IEA Heat Pump CENTRE
NEWSLETTER
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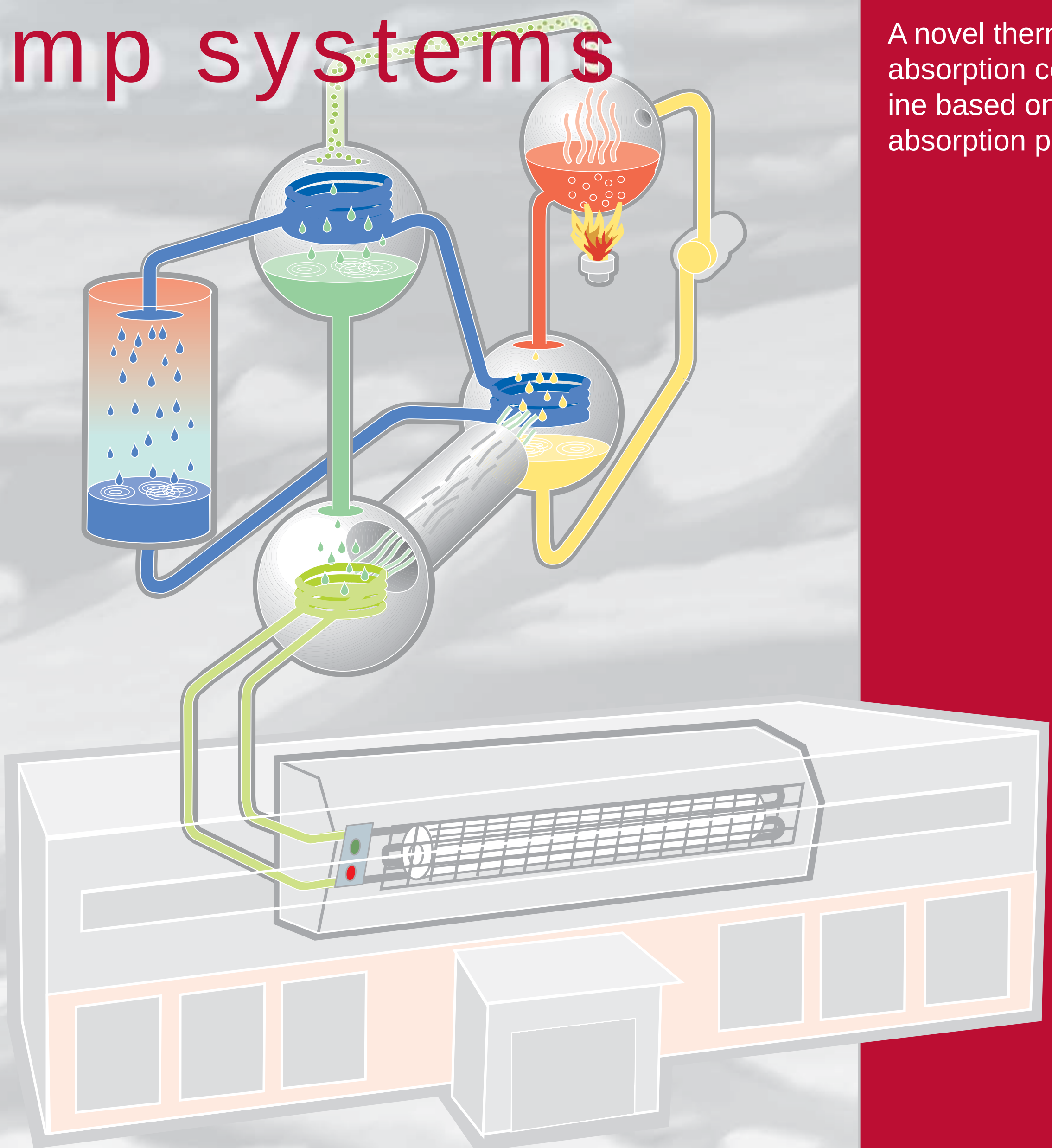
Thermally activated heat pump systems

Gas engine-driven heat pump systems

The feasibility of absorption chillers using low-temperature heat sources

A novel thermally-driven absorption cooling machine based on the diffusion absorption principle



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IEA **Heat Pump** CENTRE
NEWSLETTER

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In this issue

Thermally activated heat pump systems

Thermally activated refrigerating machinery and heat pumps can be powered by solar heat or waste heat and be integrated in CHP systems. A gas engine-driven vapour compression machine is a good alternative to the more common electrically driven machine in countries with a gas distribution network. All this, and more, is described in this issue of the HPC Newsletter - not forgetting, of course, an article on an ice hotel that is in existence year-round.

Heat pump news

Features

Topical article

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IEA OECD heat pump centre

Heat-pumping heat exchangers: thermally-activated heat pump systems transfer heat upstream with negligible need for electricity

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To drive heat upstream against a temperature gradient usually requires mechanical or electrical work as the driving energy input. The physical reason is well-known: heat carries entropy; the lower the temperature, the greater the entropy. As a consequence, upgrading of heat requires the reduction of the mean entropy which, in the case of compression heat pumps, is done by adding zero-entropy work. However, the addition of high-temperature low-entropy heat, or the subtraction of low-temperature high-entropy heat, is also possible. The heat pumping devices are then effectively just heat exchangers, grouped together in such a way that heat is upgraded. Heat-actuated heat pumps fall into two categories; heat pumps (type I, **heat** amplifiers), and heat transformers (type II, **temperature** amplifiers).

The first type, as in compression technology, is most widely used in cooling and refrigeration applications. Predominantly gas-fired absorption chillers with LiBr/water as the working pair are available on the market. Used as a heat pump, they suffer from a relatively small range of safe operation due to restrictions imposed by the working fluid. The ammonia/water pair is more versatile. Other forthcoming working pairs may be Zeolite/water or silica gel/water, which require a very different engineering approach because the adsorbent is solid. The reverse system, the heat transformer, has been and still is only seldom used. Personally I think that we will see a revival of this technology in the near future. Finally, heat-actuated heat pumps can operate on very different principles: in addition to absorption and adsorption processes, we should not forget Vuilleumier cycles and steam-jet heat pumps.

Heat-actuated heat pumps have an important advantage over compression heat pumps: their COP is much smaller, which means that they can operate with smaller sized heat sources. Now it may sound strange to praise a low COP, but as heat-actuated heat pumps are not powered by electricity their primary energy saving is easily competitive with that of electrically-driven compression heat pumps.

In this issue the focus – in accordance with the market - is on cold production, where a low primary energy demand is not achieved just by powering a chiller by gas instead of by electricity. The market pull here is not energy saving but electricity cost shaving. Using gas for cooling reduces the mid-afternoon electricity peak and thus reduces the need for peak power buying, production, and distribution. However, in order not to increase energy demand, we need waste heat or solar heat-operated chillers, or highly efficient gas-powered chillers such as triple-effect cycles. Of course, a good alternative is the gas engine-driven chiller. All these energy-saving cooling technologies are described in this newsletter. I do hope that – together with heat-actuated real heat pumps – they will find widespread use on the market soon.

Felix Ziegler

Columnist

Gas absorption heat pumps: the state of the art

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A new family of absorption machines has appeared recently on the European market, in the form of gas absorption heat pumps: new machines using an ammonia-water thermodynamic cycle and powered by a thermal source, typically combustion of methane or LPG. They can produce hot water for winter heating, with much higher efficiency than that of a condensing boiler, and cold water for summer air conditioning. They have been available on the market since 2004, and are suitable for small/medium size heating and cooling plants, built up from modular units, starting from 17 kW of cooling power and 35 kW of heating power.

Models available

The machines are manufactured in different versions:

- Air-to-water reversible version, for heating or cooling. This arrangement uses heat exchange with the outside air as a cold source during the winter and to dissipate the heat rejected during the summertime
- Air-to-water version, for heating only. This arrangement has the highest heating efficiency
- Water-to-water version for heating and cooling applications, or for heating only.
- Ground-to-water for heating, abstracting energy from the ground with borehole heat exchangers.

Overall characteristics

Gas absorption heat pumps have very low electrical power requirements in proportion to their gas power input, of about 13,9 W to 25,5 W of electrical power requirement for each kW of thermal power output. G.U.E. (Gas Utilisation Efficiency) has been measured in accordance with EN 12309.

The main characteristics of these new technologies are:

- Extremely high heating efficiency, 150% or more, as measured against gas consumption
- Only one modular system for both heating and cooling, even with reversible machines
- Electric energy saving, close to 90 % compared with the traditional electrically powered heat pumps, to reduce grid peak loads during summer or winter
- Heat rejection to air or water
- Only natural fluids inside (no CFC/HCFC/HFC), with ODP=0 and GWP=0
- Suitable for use in renewable energy systems (air, water, geothermal applications)
- Low CO2 emissions, 35% less than from the best condensing boilers
- No frost problems: even during the evaporator defrosting process, the GAHP unit supplies more than 50% of the nominal heating capacity, with no need for additional primary energy input
- Wide range of operating conditions: winter conditions down to 20 °C, summer conditions up to 45 °C
- Production of hot water up to 65 °C and of chilled water down to 5 °C.

Conclusions

There should be considerable opportunities for GAHP for heating, cooling and hot water production over the next years, in order to improve energy efficiency in European buildings in accordance with European Directive 2002/91/CE.

Ing. Alberto Lodi

The potential impact of heat pumps on energy policy concerns

At the opening of the 8th IEA International Heat Pump conference in 2005, Antonio Pfluger, Head of the Energy Collaboration Division of the IEA, challenged the Heat Pump Programme to explain what impact heat pumping technology could have on the energy policy concerns that were uppermost in the minds of IEA energy ministers. These were:

- supply security
- greenhouse gas emissions
- access to energy, especially in developing countries

In response, the programme produced a short non-technical communiqué. This can be seen on the programme's website

Shortly afterwards, the G8 meeting considered a similar range of energy policy issues and asked the IEA to take a number of actions. As part of the response, the IEA's Building Coordination Group and End-use Working Party held a joint workshop and the IEA is preparing a book on Global Energy Technology Perspectives.

Reply from the IEA Heat Pump Programme

1. Heat pumping technology could have a material impact on greenhouse gas emissions at a modest cost

Heat pumps should therefore be considered very seriously as part of any portfolio of technologies aimed at reducing greenhouse gas emissions – and of policies to support the deployment of these technologies.

The most widespread use of heat pumping technology is currently in refrigeration and air-conditioning. Although there is scope to reduce greenhouse gas emissions associated with these applications, the greatest potential impact is by expanding use of the technology for space heating.

Previous analysis by the programme has shown that a 30% market penetration of heat pumps into existing heating markets would reduce total global emissions by about 6%. This can be set alongside figures from the IEA Alternative Scenario for 2030, which showed reductions from all sources of 16% and from end-use efficiency of nearly 10%. The potential impact of heat pumps is clearly material in this context.

The 6% figure could be increased:

- Efficiencies can be improved. Unlike boiler technology, current heat pumps are not operating near the theoretical limits of efficiency. Efficiency improvements are possible, albeit sometimes at increased cost

- Electricity generation can become less carbon-intensive. Most heat pumps are electrically powered. The lower the carbon emissions from for each kWh generated, the greater the benefits from heat pumps

- Market penetration could be higher. 30% is an indicative figure. At present though, there are only a few countries where heat pump use is as high as this.

The cost of saving a tonne of carbon dioxide emissions through heat pumping technology varies between countries (as does the cost of many alternatives). For heat pumps, the main causes of differences are climate; the nature of the electricity supply system – especially its fuel base; and the local cost of alternative heating systems and their fuels.

Very broadly, in most countries the economics as seen by consumers are only currently attractive in a few market segments. From the perspective of the costs imposed on society, heat pumps are comparable with the better renewable technologies: on a par with good examples of biomass or wind energy and lower than solar energy. However, there are countries where they are already attractive to consumers.

2. Heat pumps can reduce exposure to supply risk

Supply risk is partly political and partly related to supply infrastructure reliability. Heat pumps cannot directly influence these risks but, like other energy-efficiency measures, their use reduces energy demand and therefore the scale of exposure to the risks. In so doing it makes risk management easier. The scope for reducing energy demand is essentially similar to that for carbon dioxide emission reduction discussed above.

Most heat pumps use electricity. Since electricity generation is not inherently fuel-specific, it offers more options for fuel diversification than other heating technologies.

3. Heat pumps can reduce infrastructure costs for energy supply networks

Developing economies have rising demands for energy to meet growing and essential needs of households and businesses. In consequence, large investments in energy supply infrastructure are needed. The provision of energy to households is particularly expensive. Because of the inherent economies of scale for energy infrastructure, using the same energy carrier for all services – including space heating – reduces total investment costs. The only practical universal energy carrier is electricity, and the most efficient way to use electricity for heating is with heat pumps.

4. Policy options

The policy instruments best suited to an energy problem clearly depend on the nature of the problem. Robust policies are unlikely to depend on a single technology, but to comprise a

Typical Policy Instruments		
Life cycle cost or NPV <<<<<<<<<<<<<< Better --- Worse >>>>>>>>>>>>		
Cost-effective to user and to society	**Cost-effective to society but not to user**	**Not currently cost-effective to society or user**
Remove market barriers - provide information - overcome capital constraints (eg loans) - support development of market structure	*Incentives and regulatory requirements* - minimum carbon efficiency requirements - reflect external costs through taxation - subsidies or soft loans	*Support development* (if potential appears worthwhile) - R&D support - demonstration programmes

portfolio of measures and technologies. If there is sufficient confidence in market mechanisms, they may be "technology blind" (carbon taxes would be an example). Alternatively, they might be tailored to encourage different technologies differently according to their perceived costs and benefits.

For many technologies - especially those related to buildings, the rate of implementation can be constrained by the stock turnover period. For heating system this is typically of the order of 10 to 20 years, for complete buildings 50 to 100 years. Thus decisions by consumers or by policymakers have to be based on estimates (or alternative scenarios) of likely benefits over lengthy future periods during which it is unlikely that current conditions (especially energy prices) will pertain. In this situation of spending now in order to achieve benefits in the somewhat distant future, it is unlikely that market forces alone will be very effective in the short term.

For policies that distinguish between technologies, different instruments are appropriate to different situations. The table above summarises some typical instruments for different classes of cost-effectiveness (for example in terms of lifetime cost per tonne of carbon dioxide emissions abated). Specifically, a distinction is made between cost-effectiveness to the end-user and to society (including the cost of externalities)

Decisions to adopt particular instruments clearly also depend on the cost of implementing the instrument and the scale of the benefit likely to be achieved.

Generally, heat pumps fall into the central column of this table – there are societal benefits beyond those recognised in the marketplace. The materiality has already been discussed at a global level, but will vary between countries. Instruments in the other columns are also relevant: in particular in many countries the market infrastructure is weak, and there is undoubted scope for technical development.

This reflects the general comment of the 2001 IGCC report that, for mitigation policy in general, "expanded R&D is needed … but implementation remains the major hurdle." This is however, not true for every technology: Low energy lamps, for example, are predominantly in the left hand column, and fuel cells in the right hand one.

5. Implications for the IEA

One of the G8 requests to the IEA was for "advice on alternative energy scenarios and strategies aimed at a clean, clever and competitive energy future". We suggest that the approach outlined above can be part of the structure of the IEA's response.

In order to identify where different technologies fall in the matrix of instruments, costs and carbon benefits of each technology need to be assessed, along with the their potential scale of impact. We suggest that the Implementing Agreements – and especially those within the Building Coordination Group – can provide much of this through their collective knowledge and networks. We therefore suggest that the planning and financing of the IEA's response should include provision for work by the Implementing Agreements.

Roger Hitchin
Vice-Chair
IEA Heat Pump Programme Executive Committee

General

EU agreement on energy efficiency

EU – The European Parliament and the European Council have agreed upon a directive aiming at encouraging member states to save energy and to use energy more efficiently. The directive is expected to enter into force soon. The directive, which is not binding, asks EU member states to save 9 % of the energy supplied to end users (private households and the public sector) in the nine years following the directive's entry into force. The directive covers electricity, gas, heating oil and transport fuels. Although not binding, the directive requires member states to present three Energy Efficiency Action Plans, describing each state's plans for energy efficiency measures as needed in order to reach the set targets.

Source: http://www.europarl.eu.int/news/public/story_page/051-3686-346-12-50-909-20051213STO03685-2005-12-12-2005/default_en.htm

Outcomes from the UN Climate Change Conference in Montreal

Canada – This conference was the eleventh meeting of the parties to the United Nations Framework Convention on Climate Change (UNFCCC), but the first since the Kyoto Protocol came into force in February 2005. The Kyoto Protocol commitments consist of at least a 5 % reduction in emissions of six greenhouse gases by the Article 1 countries during 2008-2012 (compared to the 1990 levels).

The conference was held in Montreal, Canada, from November 28 to December 9, 2005. The Marrakech Accords, providing the rulebook for implementation of the Kyoto Protocol, were adopted during the conference. Two Kyoto Protocol mechanisms, the Clean Development Mechanism (CDM) and Joint Implementation (JI), were also launched during this conference.

CDM means that developed countries can invest in sustainable development projects in developing countries and thus earn emission allowances. JI allows developed countries to make investments in other developed countries, in particular central and eastern European transition economies, thus earning emission allowances.

Another important decision taken at the conference was to continue discussion of further emission reduction commitments after 2012. This work will be performed by a special working group, not including non-Kyoto countries such as Australia and the USA. The first meeting of this working group will be held in May 2006. The European Union suggested a 50 % reduction of world-wide greenhouse gas emissions by 2050.

Source: UNFCC press release, and www.iifiir.org

Working Fluids

Centre for HFC-free refrigeration

Denmark – With effect from January 1, 2007, Denmark will ban the use of HFC refrigerants in new refrigerating equipment having a total charge of more than 10 kg of refrigerant. To assist this transition, the Danish Government is investing DKK 12 million (USD 1.9 million) in the development and introduction of alternatives to HFCs. Another initiative is the establishment of a centre for HFC-free refrigeration, which was officially started in October 10, 2005. The centre is staffed by experts from Teknologisk Institut, COWI and IPU, and its work is planned to run for three years. The aim of the centre is to assist a fast introduction and dissemination of alternatives to HFCs to installers, consultants and contractors etc. active on the Danish market. The centre provides five hours of free advisory service per "issue" related to HFC-free refrigeration systems. It will also compile information on Danish and international literature related to this topic.

More information (so far in Danish only) is available from the centre's web site http://www.hfc-fri.dk/.

Source: Scandinavian Refrigeration, no. 6, 2005 (in Danish)

New refrigerants under development

USA – New refrigerants that will meet the EU requirements on Global Warming Potential (GWP) for refrigerants in future automotive air-conditioning systems have been identified by DuPont Fluorochemicals. The company announces that these new refrigerants are expected to be non-flammable and compatible with conventional R134a systems with only minor modifications, unlike CO2 systems which need more substantial redesigns. The refrigerants are currently undergoing performance, toxicity and safety testing, and are expected to be commercialised within 3-5 years. In addition, they may also be of interest for use in other air-conditioning and refrigeration applications, the potential for which will also be investigated, DuPont reports.

The background to this development is that from 2017 no new cars in the EU may use refrigerants with a GWP > 150. R134a, which is commonly used in car air-conditioning systems today, will then be banned.

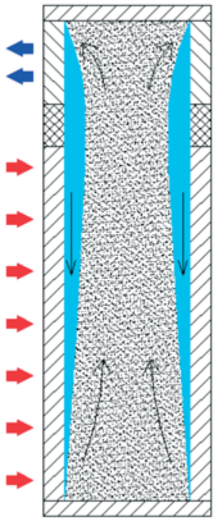
Source: http://refrigerants.dupont.com/Suva/en_US/news/article20060209.html

Technology & Applications

CO_2 Earth Heat Pipe EHP

Germany – FKW in Hanover has developed an Earth Heat Pipe using the natural environmentally friendly heat transfer fluid CO_2 for space heating of residential buildings. This means that, as opposed to earth heat collectors using brines that could affect the groundwater, the new EHP can be installed in water preservation areas.

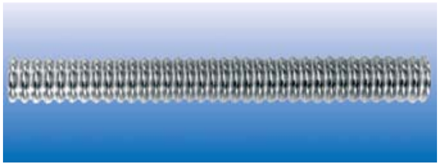
Using the thermosiphon principle, one of the benefits of this EHP is that no energy is required for a brine circulation pump. A further benefit is the improved heat exchange from the earth to the heat pump, resulting in higher evaporating temperatures. The two increase the efficiency of the heat pump by more than 15 %.



Thermosiphon earth probe principle

Working with CO_2 as the heat transport fluid requires a tube system with special characteristics. First, of course, the tube must withstand the high saturation pressure of CO_2, namely 45 bar at about 10 °C to 12 °C earth temperature down to 100 m. Secondly, the up to 100 m long tube should be flexible for easy transport and installation. In addition, the tube must be well designed to avoid flooding of the heat pipe.

Because of these demands, FKW decided to use stainless steel flexible pipes, well known as compensators in refrigerant piping, and applied this system for Patent and Registered Design.



Flexible pipe for the CO2 EHP

At an average heat flux of approximately 50 W/m pipe length, and with a carefully designed diameter of the pipe, the liquid will flow in counterflow to the rising vapour along the inner wall of the pipe without showing entrainment effects or flooding behaviour.

The upper area of the heat pipe is designed as a heat exchanger.

Heat exchanger of the CO2 EHP

In the cooling area, the CO2 is condensed by the evaporating refrigerant of the heat pump. There is therefore no evaporator inside: instead, it is in the form of an external split unit, directly mounted on top of the EHP.

With suitable heat pumps (using R134a, R407C or other refrigerants), the newly developed CO_2 earth heat pipe can be used for space heating of residential buildings. An EHP of 100 m depth can collect enough heat to deliver up to 7.5 kW.

The system will come to the market in 2006. Some demonstration systems are already in operation in Germany and Austria.

Source: FKW GmbH, Germany, e-mail@fkw-hannover.de

PV powered vapour compression heat pumps

Sweden – One argument commonly raised by heat pump critics is that heat pumps use electricity, and that marginal production of electricity is based on the use of oil or coal. A Swedish company, Ekosol, has developed a concept for powering heat pumps from photovoltaic (PV) solar panels, and thus, in theory, eliminating the need for an external power supply. In reality, as supply and demand do not always coincide, the power produced by the PV system is fed to the electricity grid, and the power needed by the heat pump is supplied by the grid.

The idea is that new houses should be fitted with PV panels on the roof, and with heat pumps as their heat sources. Ekosol, which would rent the space for the PV panels from the house owner, would sell the electricity on the electricity market. Ekosol would arrange with banks offering house purchase loans for the banks to charge a lower rate of interest on the loan for houses incorporating the Ekosol equipment, with the reduced rate of interest matching the extra interest for the PV panel investment. The first houses built according to this concept are now being built in Strängnäs, Sweden.

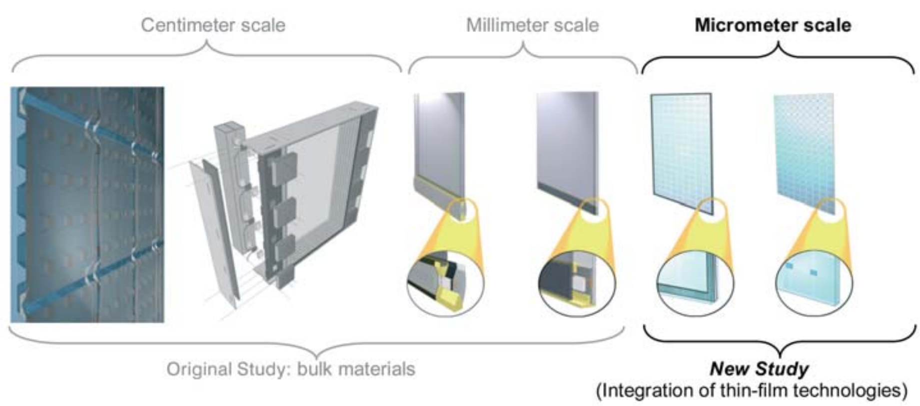
Source: VVS-Forum, no. 2, 2006 (in Swedish) and www.ekosol.se

PV powered thermo-electric heat pumps

USA – A research team at Rensselaer Polytechnic Institute is developing a heating and cooling system called Active Building Envelope (ABE). This uses photovoltaics (PV) to convert solar energy to electricity, with the electricity then being used to drive thermoelectric (TE) heat pumps that are integrated into the building envelope. This means that the building envelope is used for heating or cooling the inside space. The heat pumps heat or cool as required, depending on the direction of electric current flow. An energy storage system is also integrated in the ABE system in order to handle possible mismatches between supply and demand.

The first system developed uses traditional PV panels and thermoelectric heat pumps of approximately one square inch in size. This arrangement uses bulk components and would be costly, impractical and difficult to apply to existing buildings. Current research is focusing on micro-scale ABE systems using thin-film PV systems and thin-film thermoelectric materials, which are hoped to result in ABE surfaces less than 500 µm thick. This thin material could then function as a thermal coating which could be applied to various surfaces. It would then be possible to apply the ABE system to existing buildings as well.

Source: http://www.physorg.com/news8790.html



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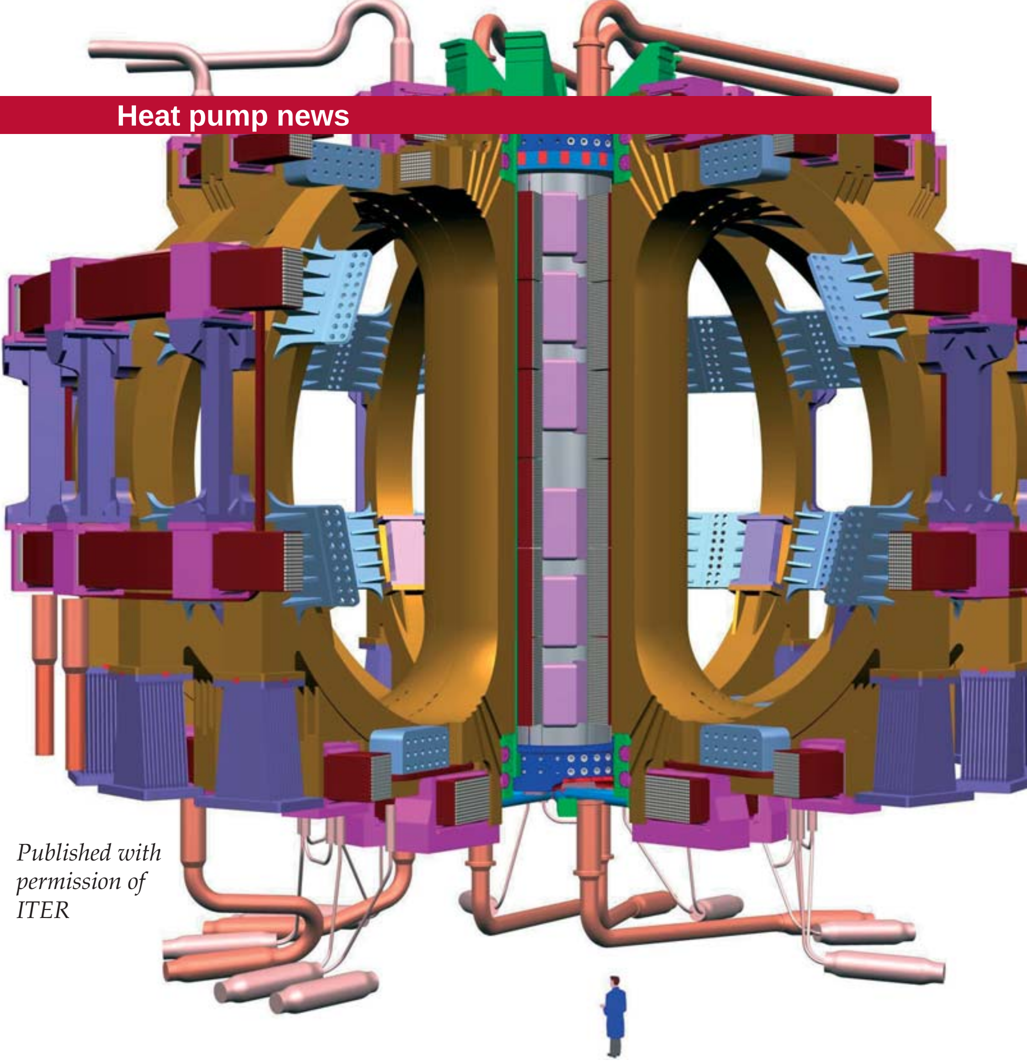

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Huge-scale cryogenics – ITER

France – The ITER plant, a fusion reactor based on a hydrogen plasma torus (Tokamak), will be constructed in Cadarache in France, with work starting in 2008. The plasma temperature will exceed 100 million °C and provide 500 MW of fusion power. A liquid helium cryogenic cooling system, with a capacity of 43 kW, will be used for cooling magnets and cryopumps. The system consists of three parts; the cryoplant, the cryogenic distribution system and the system of pipes and manifolds. An 80 K helium circuit, together with a liquid nitrogen pre cooling stage, is used for cooling the thermal shield inside the cryostat.

Source: IIR Newsletter, no. 25, January 2006

Markets

The Chinese air-conditioning market in 2005

China – The State Information Centre of China (SIC) has presented a White Paper containing detailed information on air conditioner (AC) production, import and exports and sales in major domestic cities. The statistics are based on figures gathered from 750 air conditioner retailers in 106 domestic cities.

The results show that, although the AC market is still increasing in the large cities, the rise is slowing down. Sales volumes increased by 9.5 % in 2005 compared to 2004. The number of units exported was 24.68 million, and approximately the same number was sold on the domestic market. The average price of an air conditioner in the domestic market in 2005 was RMB 2529 (approx. USD 313), and the average export price was USD 160.

The competition is fierce, and 27 AC brands disappeared from the market in 2005. 69 brands are still on the market, although 48 of them have market shares of less than 1 % in large cities. Another interesting issue for 2006 is that although the production capacity of AC units in China is estimated at 80 million units per year, total sales are expected to amount to only about 50 million units, leaving a production capacity surplus of approximately 30 million units.

Source: IIR Newsletter, no. 25, January 2006, and JARN, November 2005

Sales record (again) for the US market

USA – For the fourth consecutive year, manufacturers of air-source heat pumps and unitary air conditioners shipped a record number of units. 8.6 million units were sold in 2005 – an increase of 16 % over 2004. Several effects, such as a strong economy, growth in new construction of buildings and rebuilding in the hurricane-ravaged Gulf Coast area, are put forward to account for the continuous growth. Manufacturers are also thought to have cleared their stock of 10-SEER equipment as the new 13-SEER efficiency standard came into force on January 23.

Source: www.ari.org

World market for chillers

Total world shipments of chillers in 2004 is estimated at 200 400 units. Chillers can be divided into the following categories: centrifugal chillers, absorption chillers and positive displacement chillers. Below is a summary of each segment.

Centrifugal chillers

This is the main product for large applications. USA is the largest market, and also the production centre for these units. Carrier, McQuay, Trane and York are the dominating manufacturers, both in the USA and in the world. The US market amounted to 3 500 units in 2004, representing 41 % of the world market. The second largest market is China, with 1 500 units, followed by Japan, Korea and Taiwan with approximately 300 units each. Midea and Gree have started to manufacture centrifugal chillers in China. MHI, Hitachi and Ebara are the three Japanese manufacturers.

Absorption chillers

The market for units over 100 RT (refrigeration tonnes) is concentrated in the Far East. 4 000 units were installed in China in 2004, 1 600 units in Japan and 900 units in Korea, together making up approximately 85 % of the world market. The large manufacturers in China are Broad, Shuangliang, Dalian, Sanyo, Carrier and Ebara. In Japan, the main manufacturers are Sanyo, Hitachi, Ebara, MHI and KTE.

Positive displacement chillers

These chillers (scroll, reciprocating and screw) have penetrated a large part of the world market, unlike the two types mentioned above. These units are particularly common in Europe, with Italy being by far the largest market in terms of manufacturers and varieties of products. Major manufacturers are Aermec, Bluebox, Ciat, Climaventa, Clivet, Emicon, Ferroli, Hitsa, RC and Rhoss. Scroll compressors are commonly used for small units, and screw compressors for the larger units. Reciprocating compressors are gradually being replaced by these other two types.

Source: JARN special edition, November 2005

IEA Heat Pump Programme

Norwegian internet home page on ground-source heat pump systems

As a part of the Norwegian work on IEA HP Annex 29, "Ground-Source Heat Pump Systems Overcoming Market and Technical Barriers" (2004–2006), SINTEF Energy Research has developed an Internet web site: http://www.energy.sintef.no/prosjekt/Annex29/

Although the site has been established to serve Norwegian users, there is plenty of information for English-speaking visitors, including:

- A presentation of IEA HPP Annex 29
- Information on ground-source heat pump systems
- Installation examples
- Publications – technology, laboratory/field measurements, computer programmes, market and environment
- Internet links
- News
- International research activities

The web site has become very popular, and the average number of visitors is about 40 000 per annum.

Source: Jørn Stene, SINTEF Energy Research, Norway

Annex 30 - Retrofit heat pumps for buildings - Status report 2005

It is well known, that the market potential for heat pumps for retrofitting existing buildings is much greater than that for the supply of heat pumps for new buildings. However, in the majority of IEA HPP member countries, the heat pump market for existing buildings today is small compared with the market for heat pumps for new buildings. Annex 30 is therefore intended to help to overcome the technical and market barriers in this interesting market sector.

The members of Annex 30 at present consist of five German national and international companies and organisations, with active participation from France, The Netherlands and Sweden (via a company in Germany). The programme of work is consequently concentrated on the European situation in residential buildings. There is, however, considerable interest in active cooperation with North America and Japan in order to provide a more global view of the situation.

The programme is subdivided into four tasks:
Task 1: State of the Art, Market Analysis
Task 2: Matrix of Heat Pumps
Task 3: Overcoming Economic, Environmental and Legal Barriers
Task 4: Improvement of Components and Systems.

Work started with Task 1: "State of the Art, Market Analysis". To cover all aspects, the participants developed a matrix of information covering not only the current built environment but also heating and cooling construction and design practices in different regions, depending on climatic and cultural aspects, type of power generation, legal aspects, support programmes etc., as well as on the type of heating systems, centralised or decentralised heat supply, water or air heat distribution systems, domestic hot water production etc.

The second annex meeting took place on 02.12.2005 in Bochum-Wattenscheid/ Germany, and was attended by nine representatives from all participating countries. The main task of the meeting was a discussion of the status, content and presentation of the results of Task 1, as well as preparation of Task 2, "Matrix of heat pumps".

Detailed minutes of the two meetings as well as all information relating to the annex are presented in the password-protected web site of the IZW home page
www.izw-online.de

Task 2, and in particular the collection of case studies and demonstration projects, as well as RD&D projects directly related to the objectives of the annex, has been defined and first results have been received from the participating countries.

In order to obtain a more complete picture of the European situation, similar information as that from Tasks 1 and 2 needs to be collected from other countries - not yet participating - such as Austria, Belgium, Italy, Norway, Spain, Switzerland and the UK. If you could provide us with information, or would like to join the annex, please contact:

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Source: IZW e.V. Germany

Presentations from two workshops added to the HPC web site

In the previous Newsletter, we reported that the Heat Pump Centre web site (www.heatpumpcentre.org) now also contains presentations from workshops held in conjunction with Heat Pump Programme Executive Committee meetings and other Heat Pump Programme events. Presentations from workshops held in Montreal in May 2004 and in Paris in November 2004 have now been added. The presentations at the Paris workshop concerned performance standards for heat pumps, air conditioning energy policy, and technical and market developments. The Montreal workshop included an overview of the Canadian energy situation and examples of programs and tools promoting energy efficiency, renewable energy sources and heat pumping technologies. In all, the web site now contains presentations from all the workshops held since 2004, and will be continuously updated with new workshops.

Source: Heat Pump Centre

Annex 31 - advanced modelling and tools for analysis of energy use in supermarket systems

Supermarkets are the most energy-intensive buildings in the commercial sector. It has been estimated that 3-5 % of total electricity use stems from supermarkets in industrialised countries. In addition, it is estimated that the annual refrigerant losses are as high as 15 - 30 % of the total charge, thus making supermarkets the second largest emission source after mobile air conditioning. The supermarket sector has therefore a significant role to play, not only from the point of view of the energy consumed but also from the point of view of the impact of refrigerant leakage.

The overall objective of Annex 31 is thus to provide new knowledge, methods and tools for improved energy efficiency of, and thus reduced environmental impact from, supermarkets. The aim is also to share ideas and best practices among participating countries.

The participating countries are Canada (Natural Resources Canada), Germany (IZF) and Sweden (Royal Institute of Technology [Operating Agent] and Swedish National Testing and Research Institute). Four more countries - the U.S.A, France, Norway and Austria - have shown interest in participating in the annex. Turkey has also shown interest in participating.

In order to achieve the objectives of the annex, it is planned that the following task-sharing activities should be carried out by the participants:
Task 1: Collection of available data from different supermarkets (benchmarking)
Task 2: Development of performance indices for supermarkets
Task 3: Development and validation of a model library for specific supermarket equipment
Task 4: Development of whole-building simulation models.
Task 5: Comparison of the results obtained with the different whole-building simulation models for selected case studies
Task 6: Future perspectives and possibilities
Task 7: Dissemination of the knowledge obtained (indices, guidelines, papers, fact sheets)

The kick-off meeting was held on 20th January 2006 in Chicago in conjunction with the ASHRAE Winter Meeting, and was attended by eight participants from three countries. The discussion was principally concentrated on Tasks 1 and 2 of the annex.

A brainstorming activity/discussion was undertaken. It was decided that data for analysis and supermarket characterisation, as needed for Tasks 1 and 2, would be collected at four different system levels.

Future meeting were discussed, and it was decided to host an open workshop and a working meeting in Germany in conjunction with the IKK. Another meeting is planned in conjunction with the IIR conference in Beijing 2007. The group also decided to use the internet meeting tool, “Centra”, for meeting purposes. The first Centra meeting was held the 23rd of February, attended by 6 participants from three countries.

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Annex 32 - Economical heating and cooling systems for low-energy houses

Heat pumps are the only type of equipment which can produce both heating and cooling energy, even at the same time. Multifunctional heat pump systems for space heating, domestic hot water production, ventilation and air conditioning may therefore be a cost-effective way of meeting all building needs with one integrated system.
Fig. 1 shows a general system layout of multifunctional heat pump systems.

In the field of low-energy and ultra-low-energy houses, what are known as heat pump compact units for space heating, domestic hot water production and ventilation have already been introduced in some markets, e.g. in Germany.

Annex 32 will investigate various system configurations of integrated heat pump systems and associated source and distribution systems for application in low-energy and ultra-low-energy houses.

The principal objectives of Annex 32 are:
- to enhance multifunctional heat pump systems with regard to overall energy use, thermal comfort and costs
- to gather more field experience with real-world operation of integrated heat pump systems
- to derive design guidelines for multifunctional heat pump systems, including the control systems

The Annex has been structured in four tasks:

Task 1 – System investigation
Task 2 – Assessment, calculation and comparison of system solutions
Task 3 – Field testing of systems (in parallel with Task 2)
Task 4 – Design guidelines of systems and control systems

Annex 32 was approved at the November 2005 meeting of the HPP ExCo, and started in January 2006. The project time is scheduled for three years. So far, five countries are participating in Annex 32: Canada, Germany, Sweden, Switzerland (Operating Agent) and the USA. Other countries may join.

The kick-off meeting will be held in April 2006, with an introduction of the participants, general project planning and coordination of the national contributions. Until an Annex 32 web site is set up, information on the annex can be found on the HPC web site, under the category 'Projects'.

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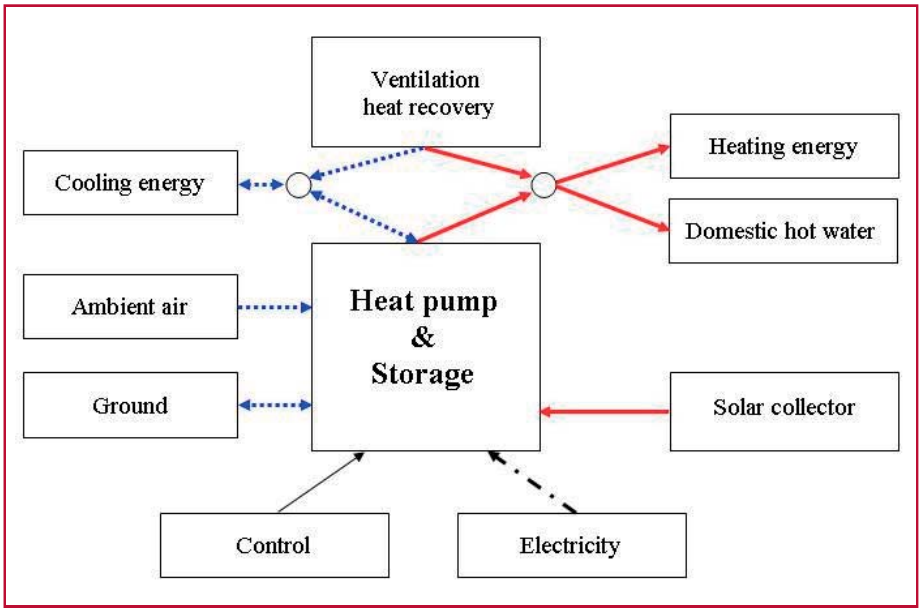


Fig. 1: General system layout, with the core components of heat pump and storage

Ongoing Annexes

Bold text indicates Operating Agent.

Annex 29 Ground-Source Heat Pumps - Overcoming Market and Technical Barriers	29	AT, CA, JP, NO, SE, US
Annex 30 Retrofit heat pumps for buildings	30	DE, FR, NL
Annex 31 Advanced modelling and tools for analysis of energy use in supermarkets.	31	CA, DE, SE
Annex 32 Economical heating and cooling systems for low-energy houses.	32	CA, CH, DE, SE, US

IEA Heat Pump Programme participating countries: Austria (AT), Canada (CA), France (FR), Germany (DE), Japan (JP), The Netherlands (NL), Norway (NO), Sweden (SE), Switzerland (CH), United Kingdom (UK), United States (US). All countries are members of the IEA Heat Pump Centre (HPC). Sweden is Operating Agent of the HPC.

Gas engine-driven heat pump systems

Toshihiko Fujita, Japan

The "gas heat pump (GHP)" uses a natural gas-powered or LPG-powered engine to drive the compressor in a vapour-compression refrigeration cycle. The Japanese market for GHP air conditioners has been growing steadily since they were commercialised, with annual shipments of about 40 000 outdoor units in recent years. The major factors in their growth are power savings and low operating costs compared to "electric heat pump (EHP)" systems. This paper introduces the technology and market trends for the GHP in Japan.

Introduction

GHP systems fall into two broad categories: individual air conditioners and water chiller-heaters. GHP air conditioners were developed and introduced in 1987 by a consortium of three major gas companies and several manufacturers in Japan. They have come into wide use in the last 18 years with diversification of types and capacities as well as improvements in energy efficiency. Recently a GHP water chiller-heater of 56 kW cooling capacity was also commercialised. As far as larger GHP water chiller-heaters in Japan are concerned, several tens of units were shipped during the 1980s to use in central air-conditioning and/or hot water supply systems, but did not subsequently come into wide use due to the decline in energy costs.

Features of GHP

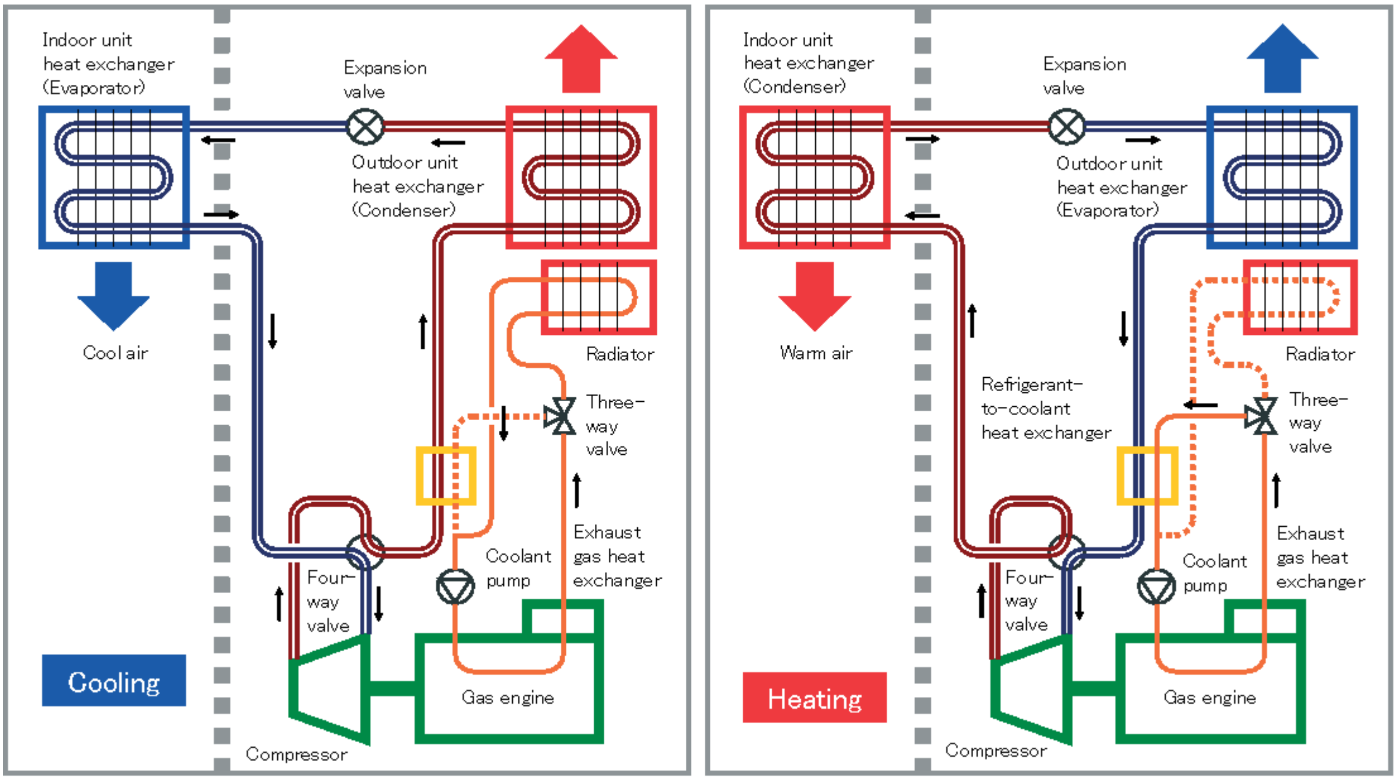
As shown in Figure 1, the basic configuration of a GHP is almost the same as that of an EHP, with indoor and outdoor heat exchangers as either evaporator or condenser, a compressor, and an expansion valve(s). HCHC22 was used as the refrigerant at first, but was changed to HFC407C in 1998 and then to HFC410A in 2004.

GHP systems with high-efficiency engines can necessarily attain higher energy efficiency than EHP systems because they have essentially the following advantages:

- Effective use of energy by recovering heat from the engine jacket coolant and exhaust gas
- High thermal efficiency at part load with simple control of engine speed

Until now, GHP technology development has concentrated on improvement of efficiencies of engines, compressors and heat exchangers, reduction of maintenance requirements

Figure 1 Schematic of gas heat pump system



and establishment of microcomputer control and remote monitoring systems. Advances in GHP technology have reduced the fuel consumption by about 40% in comparison with that of ten years ago, as shown in Figure 2. The features of GHP air conditioners are summarised as:

- Speedy pickup and powerful heating without frosting
- Comfort air-conditioning and energy savings through variable-speed operation
- Electric power savings, i.e. reduction of power consumption by a factor of about 10 compared with EHP air conditioners, and thus contributing to a reduction in demand during the summer
- Cost savings with discounted gas rates for gas air-conditioning systems

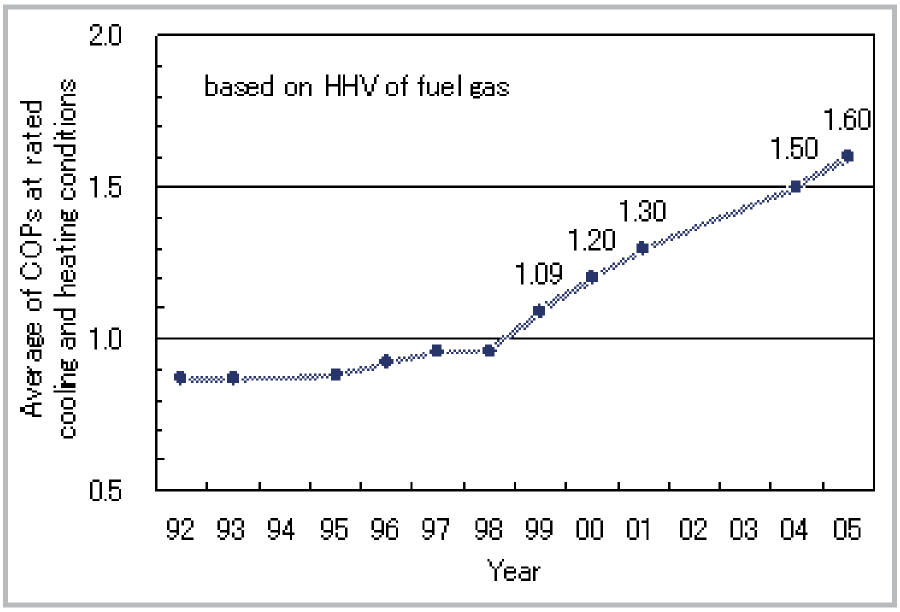


Figure 2 Progress in COP of top-rated GHP systems

Varieties of GHP air conditioners

There are two types of GHP air conditioners on the market, depending on the arrangement of outdoor and indoor units, piping, and controls: the "Building multi" type and the "Packaged" type. The "Building multi" type can connect up to 32 indoor units of various types and capacities to an outdoor unit of 22.4 to 84 kW cooling capacity, which provides advantages in the form of flexibility of piping system design, an excellent centralised monitoring system, etc. The "Packaged" type can connect up to ten indoor units to an outdoor unit of 14 to 84 kW cooling capacity. Indoor units can be of single or twin type, simultaneous operation type with 4 - 6 indoor units, or the Store Multi type, which are packaged systems with multiple-indoor units. The latest GHP variations are:

- The Ultra High-Efficiency Multi type, with average rated cooling and heating COPs of 1.60 (based on HHV)
- The High-Power Multi type, i.e. multiple indoor unit type with generator, with GHP types consuming only about 1/100 of the utility power required by the equivalent EHP type.
- The W Multi or Dual Multi type, using a simplified combination of two or more outdoor units
- The Simultaneous Heating and Cooling Multi type
- The Renewal Multi and Packaged Renewal types, which can use existing refrigerant piping systems as they are
- The Building Multi type, with a hot water supply system

GHP market trends

Figure 3 shows the domestic sales statistics for GHP air conditioners from FY 1994 to FY 2004 as the total of both natural gas- and LPG-fuelled systems. The share of the natural gas-fuelled system has gradually increased, reaching 67% in FY 2004. In recent years, shipments of GHP outdoor units have tended to decrease in number, with the effect of levelling off total capacity, which indicates the increasing demand for larger outdoor units. In fact, the Building Multi-type GHP systems have been bought even for large office buildings with floor areas of 10 000 m2 or more. Figure 4 shows the breakdown of the total

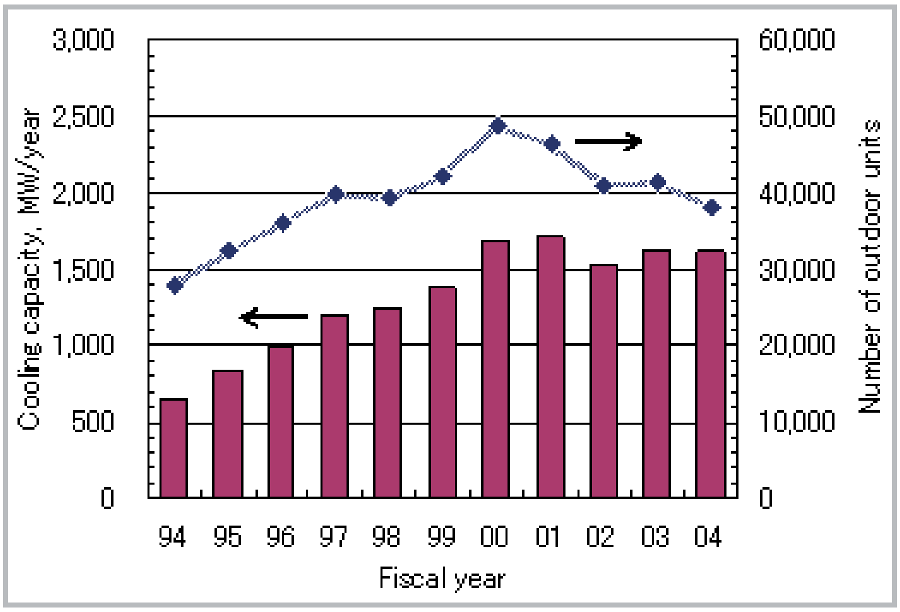


Figure 3 Domestic shipments of GHP systems (by GHP consortium, Japan)

cooling capacity of natural gas-powered GHP air conditioners in FY 2004 for reference.

Conclusions

Demand for GHP systems is expected to continue, as the replacement market for building air-conditioning systems is growing year by year, and there is a general trend toward individual air-conditioning systems even in large buildings. GHP systems are cost-efficient in Japan; and also meet the socials need of today, particularly in respect of savings of utility power in summer and of primary energy.

In addition, Japanese Industrial Standard (JIS) B 8627 – 2000 "Gas engine driven heat pump air conditioners" will shortly be revised, to reflect the increase in rated cooling capacity of up to 85 kW and new criteria for testing and rating of seasonal energy consumption.

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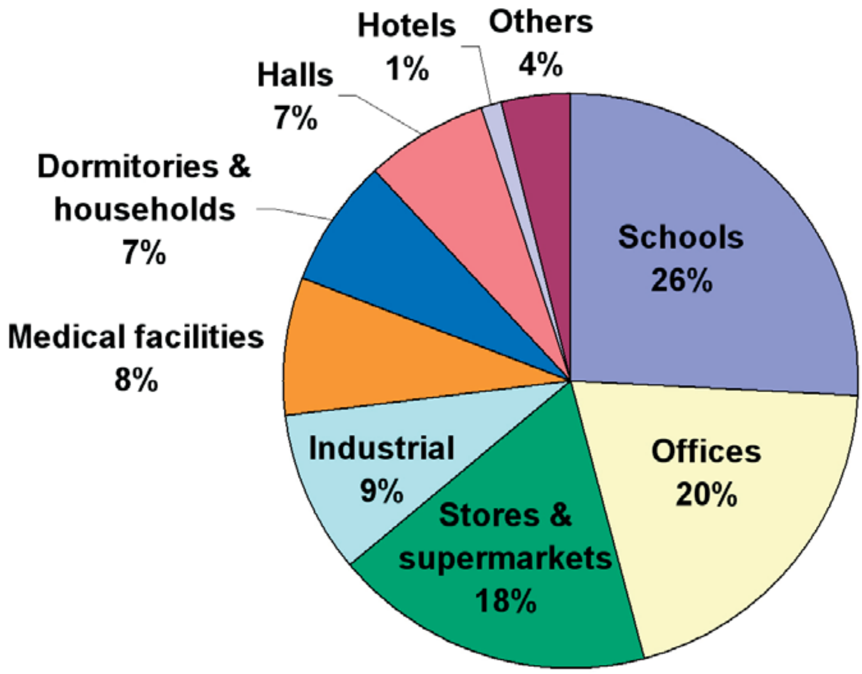

Figure 4 Breakdown of total GHP capacity by application (by The Japan gas association, JGA)

The feasibility of absorption chillers using low-temperature heat sources

Viktoria Martin, Sweden

Heat-driven cooling using environmentally safe refrigerants (e.g. salt and water) is a proven thermodynamic short cut for energy-efficient cooling. There is a theoretical potential of saving half of the primary fuel needed to produce cooling as compared to conventional vapour compression technology. In this context, the lower the heat source temperature requirement, the better suited it is for solar cooling systems, for cooling production utilizing waste heat, or for combination of absorption cooling with CHP. Researchers at KTH in conjunction with industry have worked on developing low-temperature absorption technology concepts for over a decade. The results have been published in various ways and some key issues from this research are presented here, along with main conclusions and some thoughts on future R&D requirements.

Introduction

Conventional air conditioning, using vapour compression technology, consumes large amounts of electricity, often during hours of peak power demand. In addition, conventional technology still uses environmentally harmful refrigerants. Heat-driven cooling using environmentally safe refrigerants (e.g. salt and water) is a proven thermodynamic short cut for energy-efficient cooling. There is a theoretical potential for saving half of the primary fuel needed to produce cooling as compared to conventional technology [1].

Conventional single-effect absorption chillers designed for 120 °C drive temperature can operate on heat as low as 90 °C, but with reduced cooling effect and slightly lowered COP (coefficient of performance). However, even lower temperature, as low as 70 °C, could be helpful for use with solar systems, for cooling production utilizing waste heat, or when combining absorption cooling with CHP. In addition, the distribution of energy for comfort cooling could be efficiently arranged by transportation of hot water to chillers sited near the customers. For these reasons, researchers at KTH have worked for over a decade with industrial partners to develop low-temperature absorption technology concepts. The results have been published in various ways (e.g., [2-4]) and some key issues from this research are presented here, along with main conclusions and some thoughts on future R&D requirements.

Design aspects of absorption chillers – effect of heat source and sink temperatures.

Conventional absorption chillers, designed to run on 120 °C heat, can run on heat at temperatures as low as 80 °C if a chiller with a large enough generator area is used. However, this has an adverse effect on the dimensions of other components and leads to a lower COP. For a given desired cooling effect, when operating a chiller on a temperature lower than its design value, it is necessary to choose the chiller size such that the generator heat transfer surface is large enough for this lower temperature. Consequently the low-pressure components in the chiller (i.e., the absorber and evaporator) are oversized and the system is not optimal from a cost point of view. Furthermore, since the solution flow rates in the chiller remain the same, i.e. at the design values for a higher operating temperature and cooling effect, and since the solution/solution heat exchanger (between the generator and absorber) is not ideal, the COP of the chiller will be reduced at lower operating temperatures. This COP reduction is qualitatively depicted in Fig. 1.

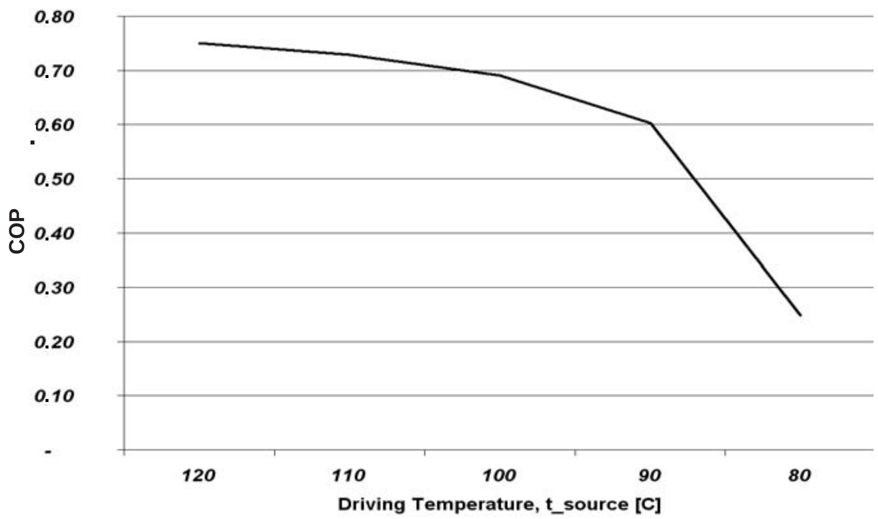

Figure 1. Coefficient of performance versus heat source temperature when the chiller is designed for 120 °C.

The low-temperature concept

The KTH design of a low-temperature absorption cooling system has included:

- optimisation of the heat transfer area in each component to suit the new lower design temperature (below 90 °C), taking into account the specific heat sink temperature of a particular application;
- working with flat plate heat exchangers, particularly suitable for flexible chiller design, and with good heat and mass transfer characteristics;
- using the flexible plates to allow the chiller's heat transfer surfaces to be installed horizontally or vertically, depending on the specific application (in a conventional absorption chiller, tube-surfaces are always horizontally aligned);
- heat transfer enhancement using new additive 2-methyl-penthanol, as compared to the conventional additive 2-ethyl-hexanol;
- a variable flow system, allowing for high COP even at part load.

Compared to conventional chillers, the generator part is larger but now the other heat transfer surfaces are optimally sized for a particular cooling effect. The work has resulted in a 1.15 $MW_{cooling}$ chiller being installed at Chalmers University in 2000. The chiller operates on heat from the district heating network, having a supply temperature of 90 °C or less. Recorded performance during the 2003 cooling season showed successful operation, delivering about 10 MWh/day at a COP between 0.7 and 0.8. Further details are given in [5].

Cost efficiency

For custom-designed solutions such as the above low-temperature chiller, the question is whether these chillers, despite their slightly higher capital cost, are energy-efficient and cost efficient in comparison with conventional, off-the-shelf absorption and vapour compression chillers? In a recently published study, an in-house optimisation program was used to model how the optimum size of components, mainly the required heat transfer area, is affected by heat source and heat sink temperatures [2]. Some results are summarised in Figures 2 and 3.

Figure 2 shows normalised costs, such that the cost for each set of conditions (t_{source} and t_{sink}) is normalised with respect to the cost for a chiller where t_{source} = 90 °C, and t_{sink} = 23 °C. For each case, the desired chiller COP was 0.75. From the figure, it can be seen that:

- for a given heat sink temperature, t_{sink}, the marginal cost is increased by about 40 % when the operating temperature, t_{source}, is lowered from 90 to 70 °C. For the case with t_{sink} = 25 °C, this increase is close to 60 %.
- for e.g. t_{source} = 90 °C, the marginal cost increases by about 50 % when tsink increases from 21 to 25 °C.

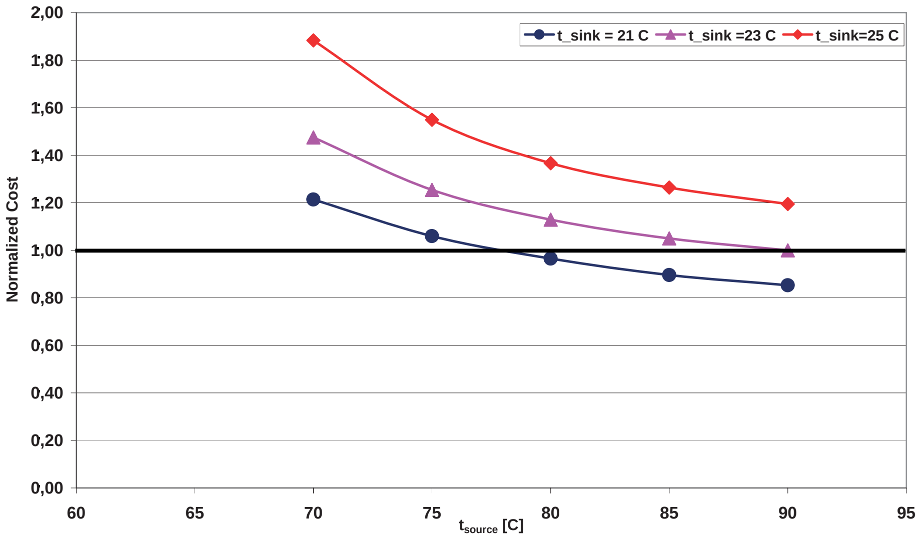

Figure 2 Influence of heat sink and heat source temperatures on the normalised chiller cost

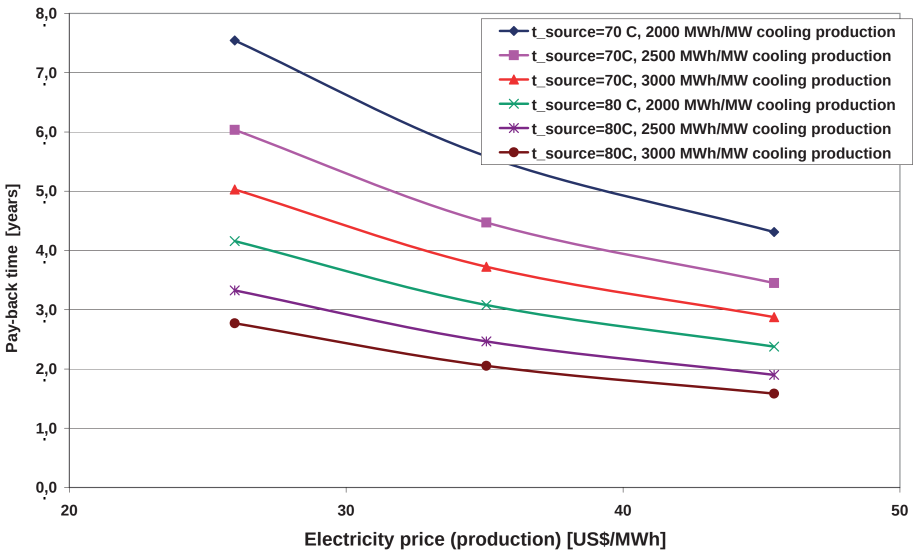

Figure 3 Payback time for lowered chiller operating temperature in trigeneration system (CHP and cooling).

Figure 3 shows that:

- although the capital cost of the chiller increases with decreasing operating temperature, the pay-back time for this extra investment is reasonable.
- at lower electricity prices, the importance of the annual cooling production per unit chiller effect [$MWh_{cooling}$/MW] increases.
- for t_{source} = 70 °C, and low electricity prices, the effect of the cooling production [$MWh_{cooling}$/MW] is larger than for t_{source} = 80 °C. This is due to the greater increase in electrical yield when reducing the temperature requirement from 90 to 80 °C, than that which is obtained when further reducing it from 80 to 70 °C.

Conclusions

The design of absorption chiller systems can best be summarised as an iterative procedure where there is a need for flexibility in input parameters so that it is easy to adapt to local conditions. Examples of such conditions are electricity price, available heat sink and heat source temperatures, demand for a certain return on investments and so on. In the design work described above, the dramatic effect of the heat sink and heat source temperatures on the chiller marginal cost (mainly cost for transfer surfaces) has been demonstrated. Thus the best design is very dependent on the local conditions.

In design, care should be taken to find as low a heat sink temperature as possible. It could be beneficial to locate the chiller near such a sink and then transport the driving heat to the chiller by, for example, a district heating network. It could also be beneficial to add on thermal energy storage to store cold generated during the night for use during the day.

Reducing the driving temperature of an absorption chiller from 90 to 70 °C increases the marginal cost by about 40 %. However, for the example with an absorption chiller integrated with CHP in a trigeneration system, the pay-back time resulting from the increased electricity production with the lower temperature requirement, is reasonable – around three years at an electricity production price (excluding grid access fees and local taxes) of USD 45/MWh_{el}, and a cooling production of 3000 MWh/MW chiller effect. Nevertheless, in a practical situation, it may be difficult for the chiller manufacturers to argue for the extra capital cost of low-temperature chillers. This situation is likely to change as utility companies take on a holistic view of the production of power, heat, and cooling.

Research into heat-driven cooling as a part of a sustainable energy system is ongoing. At present, KTH is involved in several EU-funded projects, such as one concerned with integration of absorption cooling with a biomass-fired CHP plant. A 2 MW-cooling plant is a planned outcome of this project, along with documented experience from the dynamic interaction of the absorption chiller with the CHP plant. In addition to system studies such as this EU-project, a rigorous cost assessment of the absorption chiller is needed, resulting in a cost breakdown of various parts (e.g., heat transfer components and salt solution) and an analysis of the dependency between cost and local design specifics. This should be conducted in parallel with R&D projects for cost minimisation through optimised design.

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Development and commercialisation of triple-effect absorption chiller-heaters

Kazuyuki Makita, Japan

Kawasaki Thermal Engineering (KTE) participated in the government-led project on "High Performance Development Triple-effect Absorption Chiller/heaters " to realise higher efficiency than the maxed-out efficiency of double-effect chiller/heaters for further energy saving, an urgent matter for global environmental protection. KTE has successfully commercialised a triple-effect efficient absorption chiller/heater. The newly commercialised triple-effect machine has considerably high energy-saving performance, with a part-load coefficient of performance (COP) in reaching 1.7, based on the upper calorific value of the fuel gas. Thanks to a newly developed high-temperature generator, the triple-effect machine demonstrates the same durability and reliability under higher temperature and pressure as the double-effect machine.

Introduction

The Kyoto Protocol has become effective since February 2005, under the terms of which Japan has been obliged to reduce greenhouse gas emission by 6 % relative to the base year 1990 over the period 2008 - 2012. Carbon dioxide generated in fuel combustion accounts for about 90 % of total greenhouse gas emissions in Japan, and so measures for significant carbon dioxide reduction are badly needed.

Further energy saving becomes a matter of urgency in the air-conditioning industry as well. Industrial-use absorption chiller/heaters are widely used for offices, buildings, hotels, hospitals and so on, where drastic improvement of their efficiency is a key issue. Current market-dominant double-effect absorption chiller/heaters are reaching the end of their performance improvement possibilities since the world's first double-effect chiller/heater was launched by Kawasaki Thermal Engineering Co., Ltd. (KTE) in 1968.

Under the circumstances, the New Energy and Industrial Technology Development Organization (NEDO) launched the government-led four-year development project from 2001 to 2004 with KTE, the Japan Gas Association (JGA) and others, to overcome the limits of the double-effect system. In October 2005, KTE successfully commercialised triple-effect chiller/heaters for the first time through participation in the project (Figure 1).

This article describes KTE's development efforts and the process to commercialisation of triple-effect chiller/heaters.

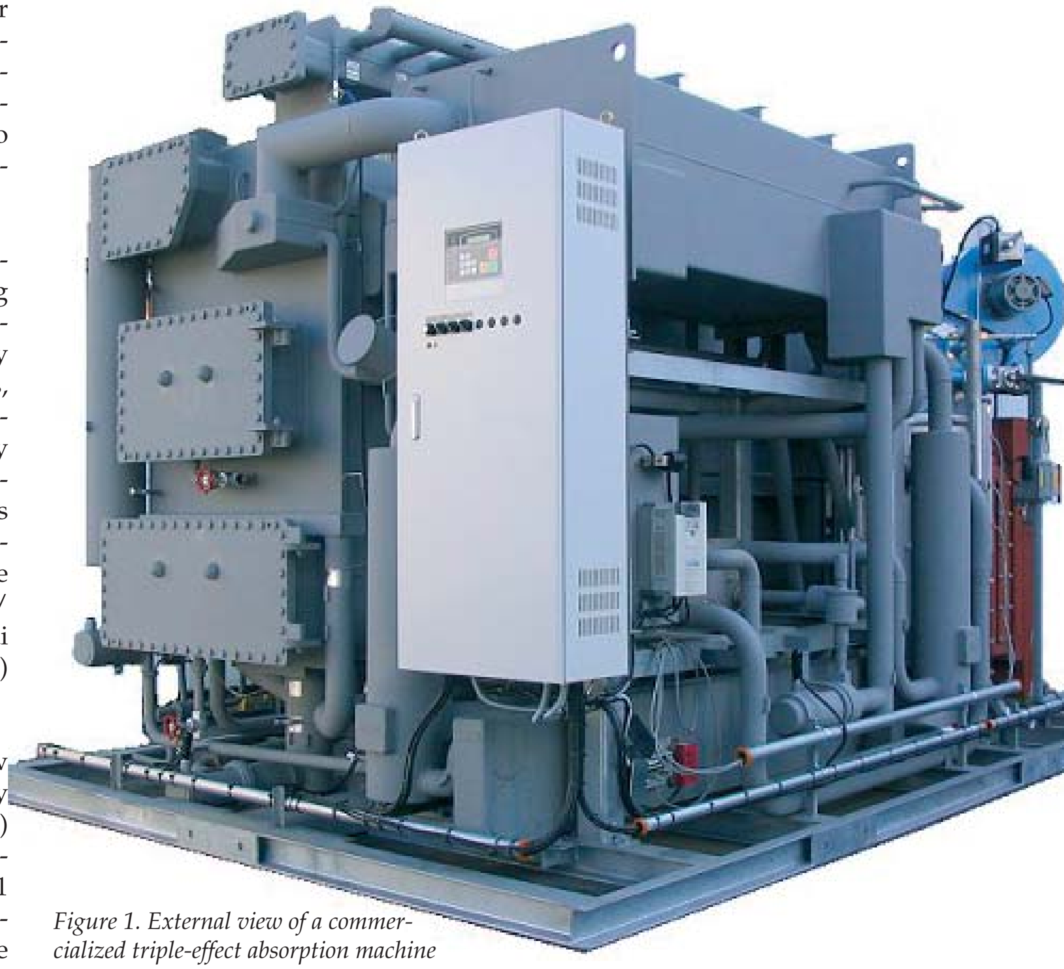

Figure 1. External view of a commercialized triple-effect absorption machine

Principle of triple-effect chiller/heater

The triple-effect chiller/heater consists of a currently prevailing double-effect system, with a newly added high-temperature and pressure generator. Figure 2 shows that the machine has a total of three generators (high, middle and low-temperature). The high-temperature generator is heated by a high-temperature heat source such as gas combustion.

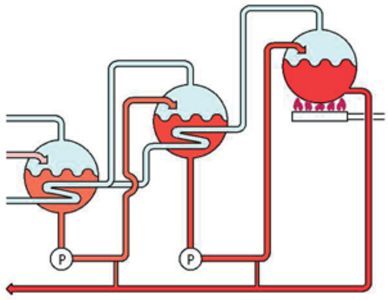

Figure 2. Principle chart of triple-effect system

Heat generated in the high-temperature generator flows successively to the downstream generators. Specifically, refrigerant vapour generated in the high-temperature generator heats the absorbent in the middle temperature generator, which in turn generates refrigerant vapour, which heats the absorbent in the next low-temperature generator. The middle temperature generator uses the refrigerant vapour as a heat source to a medium temperature level before being drained. Such medium temperature-level refrigerant drainage is still a heat source for the low temperature generator, the temperature of which is lower than the drainage temperature. The first heat input in the upstream high-temperature generator is successfully used in three stages down to the downstream high-temperature generator; with the result that the triple-effect chiller/heater has a higher COP than the double-effect system.

Points of development

The high-temperature generator of the triple-effect machine operates at higher temperatures and pressures than the double-effect machine, which is an important difference. There were two critical matters to overcome for such high temperature and pressure.

One was that the high-temperature generator would be regarded as a boiler in Japan, because the refrigerant vapour pressure generated in the high-temperature generator exceeded atmospheric pressure. This meant that we had to meet rules and regulations of the "Safety Rules of Boilers and Pressure Vessels" and the "Boiler Structure Regulations" as well as to develop a suitable high-temperature generator. Thanks to KTE's accumulated know-how as a boiler manufacturer, we have successfully developed a new and highly reliable high-temperature generator in a relatively short time.

The other critical matter was rising absorbent temperature with rising pressure. For a solution, KTE developed an anti-corrosion technology for high-temperature absorbent and evaluated the durability of the new high-temperature generator. Additional development efforts resulted in optimising heat cycles, improving the respective efficiencies of and downsizing the individual components and developing waste heat recycling technologies and optimising controls.

Development process and results

The author will outline KTE's development efforts and results to overcome the above-mentioned various challenges:

(1) Durability test and dismantlement for investigation

Anti-corrosion technology was the most critical development issue. We examined the durability of the new high-temperature generator used in the triple-effect absorption chiller/heater. Thee machine was the dismantled to determine if it successfully endured heat or not.

Table 1 outlines the durability test.

Table 1. Outline of Durability Test

Test subject	2nd generation pre-production model; of 300RT (Rated cooling capacity of 1055kW)
Test operation load	Maximum cooling capacity
Test operation hours	2100 hours (combustion time)
Operation cycle	The machine was subjected to cycles of ten-hour combustion followed by two-hour stop.

The machine operated for 2100 hours without initial troubles during the test period. For information, concentration of an inhibitor was properly controlled during the operation period.

After completion of the durability test, we dismantled the high-temperature generator and other high-temperature components to inspect internal corrosion. There was very slight corrosion, but its depth and progress indicated that the components were substantially durable.

(2) Field test

The Japan Gas Association (JGA) performed field testing at a participant company in the trial to evaluate operation and durability of the machine under actual use conditions. KTE built a pre-production model for the tests and performed maintenance during the field test.

The participant company's plant operated the monitored machine in the cooling mode throughout a year for its cooling process, giving an operating time of about 6000 hours/year. JGA and KTE acquired data for 14 000 hours' operation over the two-year test period. During the period, the machine operated properly without mechanical problems. JGA and KTE concluded that the triple-effect chiller/heater was durable and reliable enough in actual use from this test result.

Major features of the triple-effect absorption chiller/heater

KTE has commercialised triple-effect absorption chiller-heater through the above-mentioned development. Main features of the commercialised triple-effect machine are as follow:

(1) KTE Realised the world's highest cooling performance of COP 1.6 based on the upper calorific value of the fuel gas

The triple-effect machine delivered its rated cooling performance with a coefficient of performance of 1.6, which is beyond the limit of a double-effect machine. Energy saving was therefore at least 30% better than that of currently widespread double-effect machines, having COPs of 1.0 to 1.1.

KTE employs the reverse flow cycle for its products. This improves the machine efficiency while reducing temperatures and pressures in the high-temperature generator. Optimising the specific performance of the reverse flow cycle, KTE successfully commercialised a high-efficiency, compact and durable triple-effect chiller-heater.

(2) Triple-effect machine ensures far higher energy saving in partial loading

Fig.3 shows partial loading characteristics of the triple-effect chiller-heater. The triple-effect machine employs a newly developed inverter method to control solution cycling flow rates; thereby the machine ensures maximum COP 1.7 beyond the rated value in partial loading.

The new inverter control of solution cycling rates has three absorbent pumps, which are separately controlled by the inverter by operation conditions. This inverter control method enables the triple-effect machine to have an ideal cycling flow rate balance vital to high operation performance. Without the reverse flow cycle using three absorbent pumps, KTE could not have established this inverter control method.

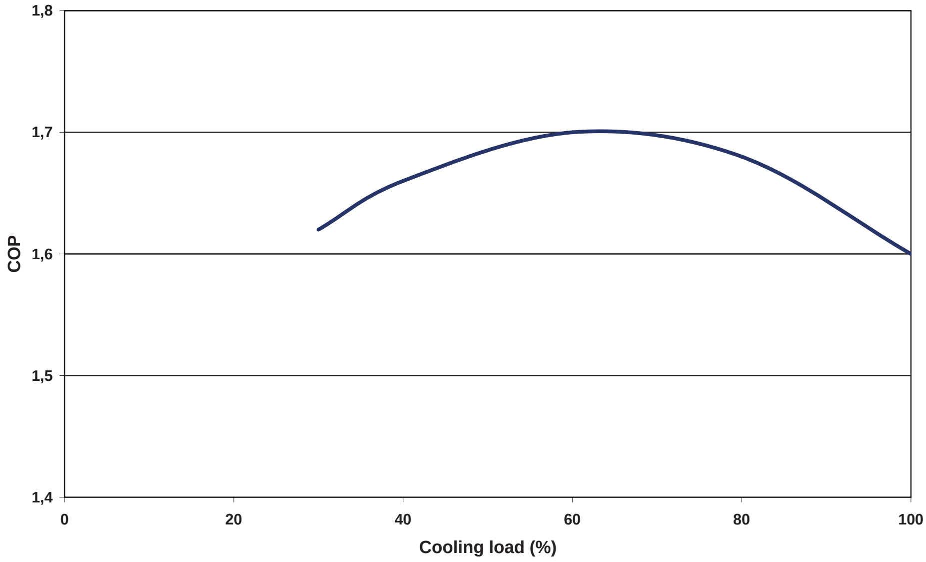

Figure 3. Partial loading characteristics

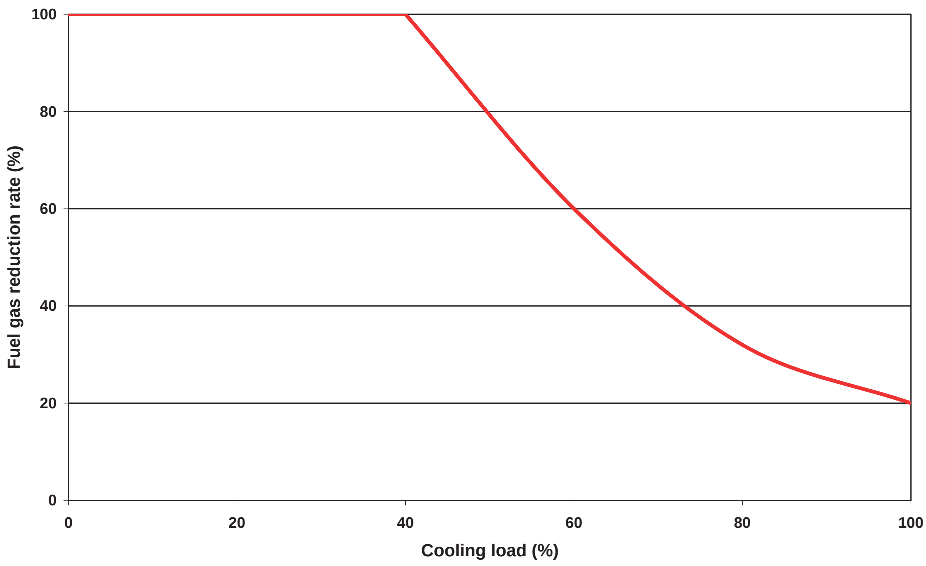

Figure 4. Fuel gas reduction rate in exhaust heat-applied operation

The triple-effect chiller-heater has excellent partial loading performance to ensure energy saving in and out of season whereby the machine significantly contributes to reduction of running costs and emission of carbon-dioxide.

(3) Further energy saving under exhaust heat applied co-generation

KTE has also commercialised a waste water heat-applied triple-effect chiller-heater. The waste water heat-applied triple-effect chiller-heater has an additional exhaust-heat-generator to collect heat from waste hot water, which enables the machine to reduce thermal dose in the high-temperature generator and reduce combustion gas consumption. The waste water heat-applied triple-effect chiller-heater is capable of reducing fuel consumption rate by 20% at rated operating condition, while it reduces more in partial loading operation. Consequently, the machine ensures cooling mode operation with waste hot water in the loading range of about 40% or lower. In short, cooling mode operation does not need fuel gas any more (Fig.4).

Table 2. Product lines of triple-effect high efficient absorption chiller heaters and main specifications

Models			Direct-fired (gas-fired) type		Waste hot water applied type	
			ΣTTG-185H	ΣTTG-340H	ΣTTJ-165H	ΣTTJ-310H
Capacities	Maximum cooling capacity	kW	651	1,196	580	1,090
	Maximum heating capacity	kW	358	658	319	600
Chilled/hot water	Chilled water temperature	°C	15.0 → 7.0°C			
	Hot water temperature	°C	55.6 → 60.0°C			
	Flow-rate	m^3/h	69.9	128.5	62.4	117.2
Cooling water	Temperature (with an exhaust-heat-generator)	°C			31.0 → 36.2°C	
	Temperature (without an exhaust-heat generator)	°C	31.0 → 35.7°C		31.0 → 35.7°C	
	Flow-rate	m^3/h	185	340	165	310
Fuel consumption rate	Maximum cooling (with an exhaust-heat generator)	kW			290	545
	Maximum cooling (without an exhaust-heat generator)	kW	407	747	363	681
	Maximum heating	kW	407	747	363	681
Waste hot water	Temperature	°C			90.0 → 80.0°C	
	Flow rate	m^3/h			14.5	27.2
High-temp generator	Heat transfer area	m^2	4.9	9.8	4.9	9.8
	Maximum design pressure	MPa	0.198	0.198	0.198	0.198

Product Specifications

(1) **Product series**
Table 2 shows the product series of the triple-effect chiller-heater and their main specifications. There are in total four models including two direct fired models of the cooling capacities of 651 kW and 1,196 kW respectively, and two waste hot water-applied models of 580 kW and 1,090 kW respectively.

(2) **Specifications of chilled water and cooling water**
The four models have a standard temperature difference of 8°C between leaving and entering chilled water. It enables them to minimise feeding power to a lower chilled water flow rate than at the conventional temperature difference of 5°C between them. They have an optional model having the temperature difference of 5°C between them.

(3) **Handling of high-temperature generator**
The high-temperature generator of the triple-effect machine is duly considered as a boiler because refrigerant vapor exceed the atmospheric pressure. To mitigate burden on users, KTE has employed simplified type and compact type of Japanese boiler categories for the high-temperature generator. They are user-friendly and bound by relatively loose regulations.

Conclusion

Energy saving by double-effect chiller-heaters has reached a limit. A newly developed triple-effect system enabled KTE to commercialise absorption chiller-heaters with significantly high energy saving performance beyond their limit, and to realise the following:

- Rated cooling performance of COP 1.6;
- Rated cooling performance of COP 1.7 in partial loading operation;
- Reduction of fuel gas consumption by 20% in rated-cooling operation with an exhaust-heat co-generation system; and
- In the loading range of 40% or lower, the machine is capable of cooling-mode operation with waste hot water only as a heat source instead of fuel gas.

Obviously, high energy-saving performance of the triple-effect machine is considerably useful for so-called heavy-load users whose machines have long cooling-mode operation. KTE demonstrated in durability and field tests that the triple-effect machine was durable and reliable enough for such heavy-load users.

The absorption chiller-heater is environmentally-friendly by its energy-efficient nature. KTE wishes that the high energy-saving performance of the machine will contribute to preserving the global environment, including carbon-dioxide emission reduction. KTE is willing to develop more efficient and reliable absorption chiller-heaters as a front-runner in energy-saving.

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A novel thermally-activated absorption cooling machine based on the diffusion absorption principle

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This report describes the development, investigation and simulation of a single-effect solar-heat-driven ammonia/water diffusion absorption cooling machine (DACM) with a design cooling capacity of 2.5 kW. The indirectly-heated, solar-powered generator with its bubble pump is the main new feature of this cooling machine. The results from the prototypes showed stable and continuous temperature and pressure levels. Coefficients of performance (COP) were between 0.1 and 0.45, while the continuous evaporator cooling performance was between 0.5 kW and 1.6 kW. An expanded, steady-state DACM model was also set up, based on the characteristic equation of sorption chillers.

Introduction

Over the last years, the air conditioning market has been continuously expanding. The Japan Refrigeration and Air Conditioning Industry Association (JRAIA) is expecting a worldwide rise in air conditioners for residential and commercial use from 60 422 000 units in 2005 (Europe 5 087 000 units) to 68 654 000 units in 2008 (Europe 6 118 000 units) [1]. The units that dominate the market are the small split type, with a cooling capacity of about 2 kW to 4 kW. Due to the large number of units manufactured, these systems are produced and offered at very low prices. However, the downside is that these units increase the adverse effects on local environments as a result of using primary energy such as electricity. At the same time, in many southern countries, they have been the main reason for the power shortages in electricity supply systems during the summer over the last few years. It is therefore very important to search for alternative air-conditioning units that are powered by either waste heat or solar thermal energy.

In the 1990s, a group of researchers developed a directly gas-heated diffusion absorption heat pump (DAHP) with a heating capacity between 3.0 kW and 3.5 kW at heating temperatures of 150 °C and evaporator temperatures from -15 °C to +5 °C [2,3]. Values of coefficients of performance for heating applications (COP_{heat}), were between 1.4 and 1.5. The industrial version of this DAHP is combined with a condensing boiler [4], but is not yet commercially available. Another industrial version of the DAHP has an output of 2.6 kW up to 8.0 kW heating capacity, with a COP_{heat} of about 1.5. A gas-powered DACM has a rating of 1.0 kW to 3.5 kW cooling capacity [5]. Bearing in mind that no suitable indirectly powered absorption cooling machines with small-scale cooling performance (1 kW to 5 kW) are available on the market, the Stuttgart University of Applied Sciences has developed and set up three single-effect solar-driven DACMs, each with a design cooling capacity of 2.5 kW [6-7].

Design of the prototypes

The well-known diffusion absorption technique, which was developed in the 1920s by the Swedish engineers von Platen and Munters [8], is based on the principle of pressure equilibrium between the high and low ammonia partial pressure sides of the unit through an inert auxiliary gas. A further feature of this type of absorption cooling machine is the use of a thermally-powered gas bubble pump for circulation of the solution cycle, instead of a mechanical solution pump, so that no mechanically moving parts are necessary inside the cooling machine. The core components of a DACM are the indirectly powered generator, condenser, evaporator and absorber, as shown in Figure 1.

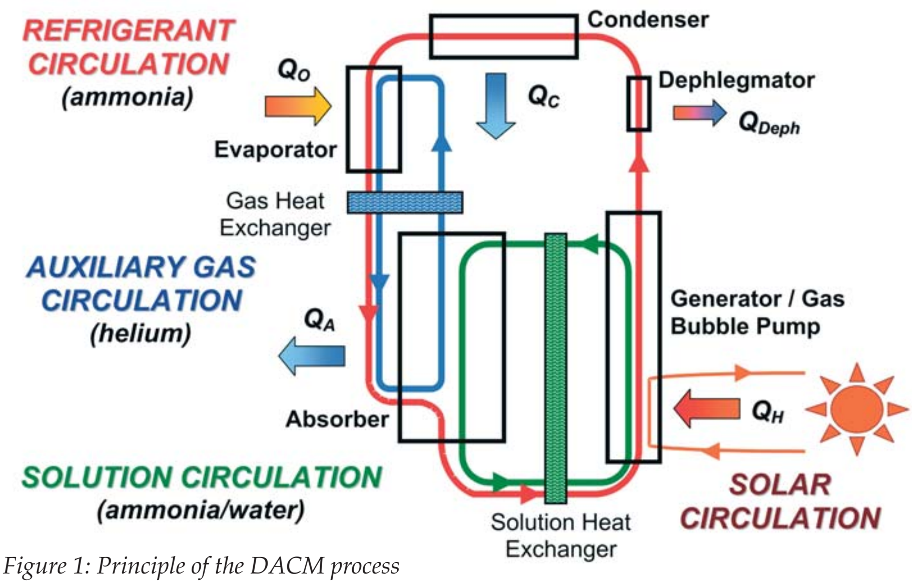

Figure 1: Principle of the DACM process

A solution heat exchanger (SHX) in the solution circuit, and a gas heat exchanger (GHX) in the auxiliary gas circuit, are also components of the DACM, together with a dephlegmator for condensation of the evaporated solvent. These components are vertical steel tubular heat exchangers or nickel-soldered plate and stainless steel coaxial heat exchangers, which are welded hermetically tight with each other. The working pair used for the solution circulation is an ammonia/water mixture. The inert auxiliary gas used is helium.

The prototypes of the DACMs are designed for air-conditioning applications as water chillers, with an evaporator temperature of 6-12 °C, and for use with cooled ceilings with an evaporator temperature of 15-18 °C. Figure 2 shows the three prototypes (Nos.1 to 3, from top to bottom), with total heights of 3.70 m, 2.40 m and 2.20 m respectively. The first prototype weighed approximately 800 kg and was in operation from November 2000 to March 2002. The second prototype was put into operation in July 2003 and ran till July 2005. With an improved, compact design, the weight of DACM No.2 was reduced to 290 kg (plate SHX) or 240 kg (coaxial SHX) was achieved. The third prototype also weighs 240 kg, and operation started in October 2005. Table 1 summarises the technical design data of the prototypes.

Operating performance

Data acquisition was conducted under laboratory conditions as well as under simulated field conditions for vacuum-tube collectors. A series of measurements were taken with the first DACM with an indirect, liquid heating system at generator heating inlet temperatures of 150 °C to 175 °C and evaporator temperatures of 25 °C down to 0 °C. The measurements were taken with and without the dephlegmator. The results showed that COP values ranged from 0.1 to 0.2 and that the evaporator cooling capacity of the pilot plant was able to reach 0.5 kW to 1.5 kW, but operation was not continuous. The lowest heating inlet temperature of the generator was 147 °C. The evaporator capacity decreased with time, due to saturation of the auxiliary gas with ammonia, as the gas circulation was insufficient. Due to the low heat recovery factors of the tubular SHXs of 39.6% and 51.1% for DACM No.1 (the low and high values correspond to the rich and weak solution sides respectively), the measured generator heating capacities were very high and so the COPs were very low.

Measured results of the second compact DACM with steady state temperature, pressure and capacity levels were obtained with variation of the heating temperatures, the cooling water temperatures and the cold brine temperatures. The heating temperature range of the generator was reduced from the 150 °C to 175 °C of the first prototype to 110 °C to 155 °C for the second prototype. This was due to the decreased lifting height

Table 1 Design data DACMs

COP (coefficient of performance, ratio of cooling output to driving heat input)		0.48
Generator	heating capacity QH	5.2 kW
	heating water in/out	130/120°C
Dephlegmator	cooling capacity QDeph	0.9 kW
	cooling water in/out	34/38°C
Condenser	cooling capacity QC	2.8 kW
	cooling water in/out	31/34°C
Evaporator	refrigerating capacity QO	2.5 kW
	cold water or brine in/out	12/6°C
Absorber	cooling capacity QA	4.0 kW
	cooling water in/out	27/31°C

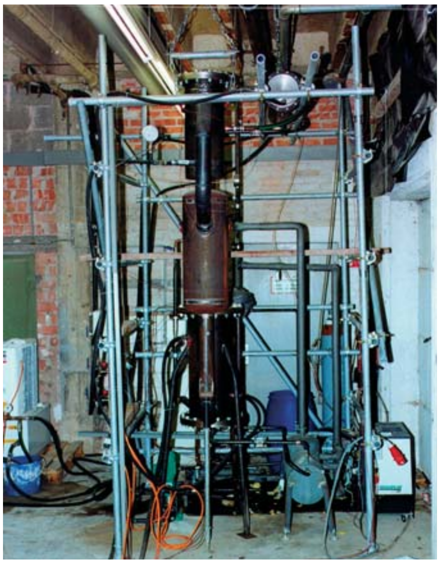

Figure 2: DACM prototypes Nos.1, 2 and 3 (from top to bottom)

(48 %) of the bubble pump. With the same heat transfer surface, the efficiency of the bubble pump increased and temperature levels dropped. COPs were between 0.2 and 0.45, and the continuous evaporator cooling capacity between 1.0 kW and 1.6 kW at evaporator outlet temperatures for air-conditioning between 22 °C and 15 °C (Figure 3). The lowest logged external evaporator outlet temperature was –5 °C, with a generator heating inlet temperature of 145 °C. The first version, with a plate SHX, was replaced by a coaxial SHX due to very low heat recovery factors of 11.4 % and 31.2 % for the rich and weak solution sides respectively. The heat recovery factors of the coaxial heat exchanger of DACM No.2 were within an acceptable range of 76 % and 92 % (values of the rich and weak solutions respectively). Due to the low solution mass flow rates, the coaxial SHX provided better heat exchange performance than did the plate heat exchanger.

The developed bubble pump worked over a wide operation range at varied temperatures and external mass flows. A theoretically possible evaporator cooling capacity was determined for the evaporator, based on the evaluated liquid ammonia mass flow of the experimental data. A comparison of the resulting theoretically possible and the actual measured cooling capacity of the existing DACM No. 2 evaporator shows that, with a generator heating inlet temperature of 125 °C, the evaporator could not evaporate all of the available liquid ammonia into the helium gas atmosphere, not even with high external evaporator inlet temperatures of around 25 °C. The evaporator therefore needs more or longer evaporation tubes in order to increase the heat transfer surface, which would reduce the film thickness and so give a longer delay time.

The first experimental results from DACM No. 3 show evaporator cooling capacities up to 1.4 kW and COPs up to 0.3. Further investigations of the performance potential will be carried out.

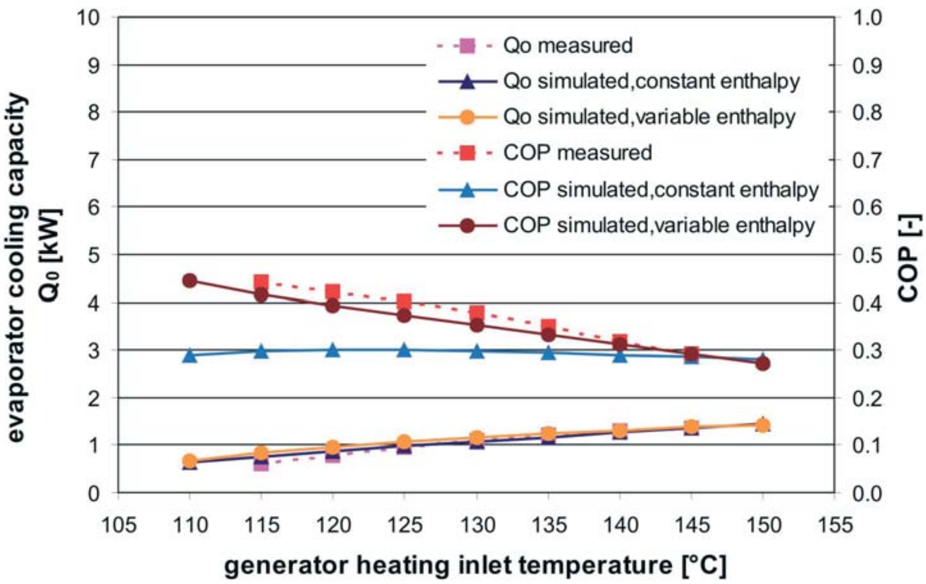

Figure 3: Comparison of measured and simulated values of DACM No.2 (design evaporator temperature is 22.5°C at 1.3 kW cooling capacity, with generator, absorber and condenser temperatures of 140°C, 29°C and 32°C respectively, and SHX and GHX efficiencies of 0.76 and 0.30 respectively)

Modelling and Simulation

The diffusion absorption cycle has been modelled starting from the constant-characteristic equation of sorption chillers, which give an exact solution of the internal mass and energy balances of each component, as well as the heat transfer between external and internal temperature levels, for only one given design point (constant enthalpy). An expanded, steady-state DACM model was developed, based on changing internal enthalpies (variable enthalpy) and changing rich solution mass flow rates due to the characteristics of the bubble pump for each time step [9]. Figure 4 shows the data reduction

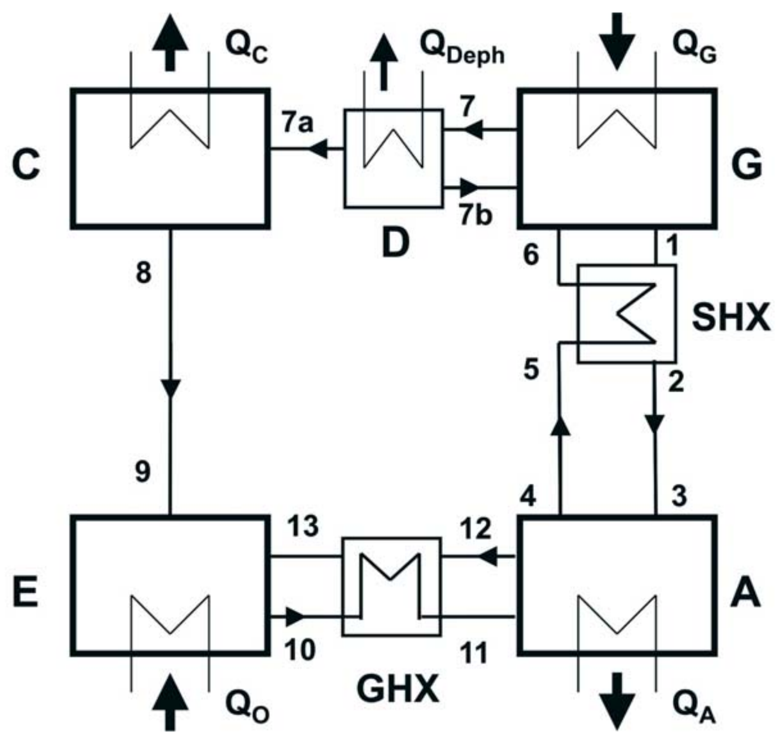

Figure 4: Ammonia/water/helium DACM data reduction model

model for the DACM. The model was implemented in the INSEL simulation environment, and validated by experimental data from DACM No.2. The results of the simulation runs showed that the performance of the DACM, with variable enthalpy, describes the experimental data of the measured performance well (Figure 3). For the constant enthalpy model case, the performance deviated from the measured data.

A parameter study was also carried out to determine how to improve the performance of the DACM at different evaporator inlet and cooling water temperatures, together with evaporator surface wetting factors and GHX heat recovery factors. As expected, the COP and the evaporator cooling capacity decrease at lower evaporator temperatures. In addition, the lower the absorber cooling inlet temperature, the higher is the resulting evaporator cooling capacity. The surface wetting factor and the heat recovery factor have a considerable influence on the cooling capacity. With a higher surface wetting factor, and a better evaporation efficiency, the cooling capacity and the COP increase by a factor of 2 for a surface wetting factor of 0.50 to 1.00. If the heat recovery factor increases from the measured value of 0.30 to 0.60, both cooling capacity and COP increase by a factor of 1.1 to 1.2. To achieve this improvement, it is necessary to optimise the heat transfer inside the GHX using constructive steps to reach higher heat recovery factors.

Conclusions

The first DACM prototype showed that COP values ranged from 0.10 to 0.20, and that the evaporator cooling capacity could reach 1.5 kW. However, the auxiliary gas circulation was not high enough, leading to fast saturation of evaporated ammonia. The second compacted prototype showed stable and continuous temperature and pressure levels. COPs were between 0.2 and 0.45, and the continuous cooling performance was between 1.0 kW and 1.6 kW. A maximum cooling capacity of 2.0 kW could be reached if the evaporator temperature was set to a value of 25 °C. A third prototype, DACM No.3, was built in October 2005, and now has marketable dimensions.

An expanded, steady-state model of the DACM based on the characteristic equation of sorption chillers showed good accordance of the compared experimental and simulated data. Efficient evaporation with high surface wetting factors are essential for high performance.

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Integration of an absorption chiller system in a supermarket heating, cooling and power system

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Introduction

Combined Cooling Heating and Power (CCHP) systems include an electric generator and a means for utilizing the waste heat from the generator. Typically the waste heat is used to heat hot water or to drive a thermally activated technology (TAT) device such as an absorption chiller [1, 2]. CCHP systems offer the potential for high fuel utilization and low emissions. These systems can provide high value, especially when used in applications where the equipment is required to operate continuously (base-loaded applications) [3]. In addition to economic value, CCHP systems provide higher fuel utilization than central power plants, resulting in reduced use of fossil fuels. The U.S. Department of Energy has identified CCHP systems as an important part of the U.S. energy strategy [4, 5].

In the current work, a commercially available, pre-engineered CCHP system was applied to a supermarket application. Supermarkets have a significant electric base load due to the refrigeration system. They also require seasonal space cooling or heating and dehumidification. The challenge was to develop and implement a thermal and mechanical integration of a CCHP system in a supermarket application. Following a description of the CCHP system, this paper will describe the integration of the system into the supermarket, including a description of the skid that was assembled and delivered to the site. Analytical results showing the predicted energy savings will also presented.

CCHP system

The CCHP system used in this work is a commercially available product known as the PureComfortTM 240M. The system, pictured in Figure 1, is pre-engineered to properly combine four 60 kWe microturbines and a double-effect absorption chiller driven by the microturbine exhaust heat. The system includes a diverter valve to bypass the exhaust flow around the chiller when additional chilling capacity is not required or desired, preventing unfavorable concentrations of chiller fluids. The requisite ducting and fuel gas boosters are included in the standard product. The double-effect chiller can be operated to provide either chilled water for space cooling or hot water for space heating. The electric output and cooling and heating capacities of the PureComfortTM 240M system have been documented [6] and are presented in Table 1.

Each microturbine in the PureComfortTM 240M system includes a recuperated turbine engine that drives a generator at speeds up to 96,000 rpm. A solid-state power electronics package housed in the turbine enclosure converts the high frequency power from the generator into Direct Current, and then converts the DC into standard three phase alternating current.

The exhaust of the microturbine is used to drive a double effect absorption chiller/heater shown in Figure 2. The chiller/heater provides either chilled water at 6.7 ºC or hot water at 60 ºC. An option for 76.7 ºC hot water is also available. Control of the energy input to the chiller is accomplished using a diverter valve to regulate the flow of microturbine exhaust to the chiller. The position of the valve, located in the ducting between the microturbines and the chiller, is determined by the chiller controller to maintain the chilled water temperature set point. Any exhaust not required to maintain

Figure 1. PureComfortTM 240M

Table 1. PureComfort™ 240M Performance

Gross/Net Electric Power [kW_e]	**15** °C: 240/229 **35** °C: 213/202 **0** °C: 240/229
Cooling Power [kW_c]	**35** °C: 420 **15** °C: 585
Heating Power [kW_t]	**0** °C: 295 **15** °C: 339

Figure 2. Waste Heat Driven Absorption Chiller

the chilled water set point is vented through a bypass. When the chiller is not being used, an air seal blower located in the diverter valve provides a slight positive pressure inside the valve to prevent hot exhaust gas from entering the chiller.

Integration with supermarket

The PureComfortTM 240M system provides electricity and either chilled or heated water, and is designed for easy integration into commercial buildings. Application of this system to supermarkets presented new challenges and opportunities. In addition to requiring electrical power and seasonal space cooling or heating, the supermarket application also required refrigeration and dehumidification. The refrigeration load is traditionally provided by electric driven vapor compression. A solid desiccant wheel that is regenerated by a natural gas fired burner is used to dehumidify the retail space.

An analysis of the supermarket energy requirements was conducted to determine the most effective way to integrate the PureComfortTM 240M with existing systems. The results of the analysis indicated that, in addition to space cooling, the chilled water output from the CCHP system could be used to sub-cool the refrigeration loop, thereby reducing the refrigeration electric power demand. Furthermore, the exhaust heat from the chiller has sufficient thermal energy to regenerate the solid desiccant wheel. Therefore, the CCHP system can reduce the electric power required by the refrigeration system and the energy needed to regenerate the desiccant wheel. The integration of the PureComfortTM system into the supermarket is shown schematically in Figure 3.

In addition to thermal integration with the supermarket, mechanical integration of the PureComfortTM 240M system was also required. The central portion of the store's roof was determined to be the best location for the CCHP system. For this reason,

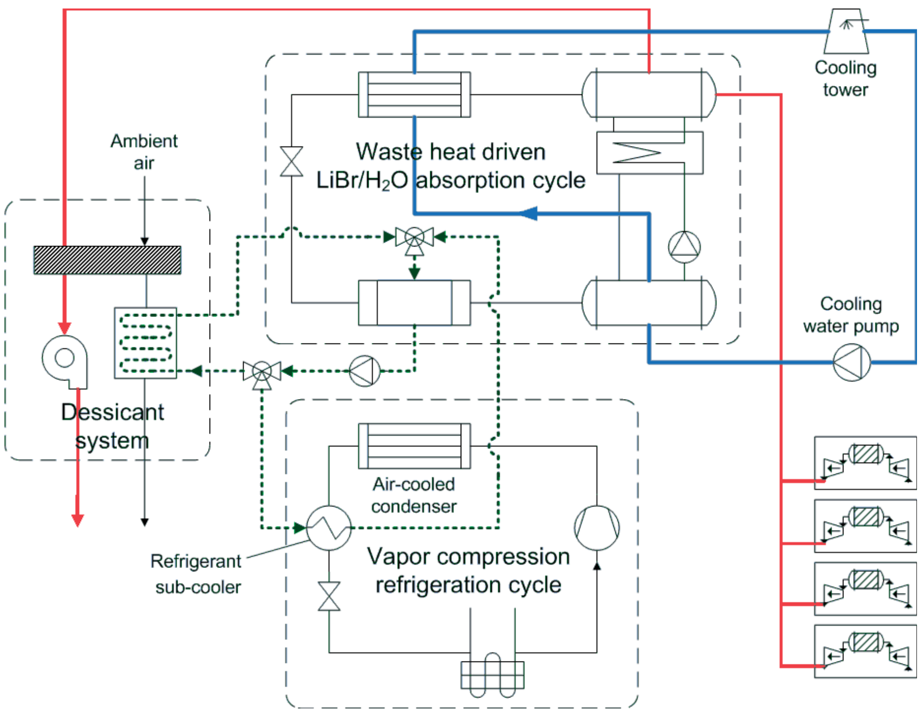

Figure 3. PureComfortTM 240M Integration with Supermarket System

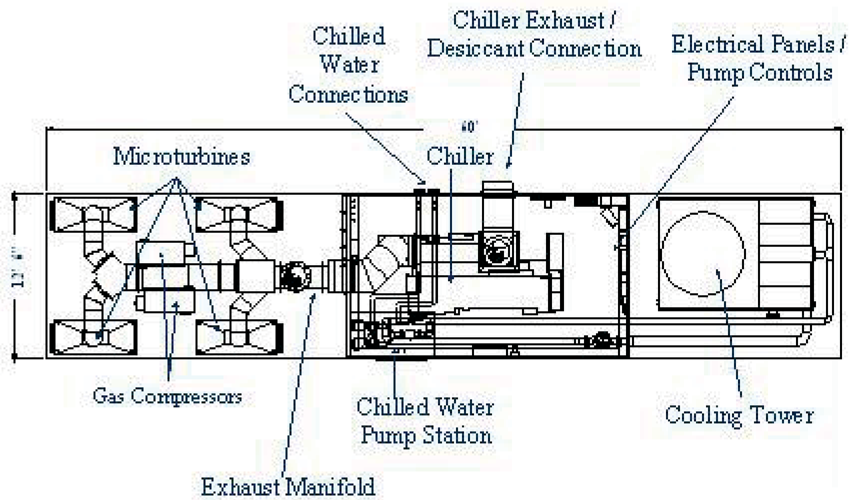

Figure 4. PureComfortTM Skid Design

and the desire to minimize on-site installation efforts, a skidded assembly of the PureComfortTM 240M was designed. The skid included the standard PureComfortTM 240M components as well as a cooling tower and circulating pumps. A housing was added to provide a weather-proof enclosure for the chiller and pumps. The final skid design is depicted in Figure 4 showing the layout of the microturbines, fuel gas boosters, chiller with outdoor enclosure, cooling tower, and ductwork.

The PureComfortTM 240M skid was installed and commissioned at a supermarket. Data have been acquired and are being analyzed. Preliminary analysis of the data indicates the system is working as designed.

CCHP benefits in supermarket applications

Based on its high utilization efficiency, the PureComfortTM system provides significant energy savings over

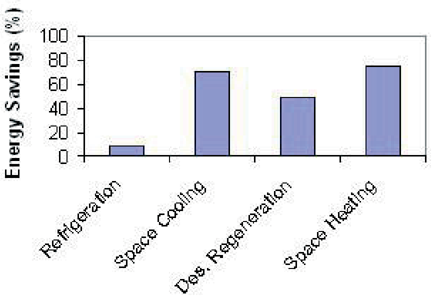

Figure 5. Predicted Annual Energy Savings

conventional equipment. These savings result from the use of efficient microturbines combined with effective utilization of the waste heat contained in the exhaust flow. Results of an analysis of energy use in supermarkets indicated that the PureComfortTM 240M provides a 65 percent reduction in grid electric demand. Details of the energy savings are presented in Figure 5 as a percentage of the annual energy required for each system. The calculated energy savings would provide approximately $140,000 per year in target markets, or about 40 percent of the annual energy cost for a supermarket.

In addition to energy savings, the PureComfortTM 240M system also provides environmental benefits. The microturbines are ultra-low NOx devices at full power. This attribute, coupled with high fuel utilization, results in significantly lower emissions than traditional systems utilizing grid electricity and traditional equipment. Another environmental benefit is that the chiller/heater utilizes water as the refrigerant, thereby avoiding the use of substances that lead to global warming or depletion of the ozone layer.

Conclusions

A commercially available, pre-engineered CCHP system was applied to a supermarket application. The system, known as the PureComfort 240M, includes four 60 kWe microturbines and a double-effect absorption chiller driven by the microturbine exhaust heat. The CCHP system was integrated into the supermarket so as to provide electricity, space heating and cooling, refrigerant subcooling, and regeneration of a solid desiccant. Analytical results indicate that the system will reduce the electrical demand from the grid by 65 percent, resulting in a 40 percent reduction in annual energy cost. The system was packaged for outdoor installation, mounted on a single skid, and installed at a customer site. Data from the system have been acquired and will be analyzed and presented at a future time.

Acknowledgement

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Year round ice hotel chilled by hot spring water

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A double lift absorption chiller ("ThermoChiller") was installed in the Aurora Ice Museum at Chena Hot Springs, Alaska. The ThermoChiller runs on locally available 75.5 °C hot spring water, and provides 4.26 kW of –28.8 °C chilling. The ThermoChiller successfully kept the Ice Museum frozen year round, and thus allowed summer visitors to experience winter amenities at the resort. The ThermoChiller was custom designed to deliver very cold chilling from a low temperature heat source, by using a double lift ammonia absorption cycle. The Chena Ice Museum is the only such structure in the world to remain frozen year round.

Introduction

Chena Hot Springs Resort is located seventy miles northeast of Fairbanks, Alaska, and is a year-round wilderness resort. The main attractions are the natural hot springs and the fantastic views of the Aurora Borealis. Chena assembled the first version of the Aurora Ice Hotel (now renamed the Aurora Ice Museum) in January 2004. The ice hotel is the first of its kind to be built in the United States, and one of just a handful worldwide. The museum features a great hall and lounge area with ice carvings created by 12 time world champion ice sculptor, Steve Brice. Long daylight hours, plus summer temperatures in the 30's melted the first Aurora Ice Hotel in July, 2004.

An ambitious plan to redesign the 2005 version of the Ice Museum so as to stay frozen year-round was formulated in late 2004. The limiting factor in using a traditional vapor compression chiller big enough to keep the hotel frozen is the cost of electricity at this remote site. Electricity at the resort is provided by diesel generators at a cost of 30¢ per kWh. In part because of the premium rate of electric power onsite, the owners have extensively developed the geothermal resource for direct use applications. Two geothermal wells producing 757 lpm to 2,650 lpm provide heating for 46 buildings onsite. In the interest of taking advantage of the geothermal resource to provide refrigeration for the Ice Hotel, the resort owners contacted Energy Concepts in December 2004 and ordered a custom built absorption chiller to keep the museum 'on ice' year round, without the high cost of generated electricity.

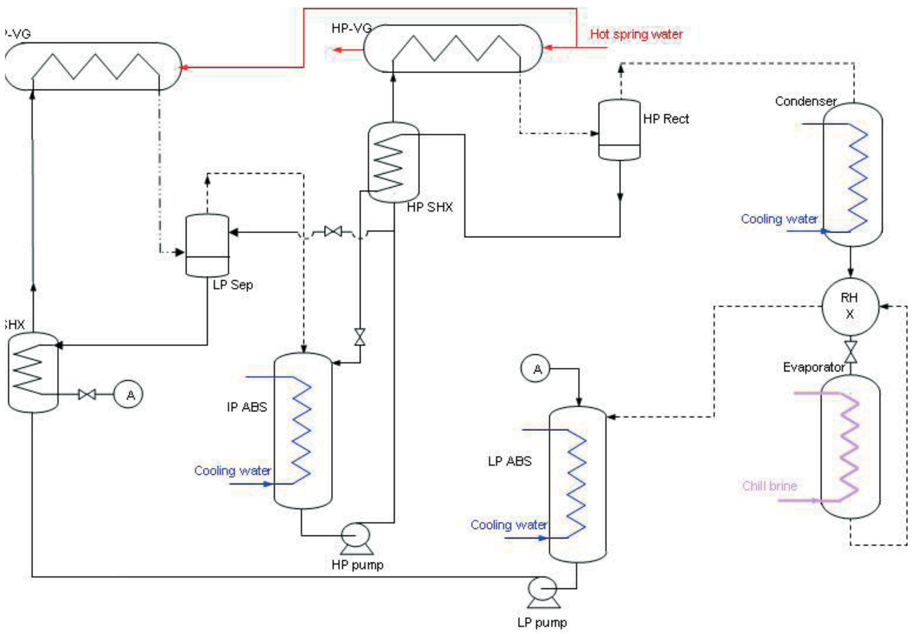

Figure 1. Chena Hot Springs Double Lift (Three Pressure) Absorption Refrigeration Cycle

The ammonia-water absorption cycle can be driven by any heat source: hot water, steam, or exhaust gas. It requires cooling water for the condenser and absorber. Standard packaged units are available in capacities up to 57 kW [1]. However, like many other low-temperature heat driven applications, this Chena Hot Springs unit is so specialized that a custom unit is required. A similar custom unit was installed in Kotzebue, Alaska twelve years ago, which makes ice using 74 °C engine jacket coolant as the heat source [2].

Cycle

Energy Concepts designed a double lift ammonia water absorption cycle, using the hot spring water as the driving heat (322 lpm @ 73 °C). Figure 1 is the cycle diagram. The ammonia-water pair is uniquely suited to deliver this performance, since it can accept heat over a temperature glide, and deliver very low temperature chilling. Hot spring water is abundant at Chena, and cold river water (303 lpm @ 4.4 °C) is available to cool the absorbers and condenser. Proprietary heat and mass exchangers are used throughout the cycle to give high thermal performance, in a compact, low cost package.

Figure 2. Double lift ThermoChiller prior to installation

The components which contact external fluids (hot spring water, river water, chill brine) are constructed of stainless steel. Other internal cycle components are carbon steel. The chill brine is a CaCl2 solution, to allow temperatures down to –45.5 °C. The brine circulates through an air handler, which cools an annular space in the ice hotel between the ice walls and the external insulation. With 73 °C hot spring water (322 lpm), and 4.4 °C (303 lpm) river water, the brine is delivered at –28.9 °C (208 lpm) and the temperature in the ice hotel is maintained at a constant –4.4 °C.

System overview

The overall system includes:

- 2 insulated air handling units, capable of delivering 226.5 m3/min at –17.8 °C
- 7,571 liter chill brine storage tank
- 45 meters of insulated 7.6 cm pipe (runs to a nearby stream for cooling water)
- 454 meters of insulated 7.6 cm pipe (runs to the geothermal well)
- backup vapor compression refrigeration system, which requires a portable 300 kW generator for startup and operation

The hot spring water is cooled to 63 °C in the absorption unit, and is subsequently used to heat a large greenhouse and an outdoor pool.

System operation

The system was installed in late February, 2005 and was initially operated as a two pressure system. After two months of nearly flawless operation, the system was reconfigured to operate in three pressure mode as originally designed, in order to meet the load requirements for summertime operation. While there have been some minor setbacks and unanticipated complications, the system has operated with about 95 % availability since installation.

A few factors have contributed to decreased system performance at times, all of which are solvable. The system was designed for a cooling water supply temperature of 4.4 °C, however there is considerable diurnal variation in supply water temperature from the creek. Not surprisingly, the warmest creek temperatures (~7.2 °C) occur in mid-afternoon, simultaneous to the highest Ice Museum cooling load requirements. This results in a decrease in system efficiency. In the future, the owners of the resort plan to use a shallow cold water well for the cooling water supply, with a stable downhole temperature of 3.9 °C.

Another factor contributing to a decrease in system efficiency is the need for frequent defrost of the air handlers. An automated CaCl2 drip system was installed, but never operated properly. As a consequence, a manual defrost has to be initiated several times per day. If the air handlers are not defrosted on a regular basis, the brine temperature drops to the point where the system crashes (around –34.4 °C). This problem is being addressed by building a bypass duct for each air handler, while simultaneously installing a low brine temperature automatic shutdown for the chiller to prevent a system crash.

System economics

While the absorption chiller per se uses only 1.84 kW to operate circulating pumps for the ammonia-water mixture, an additional 14.7 kW are required to operate the cold and geothermal supply pumps, 1.84 kW are required for the CaCl2 brine circulating pump, and 14.7 kW are required for the air handler. In total, the absorption system requires 32.4 kW, while the backup vapor compression system requires 108.9 kW to operate. This results in fuel cost savings alone of $360 per day, or more than $10,000 per month at current fuel prices ($0.57 per liter bulk diesel).

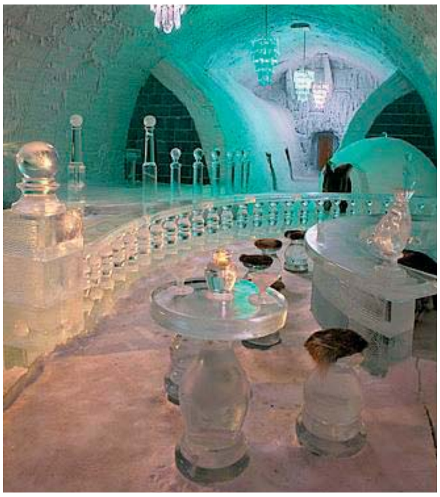

Figure 3. Interior View of Ice Hotel

Conclusions

Chena Hot Springs, Alaska is now the site of a world class ice museum/hotel which is the first in the world to remain open year round. In addition, this project illuminates the path to a more energy-responsible future by using geothermal hot spring water as the motive power to provide useful energy products. The project relies on the unique ability of ammonia water absorption cycles to convert very low temperature heat to refrigeration.

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IPCC/TEAP Special Report. Safeguarding the ozone layer and the global climate system: issues related to hydrofluorocarbons and perfluorocarbons.
This report was produced by the Intergovernmental Panel on Climate Change (IPCC) and the Technology and Economic Assessment Panel (TEAP) on the invitation of of the UN Framework Convention on Climate Change and the Montreal Protocol. It provides a balanced scientific, technical and policy-related assessment that will assist all concerned in taking decisions when considering alternatives to ozone-depleting substances. The report is published in one full version which can be ordered from Cambridge University Press or downloaded from the IPCC web site. Available from the web site are also a summary for policy makers and a technical summary, both are available in different languages.

More information about this very important report can be found at ***www.ipcc.ch***

Bibliography on CO2: 2004-2006 references and abstracts
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In the next Issue

New regulations and directives – how will they affect heat pumping technologies?

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International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among its participating countries, to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development.

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International collaboration for energy efficient heating, refrigeration and air-conditioning

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The Programme is the foremost world-wide source of independent information & expertise on heat pump, refrigeration and air–conditioning systems for buildings, commerce and industry. Its international collaborative activities to improve energy efficiency and minimise adverse environmental impact are highly valued by stakeholders.

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The Programme serves the needs of policy makers, national and international energy & environmental agencies, utilities, manufacturers, designers & researchers. It also works through national agencies to influence installers and end-users.
The Programme develops and disseminates factual, balanced information to achieve environmental and energy efficiency benefit through deployment of appropriate high quality heat pump, refrigeration & air-conditioning technologies.

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