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Measurement and Analysis of Automotive Cabin Thermal Insulation Characteristics and Elucidation of Heat-Gain/Heat-Release Behavior

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With the electrification of automobiles, improving cabin thermal insulation is essential to reduce air-conditioning energy consumption. In this study, heat transfer through cabin components such as glass, doors, roof, and floor was investigated. As shown in Fig.1, heat flux and temperature sensors were installed on a battery electric vehicle (BEV), and heat transfer during HVAC operation was measured. The results (Fig.2) show that heat loss from the roof is significantly larger than that from other components and increases under external airflow.

This difference is attributed to buoyancy-driven flow within the air layer, i.e., natural convection. To examine this effect, model experiments were conducted by varying the heat source position, as shown in Fig.3. The results indicate that when the air layer thickness exceeds a certain value, heat transfer depends on the heat flow direction. For upward and horizontal heat flow, heat transfer remains nearly constant even when the air layer thickness exceeds 10 mm, whereas for downward heat flow, it decreases monotonically. Numerical simulations further show that, in the case of downward heat flow, the flow velocity within the air layer is extremely small, indicating that natural convection is negligible and heat transfer is dominated by conduction.

The heat transfer mechanisms are summarized in Fig.4. Upward heat flow induces natural convection and enhances heat transport, while downward heat flow suppresses convection, resulting in conduction- and radiation-dominated heat transfer. These findings suggest that designing the heat flow direction downward in multilayer air-gap structures effectively suppresses natural convection and improves thermal insulation performance.

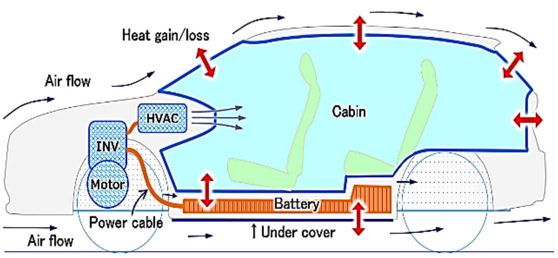

Fig.1 Overview diagram of heat gain/loss in each part of the cabin wall

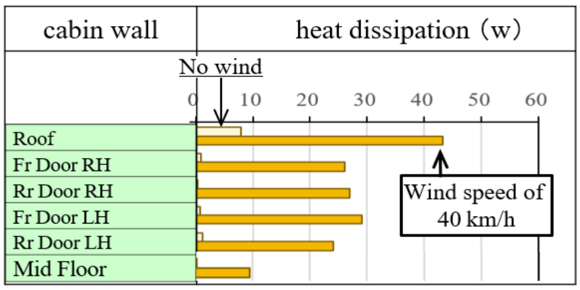

Fig.2 Heat loss of roof, doors and floor

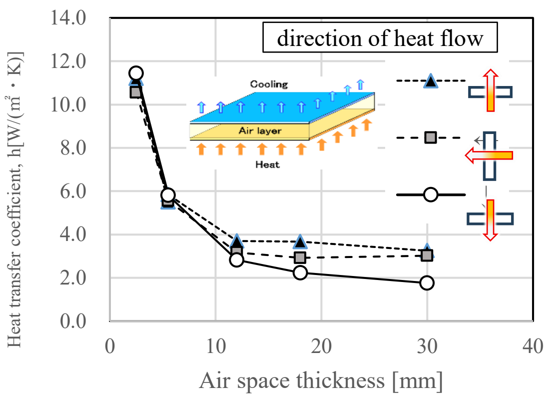

Fig.3 Effects of air layer thickness and heat flow direction on the heat transfer coefficient

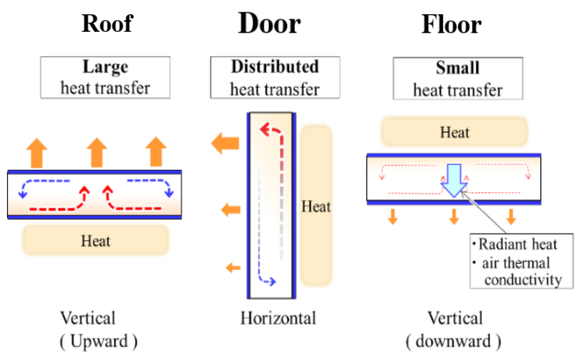

Fig.4 Schematic illustration of heat transfer mechanisms in a double-layer structure

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