difference of 750 K across a 3 mm-thick commercial Peltier module!

AN ESTIMATE OF NEW REFRIGERATOR PROPERTIES

In the following a small and very approximate pocket calculator estimate of the performance of a magnetic refrigerator of the types built up to present is compared to that of a future magnetic refrigerator applying the new thermal nanowire switch technology.
To keep the discussion of these results reasonably brief, we propose you to concentrate mainly on the blue

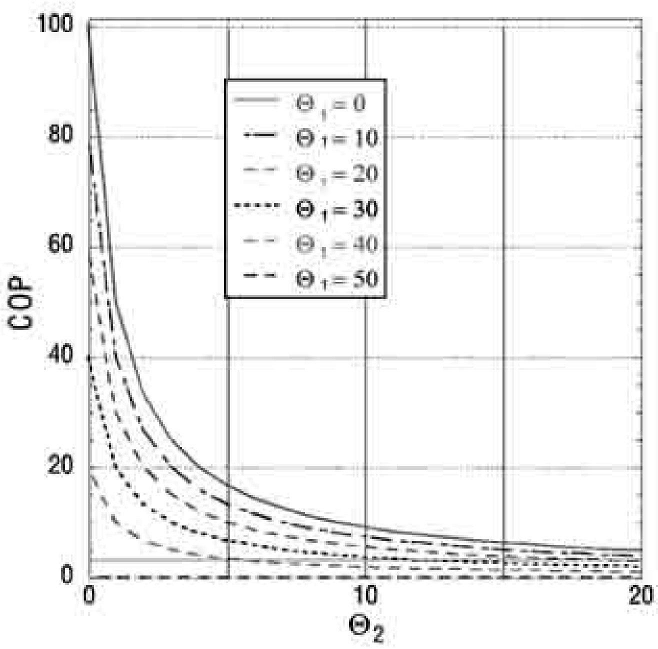

Figure 9: The coefficient of performance of a Péltier element that is simultaneously cooling and heating on the two opposite sides is shown in this figure. Such an element yields a thermal switch. As a basis for this figure the *COP* of the Carnot thermal switch is assumed to show the arbitrarily chosen value COP_{Carnot}=100. A very strong decrease of the *COP* with an increase of θ_2 can be noticed in this figure.

Table 1. Experimental results of main characteristic quantities of a Ni thermal switch.

Physical quantity	Experimental value
Film thickness, l	20 μm
Nanowire diameter, d	200 nm
Pore density, ρ_p	≈ 10^8 cm^{-2}
Thin film area, A	78.5 mm^2
Seebeck coefficient, α	-18 μV/K
Electrical resistance, R	≈ 1 mΩ
Heat conductivity, k	+++
Temperature difference	0.9 K
Current in a single element	0.2 A

+++: The thermal resistance has not yet been determined; in this first approach $R_{th} \to \infty$ is assumed for the determination of the coefficient of performance! This leads to a too high value (upper bound)!

Table 2. An approximate comparison of the performance of a usual magnetic refrigerator (ULMR) and a new thermal-switch magnetic refrigerator (TSMR) both based on the Brayton thermodynamic cycle with a layered bed. The quantities denoted by a star (*) are taken from Kitanovski et al. (2008a) and those with two stars (**) from Kitanovski and Egolf (2008b), a study bsed on pure gadolinium.

No.	Quantity	Symbol	ULMR	TSMR
	Overall machine:			
1	Nominal cooling power	P_n	50 W*	50 W
2	Maximum cooling power	P_{max}	96 W	96 W
3	Magnetic field strength (induction)	H	2 T*	2 T
4	Frequency	f	2 Hz*	10 Hz
5	Heat source temperature	T_c	-5 °C*	-5 °C
6	Heat sink temperature	T_h	45 °C*	45 °C
7	Adiabatic temperature difference	ΔT_{ad}	5 K*	5 K
8	Temperature difference Mat.-Fluid	ΔT	1 K*	2.5 K
9	Carnot coefficient of performance	COP_{Carnot}	5.4*	5.4
10	Coefficient of performance	COP	2.8*	2.8
11	Exergy efficiency	ξ	52 %*	52 %
12	Number of layers (layered bed)	N	10	10
13	Specific cooling power	p_c	2.5 kW kg^{-1}**	15 kW kg^{-1}**
14	Mass of magnetocaloric material	$m_{magneto}$	384 g	64 g
15	Volume of magnetocaloric material	V	49 cm^3	8 cm^3
16	Thickness of plates	s	≈ 0.2 mm*	0.2 mm
17	Surface area heat exchange	A	4900 cm^2	400 cm^2
18	Demanded heat transfer coefficient	h	392 W m^2 K	1920 W m^2 K
19	Estimate of magnets mass	m_{mag}	18 kg*	4-6 kg
	Thermal switches (3 layers):			
20	Surface area of thermal switches	A	---	800 cm^2
21	Temperature difference	T_h-T_c	---	2 x 2.5 K
22	Thermal resistance	R_{th}	---	∞ +++
23	Carnot coefficient of performance	COP_{Carnot}	---	216...254
24	Power thermoelectric effect	P_T	---	10 mW
25	Power electric loss	P_R	---	122 mW
26	Total power of source	P_S	---	132 mW
27	Heat flux	$\dot{Q}_1$	---	0 +++
28	First non-dimensional variable	Θ_1	---	0 +++
29	Second non-dimensionable variable	Θ_2	---	12
30	Coefficient of performance	COP	---	17-20 +++

lines with the numbers 1, 4, 10, 14, 19 and finally 30. In line No. 1 the nominal cooling power of a refrigerator is presented. Naturally for a comparison these values have to be identical for the conventional magnetic refrigerator, e.g. an active magnetic regenerator (AMR) machine (column on the left-hand side), and the new (in this article proposed) magnetic refrigerator with thermal switches (column on the right-hand side). One sees that we have assumed a faster rotation of the new machine by a factor of only five (line No. 4). We are optimistic that higher values can be obtained. On the other hand, Tishin and Spichkin (2012) made the remark that, beside the frequency limits given by the thermal switch, the magnetocaloric effect and the heat diffusion time, also the permanent magnet itself could show a limit as a result of its remanence property.

In future research the study of this effect must also be taken into consideration. As already mentioned the operation of the thermal switches utilizes a minor amount of energy per time unit and therefore can be neglected. This insight leads to identical coefficient of performance of the two types of machines as seen in line No. 10. Because of the higher frequency the magnetocaloric material makes correspondingly more heating and cooling cycles and by this the necessary mass of this solid refrigerant can be chosen smaller by a factor of six (line No. 14)!
The smaller rotator demands a smaller magnets assembly and the mass of the permanent magnets is estimated to drop down at least a factor of three (line No. 19).
This is essential for the size, weight and cost of a magnetic refrigerator. For the thermal switches a combination of three layers was assumed to be applied and the calculated coefficient of performance, *COP*, for this combined system is estimated to be approximately twenty (line No. 30). One has to note that the thermal resistance has not yet been taken into consideration, because of a lack of successfully determining it experimentally. Therefore, a lower value must be expected to finally occur.

CONCLUSIONS AND OUTLOOK

At present the most important limit to high-performance magnetic refrigerators is their low frequency. This results in large magnets assemblies which cause rather high costs of the envisaged magnetic refrigeration machines. The proposal is an alternative solution which applies thermal switches that allows higher frequencies than in up-to-present realized prototypes of magnetic refrigerators and these switches and their experimental and theoretical investigation yield the basis for this work.
The predictions made by simple estimates and calculations are based on first experimentally determined characteristic quantities of the nanowire thermoelectric switches, which are the Seebeck coefficient, the electric resistance (which still is too high) and would be the thermal resistance (not yet measured).
Further improvement by optimization is expected to occur! Additional important experiments will be the examination of the behavior with load and the determination of the maximal switching frequency of the thermal switches. A central further new idea is to drive the Péltier thermal switches by currents induced by the anyway occurring moving magnetic field in a magnetic refrigerator. Finally also many practical aspects must be investigated as e.g. the durability of the thermal switches and simple and cheap production methods!
If this technology will work, it will be possible to beat conventional refrigeration in numerous important refrigeration markets.
This technology is so promising that even magnetic automobile refrigeration, where a high mass is very critical, could become feasible! Initiated by us automobile companies today already perform extensive research on this new technology (see e.g. Tasaki et al., 2012).

ACKNOWLEDGEMENTS

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EPBD recast: energy monitoring and HVAC system mandatory Inspection. Findings from two IEE funded projects

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This topic will be discussed in the next 15th EU Conference

Introduction

Air conditioning systems can account for up to 50% of the energy used in a building, and are therefore specifically targeted in the new legislation. The Energy Performance of Buildings Directive (EPBD) was established in 2002 (Directive 2002/91/CE). Article 14 of the 2010 EPBD recast, which is aimed at reducing CO_2 emissions within the building sector, requires a regular inspection for HVAC systems with more than 12 kW cooling capacity. However, so far only a few Member States have transferred this prescription into national law.
HARMONAC (Harmonizing Air Conditioning Inspection and Audit Procedures in the Tertiary Building Sector) was a project supported by the Intelligent Energy Europe initiative in 2007-2010. The project was funded to provide actual energy consumption data on HVAC system in Europe and to establish standard inspection tools and criteria. Some results from HARMONAC project were used to recast the EPBD at this actual form (EPBD, Directive 2010/31/EU). A new project, called iSERV continuous monitoring and benchmarking project, was funded in 2011, specifically targeted to put the HARMONAC results in practice on a wider scale, with a specific emphasis on energy monitoring of HVAC systems.

Objective of the work

The IEE HARMONAC project was developed to reach a number of clear aims:

- To produce a series of HVAC inspection procedures, to be applied by member states in the framework of EPBD Directive;
- To provide new field-tested materials and tools to aid Inspectors in the inspection process;
- To understand more clearly how HVAC systems consume energy;
- To assess the opportunities for energy savings.

The project ensured that the information was presented to the main actors involved in HVAC systems mandatory inspection. The purpose was to help the defined bodies to produce regulations and legislation in this area that maximize the energy and cost benefits to the system owners, and hence to Europe, from the time and money invested in these inspections.
A clear and unexpected result achieved during the development of the project was the clear knowledge that continuous monitoring will be helpful in HVAC inspector work, and could represent the basis for reliable benchmarking of HVAC systems.
To achieve the project aims the energy consumptions of the HVAC systems and their components have been monitored in sub-hourly detail. Two types of investigations were carried out: during Case Studies systems are monitored for at least one year, while in Field Trials monitoring take place for a short time period (variable between 7 and 90 days). In other words, a File Trial basically means the inspection of an HVAC system, including pre-inspection and on-site inspection. A Case Study consists of such inspection combined with long-term monitoring and analysis of energy saving potentials, based on measurements and/or simulations.
The main idea is that the Case Studies helped to understand the HVAC consumption difference due to seasonal variation and major building/system refurbishment (e.g.: chiller substitution, windows substitution, etc). On the other hand the Field Trials were intended to simulate limited time on-site inspections and to analyze specific HVAC system aspect (e.g.: Control strategy, Chiller efficiency, etc). The majority of Field trials were enhanced by additional measurements which go beyond the current Inspection requirements, to enable further insights to be obtained about the effectiveness of the inspection process.
The Case Studies were carried out studying the energy use, operation and maintenance regime of about 40 Systems around Europe. The Case Studies were intended to analyze in as much detail as possible where the energy was being used, what energy conservation opportunities (ECOs) there were, and to quantify these ECOs where possible. This was undertaken within the project con-

	CS IT-1	CS IT-2	CS IT-3	CS IT-4	CS IT-5
Location	Torino	Torino	Trieste	Genova	Torino
Main activity	Office	Office and laboratores	Retirement home	Open plan offices	Single room offices
System Type	All water system (no mechanical ventilation)	All air, VAV, all water, air and water	All air system (CAV)	Air and water (chilled beams)	VRF with mechanical ventilation
Year of construction	1970	2000	1810 (Refurbished in 1998)	2004	1650-1950 (Refurbished in 2004)
Net conditioned area [m^2]	4840	24000	8000	8597	9500

straints and for over at least a year for the majority of the systems. The project was directed to take existing AC Inspection Methodologies and turn them into a specific HARMONAC Methodology, which allowed the elements of an inspection to be analyzed in terms of time taken, ECOs identified, and likelihood of achieving energy savings. During the project it was found that this approach also allowed ECOs and their savings to be roughly associated with inspection items as well as allowing teaching package sections to be referenced as help sections.

Further concern of HARMONAC project was directed to Field Trials. The range of ECOs identified from the Field Trials was compared to those found from the Case Studies so that the effectiveness of the Inspection process in identifying all the ECOs that potentially existed could be gauged. The Field Trials and Case Studies are complementary, as without the Case Studies we would not have the detailed information needed to understand how AC systems generally consume energy, and therefore the additional ECOs that may be present in reality that the Inspection procedures are not finding – along with the relative importance of these 'missed' ECOs in the overall energy use of AC systems. The Field Trials are crucial, however, to assessing the realities of the practical implementation of Inspection procedures on real systems, and which ECOs are likely to be found, and which are likely to be missed.

Findings from Field Trials and Case Studies

There are some practical limitations to an inspection in terms of the time available to undertake it and its inherent 'snapshot-in-time' nature. During the project different tools were developed and tested to increase understanding of the potential energy savings to be achieved in the systems inspected, and hence increase the value of the inspection. Nevertheless it was made clear that without reliable energy consumption data it is almost impossible to achieve reliable ECOs evaluation and reliable ROI (Return of Investment) associated to those ECOs.

Five Case Studies and fourteen Field Trials have been carried out in Italy. The Case Studies and Field Trials have been organized by Politecnico di Torino. Most Italian Case Studies were carried out in large office buildings; one Case Study examined a retirement home. The examined buildings are located in Northern Italy, in the cities of Torino, Genova, and Trieste. The conditioned floor areas of the buildings range between 4800 and 24000 m^2. HVAC systems analyzed are of different types:

- All air (CAV)
- All air (VAV)
- All water (with fan coils)
- Air and water (with active chilled beams or fan coils)
- VRF air to air reversible heat pump

Central heating and cooling production includes conventional electric chillers (air cooled or water cooled) coupled with gas-fired boilers, absorption chillers coupled to biomass combustion boilers, tri-generation units with IC engines, and VRF heat pumps.

Building structure typologies are quite diversified: CS IT-5 is a XVII century masonry building, largely rebuilt in reinforced concrete after WW-II; CS IT-3 is an early XIX century building with bearing masonry walls (average thickness 50 cm); CS IT-2 is a technology park built in the 1990s with a number of high energy performance envelope technologies (green roofs, ventilated façades, low U-value glazing, etc.); two CSs (IT-1 and IT-4) are high-rise office towers with curtain walls and large glazed surfaces.

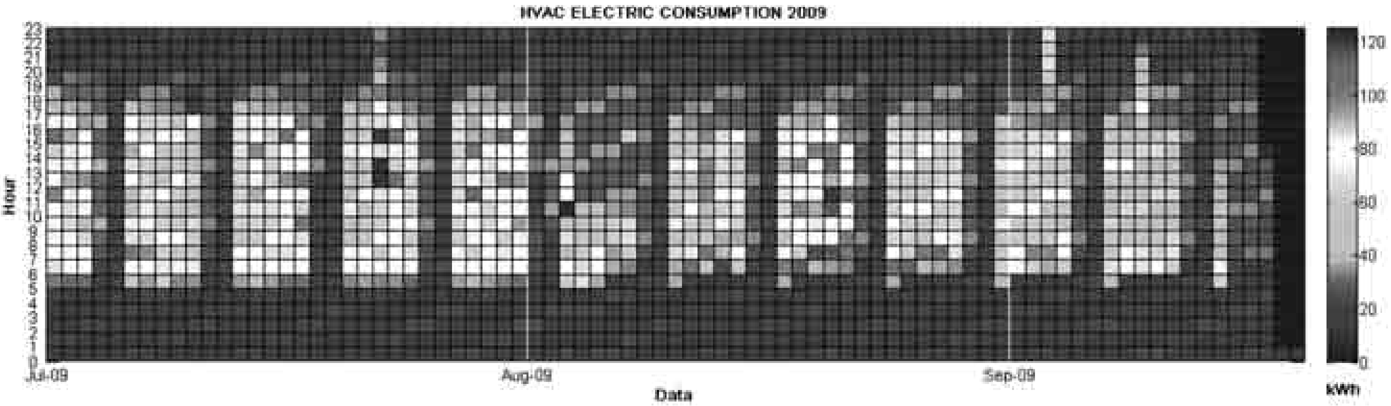
Results from a sample Case Study

The case study addressed the energy analysis for the installation of an absorption chiller coupled to a Combined Heat and Power (CHP) generator. The preliminary analysis assumed that the waste heat from CHP system should be directed to an absorption chiller. The base cooling load (kWh) then can be covered by the absorption unit, while the peak load would be provided by the existing electric chiller. Preliminary simulations to address the economic feasibility of the installation indicated a 75.5% energy saving. The graph in Figure 1 shows the cumulate electrical load of the two chillers, during the first season and during the second season. The overall result is a 20.8% saving on total chiller electric energy consumption. This is a good operational result, but it is dramatically lower than the 75.5% expected from the simulation.

The major explanation for the different values is that in current operation the absorption unit is not working as stated in the simulation. The nominal performance of the unit is calculated with inlet hot water at 90°C. In the building the hot water to the absorption unit is provided by an IC engine rated at 1 MW electric power. The CHP system was installed before the chiller; its circuit was designed for a maximum temperature of 90 °C. During operation, when the water temperature reaches 85 °C, the system stops due to safety valves. For this reason the inlet water to the absorption unit is delivered at 83-84°C, and the COP of the unit decreases.

The other reason that implies a huge difference between simulation and monitoring is the system schedule. In the simulation the absorption chiller schedule was not considered. In the real plant, the CHP unit is turned on just from 8:00 AM to 7:00 PM for eco-

Figure 1.
Carpet plot of the chiller plant electric consumption. (The chiller plant includes the electric chiller, the absorption chiller and the chilled water circulation pumps).



nomic reasons. During this time the electric energy produced by the CHP is sold at the maximum rate (peak hour). This implies that the absorption unit cannot be turned on before 8:00 AM. Moreover, the unit needs some time (almost one hour) to provide full performance. The two seasons are not completely comparable, due to the complete substitution of the windows on the north façade. The refurbishment of the façade lowered the heating demand for the winter season, but raised the cooling load requested during Summer since the window retrofit reduced the night time free cooling effect. Substitution of windows with low permeability and low U-value ones should be carefully considered in respect of effects on cooling loads.

iSERV project

The iSERV project, by collecting sub-hourly HVAC system energy use data from around 1600 HVAC systems in the EU Member States, is intended to demonstrate that a comparison with specific benchmarks will help the energy consumption reduction of HVAC systems. To reach this objective, the project will be able to:

1. Provide the system owners feedback on energy use patterns;
2. Establish a detailed understanding of the energy consumption of European HVAC systems meeting specified end use activities;
3. Provide evidence-based information to HVAC system manufacturers, EU Member State Legislators, European Standards Bodies, Professional Building Services Bodies and HVAC system owner/operators on how to improve the in-use energy efficiency of HVAC systems.

According to article 14 of the 2010 EPBD recast, it will be possible to allow owner/operators of systems showing good energy performance to avoid needless Inspections.

The core of the project is a web-based data collection and reporting application for the EU member state HVAC systems. The application is fully web-based and requires only an internet connection, the use of standard software. This makes it ideal for use as such tools are all free to end users. The application itself is also free to use.

End users of the application receive their own secure login details and are able to enter their own data manually or automatically if their data collection systems already allow this. This process involves entering the data directly via a manual interface or uploading a spreadsheet with manually/automatically read data to the application. These data are usually supplied in the industry standard .csv format.

The definition of an HVAC system for iSERV is: "An area served by separate Ventilation and AC components which are individually metered such that the energy consumption of the AC and Ventilation systems can be physically separated from other VAC systems. Heating systems do NOT need to be separate to each of these areas". Under this definition a building may have more than one system.

The database is sized for 1600 systems, with 125 different readings (meter or sensor) and recordings at 15 minutes interval. This allows for a greater number of readings (due to more meters/sensors or lower intervals) or more systems.

Users initially need to describe their building spaces in terms of floor areas, activities undertaken, etc., but little effort is then needed after this point other than to enter the consumption data at a minimum of monthly intervals. It is considered that the optimum interval is 15 minutes for automated systems, and, where possible and feasible, this should be the preferred method. The application is designed to allow them to either manually produce their own reports or to automatically run off a bespoke report when their data is entered. There is a data entry error notification function in the system to alert them to data problems as they enter the data.

Conclusions

The key to increased long-term energy efficiency in AC systems rests with making it cheaper for the owner to run their systems efficiently and to specify low energy equipment, than it is to just accept an Inspection. This implies Inspections should be expensive, and that there should be an alternative that rewards good energy management by allowing systems to avoid inspection if they achieve certain standards: specific benchmarks harmonized on building use and size. iSERV cmb project will provide benchmarks for specific building uses.

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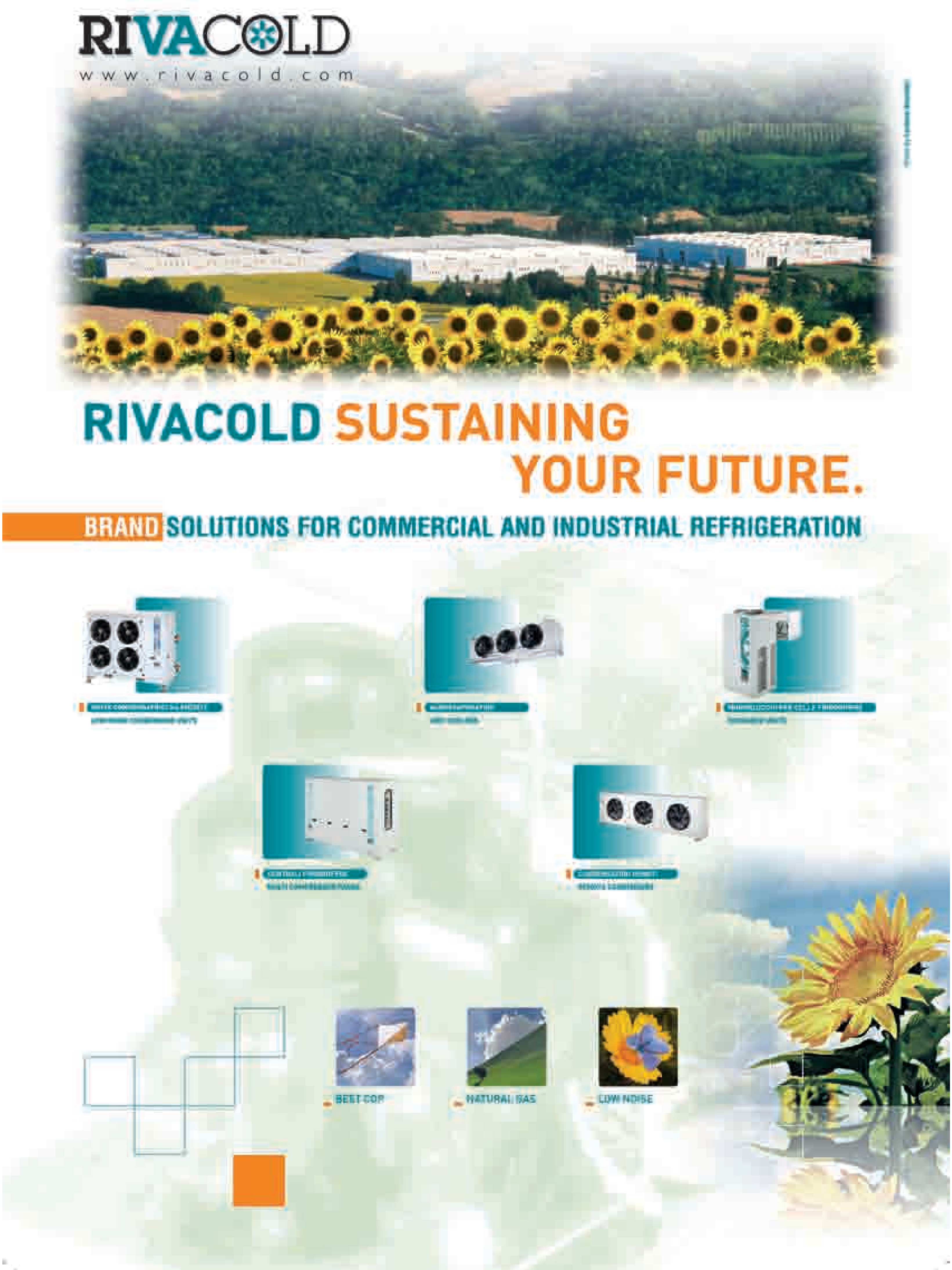
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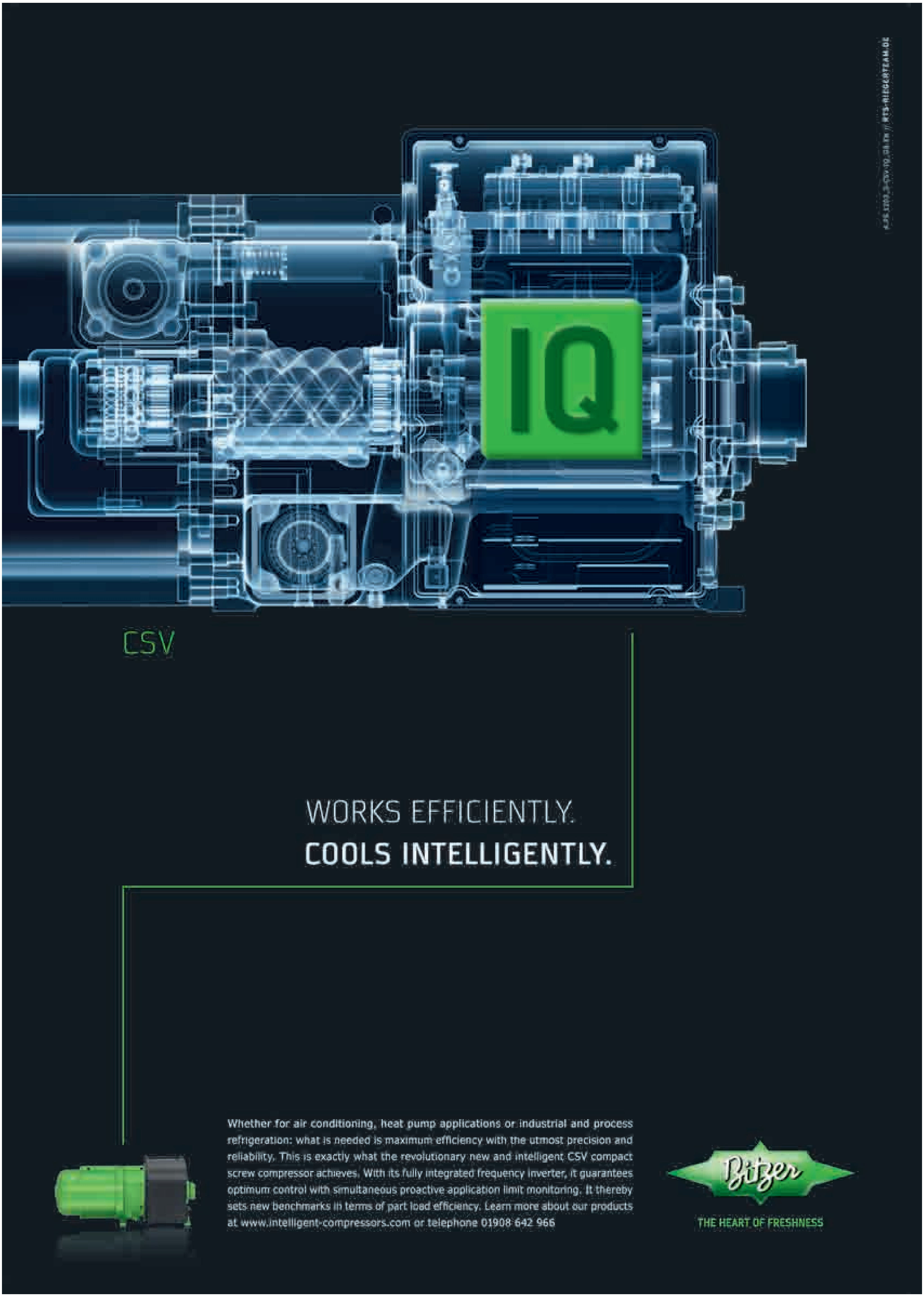
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