Thermal Comfort Prediction for the Passengers based on HVAC System Data from Electric Vehicles

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SUMMARY
The aim of this study is to predict passengers' thermal comfort using Random Forest. A prediction model is using data collected from a vehicle parked in an environmentally controlled chamber, and the accuracy of the RF model is 82.1% in this instance. Furthermore, it is identified that the environmental factor with the greatest impact on passengers' thermal comfort is the heating seat.

KEYWORDS
Overall Thermal Comfort; Predictive Model; Electric Vehicle Comfort; Random Forest

1 INTRODUCTION
Today, the vehicles have evolved beyond means of transportation, expanding their role as the living spaces. The research findings that the car cabin environment effects driver's comfort, performance, and fatigue (Tsutsumi et al., 2007) imply that the car cabin environment is associated with safety. Therefore, the comfort of the car cabin environment has become increasingly important. Over the past decade, various studies have been conducted on the thermal comfort of vehicle passengers. The UC Berkeley (UCB) model proposed by Zhang (2003) has been widely adopted for several years as a model to assess the thermal comfort of vehicle passengers. Since 2016, research has been conducted on developing models for human thermal comfort using machine learning (Zhao, 2021). This study investigated the feasibility of developing a predictive model for the vehicle passenger thermal comfort using passenger information and environmental data from the electric vehicle through a car in an environmentally controlled chamber.

2 METHODS
In this study, a total of 32 experiments were conducted using a car parked in an environmentally controlled chamber. The used vehicle was an electric car, equipped with heated seats and a radiant panel. The outdoor temperature in the environmentally controlled chamber was set to four conditions: -20℃, -10℃, 0℃, 10℃. Eight experiments were conducted for each condition. Thirteen people participated in this experiment and all participants were male. Convection heating, radiant heating, and contact heating were used in the experiments. Convection heating operated at a fixed target temperature of 22℃, while radiant and contact heating were operated in four stages (3, 2, 1, off) over time based on the conditions. Thermal comfort assessments were conducted at 5-minute intervals over a total of 13 surveys during a 60-minute period, starting with the first survey (0 minutes) after the participants entered the vehicle and operated all heating methods. The thermal comfort scale ranges from -4(very uncomfortable) to 4 (very comfortable) and the collected thermal comfort data were recoded as follows: values below -1 were categorized as discomfort, values between -1 and 1 were categorized as neutral and values above 1 were categorized as comfort. In this study, the Python scikit-learn library was utilized, and the thermal comfort prediction accuracy was compared using commonly used machine learning models, including logistic regression (LR), k-nearest neighbors (kNN), decision tree

(DT), random forest (RF), gradient boosting machine (GBM), and support vector machine (SVM).

3 RESULTS

3-1 Comparison of machine learning model prediction accuracy

The independent variables included personal characteristics (age & BMI) and environmental characteristics such as outdoor temperature, average convection temperature, average radiant panel temperature, and average heated seat temperature. The dependent variable was the overall thermal comfort. 80% of the entire dataset was utilized as the training set and the remaining 20% was used as the test set. To solve the data imbalance, SMOTE (Synthetic Minority Oversampling Technique) was used among oversampling methods.

Table 1. Thermal comfort prediction accuracy and f1 score

	Accuracy		F1 Score	
Algorithm	Avg	St dev.	Avg	St dev.
LR	0.623	0.055	0.608	0.046
kNN	0.666	0.037	0.632	0.040
DT	0.680	0.036	0.626	0.056
RF	0.724	0.025	0.677	0.038
GBM	0.675	0.057	0.640	0.056
SVM	0.575	0.057	0.563	0.052

Table 1 presents the average accuracy and the average f1-score of 5-fold cross-validation for each algorithm. Most of algorithm exhibited 65% or higher, with Random Forest (RF) showing the highest performance.

3-2. Variable importance analysis

The variable importance was derived using the Random Forest algorithm which exhibited the highest performance; optimized by finding the hyper parameters that could achieve the best performance. At this point, the accuracy of RF is 82.1%. The variable with the highest importance was the average heated seat temperature (0.253), followed by the average convection air conditioning temperature (0.198), average radiant panel temperature (0.177), outdoor temperature (0.172), BMI (0.126), and age (0.074) in order of variable importance.

4 DISCUSSIONS and CONCLUSIONS

This study employs Random Forest for predicting passenger thermal comfort with a maximum accuracy of 82.1%. Significantly, the heated seat temperature is identified as the most influential factor. This study holds significant importance as it conducted experiments with participants in an electric vehicle equipped with a heated seat and radiant heating panel. The use of proximity heating methods will become increasingly crucial for securing the mileage efficiency of electric vehicles. Against this backdrop, the findings of this study are expected to contribute to predicting the thermal comfort of occupants in electric vehicles equipped with proximity heating. However, limitations include the exclusion of diverse age and genders, as well as the possibility of the impact on the outdoor environment being amplified or reduced. Additional research is needed to address and overcome these limitations.

6 REFERENCES

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