ENERGETICS

Ammin/Dumarey - A Methodology to Optimally Design Innovative Thermal Management Systems for Electrified Powertrains

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Context of the research activity	Battery Electric Vehicles (BEVs) continue to face key limitations, particularly regarding driving range, recharging times, and sensitivity to ambient temperature — all of which significantly impact battery efficiency and increase auxiliary energy demands, especially for cabin and battery thermal conditioning in cold climates. These challenges underscore the urgent need for more efficient and environmentally sustainable Thermal Management Systems (TMSs). Among the technologies under investigation, Heat Pump (HP) systems represent a promising alternative to traditional resistive heating solutions. However, their effectiveness is strongly influenced by the choice of working fluid. In this context, the adoption of PFAS-free refrigerants (such as R290, R744, or refrigerant blends) is becoming increasingly important to comply with stringent environmental regulations and to reduce the overall climate impact of vehicle systems. Despite their potential, these refrigerants present significant challenges — including flammability, higher operating pressures, and material compatibility — which must be carefully addressed to enable safe and efficient system integration. To support the shift toward these more sustainable solutions, the development of a robust, physics-based virtual test rig is essential. This tool enables a comprehensive evaluation of the coupled thermal and energy performance of BEV thermal systems under realistic and dynamic boundary conditions. The proposed methodology plays a key role in assessing the impact of alternative refrigerants, optimizing component and architecture design, and supporting the development of predictive thermal management systems capable of leveraging the potential of AI-based control techniques.

	Building upon the challenges outlined previously, this PhD research aims to develop a comprehensive physics-based virtual test rig to optimize the

Objectives	thermal architecture and selection of working fluids for electric vehicles. This advanced numerical tool will integrate detailed multi-domain models of key thermal subsystems—including battery thermal management, cabin conditioning, and heat pump systems—to enable a holistic evaluation of vehicle performance across a wide range of environmental and operational conditions. A primary focus of the research is to assess the impact and integration of environmentally sustainable refrigerants within the thermal systems, addressing their unique characteristics and challenges to facilitate regulatory compliance and reduce the overall environmental footprint. The proposed digital twin will also incorporate modules to simulate and evaluate advanced control strategies leveraging AI and vehicle connectivity. The emphasis will be placed on physically grounded system modeling and validation, which form the foundation for reliable and energy-efficient thermal management solutions. Ultimately, this research will support the design and development of optimized BEV thermal systems that balance energy efficiency, environmental sustainability, and compliance with emerging regulatory standards.

Skills and competencies for the development of the activity	To achieve the targets of this research project, the PhD candidate should have a comprehensive knowledge of the electrified powertrains. In particular, he/she should know the fundamentals of the main powertrain subsystem, i.e. internal combustion engines, electric machines, batteries as well as the basic of powertrain control techniques. Attitude to model design and programming will be fundamental while basic knowledge of SiL and HiL environment would represent a plus.