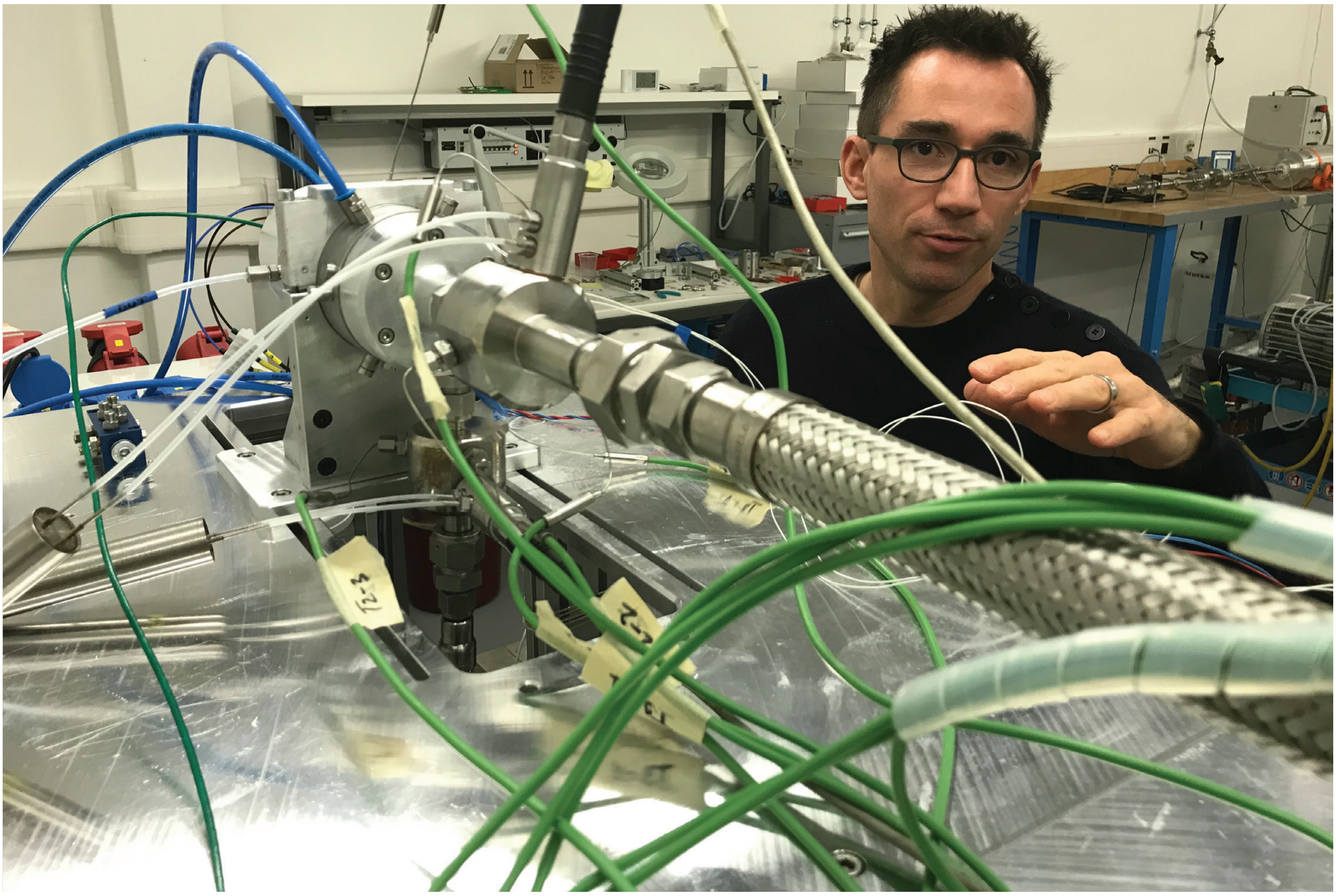
NEUCHÂTEL REINVENTS THE HEAT PUMP

Heat pumps are widely used today. They produce heat and hot tap water reliably and in an environmentally friendly manner. But they can be made even better: A research team from the École Polytechnique Fédérale de Lausanne (EPFL) at the Neuchâtel site wants to significantly improve one of the main components of heat pumps - the compressor - and thus increase the efficiency of heat pumps by about 20%. As part of a SFOE research project, an oil-free radial compressor has been developed that has a good chance of achieving this ambitious goal.



Prof. Jürg Schiffmann shows the test bench in the laboratory, on which the oil-free radial compressor can be tested as a component of a heat pump circuit. Photo: B. Vogel

A technical report about the results of a research project in the field of heat pumps and cooling, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Swiss Engineering STZ (issue April 2020).

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If Switzerland wants to implement the goal of a sustainable energy supply, energy must be increasingly obtained from renewable sources and the available energy must be used more efficiently. "We see the national energy strategy as a mandate to design machines that use energy sources more efficiently, thereby reducing energy consumption and CO_2 emissions," says Jürg Schiffmann, Professor at the Laboratory for Applied Mechanical Design (LAMD) at EPFL's Neuchâtel site. Microtechnology has a long tradition at the southern foot of the Jura mountains, the traditional center of the watch industry. But the machines that Jürg Schiffmann and his research team build are not watches. Instead, the scientists develop small turbomachines, namely compressors and turbines in the power range from a few watts to a few kilowatts.

Turbomachines are used in various applications. Thanks to their widespread use, these machines - designed to save energy - can make an important contribution to an efficient energy supply, even if individually they have a relatively low power output. The Neuchâtel researchers have shown that car and truck engines could be operated 10% more efficiently by recovering heat from hot exhaust gases using a turbine. The same technology can be applied to SOFC-type fuel cells, which convert natural gas, biogas or hydrogen into electricity without combustion. This results in an efficiency of 66% - an excellent value for such a small device. The heart of the innovation in both cases is a small, fast-rotating turbo machine.

The Triumph of the Heat Pump

Jürg Schiffmann studied mechanical engineering at the EPFL in Lausanne in the 1990s. Later he worked at Fischer Engineering Solutions (Herzogenbuchsee). Supervised by EPFL professor Daniel Favrat he began working on his doctoral thesis on turbomachinery in 2005. Today, the scientist's research interests include turbocompressors, as they are used in heat pumps. Turbocompressors are a central component of these heating devices: Once the refrigerant has absorbed heat from the ambient air or the ground, it needs to be compressed by a compressor and thus brought to a higher temperature in order to provide heat and hot water. Heat pumps had already been propagated in the 1970s in the wake of the oil crisis. However, they did not become generally accepted at that time. For a long time, the devices had a reputation for being unreliable.

During the last two decades, however, heat pumps have experienced a boom in Switzerland. They have become the

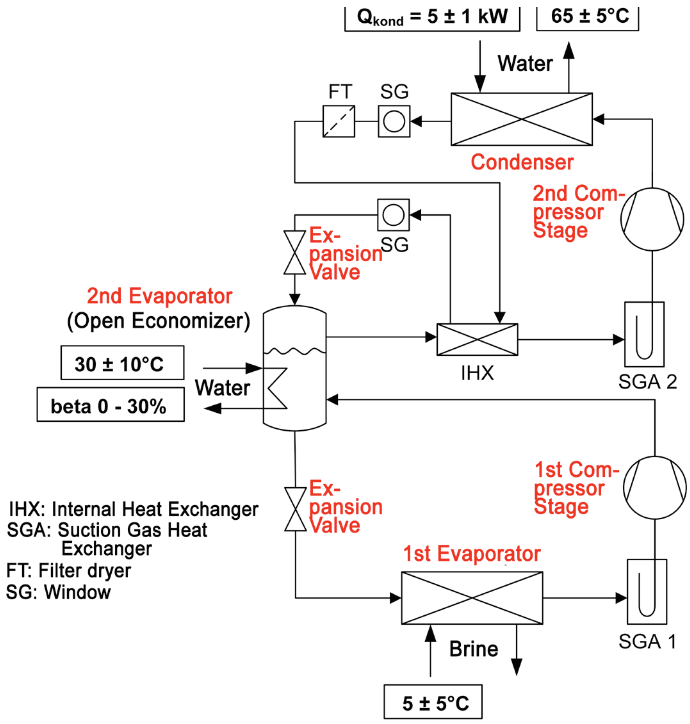


Diagram of a heat pump in which the compression process takes place in two stages, based on the work of EPFL researchers in Neuchâtel: The working fluid absorbs ambient heat in the first evaporator and changes from liquid to vapor phase. The gas enters the first compressor stage, which compresses it to a higher pressure and thus also to a higher temperature. After the second compressor stage, the gaseous working fluid enters the condenser at a higher temperature and rejects heat (heat, hot water). In the process, the working fluid changes back to the liquid state. In the expansion valve (also two-stage) the pressure is reduced. In order to enable the two compressor stages while increasing efficiency, the researchers have incorporated some special features: After the first compressor stage, the gaseous refrigerant is liquefied with partially expanded refrigerant from the condenser and evaporated again by supplying heat from an additional heat source. Before the second stage, the working fluid is also further heated by an internal suction gas heat exchanger. This achieves a significantly higher temperature and improves the efficiency of the heat pump. Graphic: NTB

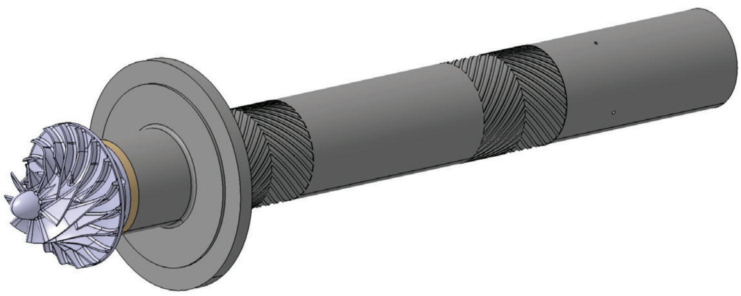
preferred heating system for new buildings. An important prerequisite for this success story was the development of the so-called scroll compressor in the early 1990s. Like the piston compressor used previously, the scroll compressor operates according to the positive displacement principle, but thanks to design innovations it enabled higher efficiency. "Such a technological leap could be achieved again today and make heat pumps 20% more efficient," says Jürg Schiffmann. While the innovation at the time consisted of the scroll compressor, hopes are now resting on the centrifugal compressor. Schiffmann and his research team are working on a new generation of this type of compressor. "Improvements in compressors are key to improving the energy efficiency of heat pumps, because in a heat pump the compressor is responsible for around half of the conversion losses," emphasizes Schiffmann.

Stable and Frictionless Bearings

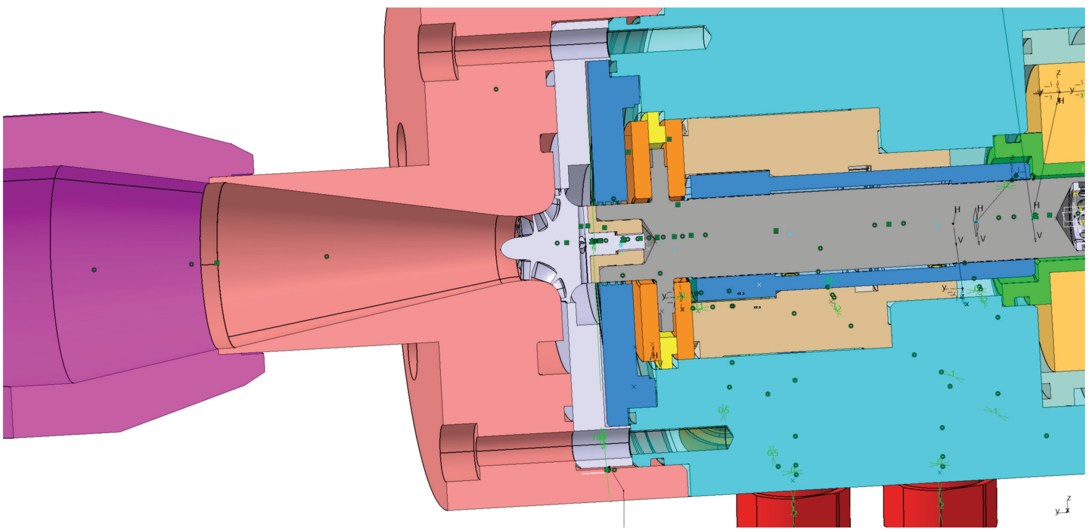
The key difference between scroll compressors and centrifugal compressors is the way in which the gaseous working fluid (refrigerant) circulating in the heat pump is compressed (see text box p. 4). In the radial compressor, the working fluid reaches a rapidly rotating impeller, which deflects the gas laterally (radially) and thereby compresses it. The radial compressor designed by the Neuchâtel scientists has the characteristic that the shaft (driven by an electric motor) with the impeller rotates very quickly (up to 300,000 revolutions per minute/rpm). At such high speeds, the rotor must be stable and at the same time be supported in a practically friction-free manner.

The Neuchâtel scientists achieve this double objective with gas lubricated bearings: the rotor (approx. 10 mm in diameter) floats on a 5 to 10 micron thick «air cushion» (which is not made of air but of the gaseous refrigerant). This air cushion is built up solely by the rotation of the shaft, i.e. it is created without the active injection of a pressurized fluid. Thanks to the air cushion, there is no contact between the rotor and the stationary parts during operation, thus eliminating the need for lubrication oil.

Supporting this oil-free centrifugal compressor is a great challenge. The rotation of the shaft generates forces within the small bearing clearance, which can deflect the rotor tangentially and lead to instability. The Neuchâtel researchers tamed these forces by initially choosing a very small bearing clearance and designing the surface with opposing V-shaped grooves. The grooves create a pumping action, thereby increasing the pressure in the gap, which increases damping, counteracts the tangential forces and stabilizes the rotor. The pattern of these grooves alone is a science in itself: by selecting suitable shapes, the researchers were able to increase the air gap by 60% compared to conventional grooves. As the air gap increases, the shear forces generated in the gas film decrease, thus reducing friction (i.e. losses). A larger air gap also allows the manufacturing tolerances to be relaxed, thus reducing costs.



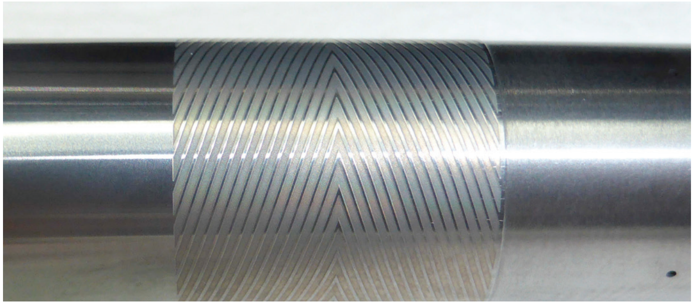
CAD representation of the rotor of a radial compressor: The bladed impeller is at the front , which radially deflects the heat pump's gaseous working fluid (flowing in from the left). The rotor is outfitted with V-shaped grooves, which create a gas film through the rotational movement, so that the rotor «floats» without touching the moving parts. Illustration: LAMD



Cross-sectional view of a centrifugal compressor: The gaseous refrigerant reaches the compressor impeller via an inlet cone (light grey in the middle of the picture). The impeller transfers kinetic energy to the working fluid (energy of movement) and deflects it laterally. Graphic: LAMD

Industry Shows Lively Interest

The development of an oil-free radial compressor by EPFL researchers in Neuchâtel was financially supported by the Swiss Federal Office of Energy (SFOE). Important intermediate successes were achieved within the framework of the project: In the laboratory, the oil-free radial compressor is now running stably up to a speed of 260,000 rpm. In the meantime, the scientists have also been able to show on a specially constructed test rig that the compressor not only runs in air, but also with a working fluid (R134a), which enables to achieve the targeted performance values. During 2020, the novel compressor will be tested as a component in the system environment of commercially available heat pumps. These tests will be conducted under the direction of Prof. Stefan Bertsch at the Institute of Energy Systems of the Interstate University of Applied Sciences (NTB) in Buchs (SG).



The V-shaped grooves are lasered or etched into the steel rotor. The pattern of the grooves has been chosen so that the air gap between the rotor and bearing is as large as possible, due to operational advantages. Illustration: LAMD

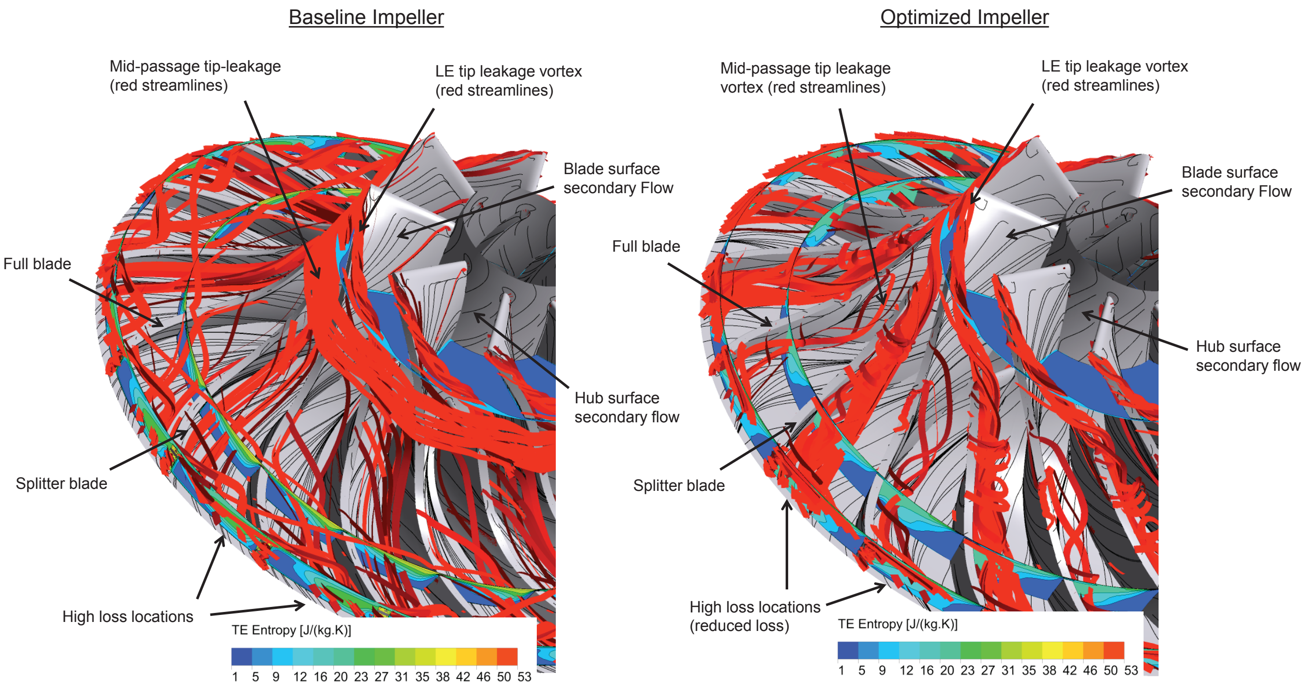
The goal of the researchers is an operational heat pump system in the laboratory environment (proof of concept). Once the oil-free centrifugal compressor is commercialized, a new component will be available for heat pump manufacturers that has the potential to trigger a global innovation surge in heat pumps. “We are convinced that the use of a two-stage centrifugal compressor will enable heat pumps with a 20% higher efficiency (COP) than the units currently available on the market,” says Jürg Schiffmann, looking to the future. There is a good chance that the findings from the EPFL labo-

FROM SCROLL COMPRESSOR TO CENTRIFUGAL COMPRESSOR

A positive displacement compressor generally serves to reduce the volume filled with a gas. This process increases the pressure and temperature of the gas. A known application is the combustion engine, where the compression is done by a piston. In a scroll compressor, on the other hand, two spiral elements move in such a way that the volumes (chambers) are reduced gradually. Radial compressors work in a different way: Here, the gas flows axially onto a fast-rotating impeller and is deflected laterally (radially) by it. The impeller transfers kinetic energy to the gas, which is then converted into pressure in a so-called diffuser.

Centrifugal compressors - also known as radial compressors - are widely used today and are used for larger (100 to 1000 kW) to very large (2 to 20 MW) heat pumps and chillers (for example, by the Swiss company Friotherm in its very powerful Unitop heat pumps). Radial compressors are also used in car turbochargers, helicopter turbines, turboprop aircraft and industrial processes. By contrast, the Neuenburger scientists aim to develop micro radial compressors with smaller power (some Watts to few kilowatts). The Swiss companies Celeroton and Fischer already manufacture small-scale, oil-free radial compressors for heat pumps in the output range from 700 W to 12 kW. The SFOE support provided by EPFL scientist Schiffmann was primarily aimed at researching the fundamentals of a multistage micro-radial compressor.

If centrifugal compressors are to be used in the capacity range of domestic heat pumps, they have to rotate very quickly (up to 300,000 rpm). Only at high rotational speed - according to the laws of physics - do they work at low power with high efficiency. In order to operate economically, a service life of 20 years (i.e. 120,000 to 150,000 operating hours) is targeted. Energetic advantages result if it is possible to develop a radial compressor that does not require oil for sealing and as a lubricant. Oil is used in compressors, as has been the case up to now, migrates into the cooling circuit. There the oil settles on the inside surface of the tubes including the heat exchangers and reduces the heat transfer, which reduces the efficiency of the heat pumps. The oil-free radial compressor avoids these negative effects. BV



The compressor impeller of the 15 mm diameter centrifugal compressor in the original (left) and the optimized (right) version. The very fast rotation of the impeller transfers kinetic energy to the incoming working fluid. The color charts below show the entropy of the two impeller versions: The optimized version has lower entropy, which means that this blade design yields lower losses. Entropy is a measure that helps the designing engineer to make the compressor impeller blading as efficient as possible. Illustration: SFOE final report

ratory will reach heat pump users soon: the scientists are already working with two compressor manufacturers and two manufacturers of refrigeration units who want to build the compressor themselves in future.

- The **final report** on the SFOE research project ‘Oil-free radial compressors for multistage heat pumps’ can be foundat: https://www.aramis.admin.ch/Grunddaten/?ProjectID=36212

- **Information** on the project can be obtained from Stephan Renz (info[at]renzconsulting.ch), head of the SFOE research program Heat pumps and cooling.

- Further **technical papers** on research, pilot, demonstration and flagship projects in the field of heat pumps and cooling can be found at www.bfe.admin.ch/ec-wp-kaelte.

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