Microclimate Comfort System: Solution for Increasing Driving Range of Electric Vehicles

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GM Project Objective

Energy efficiency & perfect thermal comfort in one intelligent, integrated system

Develop a Proof of Concept micro-climate seat-centric climate control system.

GM Objective: 30% overall reduction in energy to achieve equal/superior comfort. Comfort is evaluated by maintaining EHT within ±1°C.

Gentherm/GM Solution

- Design & integrate two zone ClimateSense™ system into Chevy Bolt EV
  - ✓ Microclimate heating and cooling elements with Gentherm ECUs and software algorithm
- Collaborate with GM on developing and implementing comfort measurement methodology

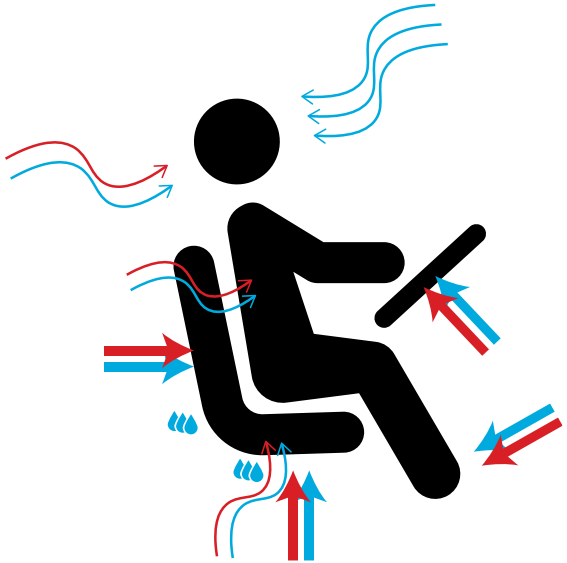
Human, physiological system exchanging heat with the environment

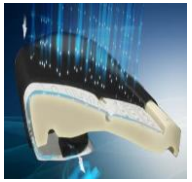
Conductive Heat Transfer

Convective Heat Transfer

Radiative (Warm Surface) Heat Transfer

Evaporative Heat Transfer





Ventilation and Active Cooling

Convective Heating

Radiative Heating

Humans are the center of our care and comfort. We use thermophysiology principles to design efficient components and effective integration in vehicles.

Heating Comfort

Focused heating on body core

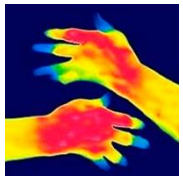
Body naturally manages heat flow to provide energy to our core.

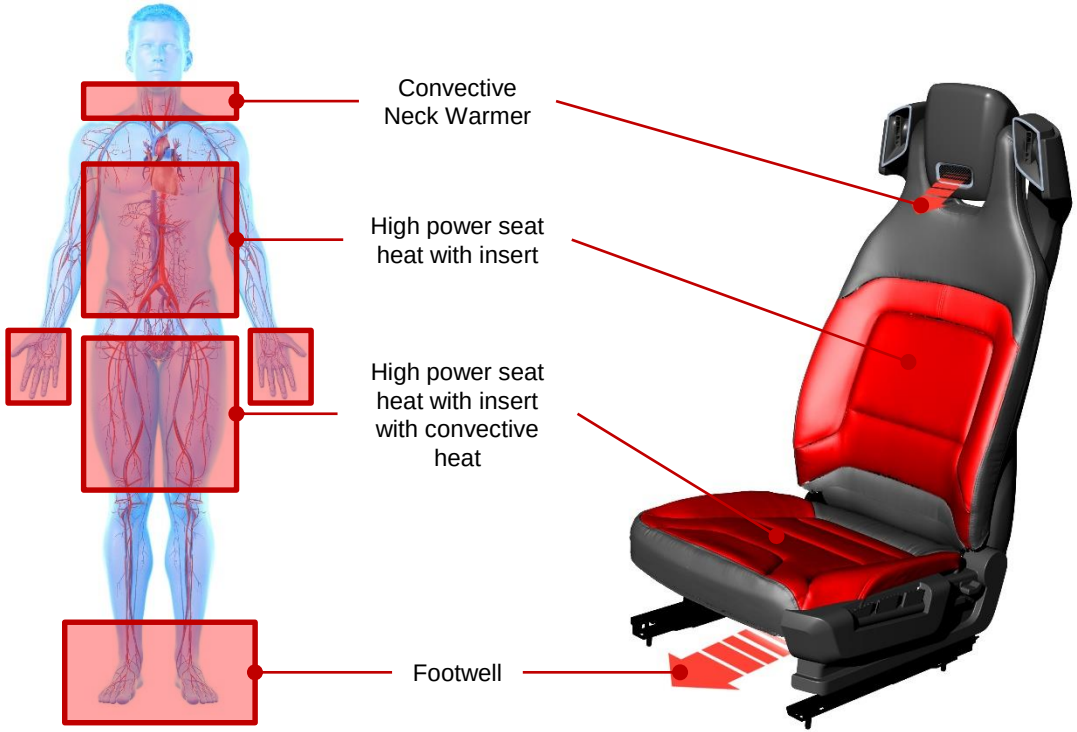
Direct heating of back and cushion is the most efficient heating method.

Large blood vessels deliver heat to organs and periphery. Neck heating is gateway to delivering instant heating sensation.

Fighting vasoconstriction

Blood flow to periphery is limited, affecting strong sensation of discomfort in hands and feet.





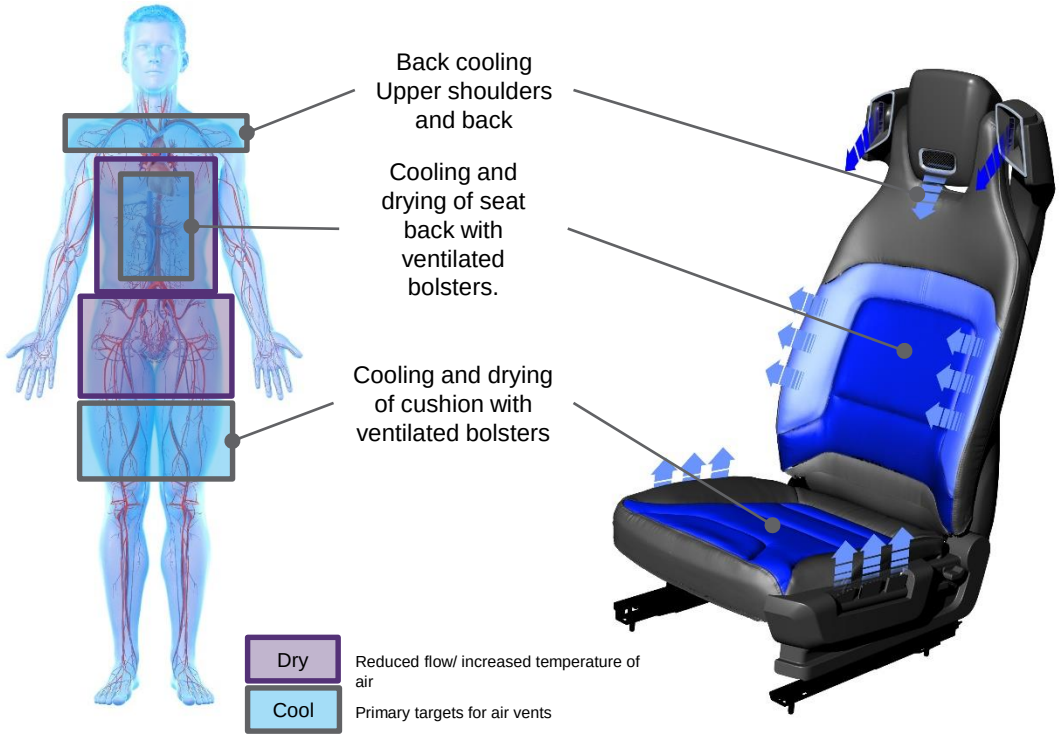
Cool Comfort

Focused cooling on body core

In hot weather the body manages heat while trying to reach physiological comfort through

1. **Evaporation/sweating**
2. **Conductive cooling**
3. **Convective cooling**
4. **Radiative cooling**

Additional discomfort is achieved through sensation of wetness. Sweating is a function of average skin temperature.



ClimateSense™ Heating Subsystem Architecture

CONDUCTIVE ELEMENTS

Seat heaters (includes bolster heat).

Heated interiors – console, steering wheel and door arm rests.

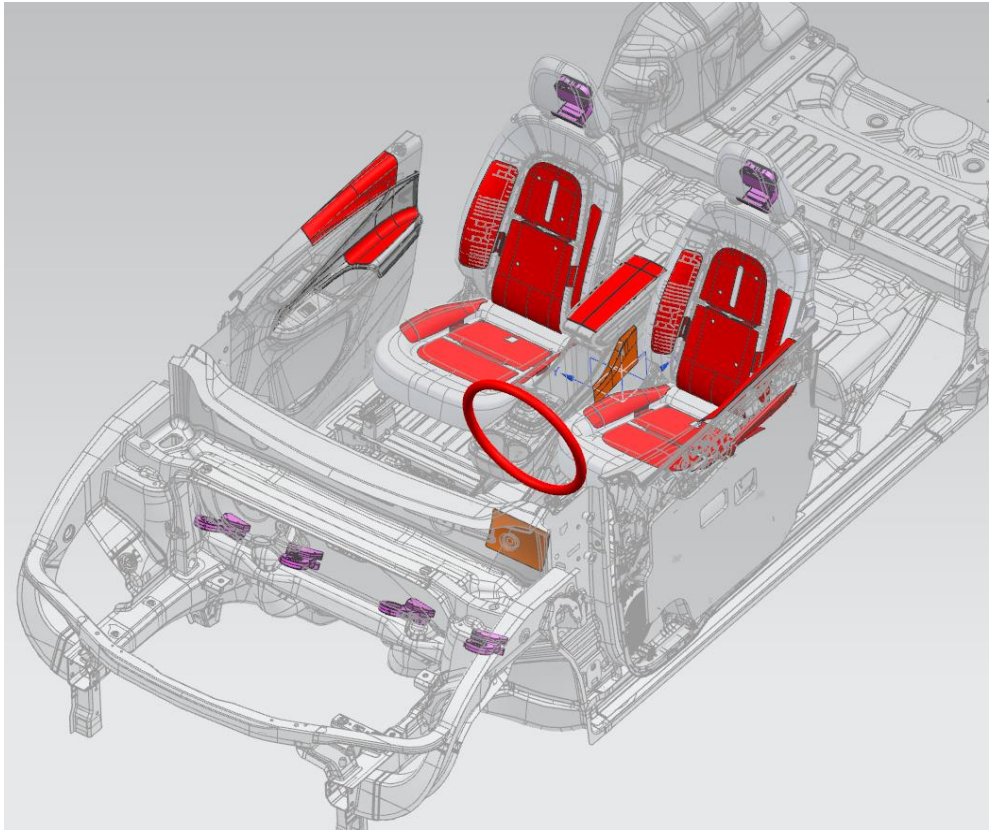
RADIANT (WARM SURFACE) ELEMENTS

Heated interiors – side console, door and knee bolster area

CONVECTIVE ELEMENTS

Foot warmers

Neck warmers



ClimateSense™ Cooling Subsystem Architecture

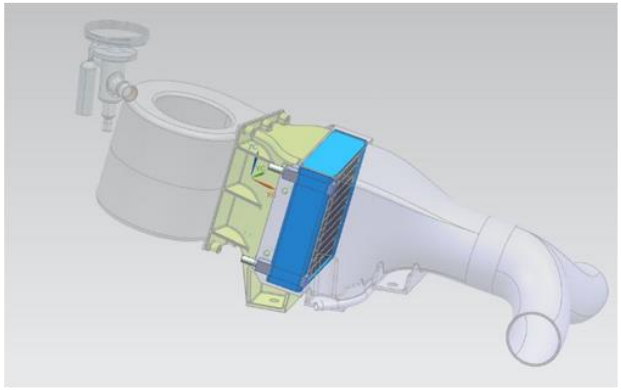
CONDUCTIVE ELEMENTS

Active Climate Controlled Seats.

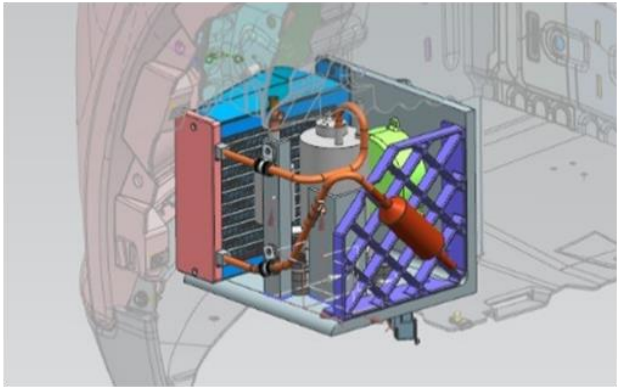
CONVECTIVE ELEMENTS

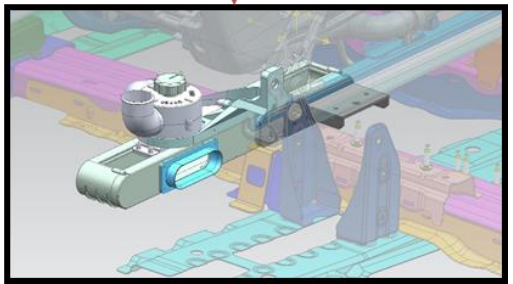
Seat cooling powered by mini-compressor with trolley duct and air flow control.

Evaporator / Blower assembly



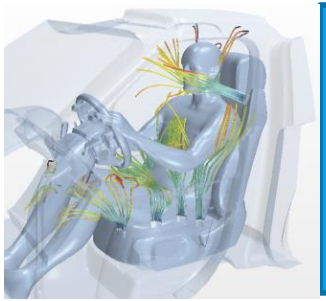
Mini-Compressor / Condenser sub-assembly near front bumper





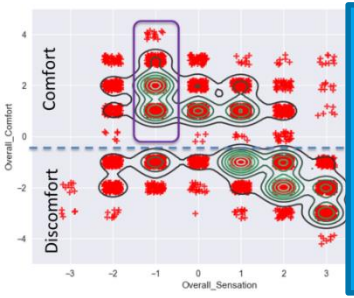
How to Evaluate Microclimate Systems?

Subjective vs Objective Measurements



Numerical Studies

Vehicle Build and Chamber Tests



Human Trials

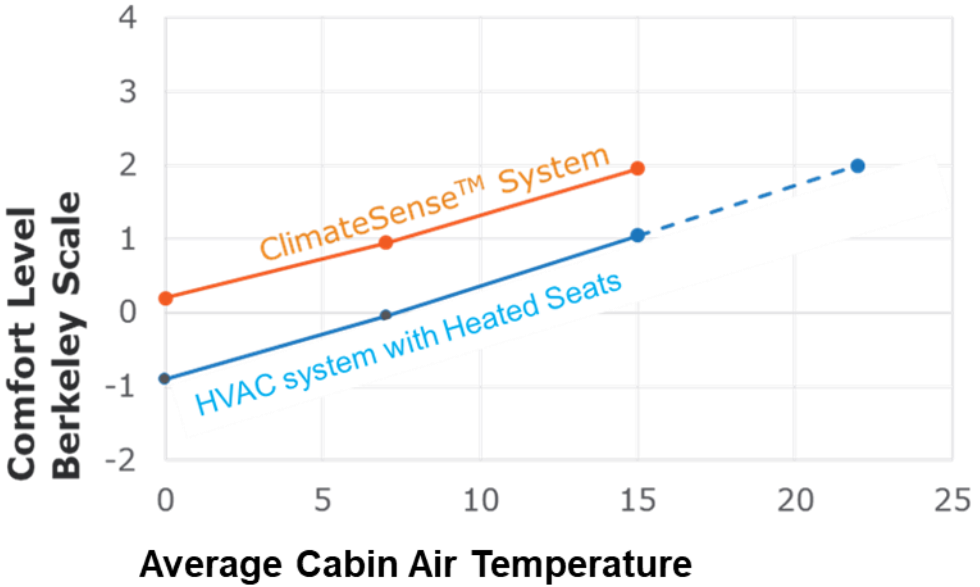
Manikin Tests corelated to comfort

Clinical Trials: Subjective Evaluations

- The study was conducted in the cabin of an i3 vehicle.
- The cabin of the vehicle was appropriately conditioned using external air source.
- Subjects report comfort on Berkeley scale.
- 14 individuals hired through Opinion Search based on their gender, age, height and weight.

OPINION SEARCH Since 1976 Unique. Experienced. Trustworthy.

7 male
7 female
20-56 year old
60-100kg
160-190 cm tall



ClimateSense™ system provides sustained comfort at lower cabin air temperatures.

Quantitative Comfort Measurement – Total Body EHT

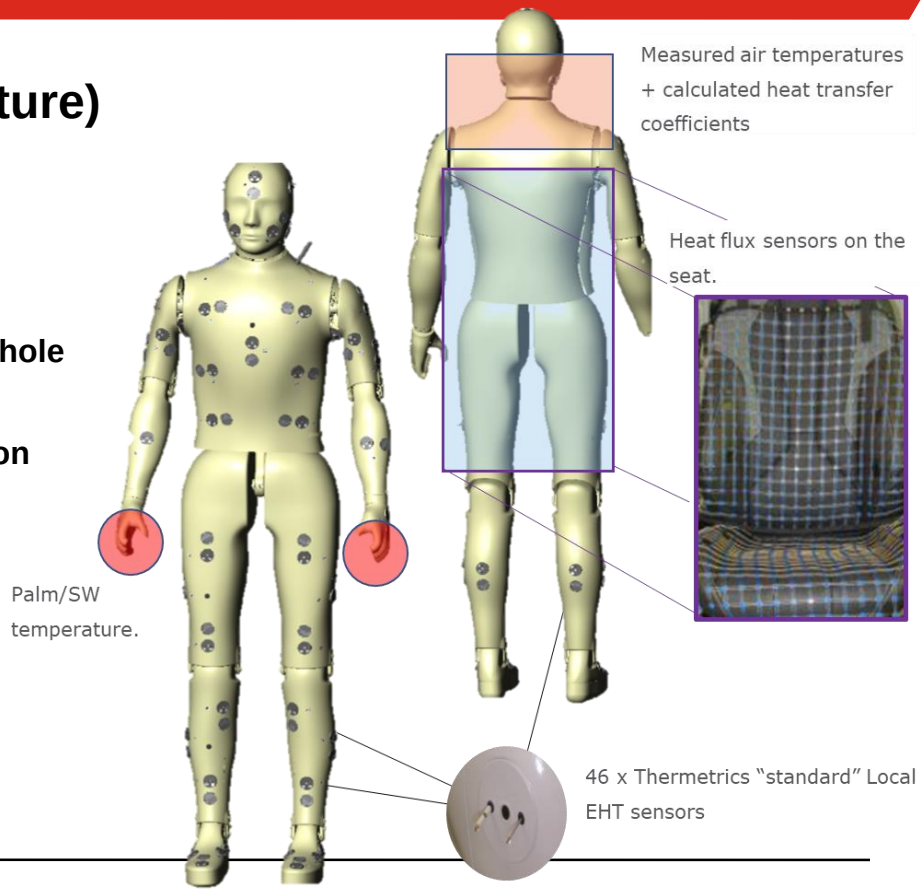
EHT (Equivalent Homogeneous Temperature) Measurement & Calculation

Measured Values

- **Local EHT values from HVAC manikin (Thermetrics)**
- **Local seat surface heat flux & temperature (Gentherm Mahole mat)**
- **Upper back/neck area to capture neck warmer & air cocoon cooling**
- **Driver hands to capture steering wheel heater**

Total Body EHT calculation

- **Calculate total body EHT using protocol developed by ThermoAnalytics**
- **Following ISO14505-2**



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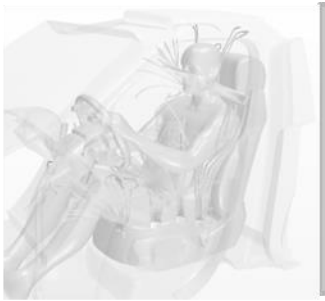

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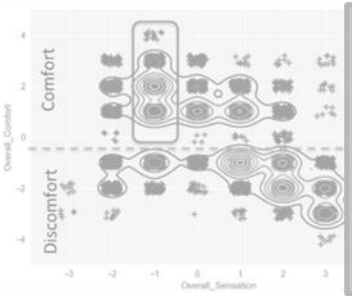
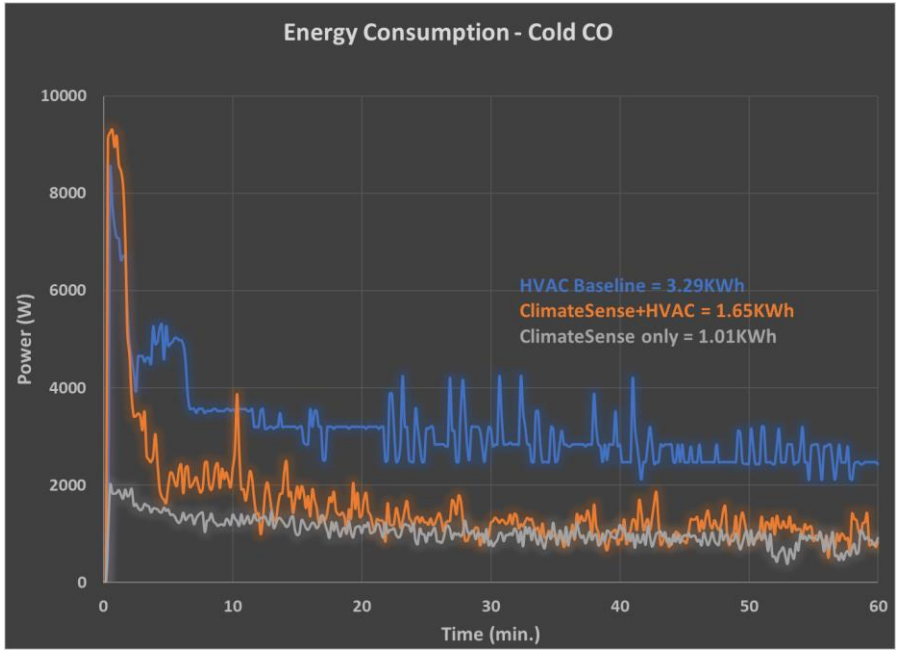
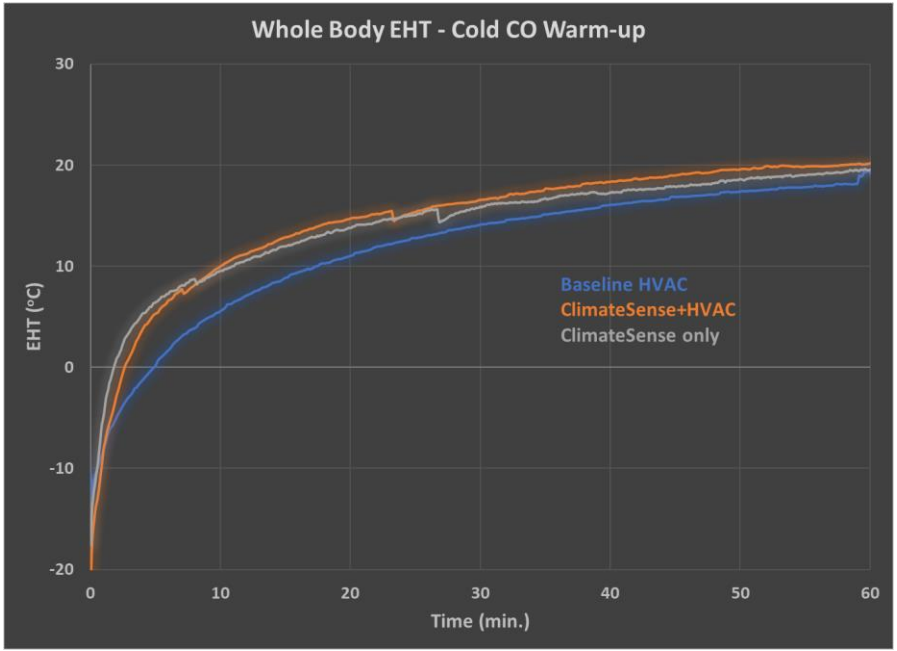


Human Trials

Manikin Tests corelated to comfort

Validation Testing – Cold CO Test





ClimateSense™ beats 30% target energy savings (2 zones active) with significant improvement in EHT in first 5 minutes of testing (customer satisfaction)

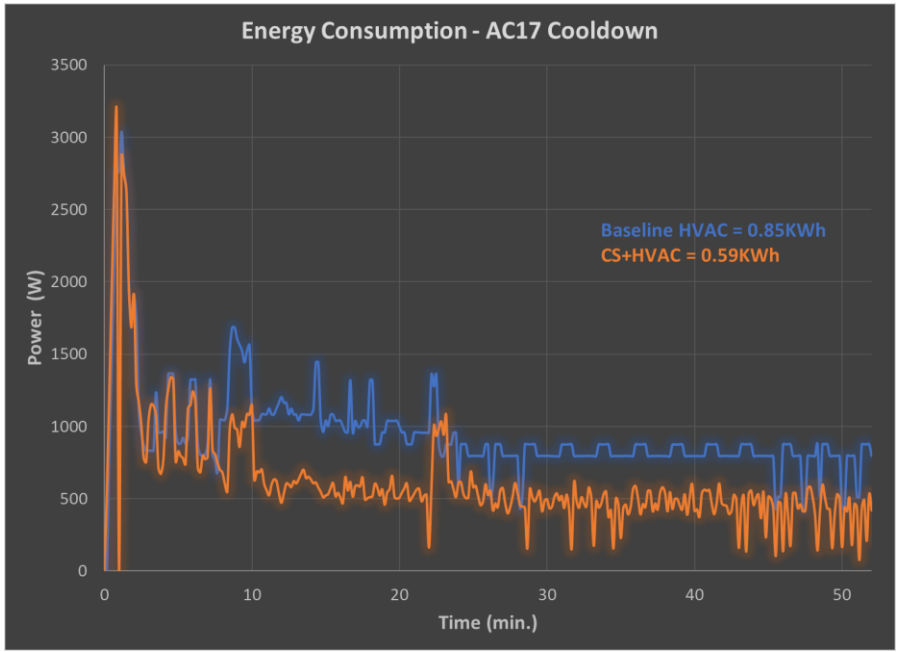
Validation testing – Cold CO Test

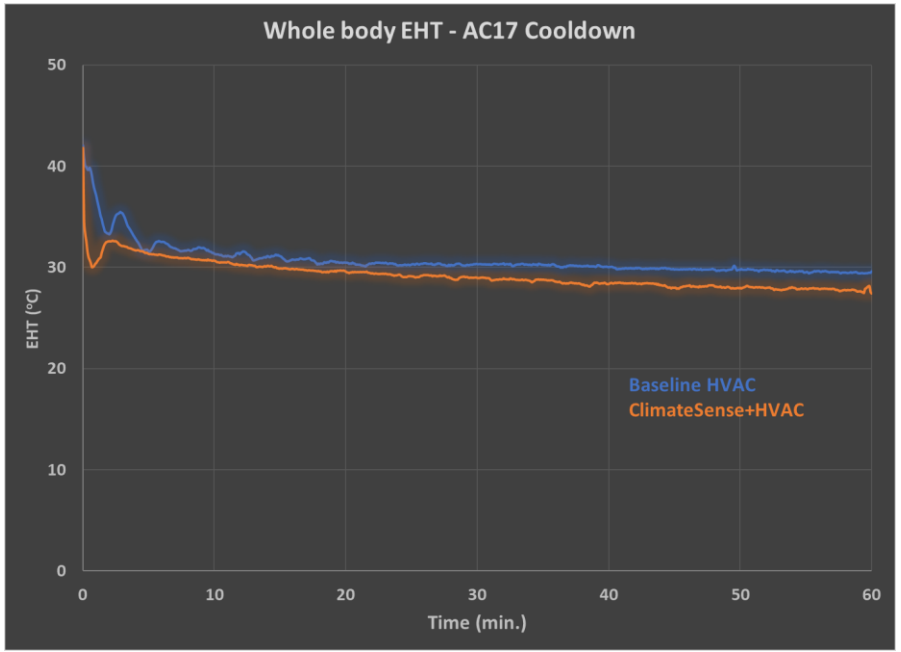
Test at GM Milford Proving Ground*	Objective	HVAC mode	ClimateSense™ mode	Heating Test		Energy Consumption (% change)
				10 min	60 min	
				EHT Calculated	EHT Calculated	
Cold CO **Outside Temperature = -7°C** **Interior soak at -7°C for 7+hrs** **Driver Seat - Manikin** **Passenger Seat - Heat Flux Mat with occupant**	**Baseline HVAC** Measure EHT & Pwr. Consumption	**Auto 22**	**OFF**	**5.6 °C**	**18.2 °C**	**Baseline (3.29kWh)**
	ClimateSense + HVAC Measure EHT and Pwr. Consumption	**Manual***	**Auto 22**	**10.0 °C**	**20.1 °C**	**↓ 50 % (1.65kWh)**
	ClimateSense only Measure EHT and Pwr. Consumption	**OFF**	**Auto 22**	**9.5 °C**	**19.4 °C**	**↓ 69 % (1.01kWh)**

*Full Vehicle Climate Chamber at Emissions Qualifications Laboratory

ClimateSense™ – Microclimate system provides 50% energy savings with 2 zones active and improves overall EHT in -7°C cold weather test

Testing – AC17 Hot Test





ClimateSense™ meets 30% target energy savings (2 zones active) with significant improvement in EHT in first 5 minutes of testing (customer satisfaction)

Validation Testing – AC17 Hot Test

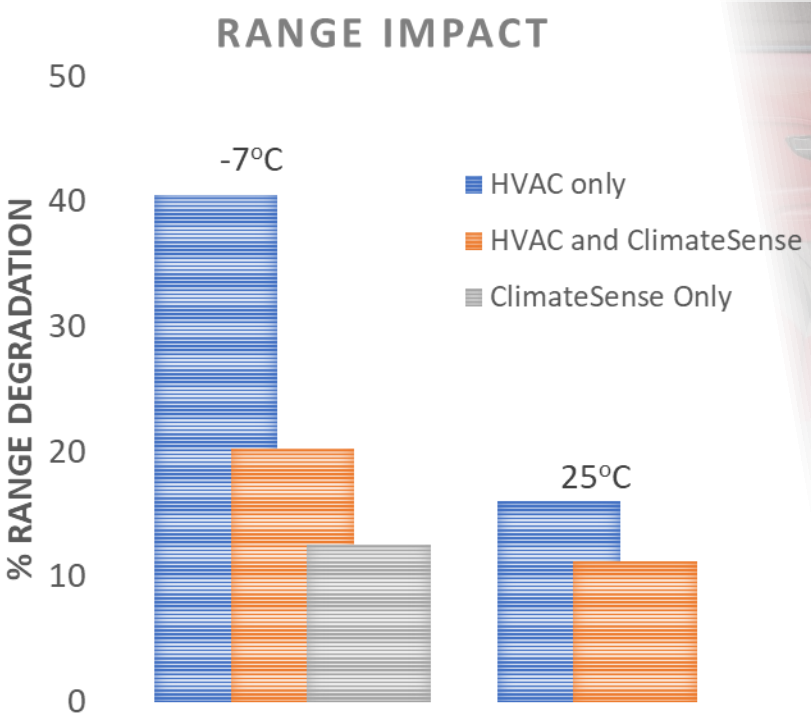
Test at GM Milford Proving Ground**	Objective	System Set Points (°C)	CS (°C)	Heating Test		Energy Consumption (% change)
				10 min	60 min	
				EHT Calculated	EHT Calculated	
AC17 Drive cycle **Outside Temperature = 25°C** **Solar load = 850W/m²** **Driver seat - Heat Flux Mat and occupant Passenger seat - EHT Manikin**	Baseline HVAC Measure EHT & Pwr. Consumption	**Auto 21.5**	**Off**	**31.3 °C**	**29.6 °C**	**Baseline (0.85kW)**
	ClimateSense + HVAC EHT and Pwr. Consumption	**Manual***	**Auto 22**	**30.6 °C**	**27.6 °C**	**↓ 30 % (0.59kW)**

**Full Vehicle Climate Chamber at Emissions Qualifications Laboratory

*HVAC setting in combination with ClimateSense™
0-2 min Auto 21.5
2- 58 min Auto 21.5 Blower level 2

System meets 30% energy savings with 2 zones active and improves overall EHT in hot weather (based on AC17 test cycle).

ENERGY EFFICIENCY & PERFECT THERMAL COMFORT IN ONE INTELLIGENT, INTEGRATED SYSTEM



*Baseline February 2019 “AAA Electric Vehicle Range Testing

THANK YOU!