Cooling with heat

A new generation of compact chillers cools and heats with low-temperature heat

The economic and ecological success of many CHP plants, district heating networks and large-scale solar power systems very much depends on the utilisation of heat outside of the heating periods. An increasingly interesting market for low-temperature heat is cooling and air-conditioning buildings as well as generating process cooling energy with thermally driven chillers. Scientists from Berlin and Bavaria have developed a new generation of particularly compact, efficient absorption chillers with small capacities for cooling and heating operations.

Absorption chillers are considered to be very robust. A disadvantage, however, is that the units often have very large dimensions. This means that it is often not possible to retrofit them in basements or only with considerable effort. Furthermore, most commercially available absorption chillers are designed for high output ranges from 300 kW upwards – too large for decentralised use in many buildings.

In a research project conducted by the Technische Universität Berlin in cooperation with Vattenfall Europe Wärme AG, scientists from the university working together with ZAE Bayern and further partners from research and industry have extended the output range downwards. The focus was not just on their weight and dimensions but also on removing other hurdles preventing the use of absorption chillers. For example, the systems currently available are relatively expensive and present considerable demands in terms of the recooling. The researchers also want to improve the temperature difference of the drive heat. In many chillers that use district heat, the
heat transfer medium only cools by around 10°C. This means that a large proportion of the usable heat at a very usable temperature level is therefore circulated unnecessarily and also requires a high pump capacity.

**Bee and Bumblebee – two model systems**

A 50-kW plant, called 'Bee' by the researchers, has now passed comprehensive tests and undergone the subsequent optimisation work. Two of these systems have been undergoing practical testing in buildings since the middle of 2011. Based on the experience with Bee, a larger ‘Bumblebee’ system has also been developed with a 160 kW cooling capacity. This has also already completed initial testing and meets the requirements with a rated operational output of 168 kW.

The single-level absorption chillers work with water as the refrigerant and lithium bromide as the absorber. With this pairing of materials, it is sufficient to use the drive temperatures that are provided by district heating systems and solar power systems. Cold water temperatures as low as 5 °C can be generated. When suitably incorporated into heating systems, the chillers can also work as heat pumps for heating buildings. In contrast to most absorption chillers that have been commercially available until now, Bee and Bumblebee are modularly built as twin-container systems. With difficult transport routes they can be disassembled, transported and reassembled on site. “However, our aim was not only to achieve good access through doorways and a low transport weight,” explains Project Head Stefan Petersen, “our development goals also included keeping the investment and operating costs as low as possible with a high system efficiency.”

**On the test rig**

From Easter 2010 to the end of 2011, an initial function model for the 50-kW system achieved around 8,000 operating hours on a test rig at the TU Berlin. The chiller can be operated with significantly varying volume flows through a temperature range from 55 °C to over 100 °C. That is particularly significant in terms of its use in district heating networks. Firstly, different district heating networks provide their own specific framework conditions in terms of the temperature level and available volume flows. These were all achieved by the system. Secondly, reducing the volume flow with partial loads makes it possible to optimise the return flow temperature in the district heating network.

With existing commercially available systems, the output is controlled by varying the inlet temperature of the drive. The new systems enable three additional options. For example, if the volume flow of the district heating is reduced from 0.9 l/s to 0.6 l/s, this reduces the cooling capacity by just 10 % across the entire load range. However, the spreading in the drive temperature increases by more than 35 %. With variable volume flows, the entire output range between 50 and 10 kW can be achieved with a constant temperature difference. This creates new potential, in particular when connecting engine-driven CHP plants to absorption chillers. In solar operation, the chiller can be kept operational even with low insolation by varying the volume flow, thus increasing the solar coverage. The two other options take into consideration the control of the cooling water temperature and the volume flow. In particular, this helps to reduce the bypass flow consumption.

**Recooling**

As with all chillers, the cooling capacity of the system depends on achieving a recooling temperature that is as low as possible. 40 °C was considered to be the upper limit value for the operation up to now. Consistent avoidance of thermal bridges on the process side and an innovative heat exchanger layout enable the system to establish excellent thermal conditions (COP) even at high recooling temperatures of up to 50 °C. The expansion of this limit in conjunction with the constantly higher COP now also enables dry recooling systems to be used in central and northern Europe.

Fig. 3 depicts the relation between the cooling water temperature, volume flow and cooling capacity. At approx. 25 % of the volume flow, the cooling capacity still remains at roughly 60 % of the basic capacity with constant cooling water inlet temperatures. However, the hydraulic energy required in the recooling circuit is reduced at the same time by 98 %. The researchers

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<table>
<thead>
<tr>
<th>Characteristic values</th>
<th>Bee (kW)</th>
<th>Bumblebee (kW)</th>
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<tbody>
<tr>
<td>Rated cooling capacity</td>
<td>50</td>
<td>160</td>
</tr>
<tr>
<td>Heat capacity [kW]</td>
<td>63</td>
<td>202</td>
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<tr>
<td>Cooling tower capacity [kW]</td>
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<td>362</td>
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<tr>
<td>COP</td>
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<td>0.79</td>
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<tr>
<td>Cold water</td>
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<td></td>
</tr>
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<td>Inlet temperature [°C]</td>
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<td>21</td>
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<tr>
<td>Outlet temperature [°C]</td>
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<td>16</td>
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<tr>
<td>Volume flow [m³/h]</td>
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<td>27.7</td>
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<tr>
<td>Heating water</td>
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<td>Inlet temperature [°C]</td>
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<td>Outlet temperature [°C]</td>
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<td>Volume flow [m³/h]</td>
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<td>Cooling water</td>
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<td>Inlet temperature [°C]</td>
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<tr>
<td>Outlet temperature [°C]</td>
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</tr>
<tr>
<td>Volume flow [m³/h]</td>
<td>14.4</td>
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**Fig. 1 Bee and Bumblebee in comparison. Source: TU Berlin**

**Fig. 2 The absorption chillers currently available on the market are heavier and larger than the new models. Source: TU Berlin**
believe that this provides the basis for new, efficient control strategies for optimising the drive heat and secondary consumption with a prescribed cooling load.

**Cooling in summer and heating in winter**

When incorporated into heat distribution systems, chillers can also be used as heat pumps for heating buildings, for example in traditional applications with brine from geothermal systems or with solar thermal collectors. Whereas the currently commercially available systems of this type are limited to usage temperatures of around 45 °C, Bee and Bumblebee can provide exhaust or rather useful heat of up to 60 °C. The researchers see particularly large potential in the more efficient use of district heating systems. Fig. 4 shows a possible interconnection. Until now it has been common practice to provide cooling energy in summer and heat in winter via two separate district heat connections. Whereas in summer the chiller in conjunction with the domestic hot water determines the return flow temperature in the district heating network, in winter the return is limited to temperatures above the return flow temperature in the building’s heating network and is therefore frequently above 50 °C. The new systems enable the summer-time chiller to be used as a heat pump in winter and, for example, cool the district return flow to temperatures considerably below the heating network temperatures. Here around 55 % of the district heat is cooled by the desorber and around 45 % by the evaporator without the provision of domestic hot water, whereby integrating domestic hot water provision enables even greater cooling. In particular, this leads to savings for the pump electricity in the district heating system. With the same thermal load in winter, the new systems enable savings here of up to 40 %.

The reduced return temperature also improves the electrical efficiency of CHP plants incorporated in district heating networks.

**Testing in practice**

Two model systems using the initial 50-kW chiller have been tested in practice since the middle of 2011. For the first property, an office building belonging to an energy supply company in Berlin was equipped with the absorption chiller. Owing to the location, the district heating supply temperature in the summer is around 75-80 °C. The property has a peak cooling demand of around 42 kW. For recooling, the cooling system was designed using a tabletop cooling unit with a rated output of 102 kW under design conditions. The system has been in continuous operation since June 2011. It creates cooling energy for cooling the office spaces without dehumidification by using the heating distribution network in summer to provide cooling at a temperature of around 16 °C.

However, the cool summer in 2011 meant that the system was only able to demonstrate its capabilities under full load on just a few occasions. As a result of the weather, the peak loads during three months of continual operation reached around just 15 kW and the average load was approximately 6 kW. However, the secondary flow consumption for the recooling unit, pumps, etc., was less than 6 % of the cooling load. During this test phase, the chiller particularly proved itself in terms of the partial and low load behaviour.

Another model using the 50-kW chiller cools a lecture theatre in Dessau and the computer centre belonging to the German Federal Environment Agency. The drive heat is provided by a solar thermal system (216 m² of heat pipe collectors (absorber surface)) in combination with district heating as backup. The backup system ensures temperatures of around 60 °C to cover 25-35 kW of cooling energy in combination with a hybrid recooling system. A cooling network is supplied with an operating temperature of 9 °C. The researchers were able to establish fault-free operation with a drive temperature of just 55 °C.

Compared with previous systems, the thermal expenditure reduces by approximately 40 %, the specific secondary flow consumption by approximately 60 % and the primary energy use by approximately 50 %. The researchers are aiming to achieve further savings in 2012. By optimising the system operation, they want to reduce the primary energy use by 70 % relative to the old installation.
The market is there

The share of CHP generation used in the heating, cooling and electricity market is increasing throughout Europe. The EU, countries and local authorities are supporting this trend in order to achieve their climate protection goals. In some European countries such as Germany, Sweden, Denmark and Finland, district heating provides more than 25 % of the heating energy requirement. However, many of the district heating networks are only partially loaded during the summer months. At the same time, the market for air-conditioning in buildings is growing by around 15 % each year. Absorption chillers can combine the heating supplies with the cooling requirements. They work silently, are almost wear-free and require little maintenance. Although the thermal efficiency (COP) is relatively low, it is still worthwhile using them for recycling surplus heat that would otherwise remain unused. More favourable operating costs can then be attained with higher system loading. Everyone benefits: the district heating providers can unlock new markets and the operators of chillers acquire cheap, reliable and ecologically sensible drive energy.

Until now, the main obstacle hindering the use of sorption cooling by means of district heating has been the limited product range with greater cooling generation costs relative to compression cooling. With the newly developed units, this ought to expand. The project partners have set high aims for the series product: they want to cut the investment-related cooling costs by half to a third relative to comparable systems, double the electrical efficiency and make the cooling generation costs competitive. The new chiller can significantly reduce the investment costs in this output class. The aim is to achieve systems in the 50-320 kW output range with investment costs between 200 and 240 euros per kW.

The researchers want to gain further knowledge about the chillers, particularly in system networks, with a wide-ranging field test. In the project, which is due to be launched in autumn 2012 as part of the EnEff: Wärme research programme conducted by the German Federal Ministry of Economics and Technology, fifteen installations will be monitored for five years. Cooperation partners include the AGFW, the BHKS and other scientific partners. In cooperation with the operators and district heating suppliers, the scientists aim to achieve systems in the 50-320 kW output range with investment costs between 200 and 240 euros per kW.

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