Cabin Thermal Comfort Analysis Using a Transient 1D-3D Coupled Analysis with TAITherm, OpenFOAM, and a 1D System Tool FMU

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Optimization of electric vehicle energy consumption is critical, since the vehicle energy consumption impacts vehicle range. The HVAC system is using a substantial amount energy to cool down the cabin in a hot summer scenario or heat-up it up in a winter scenario. The battery pack may also generating a significant amount of heat and has to be maintained within the right operating temperature range. All the energy required to manage the temperature of the battery and cabin directly impacts electric vehicle range. Therefore, it is crucial to predict the required energy consumption accurately.

Battery packs and cabin HVAC models are frequently designed and simulated in 1D system models, which are very useful for early design analysis, but a significant challenge is modeling complex components that cannot easily be represented through simple correlations or empirical data. Transient, three-dimensional, coupled thermal-flow simulations are necessary in order to accurately resolve the conductive, convective and radiative heat transfer physics inherent to the vehicle cabin and to the battery pack. Coupling a 3D CFD-thermal for the cabin as well as for the battery pack together with 1D dynamic system models improves the fidelity of both models while providing more realistic boundary conditions that can be used throughout the vehicle design process.

In this study, the battery pack thermal management and the cabin cooling efficiency during vehicle operation are analyzed together via numerical simulation. A 3D model for both the battery pack, as well as the cabin is used and combined in a transient coupling methodology between the 3D TAITherm thermal solver, the 3D OpenFOAM CFD solver and a 1D system tool FMU (Functional Mock-up Unit, a system model compliant with the Functional Mock-up Interface). This study demonstrates the advantages of using a 3D thermal, 3D CFD and 1D coupling to simulate the thermal management of an (electric) vehicle for a realistic transient drive scenario and how this can be used to predict the vehicle energy consumption and optimize vehicle range.