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# Development of a Personalized Thermo-regulation Model

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In recent years, vehicle electrification has progressed rapidly, cabin air conditioning has become a significant contributor to vehicle energy consumption, particularly under winter conditions. In order to mitigate energy consumption while maintaining occupant thermal comfort, model-based development approaches that explicitly account for individual differences in human thermoregulation are increasingly required. In actual vehicle cabins, thermal environments are highly non-uniform, and inter-individual variability in thermal sensitivity further complicates comfort-oriented control. Consequently, personalized human thermo-regulation models, rather than population-averaged models, are essential for advanced climate control design.

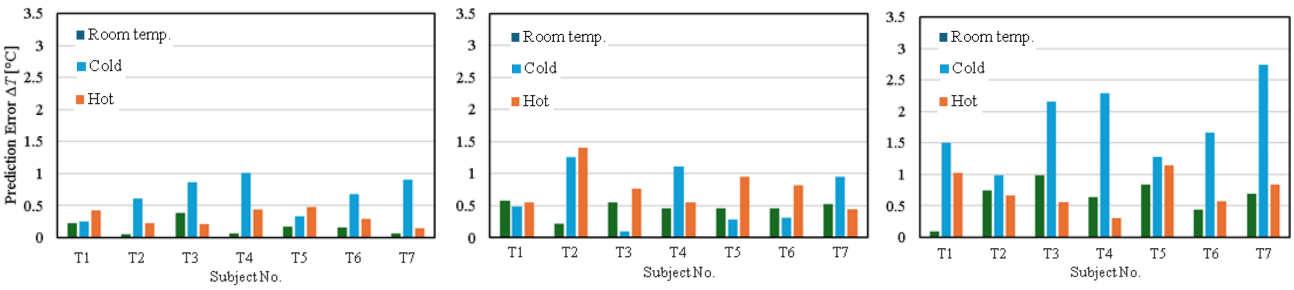
The objective of this study is to establish a fundamental personalization method for a multi-node human thermo-regulation model applicable to vehicle development. The target model is a segmented two-node exergy model (STEM), which represents the human body as a lumped-capacitance system divided into 22 segments. This model achieves a balance between computational efficiency and spatial resolution, enabling prediction of both local skin temperatures and core temperatures.

Model personalization was conducted by adjusting thermo-physiological parameters related to shivering, sweating, blood flow, internal heat transfer, and metabolic rate. The parameters were identified using experimentally measured skin temperature responses obtained from step-change exposure tests under cold (15 °C) and hot (35 °C) uniform environments. Experiments were conducted with seven male subjects under seated, resting conditions. Despite identical environmental and clothing conditions, whole-body mean skin temperature responses varied by up to approximately 2 °C among subjects, clearly demonstrating the necessity of individual adaptation.

The personalization problem was formulated as a single-objective optimization to minimize temperature prediction errors. A penalty-based objective function was employed to strongly penalize deviations exceeding the target accuracy of ± 1 °C. To ensure physiological plausibility, constraints were imposed on core temperature setpoints, skin blood flow, and internal heat transfer parameters. Furthermore, a sectional personalization approach was adopted, in which model parameters were independently identified for each phase of the step-change exposure, resulting in improved prediction stability.

After personalization, the models were fitted to the measured skin temperature responses and exhibited good agreement with the temporal trends for most subjects. As summarized in Fig. 1, prediction errors for whole-body mean skin temperature and peripheral segments such as the hands generally satisfied the target accuracy under neutral and hot conditions. In contrast, larger residual errors were observed for the seat-contact segment (thigh back) under cold conditions. This limitation is primarily attributed to uncertainties in heat transfer characteristics between the human body and the seat, as well as differences in seat specifications between experiments and model assumptions.

These results indicate that the proposed personalization framework enables stable adaptation of a human thermo-regulation model with multiple nodes while avoiding a physiologically unrealistic solution. The method is suitable for preliminary evaluation of energy-efficient climate control strategies and functional allocation studies that consider individual occupant characteristics. Future work will focus on improving contact heat transfer modeling and extending the approach to more complex and realistic vehicle cabin environments.




(a) Whole body (b) Hand (c) Thigh Back (Seat-contact Segment)

Fig. 1 Mean Prediction Error of each Subject’s Best Solution for Selected Body Segments.

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