The continuous growth of the global population, the desire to improve living comfort, and climate change are the main factors driving the increasing demand for heat pumps and air conditioning systems. Their use leads to higher energy consumption. Therefore, the development of efficient and eco-friendly heating and cooling technologies is crucial. Similarly, limiting the use of refrigerants that are greenhouse gases or exhibit toxic properties, which are used in conventional vapor-compression refrigerators, is also important. Recently, an innovative heating and cooling strategy based on the use of superelastic shape memory alloys (SMAs) has been developing. These advanced functional materials are characterized by a wide range of reversible deformation, accompanied by significant temperature change caused by stress-induced phase transformation. During loading, this results in a temperature increase (heating), while during unloading, it results in a temperature decrease (cooling). These effects are called the elastocaloric phenomenon, which the World Economic Forum ranked among the ten emerging technologies in 2024. The application potential of elastocaloric heating and cooling technologies spans sectors such as automotive, construction, electronics, and household appliances.

Most solutions described in the literature propose the use of Ni-Ti (nitinol) SMAs, which have been known and developed since the 1960s and are commercially available. Therefore, the main goal of the project is to conduct comprehensive research on modern Ni-free Ti-based SMAs. Currently, these alloys are not commercially available, yet they have significant application potential in elastocaloric heating and cooling systems. The project plan includes characterizing samples of Ti-Nb and Ti-Zr-based alloys produced using conventional techniques. These materials were developed and initially characterized by a group of scientists from the University of Tsukuba in Japan, a leading center specializing in the development and testing of SMAs worldwide. Selected compositions of such SMAs were shown to exhibit relatively stable superelastic behavior during cyclic deformation, which is crucial for applications in elastocaloric systems. Stable superelastic deformation is achieved by doping these alloys with oxygen or nitrogen atoms in the case of Ti-Nb-(O,N) systems, or by mechanical pre-training, as in the case of the Ti-Zr-Nb-Sn system. Preliminary studies conducted by the Principal Investigator in Poland in collaboration with scientists from Japan demonstrate that this group of SMAs exhibits significant temperature changes, reaching 19 K, during a single load-unload cycle. The project will also utilize shot peening and heat treatment to further improve the functional properties of these materials. Samples of reference alloys and those modified accordingly will be tested and evaluated in the context of optimal thermomechanical characteristics. Advanced tools for microstructure and phase composition characterization will be used, as well as tensile tests monitored using full-field measurement methods. The project aims to answer the following questions:

1. What is the potential for using Ti-Nb-(O, N) and Ti-Zr-Nb-Sn alloys in innovative elastocaloric heating and cooling systems?

2. How do the proposed processes (shot peening and heat treatment) change the microstructural features, local and global strain characteristics, and thermal responses of these alloys during cyclic deformation?

The project's implementation could significantly contribute to the development of efficient and environmentally friendly elastocaloric heating and cooling solutions by proposing improved materials for use in these innovative systems. The project's results are expected to meet the demand for this type of technology while simultaneously meeting climate targets. Currently, teams of scientists, from different countries, inlcuding Germany, Spain, Slovenia, China, and the USA are working on selected elastocaloric solutions. The proposed project will enable competitive research to be conducted also in Poland, in collaboration with researchers from the University of Tsukuba in Japan.