Modification of the UCB Comfort Model for Predicting Thermal Comfort in Electric Vehicle Cabins for Korean Drivers

Sohyun Kwun[1], Jiwon Yoo[1], Chungyoon Chun[1*], Junseok Park[2]

[1] Yonsei University, Seoul, Republic of Korea
[2] Hanyang University, Seoul, Republic of Korea

[*]*Corresponding email: chun@yonsei.ac.kr*

SUMMARY
This study has modified the UCB Comfort Model that predicts drivers' thermal comfort in vehicle cabins for electric vehicles and Korean drivers. To modify this model, a subject experiment was conducted. With an actual electric vehicle installed in a climatic chamber, the Korean subjects were exposed to a summer cooling environment. Environmental data, skin temperatures of 16 body parts, and thermal comfort votes were collected. The skin temperatures were compared with the skin temperature results calculated through Hanyang University's thermal physiological model and used to increase the predictive power of the thermal physiological model. Calculated skin temperatures were entered into the UCB Comfort Model, and the predicted thermal sensation was calculated. This result was compared with the subjects' actual responses, and coefficients were modified to minimize the difference between the two.

KEYWORDS
Thermal comfort model, Thermal comfort prediction, Electric vehicles, Thermoregulation model, Vehicle tests

1 INTRODUCTION

Applying the comfort model to the vehicle, there can be differences such as the type of vehicle used, the subjects' ethnicity, the language used in the evaluation scale, etc. And this can lead to discrepancies in the prediction results and thus should be considered in the prediction. This study investigated the thermal sensation of Korean subjects when cooling an electric vehicle by experimenting. By comparing the results with the prediction results from the UCB model, modifications were made for electric vehicles, cooling, and Koreans. And in the process, linking to the thermal physiological model has proceeded.

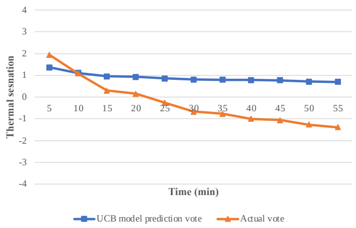
2 MATERIALS/METHODS

The experiment was conducted on 17 Koreans in their 2-30s. An electric vehicle was installed in the climatic chamber, and the temperature was set to 35℃. An artificial sun was installed, and the solar radiation was 850W/m^2. Subjects changed into uniforms, attached sensors, and waited in a pre-conditioning room for their body to be stabilized in a thermally neutral state. Afterward, subjects moved inside the vehicle and responded to the questionnaires. Since the car simulated the situation of parked outside in summer, it started at 50 degrees due to the solar radiation and gradually stabilized at 27 degrees as the cooling started. For the environmental data, indoor air temperature, relative humidity, radiant temperature, and air velocity were measured by the HVAC manikin. The subject's local skin temperature was measured at 16 body parts every 10 seconds. Subjects answered the questionnaires every 5 minutes about their local thermal sensation, overall thermal sensation, local thermal comfort, and overall thermal comfort. For the questionnaire, a 9-point thermal sensation scale and a 10-point thermal comfort scale with a separate center were used.

3 RESULTS

As an experimental result, the mean skin temperature gradually decreased from 35.3℃ to 33.8℃. Similarly, the whole-body thermal sensation started at 2 (warm) and decreased to -1 ~ -2 (slightly cool ~ cool) as the experiment progressed. Through the thermoregulation model developed by Hanyang University, the predicted skin temperature of 16 body parts was derived based on the environmental data from HVAC manikin, clo value, and metabolic rate. And by comparing with the measured skin temperature data, the prediction accuracy was increased. By using this predicted temperature in the UCB comfort model, the predicted thermal sensation was calculated. The thermal sensation showed a difference of 0.6 at the beginning and the difference gap widened to 2 at the end. (Fig. 1, a) To reduce this discrepancy, the local sensation model (Eq. (1)) modification was performed. The modification was performed in the set points of local and mean skin temperature and the coefficients. As the coefficients, there are C1 and C2, which are regression coefficients for the slope of a logistic curve, and K1, which is the factor for the effect of mean skin temperature. (Table 1) After the modification, the discrepancy decreased to 0.3 at the beginning and 0.8 at the end. (Fig 1, b) This means that the prediction performance has been improved through modification to the optimal coefficient.

$$Sensation_i = 4\left(\frac{2}{1+e^{-C1\left(T_{skin,i}-T_{skin,i,set}\right)-K1\left[\left(T_{skin,i}-\bar{T}_{skin}\right)-\left(T_{skin,i,set}-\bar{T}_{skin,set}\right)\right]}}-1\right)+C2_i\frac{dT_{skin,i}}{dt}+C3_i\frac{dT_{core}}{dt} \quad (1)$$

a) 

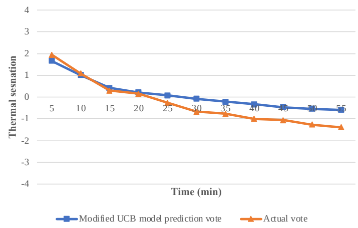
b) 

Figure 1. a) Comparison of the UCB model prediction vote and the actual vote, b) Comparison of the modified UCB model prediction vote and the actual vote

Table 1. Modified coefficients and set points of local thermal sensation prediction

Body parts	*Tskin,i–Tskin,i,set < 0*			*Tskin,i–Tskin,i,set ≥ 0*			$T_{skin,i,set}$	$T_{skin,set}$
(*i*)	C1	C2	K1	C1	C2	K1		
Head	1.18	1500	1.91	0.94	1500	-2	35.5	
Chest	2	0	-0.49	-0.21	0	-1.85	35	
Back	2	0	-1.34	0.38	0	1.94	35.7	
Pelvis	2	0	-1.48	0.96	0	-0.59	34.5	
Upper Arm	0.74	17	0.99	0.57	0	1.4	34.8	34.9
Lower Arm	1.87	282	1.33	1.74	0	-2	33.3	
Hand	2	166	-2	1.72	0	-2	34.2	
Thigh	-1.64	392	-2	1.24	222	-1.31	34	
Leg	1.11	1442	-1.03	0.85	278	-1.02	35	
Foot	2	1500	2	0.27	1354	-0.49	35.4	

4 CONCLUSIONS

This study examined the difference between the predicted and actual votes when applying the UCB model to an electric vehicle cooling experiment with Korean subjects. In addition, prediction accuracy was improved by connecting with the thermoregulation model and modifying it to the optimal coefficients and set points.

ACKNOWLEDGEMENT

This work was supported by the Technology Innovation Program(1415177965, 20011377) funded By the Ministry of Trade, Industry & Energy(MOTIE, Korea)