Vehicle Cabin Energy Management Considerations in Electric Vehicles

ThermoAnalytics Webinar

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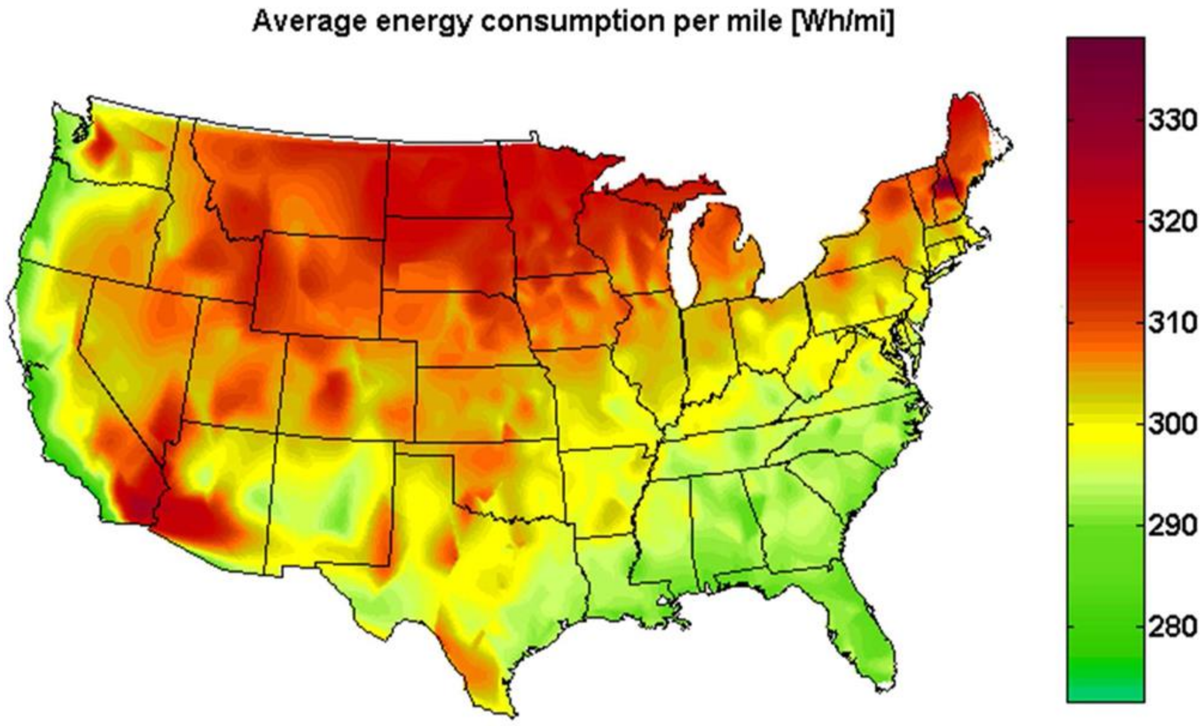
THERMO ANALYTICS

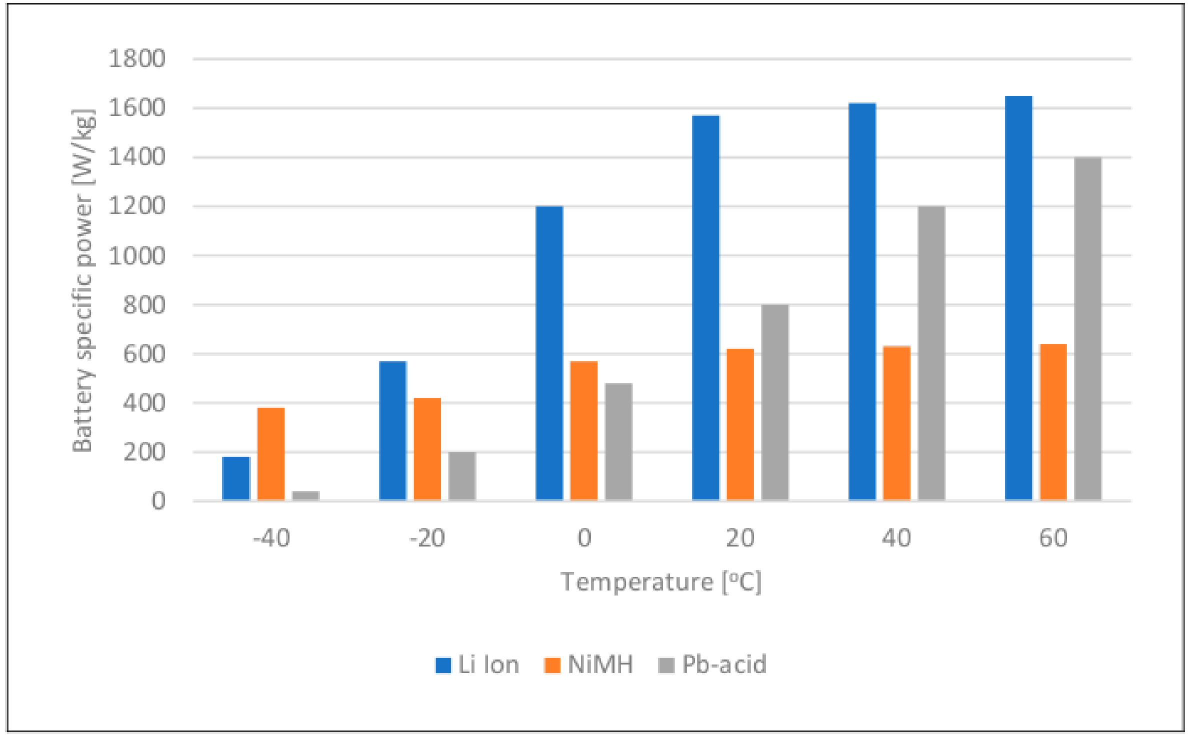
Widespread adoption of EVs by consumers depends on:

- Range satisfaction (driver's range anxiety)
- Public and private charging infrastructure
- Vehicle purchase price in comparison to ICE vehicles
- Maintenance costs
- Cost of exploitation
- Reduced greenhouse gas emissions
- Existence of a reasonable thermal comfort in the operation of an EV

EV range is strongly influenced by temperature



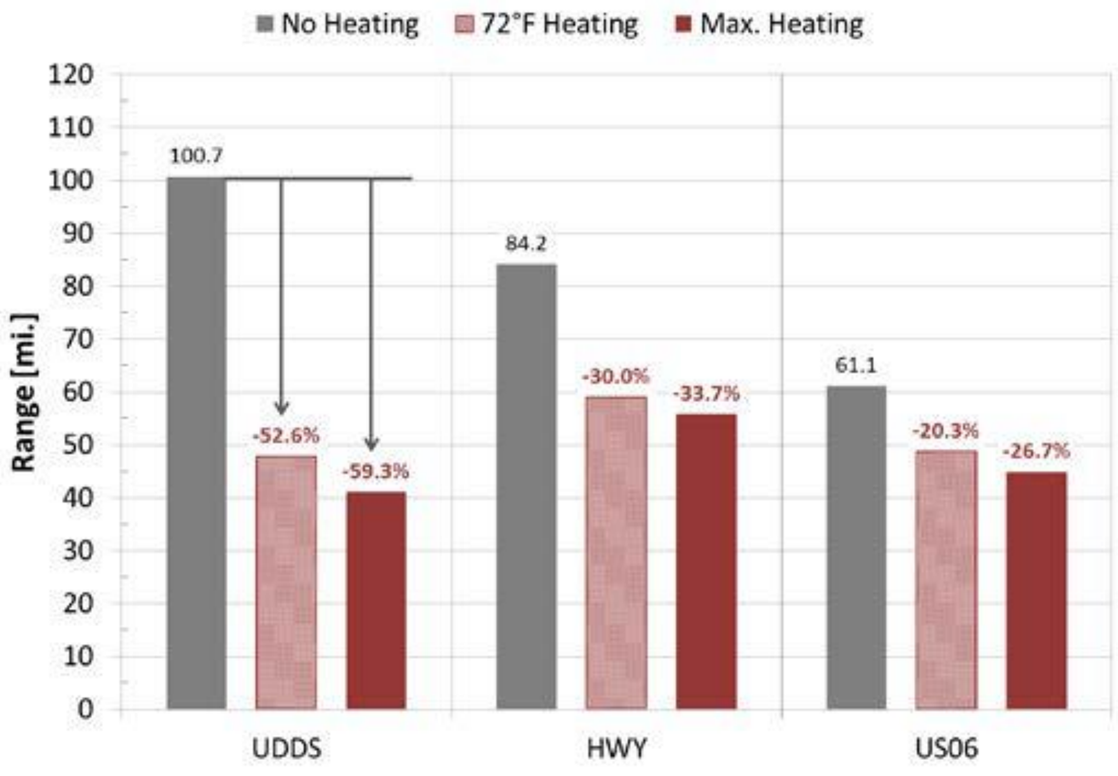
Energy consumption per mile averaged across a fleet of Nissan Leaf EVs over a full year. (Environ. Sci. Technol. 49, 2015.)



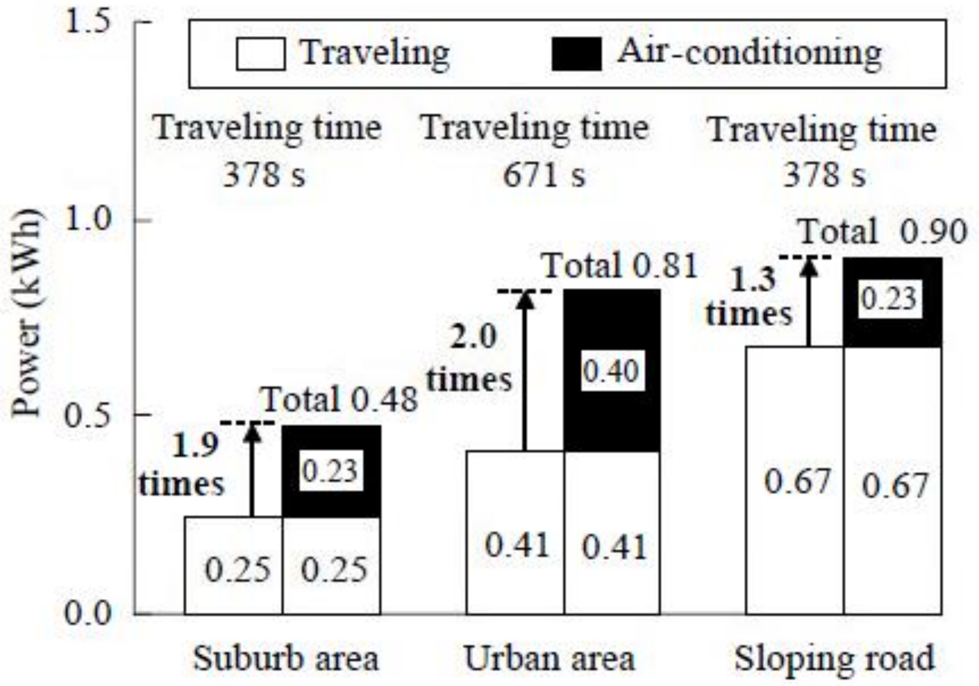
Influence of temperature on energy performance of different battery types (Energies 2019, 12, 946)

Climate control loads cause significant range reduction

- 17-37% in summer*
- 17-54% in winter*



Impact of cabin heating on EV driving range in 20F (-7C) ambient



EV Power consumption with operating the air-conditioner in different environments. Shibata et. al. JEPE 9 (2015)

Active technologies for HVAC efficiency improvement

- Localized heating/cooling
- Heat Pumps: capture heat from the atmosphere to heat cabin
- Thermoelectric generator: use exhaust heat to generate electricity for HVAC
- Ambient Air circulation: allow heat transfer to continue even after engine and HVAC system have shut off

Resistive heater and electric compressor

- The simplest adaptation of an ICE HVAC for EVs is to use a resistive heater and electric refrigerant compressor for cooling
- Some heat can be recovered from the electric motor
- Causes up to 50% reduction in EV range
- Rely on a single point sensor for temperature control
- Alternative options are desired

Positive Temperature Coefficient (PTC) Heaters

- Provides rapid, noiseless warming of cabin and windshield defrost, independent of waste heat
- Made of specialized heating discs from advanced ceramic materials
  - Self-regulating
- Poor efficiency:
  - Can provide sufficient heat to warm cabin, but energy is derived from battery electricity, reducing driving range
  - At -7C temperatures can take 6kW power to heat cabin. About the same power needed to propel small vehicle at 50km/h.

Heat Pumps

- Power consumption can be ~1/3 of PTC heating systems of same capacity
- Heating and cooling in single refrigerant circuit with reversible flow. Direction of flow determines heating or cooling.
- Dominant AC system in EVs
- Disadvantage: Slow warm up times compared with PTC heaters
  - May be supplemented with PTC for fast response

Localized heating and cooling

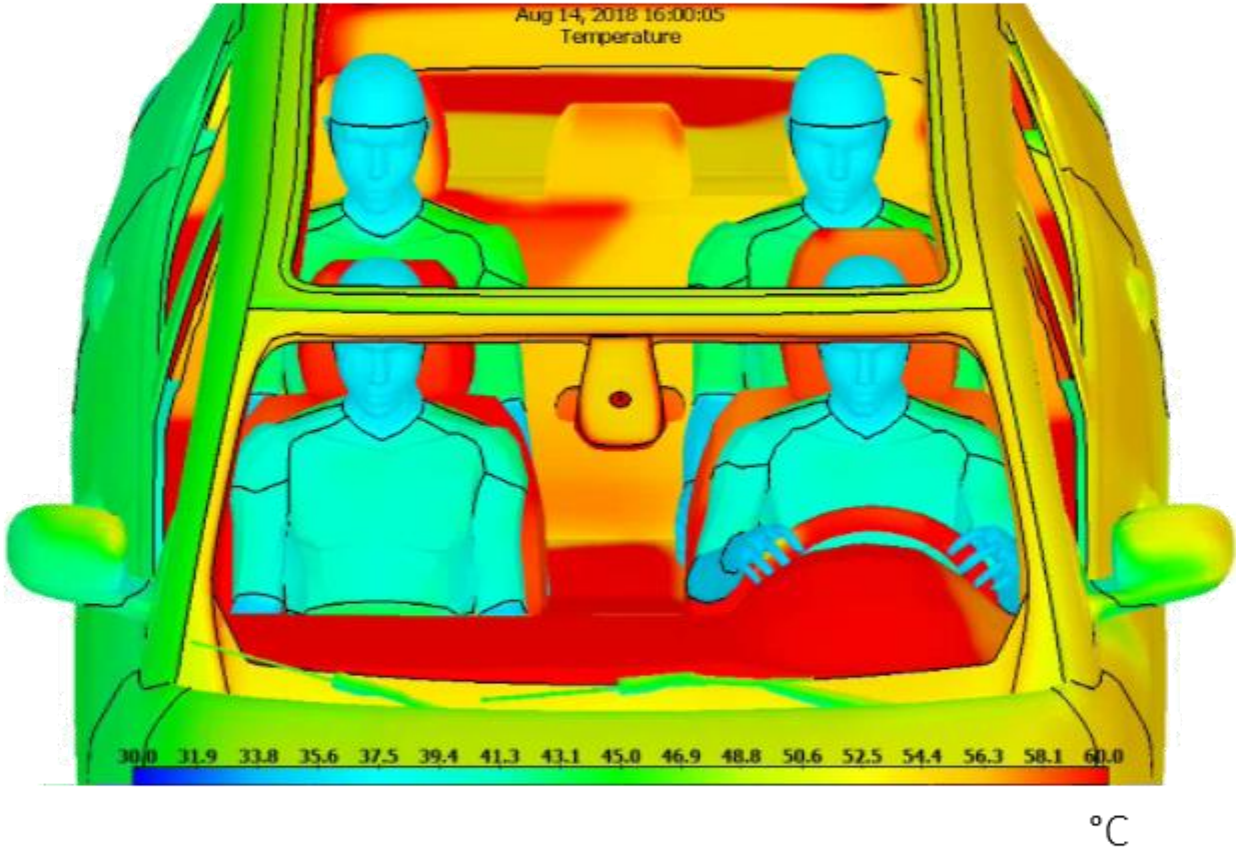
Heated Steering Wheel

Heated Seat

Radiant Panels

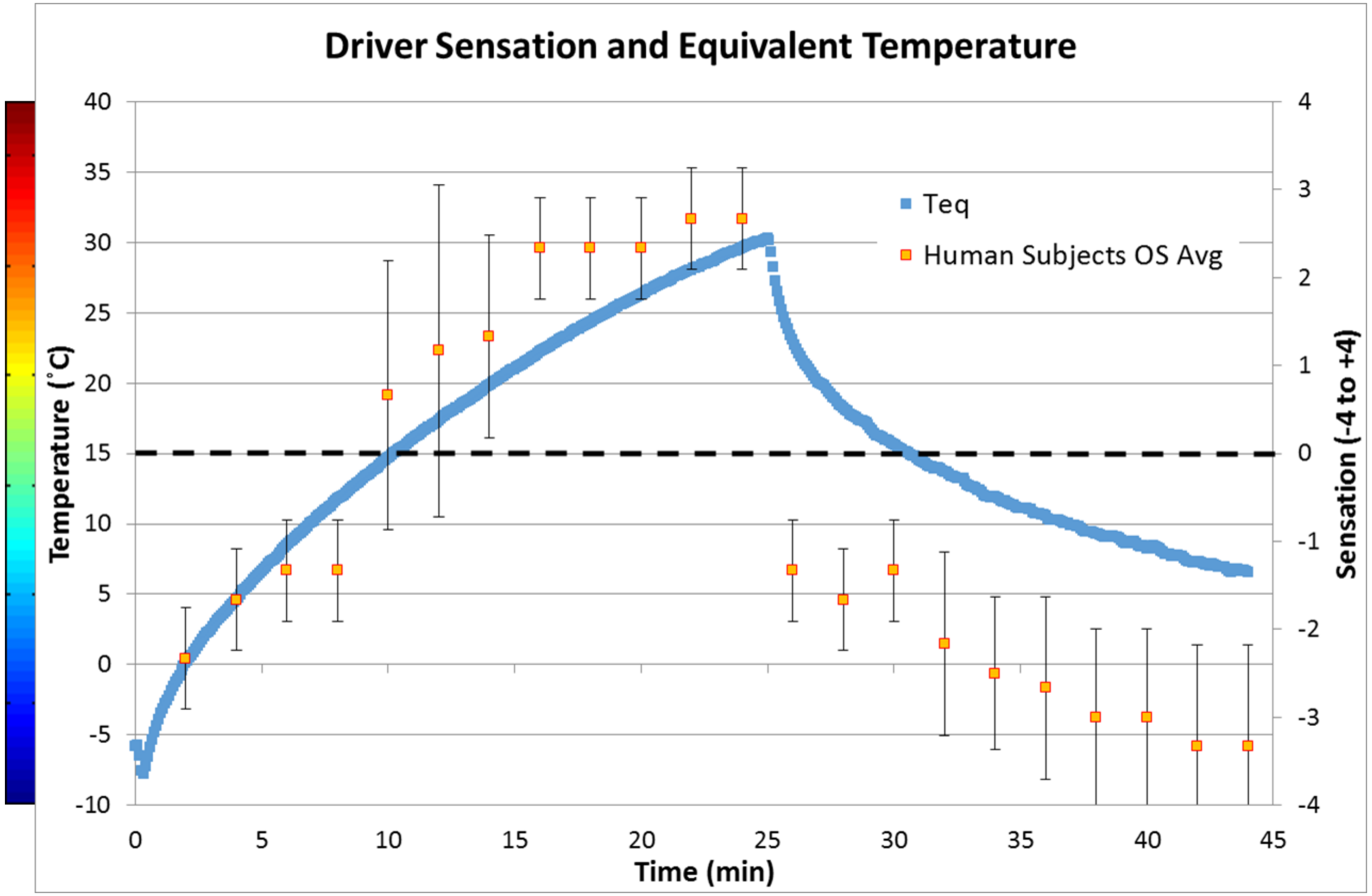
Human Thermal Comfort

"That condition of mind that expresses satisfaction with the thermal environment" (ASHRAE, 2005)



Equivalent temperature is not enough

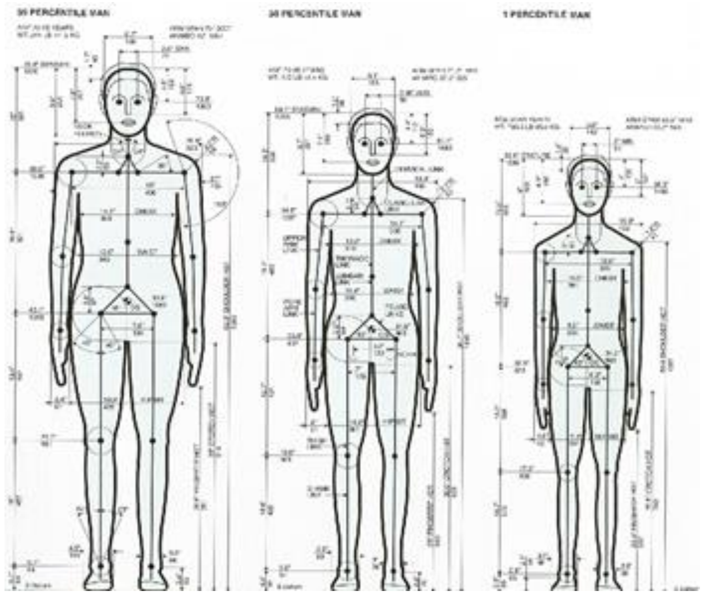
- Test subject reports feeling **warm** while temperature is still only **15˚C**
- Then, report feeling **cool** while the temperature is **22˚C**
- Average environment temperature is a poor way to predict sensation in a transient scenario



Taken from: Hepokoski, SAE TMSS 2018, session TMSS200

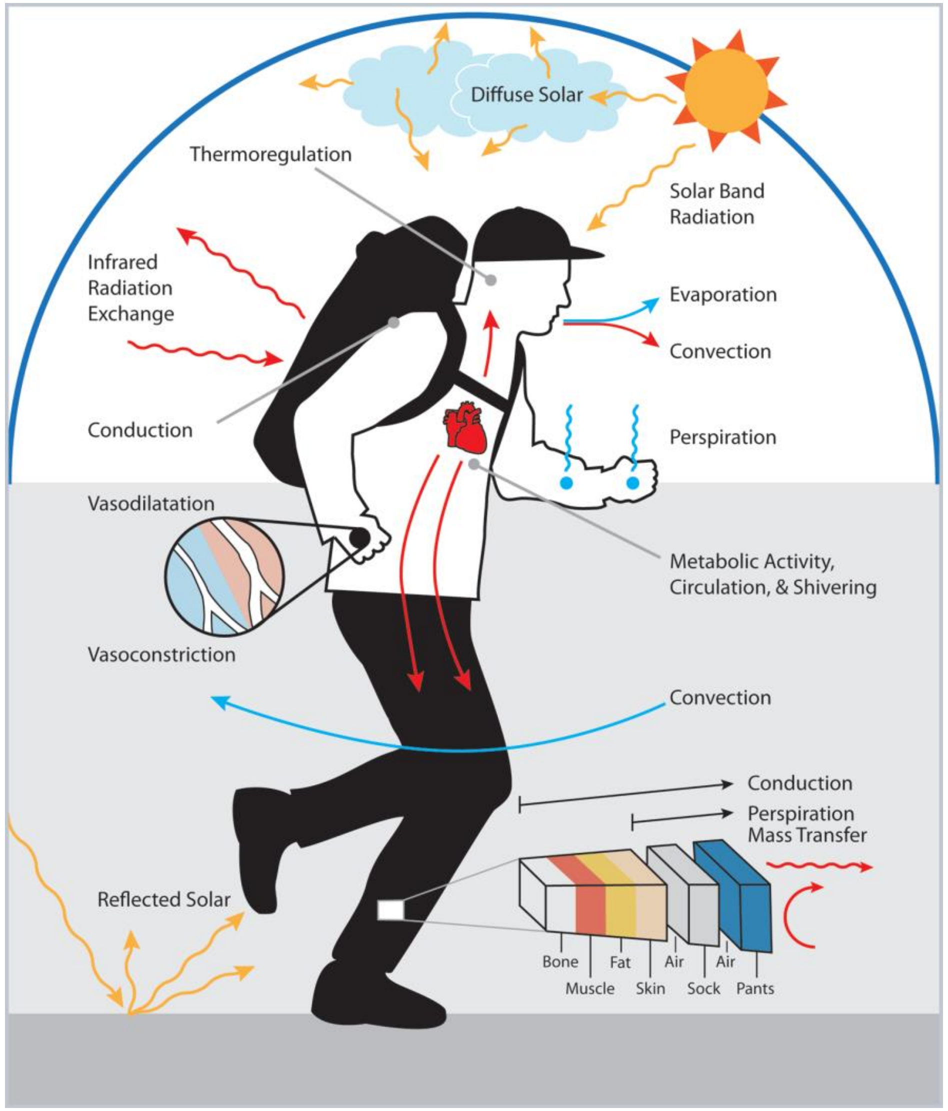
TAITherm Human Thermal Extension

- Human Thermal Model:
  - Multiple (20+) body segments
  - Multiple tissue types per segment
- Model Inputs
  - Clothing thermal properties
  - Activity level
  - Anatomical description
- Model Outputs
  - Clothing & Skin temperatures
  - Core body temperature
  - Interior tissue & Blood pool temperature
  - Thermal Sensation & Comfort



Thermoregulation Model

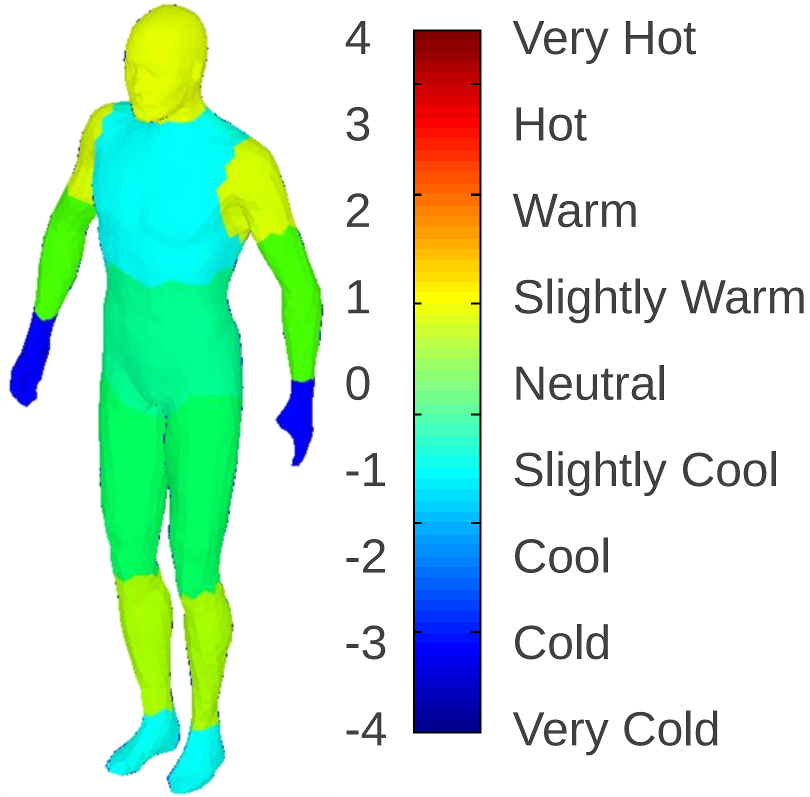
- Heat Transfer with the Environment
- Metabolic heating (activity)
- Shivering
- Sweating
- Vasomotion



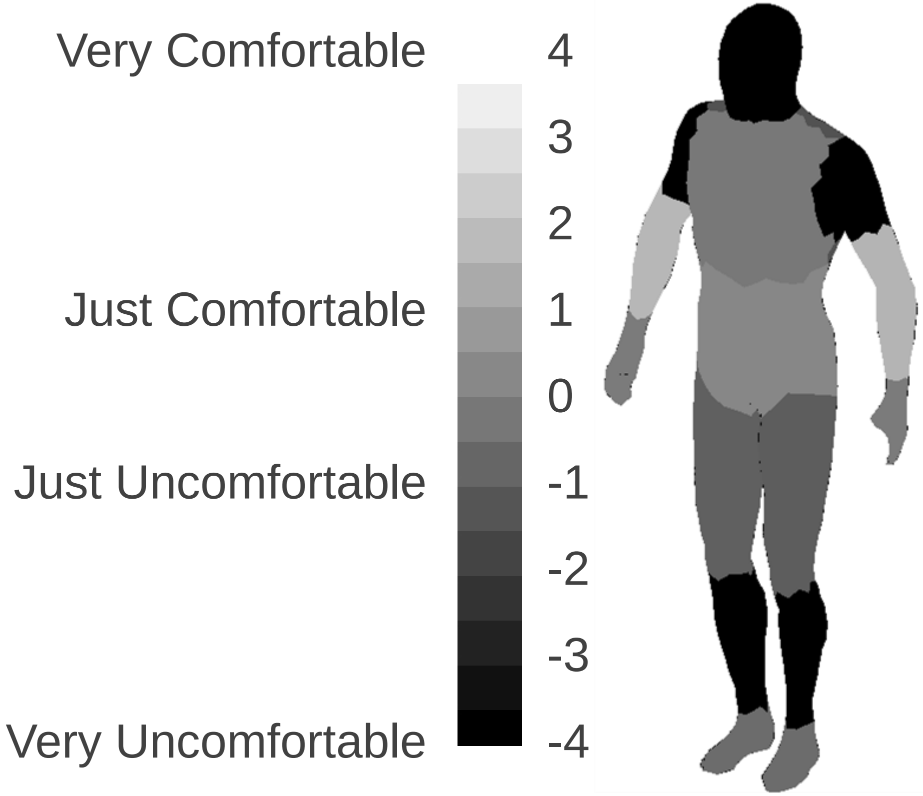
Thermal Sensation & Comfort

- Sensation – How hot or how cold something is perceived to feel
- Comfort – Whether the sensation makes the person feel good or bad

Sensation



Comfort



Design Objectives of Common Cabin Studies

1. Reduce energy consumption
2. Balance occupant comfort and vehicle range
3. Shorten time to comfort
4. Maintain comfort
   - Improve/Study Localized Comfort
   - Transient Environments (warm up & cool-down)
   - Autonomous Seating Design

Methods Available

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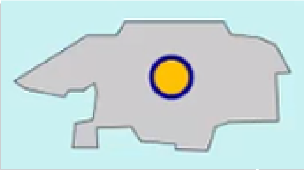
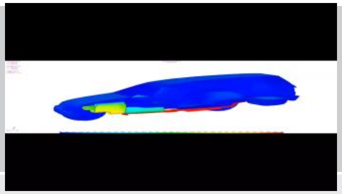
<tr><th>Method</th><th></th><th></th></tr>
<tr><td>TAITherm Standalone
Single Fluid Node</td><td></td><td></td></tr>
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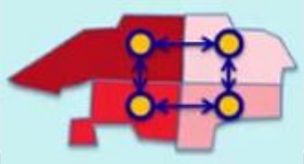
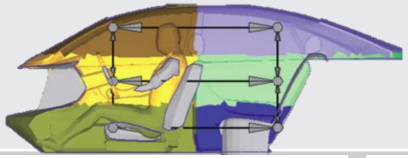
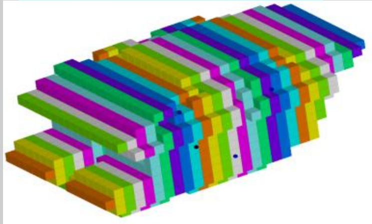
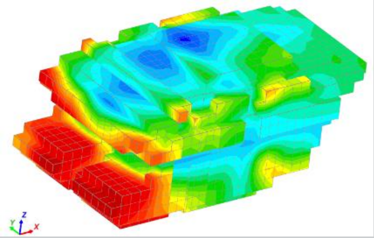
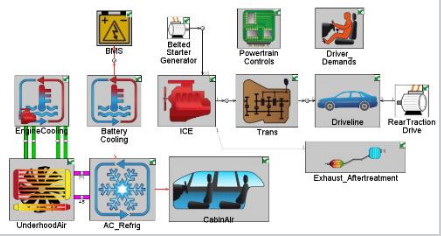
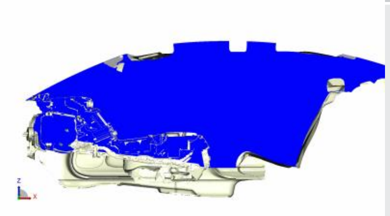
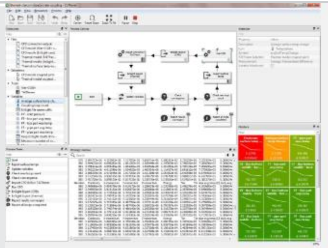
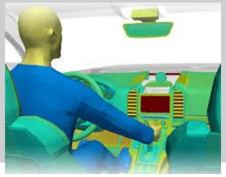
Multiple Fluid Node</td><td></td><td></td></tr>
<tr><td>TAITherm
1D Coupling (GT Suite
& Amesim)
20-10k Cells</td><td></td><td> </td></tr>
<tr><td>TAITherm
CFD Coupling
Millions of Cells</td><td></td><td></td></tr>
<tr><td>TAITherm
Manikin Coupling</td><td></td><td></td></tr>
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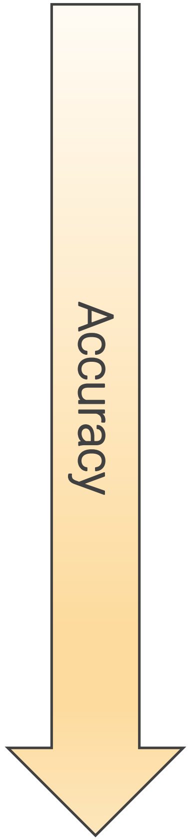
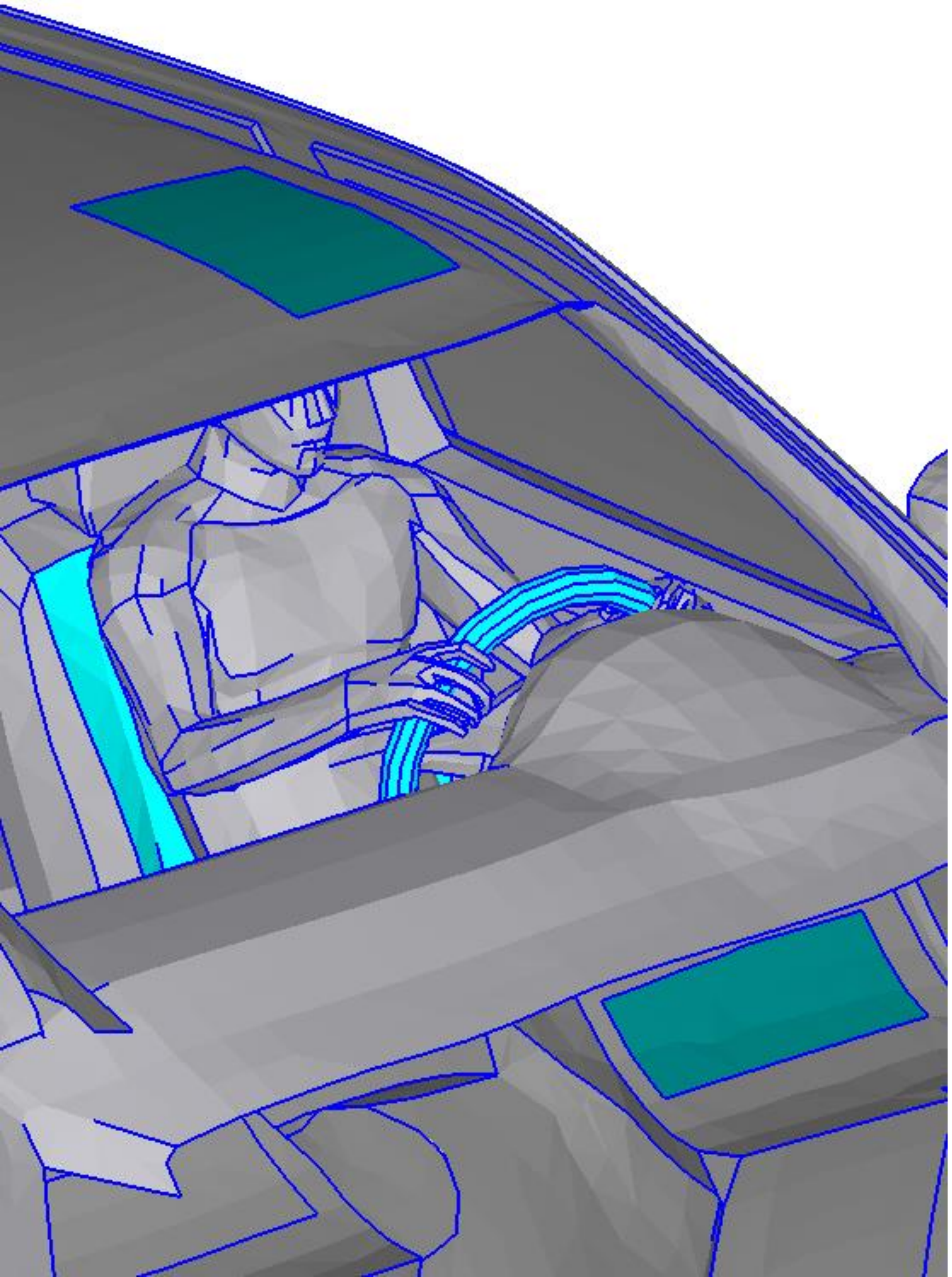
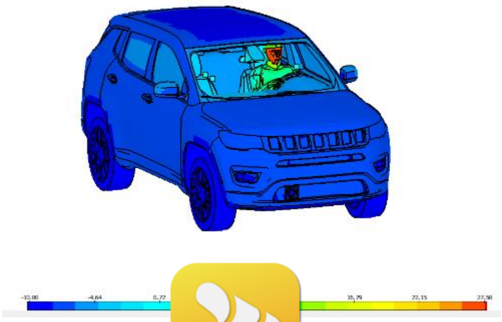




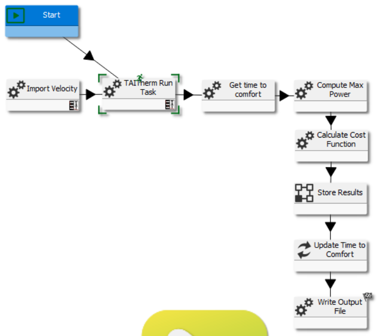
TAITherm Setup – Heated Surfaces

- Energy use optimization using CoTherm CAE process automation software
- Three cases considered with variable power to heating sources
  - HVAC only, foot heaters
  - HVAC only, panel heaters
  - HVAC + localized heating
    - Radiant panels
    - Seat heater
    - Steering wheel heater

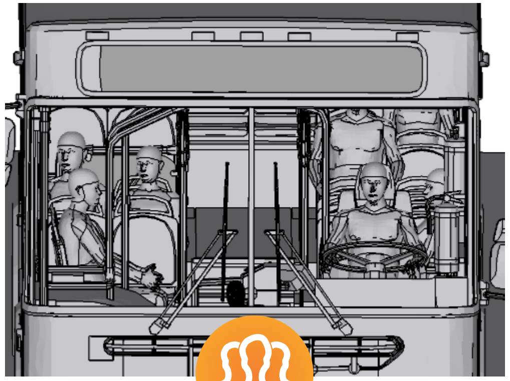
Case Study: Cabin Comfort Energy Optimization with Localized Heating



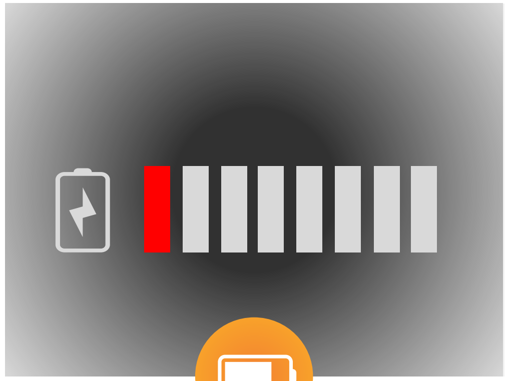
TAITHERM



COTHERM



HUMAN



BATTERY

CoTherm Optimization Process

Inputs

Variables with bounds

Cost Function

Optimization Method

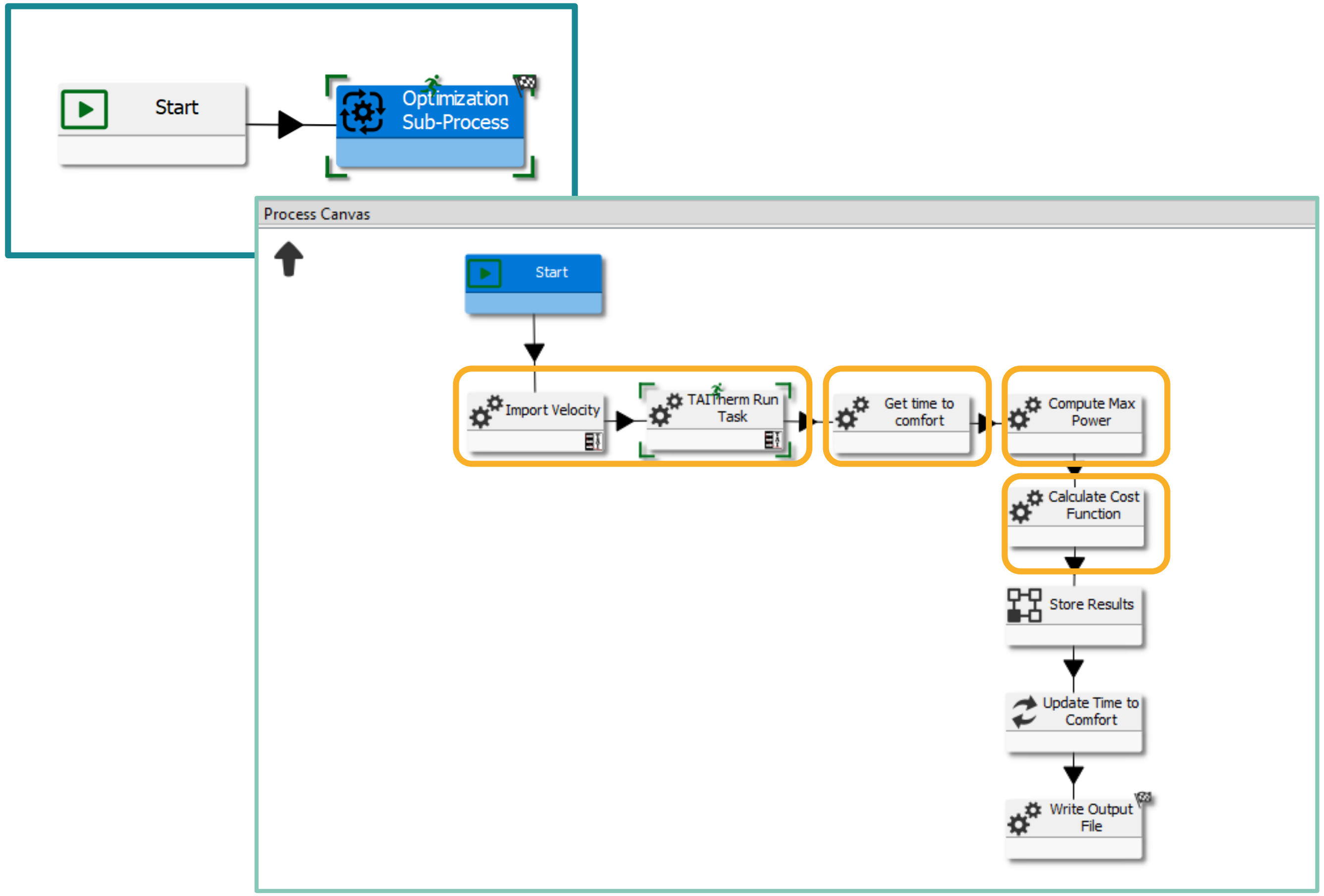
Stopping Criteria

Runs optimization to determine best variable values

Output

Optimized variables that minimize cost function based on user requirements

CoTherm Optimization Process



Import boundary conditions and run the thermal model

Read time to comfort from the berkeleycomfort text file

Compute the power used during the run

Calculate the cost function

Optimization Inputs

VARIABLES

HVAC Power – Panel

HVAC Power - Floor

Roof Radiant Panel Power

Console Radiant Panel Power

Seat Back Power

Seat Bottom Power

Steering Wheel Power

COST FUNCTION

Max Power + Penalty based on distance from target

OPTIMIZATION METHOD

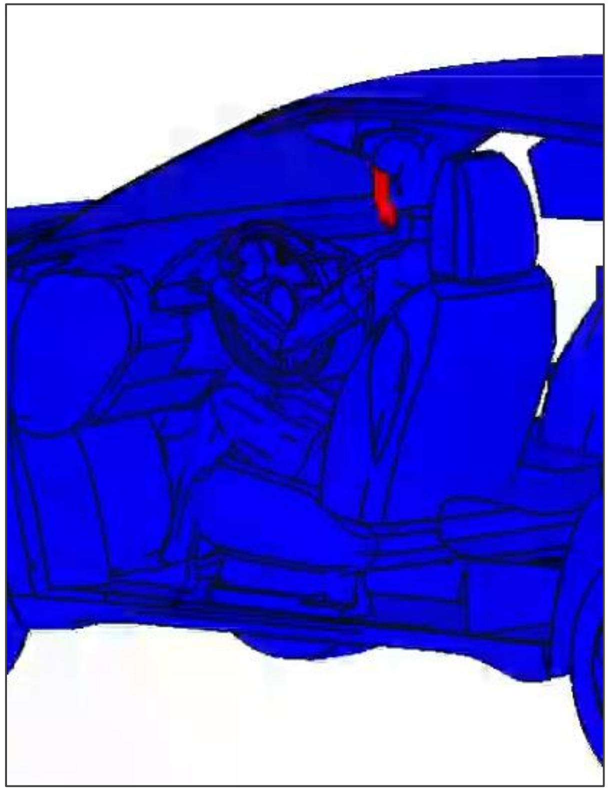
Global – Coliny Direct

STOPPING CRITERIA

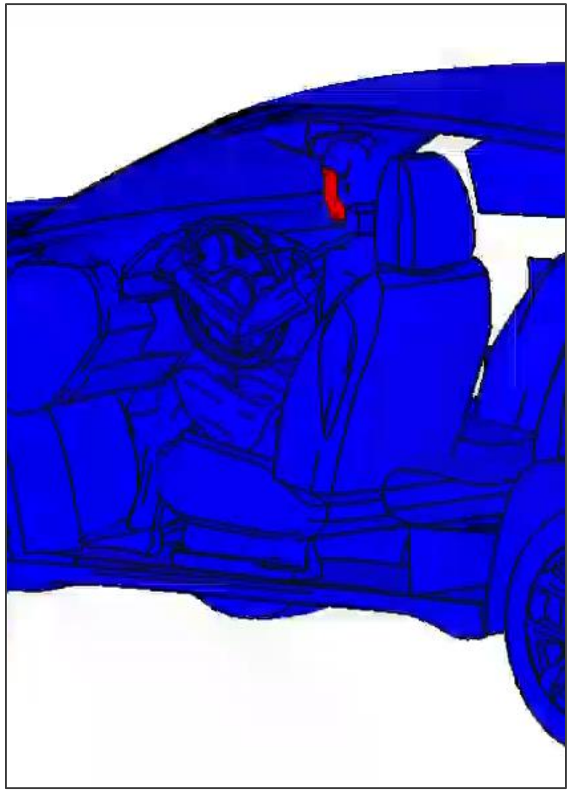
300 iterations

Thermal Results

HVAC Floor Mode



HVAC Panel Mode

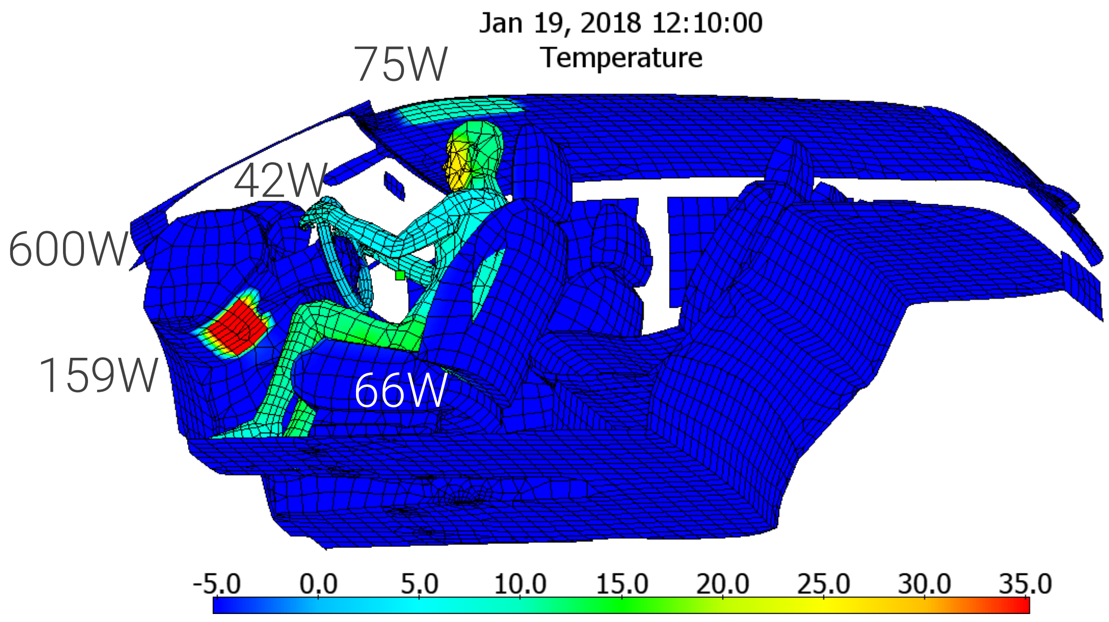


Heated Surfaces Mode

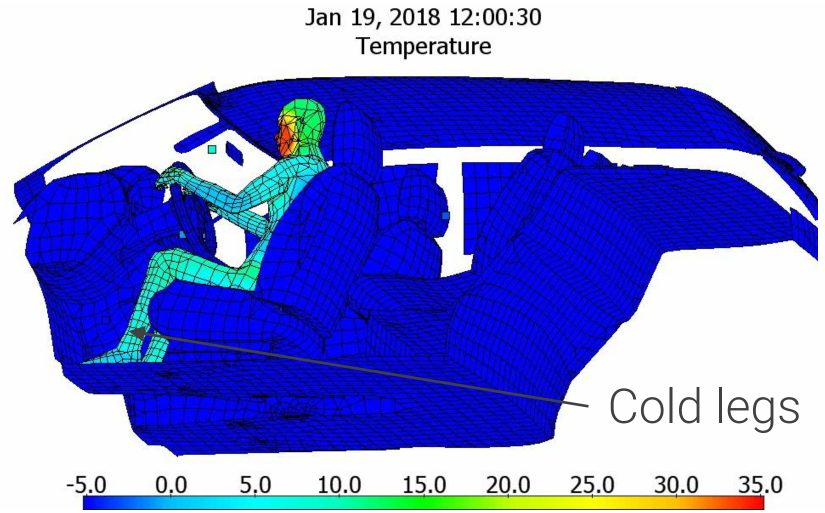
Energy Comparison

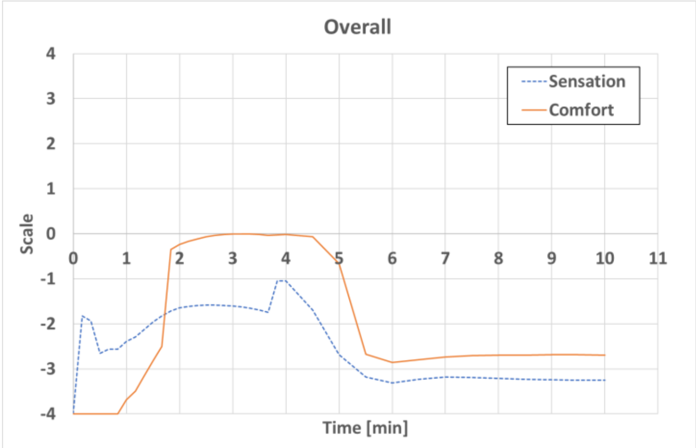
- HVAC directed at upper body: 3376W
- HVAC directed at upper body and Legs: 3334W
- HVAC + Heating panels
  - HVAC: 600W
  - Seat: 66W
  - Overhead panel: 75W
  - Feet panel: 159W
  - Steering wheel: 42W

  Total: 942W

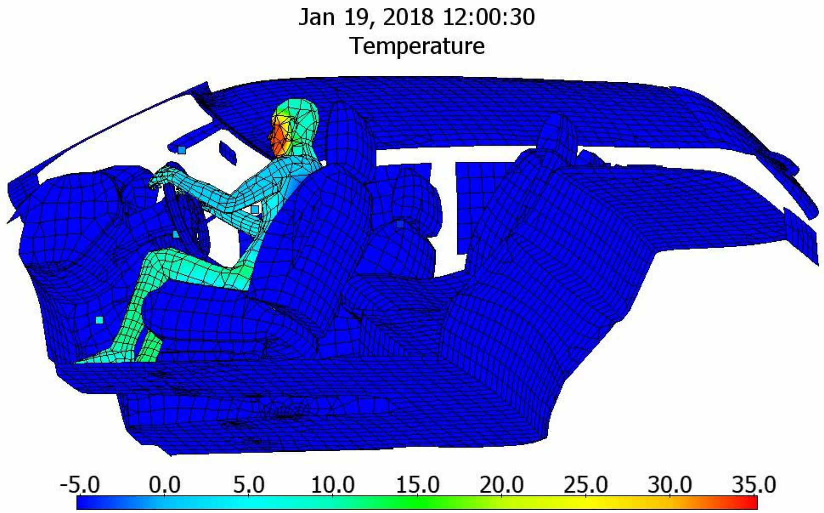


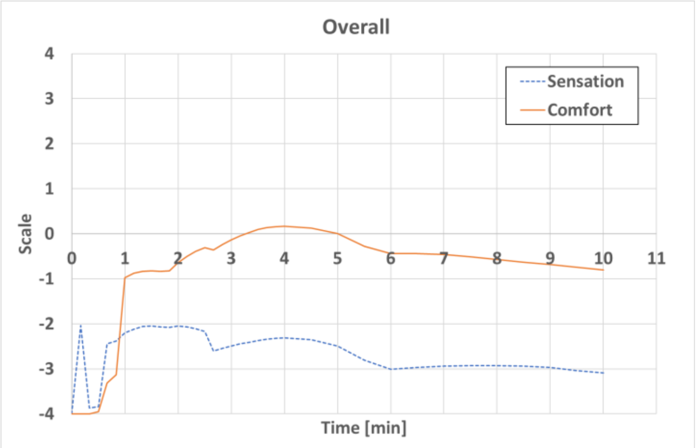
HVAC directed at Upper Body 3376 W



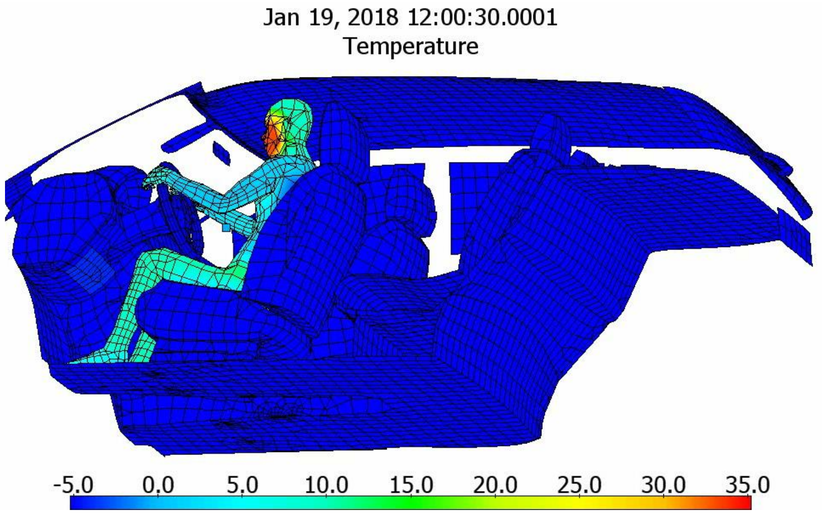


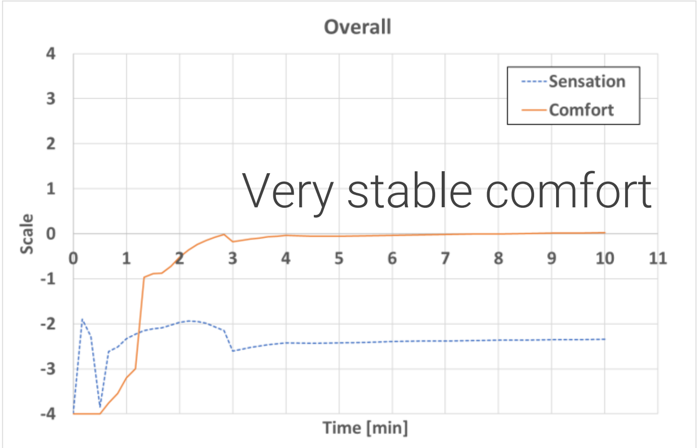
HVAC directed at Upper Body and Legs 3334 W





HVAC, Heated foot panel & head panel, seat & steering wheel 942 W





Conclusion: Local comfort can greatly increase overall comfort

- Local comfort provides stable comfort over time
- Local comfort uses much less energy
    - HVAC only: 3334W during 10 minutes = 555Wh
    - HVAC + heated surfaces: 942W during 10 minutes = 157Wh

Possible Next Steps

Add additional fidelity to the fluid node and velocity model to better represent different HVAC modes and settings

Add additional HVAC setting including re-circulation

Explore additional variables for the optimization runs (ex. Glass properties)

Explore different cost functions

Explore different ways to apply heat to the model (other than just one flat value)

Thank you

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