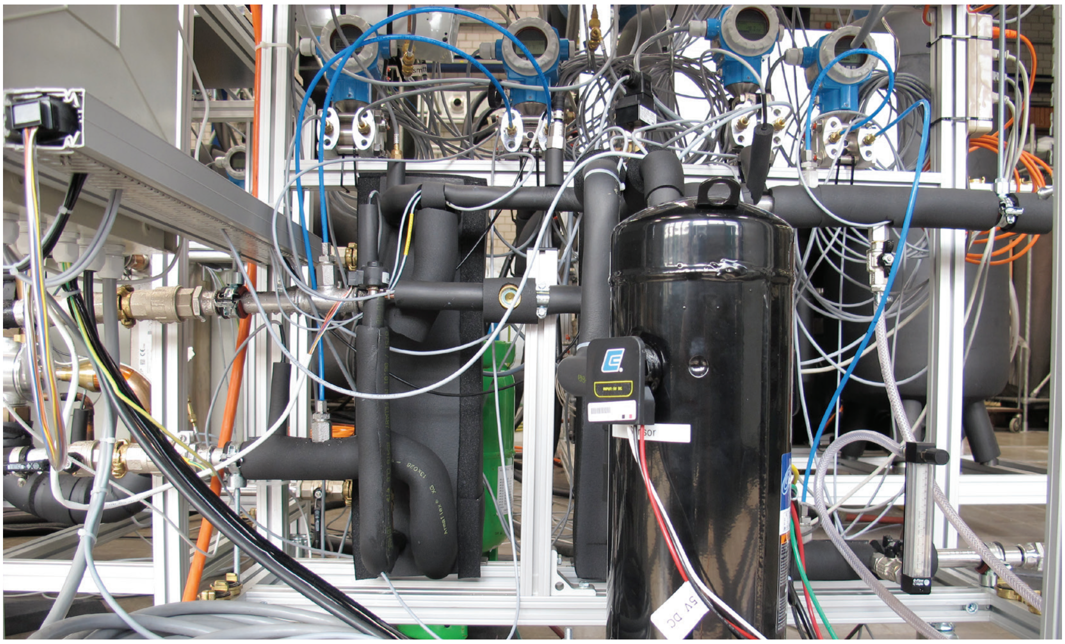
Smart construction combined wisely

Heat pumps are now standard technology in both domestic and industrial applications. Despite their widespread use, there is still considerable room for improvement. Not only can equipment design itself be optimized, but also control of heat pumps in combination with other energy-producing equipment. Big gains can come from the clever integration of the heat pump with the power grid. A look at current heat pump research in Switzerland.



In the research laboratory of Prof. Dr. Beat Wellig at the Lucerne University of Applied Sciences and Arts: Regulated power brine / water heat pump prototype with inverter scroll compressor (Emerson Copeland ZPV36). Photo: University of Lucerne

Dr. Benedikt Vogel, commissioned by the Swiss Federal Office of Energy (SFOE)

The use of heat pumps to provide heat and hot water is standard practice in Switzerland today. Heat pumps use heat energy stored in the ambient air or in the ground as thermal energy, thus making an important contribution to efficient energy use. The number of heat pumps sold annually in Switzerland since the early 1990s has grown almost tenfold to currently 18 500 pieces (2014). Nearly two-thirds of the growth in sales is attributable to air / water heat pumps and one-third to brine / water heat pumps. Around 70 to 80% of newly built single-family homes are now equipped with such systems. "With the existing buildings, there is a need to catch up; many of them could have new heat pumps installed, which would make sense in terms of energy efficiency," says Rita Kobler, heat pump expert at the Swiss Federal Office of Energy (SFOE). "Whether in each particular case a new heat pump system would be beneficial depends largely on the required flow temperatures of (radiator) heating," explains

A technical report about the results of the heat pump conference of June 17th in Burgdorf/BE, which was financially supported by the Swiss Federal Office of Energy.

Kobler. "Homeowners who want to renew their heating usually don't know the parameters. But they can consult energy experts to help them find the best solution."

Further increases in efficiency

As good as heat pumps already are, they still have huge potential for improvement. "Heat pumps today reach theoretical efficiencies of only about 50%," says ETH licensed engineer Stephan Renz, Head of the BFE-research program Heat Pumps and Refrigeration, "the long term aim is to reach 65 to 70% efficiencies." To realize the untapped potential, intensive efforts in research and development are needed in Switzerland and on an international level. The European Union has launched the research project 'Next Generation Heat Pump' in this context. The participating scientists are charged with examining all of the the components of the heat pump from an optimization point of view. From Switzerland, ETH Lausanne is involved (Prof. John R. Thome) in the EU project. The core of their work focuses on enhancing the heat exchanger.

Optimization the heat pump design is a central objective of heat pump research. This was decided on June 17th 2015 in Burgdorf during a heat pump conference where Lukas Gasser of the Lucerne University of Applied Scienes and Arts presented his findings on the power control of brine / water heat pumps. In Lucerne, researchers have been working for ten years on tuning the generated heating capacity of brine / water and air / water heat pumps to the effective needs of each building, thus achieving significant efficiency gains. The necessary regulation of the power takes place essentially via the compressor and any additional machinery that may be required, such as fans or brine circulation pumps. The performance of the compressor and any additional units are infinitely variable; they are set so that a needs-based heating system can result in maximum efficiency.

Efficiency gains even with brine / water heat pumps

For air / water heat pumps, the Lucerne researchers have been able to achieve power control efficiency gains of 20 to 70% (compared with on / off-controlled pumps in the field) in recent years thanks power regulation. For the brine / water heat pumps that Lukas Gasser developed and tested at the University of Lucerne, the efficiency gain is expec-

Borehole Temperature / Probe Depth	Minergie Standard Flow/return temp. 30/25°C at -10°C		Renovated old construction Flow/return temp. 46/38°C at -10°C	
	Annual Performance Value ON / OFF regulation	**Annual Performance Value** Power Control	**Annual Performance Value** ON / OFF regulation	**Annual Performance Value** Power Control
6°C / ~100 m	**4.54**	**4.88**	**3.64**	**3.83**
9.5°C / ~180 m	**5.39**	**6.02**	**4.21**	**4.58**
13°C / ~320 m	**6.21**	**6.90**	**4.62**	**5.09**

Annual performance values of power-controlled brine / water heat pumps are about 5 to 12% higher than those of on / off controlled heat pumps, according to research by Lukas Gasser at the College of Luzern. Examined were applications for Minergie certified buildings (left) that require lower forward flow and return temperatures, and renovated old buildings (right). For the calculation of the seasonal performance value, a design outside temperature of -10 ° C was used. Table: Gasser ted to be lower. "Compared to the on / off-controlled prototype, the brine / water heat pump with power control can achieve up to 12% higher annual performance, depending on factors such as the heating curve and the length of the geothermal probe used," Gasser says of the summary findings of his study (see Table p. 2).

For Prof Dr. Beat Wellig, Head of the Competence Centre Thermal Energy Systems & Process Engineering at the University of Lucerne, this result is not surprising. For air / water heat pumps that have power control, relatively greater efficiencies are possible than with brine / water heat pumps because air temperature features greater bandwidth than ground temperature. "The results make it clear that it would be harder for the power-controlled brine / water heat pumps to penetrate the market than the air / water heat pumps," says Beat Wellig. Because the lower the efficiency gain, the longer it takes until the additional costs of power controlled equipment are amortized.

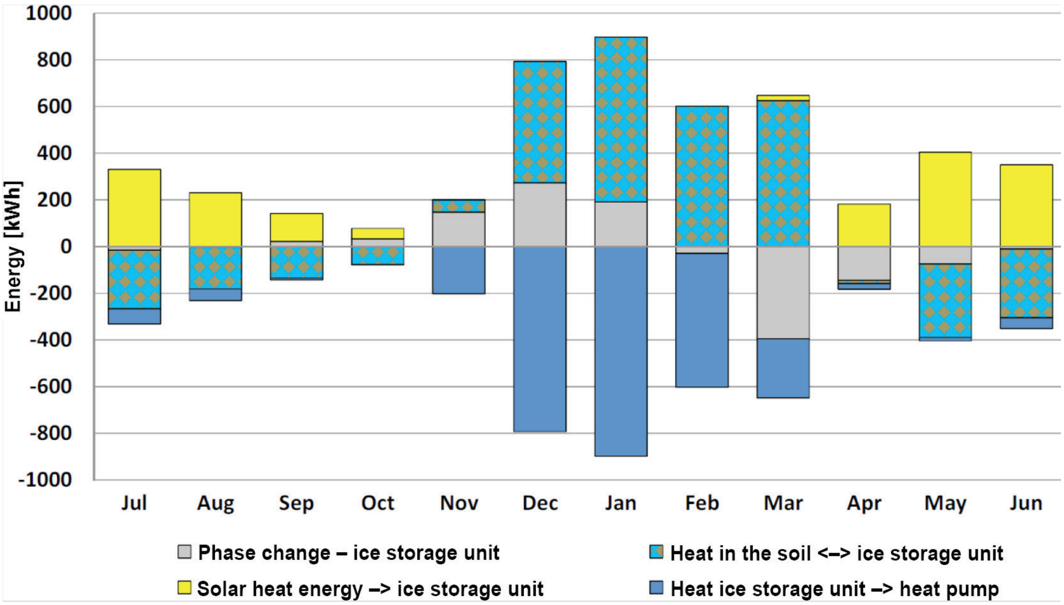
Wanted: the right combination

Optimized energy efficiency is a prerequisite so that heat pumps can make a significant contribution to energy supply. But also of great importance is how well the individual heat pump is combined with other energy systems. What counts in the end is the energy balance of the whole system. Here there is plenty of room for improvement, of that BFE research program director Stephan Renz is convinced: "With the combination of heat pumps with additive energy systems, there is a large need for new research." By additive systems Renz means solar thermal and photovoltaic systems, as well as mixed systems of solar thermal / photovoltaic including hybrid modules (PVT) that transform solar energy into electricity and heat simultaneously. There are also combined systems that involve ice storage or geothermal probes, that buffer the generated heat in solar thermal systems for hours, days or even months.

At that point sits the research of Prof. Dr. Thomas Afjei, researcher and lecturer at the School of Architecture, Civil Engineering and Geomatics in Muttenz (BL). At the heat pump conference in Burgdorf, Afjei presented the current results from a study in which he simulated four energy systems for houses (single-family) and partially measured in a parallel project at a home in Oberwil (BL). Of particular interest are two of the four studied energy systems that use an ice storage unit. A container similar to a water cistern is used to store the ice, which has a volume of 10 m^3, and maintains the water at 0 °C. If heat is withdrawn from the ice storage unit, the water freezes. The extracted heat can be later transferred by a heat pump to use for heating and hot water. To thaw the ice storage again, heat must be supplied – for which solar thermal collectors are especially suited. In this way, heat in the amount of 832 kWh can be temporarily stored in the ice storage unit. This corresponds to filling about 150 bathtubs with 40 °C water.

Low-temperature absorber supplies ice storage

The Muttenzer researcher and his team have studied the ice storage system in two variations: The first variation involves unglazed solar absorbers (UC) that deliver low temperature heat (20 - 40 °C), which are used for defrosting the stored ice; photovoltaic modules provide additional electricity to operate the heat pump. In the second variant, heat and electricity come from a hybrid module (PVT). "Solar ice absorbers in combination with unglazed absorbers are energetically a good solution," says Thomas Afjei, "the heat pumps achieve annual performance factors of up to 4, about as much as conventional heat pump systems with geothermal probes." This was also reflected in a field measurement at the house in Oberwil (BL). Whether this holds true is true for ice storage with PVT, Afjei cannot yet say. This system variant was simulated, but has not been verified by measurements in the field.



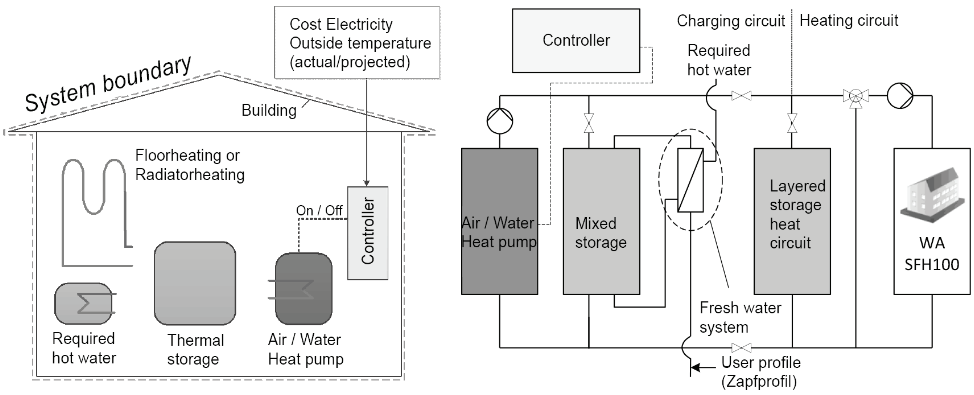
Prof. Thomas Afjei and his research group have combined a heat pump with an ice storage unit to provide hot water in a single family home and created a simulation: The chart shows the monthly heat balance of the ice storage for a building with a heat demand of 45 kWh / m² / a. Heat gains in the ice storage unit appear on the y-axis as positive values (yellow: heat from the solar absorber, gray: latent heat when freezing water, checkered: soil heat gains), heat loss is negative (blue: heat usage of the heat pump, gray: thawing of the ice, checkered: heat losses to the soil). Graphics: Dott

If heat pumps are to be optimally integrated into energy systems, the right system components and appropriate control strategies are also required. Current control strategies also relate to the power of the heat pump from decentralized production units (eg photovoltaic systems) and the power grid. In buildings, heat pumps are among the primary electricity consumers. Control systems achieve, by systematic inclusion of weather data for example, not only better quality, but also greater complexity. "In modern car engines tens of thousands of control curves serve to operate the engine optimally in every situation," says Stephan Renz who draws a comparison to the auto industry, "this shows us which way we have to go in heat pump technology."

Flexible use in smart grids

Exemplary of research in this area is research performed by Prof. Dr. Jörg Worlitschek at the Lucerne University of Applied Sciences and Arts. The aim is to develop a unit consisting of a heat pump and the associated thermal energy storage device, which can be integrated perfectly into an intelligently controlled electricity grid (smart grid). As a starting point, Worlitschek and his research team developed a new model which, through the combination of validated models of heat pump, storage and home, can simulate the behavior of the entire system for a long time. To quantify the gain in flexibility of the system when used in combination with renewable energy sources, prices from the electricity exchange Epexspot were used.

"We could show in the first major parameter studies (with more than 800 simulations) that optimization of control and storage units brought substantial gains in flexibility with minimal loss of efficiency of the heat pump operation," says Worlitschek. An example is the optimization of a radiator heating system of a renovated old building with a heat demand of 100 kWh / m² / a: Through the use of a 2000 l layered storage tank and predictive control, the heat pump can be switched off at specific times, amounting to a total of



Left: Overview of the analyzed components in the overall model studied by Prof. Dr. Jörg Worlitschek at the University of Lucerne. This model is characterized by three features: the influence of the building is explicitly included, the model considers dynamic electricity market prices, thus enabling predictive control (Model Predictive Control, for instance). Right: representation of the modeled system to illustrate the analyzable system variants. Illustration: Worlitschek

16 hours of "off time" per day. The pulsing of the heat pump is thereby reduced by 75%. Jörg Worlitschek's project is part of an international research project of the International Energy Agency (IEA), that also involves nine countries in Asia, Europe and North America.

» For further information on research activities related to heat pumps, contact Stephan Renz (info[at]renzconsulting.ch), head of the BFE-research program Heat pumps / refrigeration.
» For more technical papers on research, pilot, demonstration and flagship projects in the field of heat pumps / refrigeration, see www.bfe.admin.ch/CT/WP-Kaelte

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07/2015