ELECTRIC VEHICLE RANGE IMPROVEMENT BY UTILIZING DEEP LEARNING TO OPTIMIZE OCCUPANT THERMAL COMFORT

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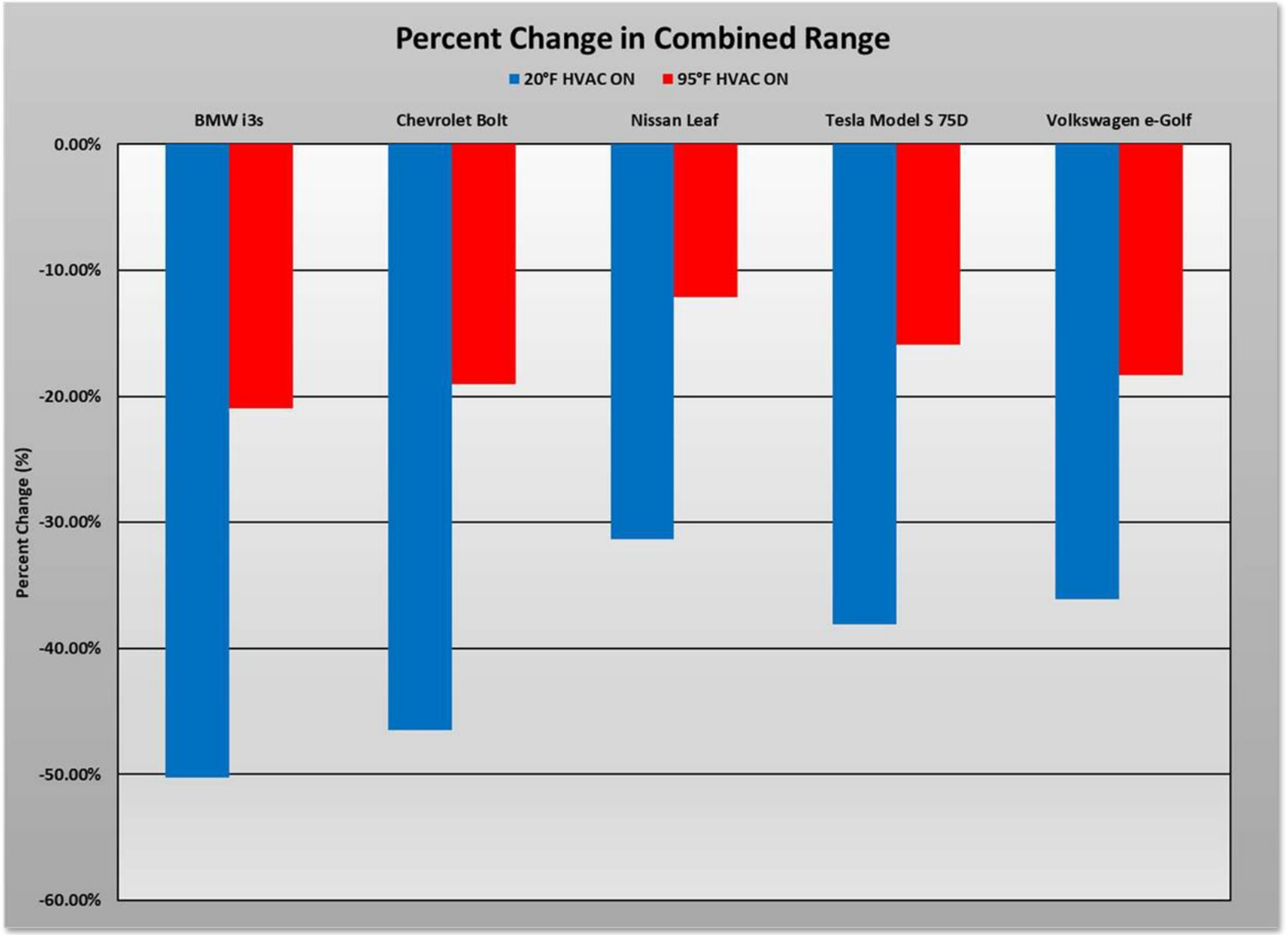
PROBLEM – EV RANGE

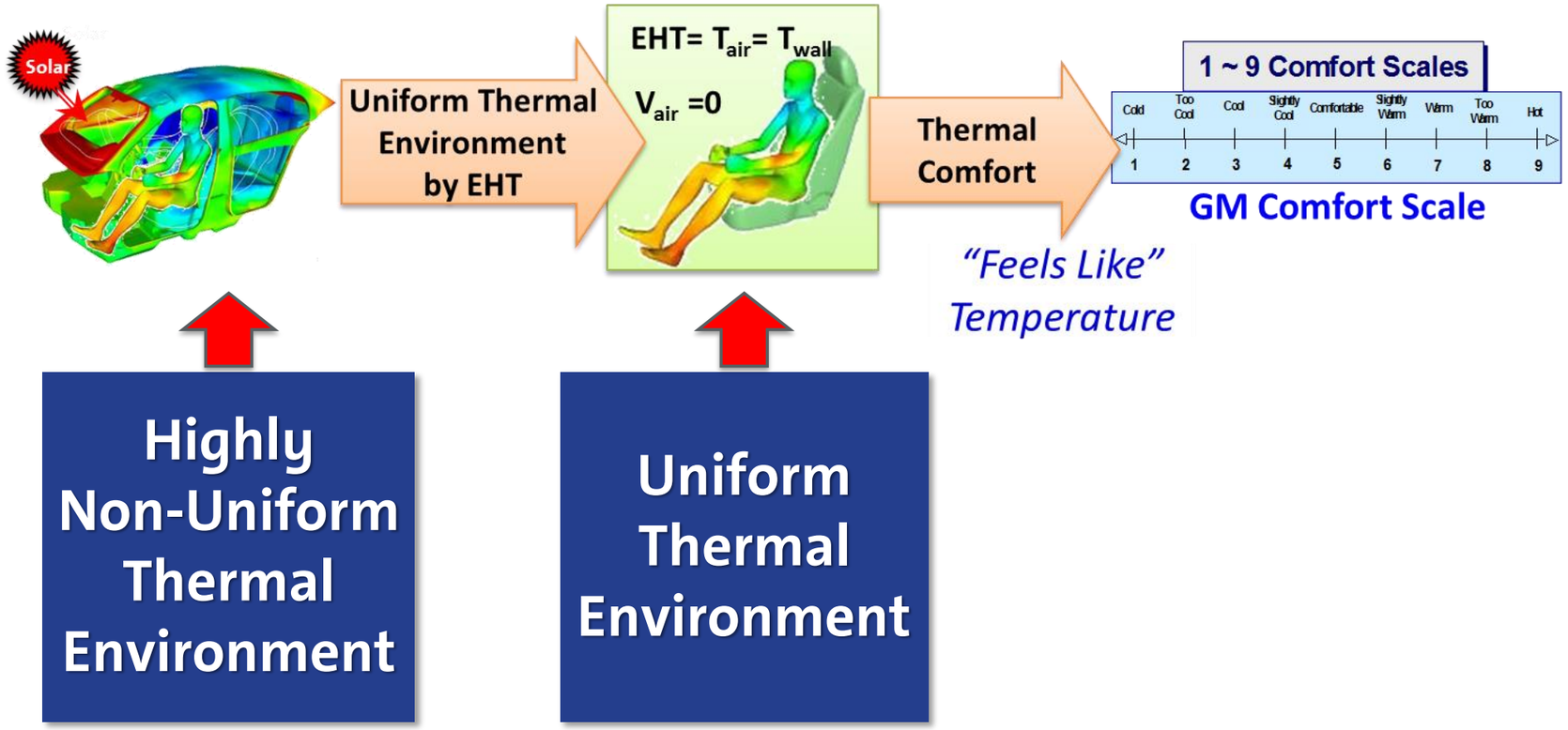
Energy-efficient HVAC systems are critical for increasing EV range

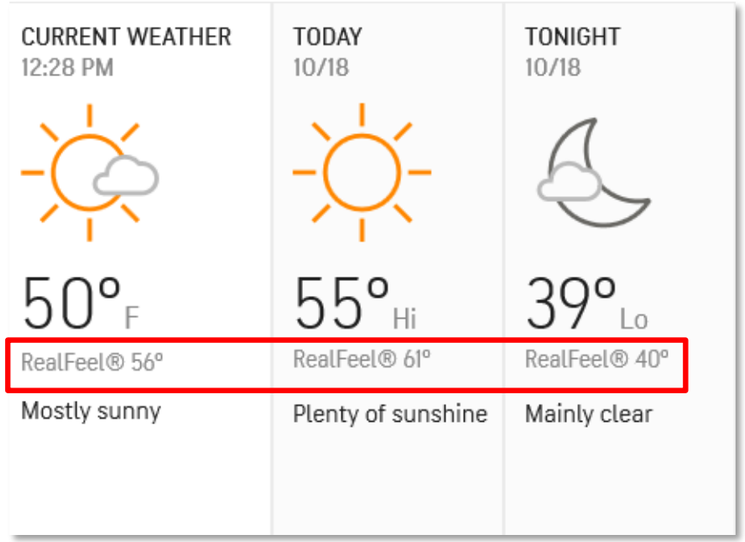
AAA Newsroom: Icy Temperatures Cut Electric Vehicle Range Nearly in Half



Source: AAA Newsroom, Icy Temperatures Cut Electric Vehicle Range Nearly in Half, https://www.aaa.com/AAA/common/AAR/files/AAA-Electric-Vehicle-Range-Testing-Report.pdf, 2019

EQUIVALENT HOMOGENEOUS TEMPERATURE (EHT)





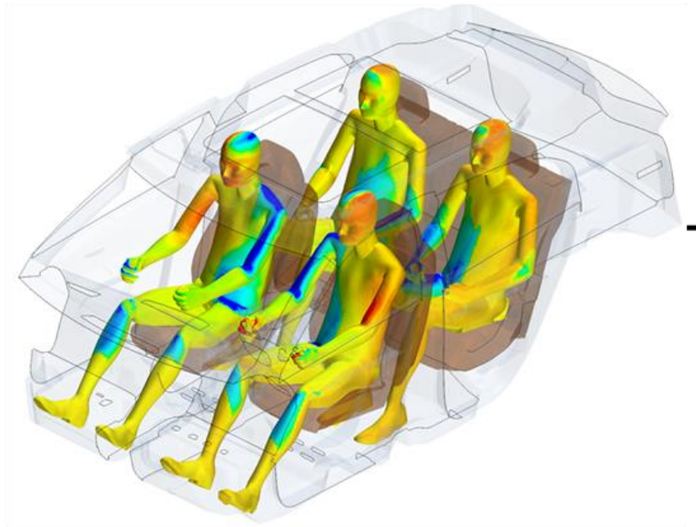
Snapshot of weather demonstrates the concept of EHT with the "RealFeel®" forecast

[1] T. Han, L. Huang, S. Kelly, C. Huizenga, Z. Hui, Virtual Thermal Comfort Engineering, SAE Technical Paper 2001-01-0588, 2001, https://doi.org/10.4271/2001-01-0588.

[2] T. Han, L. Huang, A Model for Relating a Thermal Comfort Scale to EHT Comfort Index, SAE Technical Paper 2004-01-0919, 2004, https://doi.org/10.4271/2004-01-0919.

[3] T. Han, L. Huang, A Sensitivity Study of Occupant Thermal Comfort in a Cabin Using Virtual Thermal Comfort Engineering, SAE Technical Paper 2005-01-1509, 2005, https://doi.org/10.4271/2005-01-1509.

METHODOLOGY: STEADY-STATE



Cabin CFD Model

Training Data

Input Layer

Hidden Layers

Output Layer

Overall EHT for each occupant

Model Evaluation

Test Data

DATA SPLIT

Training Data

– 1535 CFD generated cases (694 Winter and 841 Summer)

Test Set

– 150 CFD generated Cases (100 Winter and 50 Summer)

INPUT FEATURES/PREDICTED VALUES

- **Total number of input variables/features:** 104

Feature Category	# of Features
Environmental Variables	6
Convection HVAC Settings	14
Glass Glazing Properties (Visible and IR)	28
Heated Glass	6
Radiant Heating Pads	40
Climate Seats	8
Heated Steering Wheel	1
Passenger Profile	1
	Total: 104

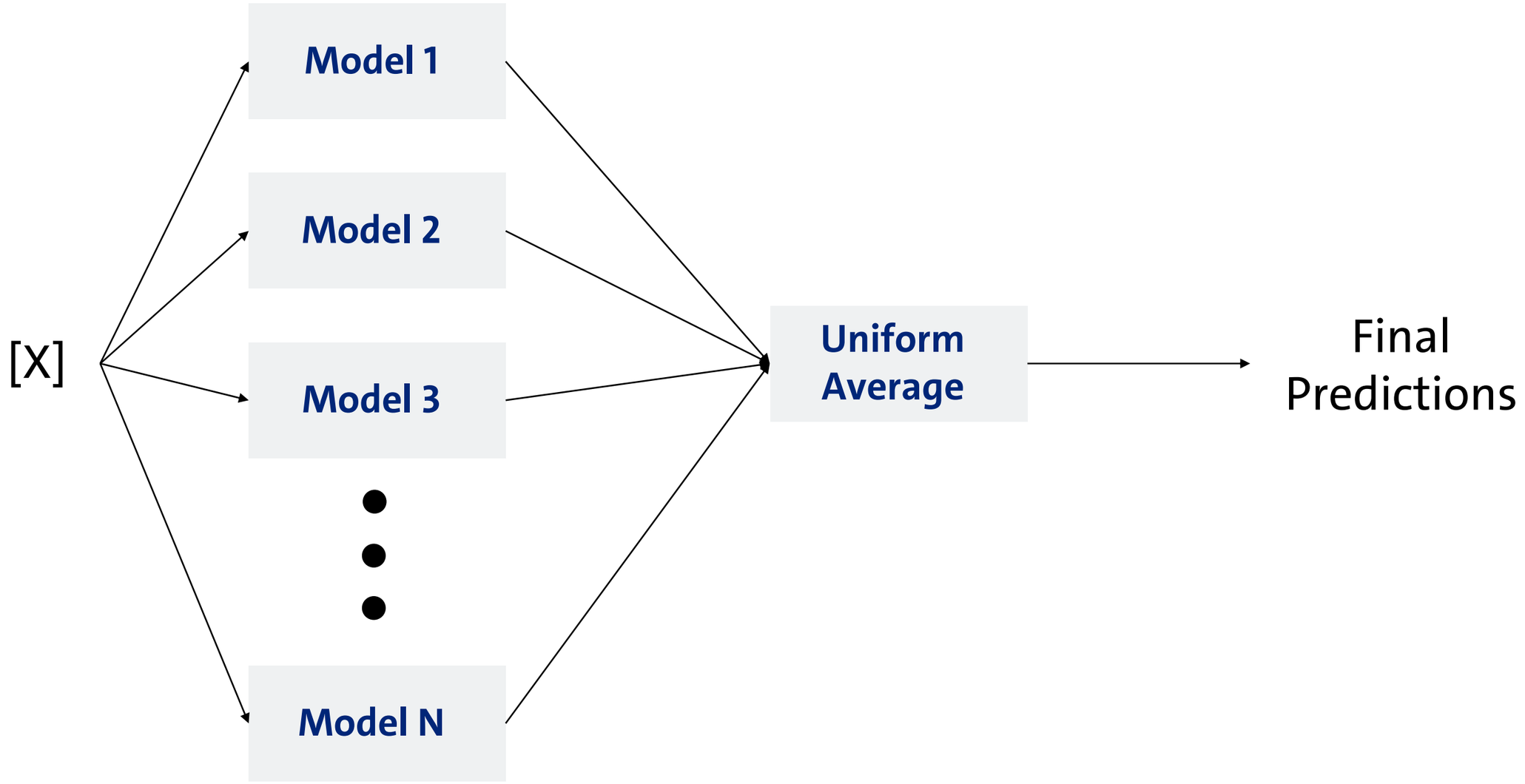
- **Total predicted variables:** 4 (Overall EHT values for each occupant)

NEURAL NETWORK DETAILS

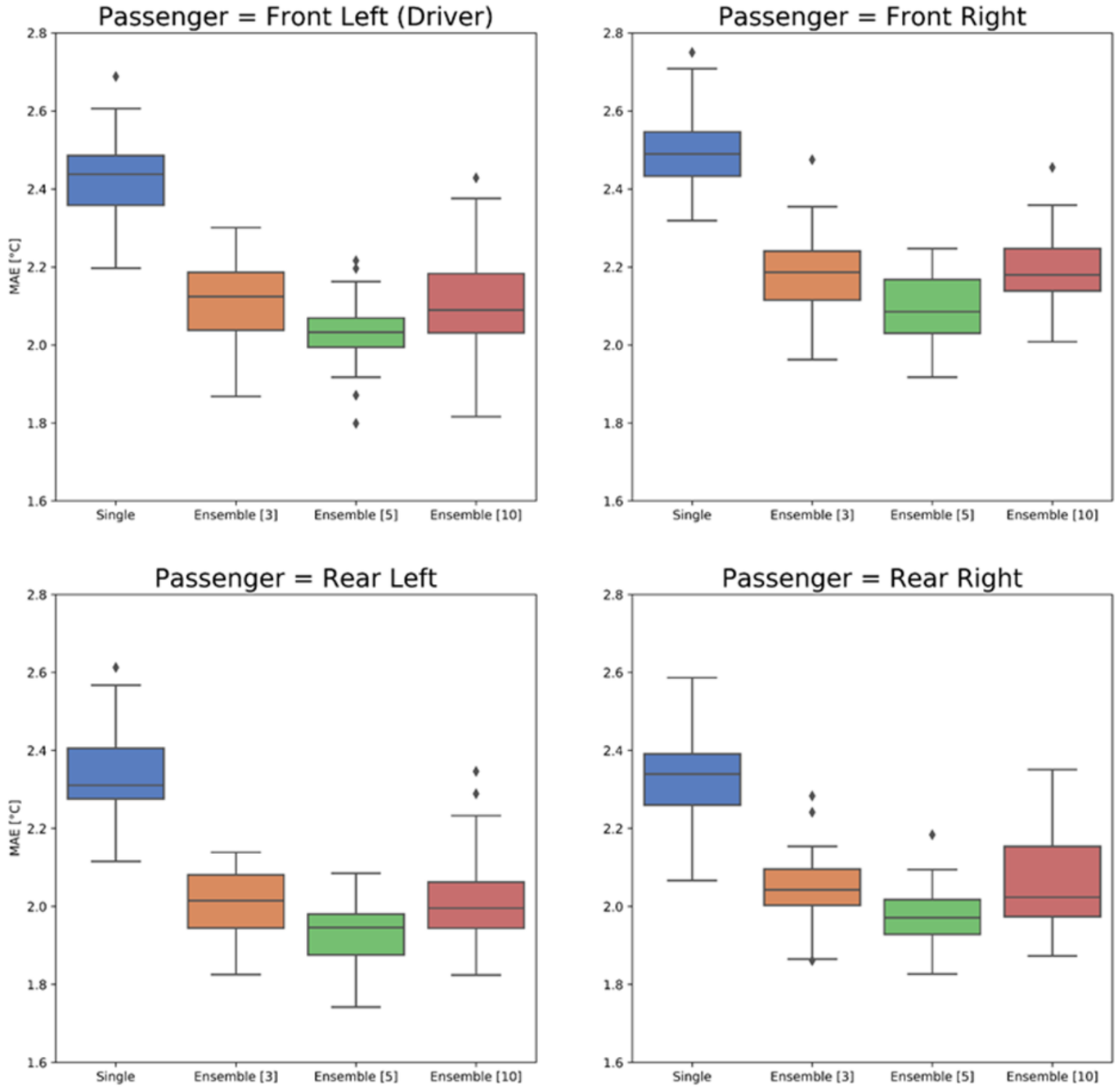
- Network architecture and hyperparameters tuned using Keras Tuner (Bayesian Optimization) and 5-fold cross validation on GPU nodes (NVIDIA Tesla P100).

Parameter	Search Space
Neurons in the first hidden layer	[8-512]
Additional hidden layers	[0-10]
Neurons in the additional hidden layers	[8-512]
Activation	[ReLU, ELU, Swish]
Optimizers	[Adam, RMSprop]
Dropout after each hidden layer	[0-0.5]
Batch size	[4-64]
Learning rate	[1e-5 - 1e-2]

NEURAL NETWORK ENSEMBLE – UNIFORM AVERAGE

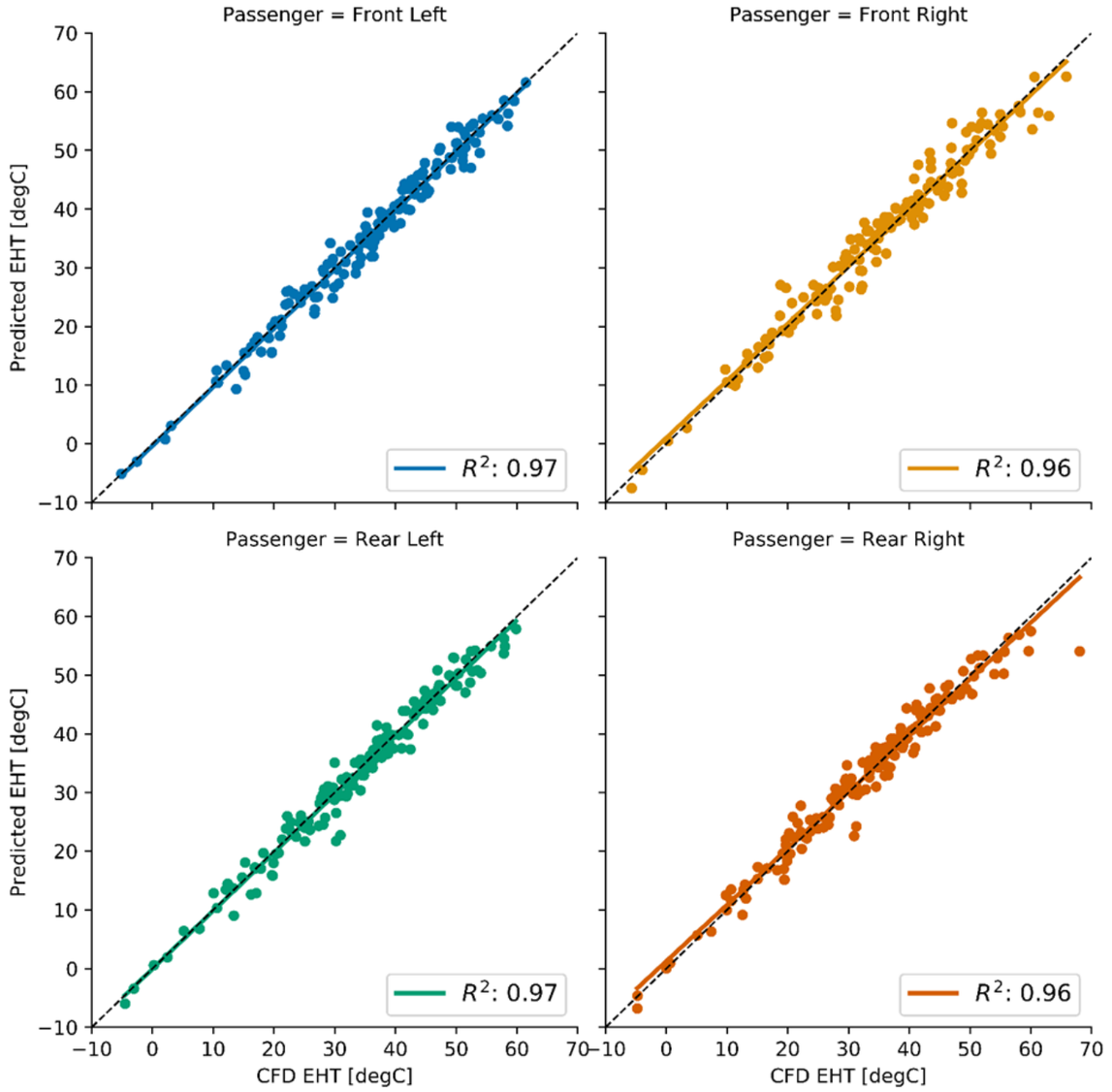


UNIFORM AVERAGE ENSEMBLE RESULTS USING REPEATED CROSS VALIDATION ON TRAINING DATA



UNIFORM AVERAGE ANN ENSEMBLE PERFORMANCE ON THE TEST SET

Metric	EHT: Front Left (Driver)	EHT: Front Right	EHT: Rear Left	EHT: Rear Right
MAE [°C]	1.7	2.0	1.7	1.8
RMSE [°C]	2.2	2.7	2.2	2.5
MAPE [%]	5.6	6.8	6.3	6.8



DEPLOYMENT AND FUTURE DEVELOPMENT

- **Deployed an easy-to-use web-application accessible to any HVAC engineer.**

- Enables predictions of thermal comfort for any combination of steady-state boundary conditions in real-time without being limited by time-consuming and expensive CFD simulations or climatic wind tunnel tests.

- A/B comparisons, estimates of EV range impact, sensitivity analysis etc.

- Future work will include addition of new cabin architectures and development of a physics-guided machine learning model to predict occupant thermal comfort under transient conditions and emissions drive cycles.

THANK YOU!

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