

Development of a Method for Predicting Ambient Temperature of In-Vehicle Electronic Components Using 3D Fluid Analysis (Second Report)

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With the enhancement of functionalities in automotive electronic components and the diversification of vehicle designs and applications, the thermal design of electronic components based on their installation positions has become increasingly critical. To predict the temperature within the cabin, we developed a three-dimensional analysis technique employing fluid dynamics. By comparing actual measurements of solar radiation and cabin temperature during outdoor parking with the simulation results, we examined how variations in solar radiation due to seasonal, weather, and temporal factors affect cabin temperature.

This study evaluates the applicability and validity of a three-dimensional CFD-based method for predicting the thermal environment of in-vehicle electronic components under various real-world conditions. The target application range was defined as solar elevation angles between 20° and 90°, where direct solar radiation enters the cabin. Based on spherical trigonometry, the theoretical range of the angle between the windshield normal and solar direction was calculated as 0.00° to 76.24°. The validation experiments covered 90.7% of this range, corresponding to incident angles from 5.69° to 74.83°.

Vehicle tests were conducted using two vehicle models in Toyota and Shibetsu under different seasonal and orientation conditions.(Table1) Measured solar radiation and instrument panel surface temperature rise (ΔT_{IP}) were compared with simulation results to assess prediction accuracy.(Table2) For a representative case conducted in Toyota, solar radiation prediction showed high correlation with measured data during periods unaffected by intermittent cloud cover, achieving coefficients of determination (R^2) of 0.82 and 0.90. The corresponding ΔT_{IP} predictions yielded R^2 values of 0.97 and 0.48, indicating that temperature trends were not consistently reproduced even when average errors decreased.

In another validation case conducted in Shibetsu, solar radiation prediction achieved an R^2 of 0.86, whereas ΔT_{IP} prediction remained low at 0.10. Analysis suggests that these temperature prediction errors originated mainly from simplified heat-transfer pathways around the instrument panel and uncertainties in assigned material properties. The results demonstrate that the proposed method can accurately predict direct solar radiation entering the cabin, except under rapidly changing cloud conditions, while further improvements in thermal modeling are required to enhance temperature prediction accuracy.

Table1 Test conditions

No.	Vehicle	Location/ Month	Time	Vehicle Orientation [deg.]
1~4	A	Toyota/ Sep.	13:56-15:47 Four 30-minute sessions	220-260
5~6	A	Shibetsu/ Jan.	14:57-06:18 08:45-13:12	240
7~10	B	Toyota/ Dec.	13:19-14:23 Four 10-minute sessions	210-224
11	B	Shibetsu/ Jan.	09:00-14:31	240

Table2 Validation Results of Solar Radiation and ΔT_{IP} Predictions

No.	Analysis Interval	Target	MAE [W/m ²]/ [°C]	RMSE [W/m ²]/ [°C]	R ²
7	Entire Period	Solar Radiation	15.83	42.99	0.05
		ΔT_{IP}	2.39	3.10	0.12
	First 10 Minutes	Solar Radiation	2.77	5.12	0.82
		ΔT_{IP}	2.19	2.27	0.97
	Last 10 minutes	Solar Radiation	0.90	1.15	0.90
		ΔT_{IP}	0.52	0.66	0.48
11	Entire Period	Solar Radiation	11.71	14.19	0.86
		ΔT_{IP}	7.09	8.73	0.10