Cooling and air-conditioning systems available on the market operate almost exclusively on the basis of compressors. Compressors have been used for cooling for over one hundred years now. They require a great deal of energy and use refrigerants which are harmful to the environment, toxic or easily flammable and can sometimes only be operated at high pressure. In addition, they no longer meet the current requirements of certain markets: there is above all a need for small and lightweight cooling systems which operate for long periods without the need for maintenance and which are insensitive to major temperature fluctuations and vibrations – for use in refrigerators or automobiles, for instance.

Efficient cooling without harmful refrigerants

Solid-state cooling systems based on caloric materials are a forward-looking alternative to compressor-based cooling engineering. Various magnetocaloric cooling systems have been implemented in recent years. But also elastocaloric and electrocaloric materials are suitable for constructing heat pumps which operate without harmful refrigerants and are up to 30 percent superior to conventional cooling systems as regards energy efficiency.

Caloric materials show a strong, reversible increase in temperature when a corresponding field (magnetic field, electric field or mechanical force) is applied to them and cool down again when this field is no longer applied. This causes the temperature to drop below starting temperature. This effect can be utilized to construct a cooling circuit: the heated material is connected to a heat sink in order to dissipate the heat produced. If we connect it to a point to be cooled, it absorbs heat until the starting temperature is reached. This results in an efficient heat pump (Fig. 4).
Heat transfer with heat pipes boosts efficiency

Various cooling systems, primarily magnetocaloric cooling systems with high cooling capacities and wide temperature ranges have been implemented worldwide in the past few years. This has resulted in cooling cycles with temperature ranges of up to 50 K or cooling capacities of several kilowatts. However, these prototypes have not shown any increase in efficiency compared to conventional, compressor-based cooling systems to date. The crucial factor for the efficiency of caloric cooling circuits is efficient heat transfer. Virtually all prototypes implemented to date are based on the »Active Magnetic Regeneration (AMR)« concept. Here, the material is flushed with a pumped fluid that transfers the heat from the source to the sink. The AMR approach proves to be inefficient owing to the low cycle frequency and the high pump energy required.

For the first time, systems developed by Fraunhofer IPM combine caloric materials with latent heat transfer, analogous to heat pipes, for efficient heat transmission. This patented method involves heat being transferred by the evaporation and condensation of a fluid such as water or ethanol in a hermetically sealed chamber (see Fig. 3). The principle of this so-called thermosiphon allows heat transfer coefficients which are several orders of magnitude higher than with conventional heat transfer by conduction or convection.

Caloric Cycle

Magnetization / polarization / deformation
The caloric material heats up from the starting temperature $T_0$ to $T_0 + \Delta T$ when a corresponding field is applied.

Heat dissipation
The caloric material is connected to a heat sink so that the resultant heat can be dissipated. The caloric material cools down to the starting temperature $T_0$.

Demagnetization / depolarization / relaxation
If the field is no longer applied, the caloric material cools down and is at a lower temperature $T_0 + \Delta T$ than at the start of the cycle.

Heat input
The caloric material is connected to the system to be cooled and absorbs heat until the starting temperature $T_0$ is reached.