

# Analysis of the Impact of Reduced Vehicle Thermal Load on AC Fuel Use

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National Renewable Energy Laboratory



# Improved Mobile Air Conditioning Cooperative Research Program



- ~\$3 million budget (2005 and 2006)
- Government/Industry partnership
- Demonstrate technologies to reduce direct (leakage) and indirect (tailpipe) HFC-134a refrigerant emissions
- Administered by Society of Automotive Engineers (SAE)



# Thermal Load Reduction Goal

To demonstrate vehicle-level technologies that  
**reduce the cooling load** by 30%



# 2005 Test Campaign Advanced Thermal Management Technologies

**Webasto  
photovoltaic  
sunroof  
ventilation**

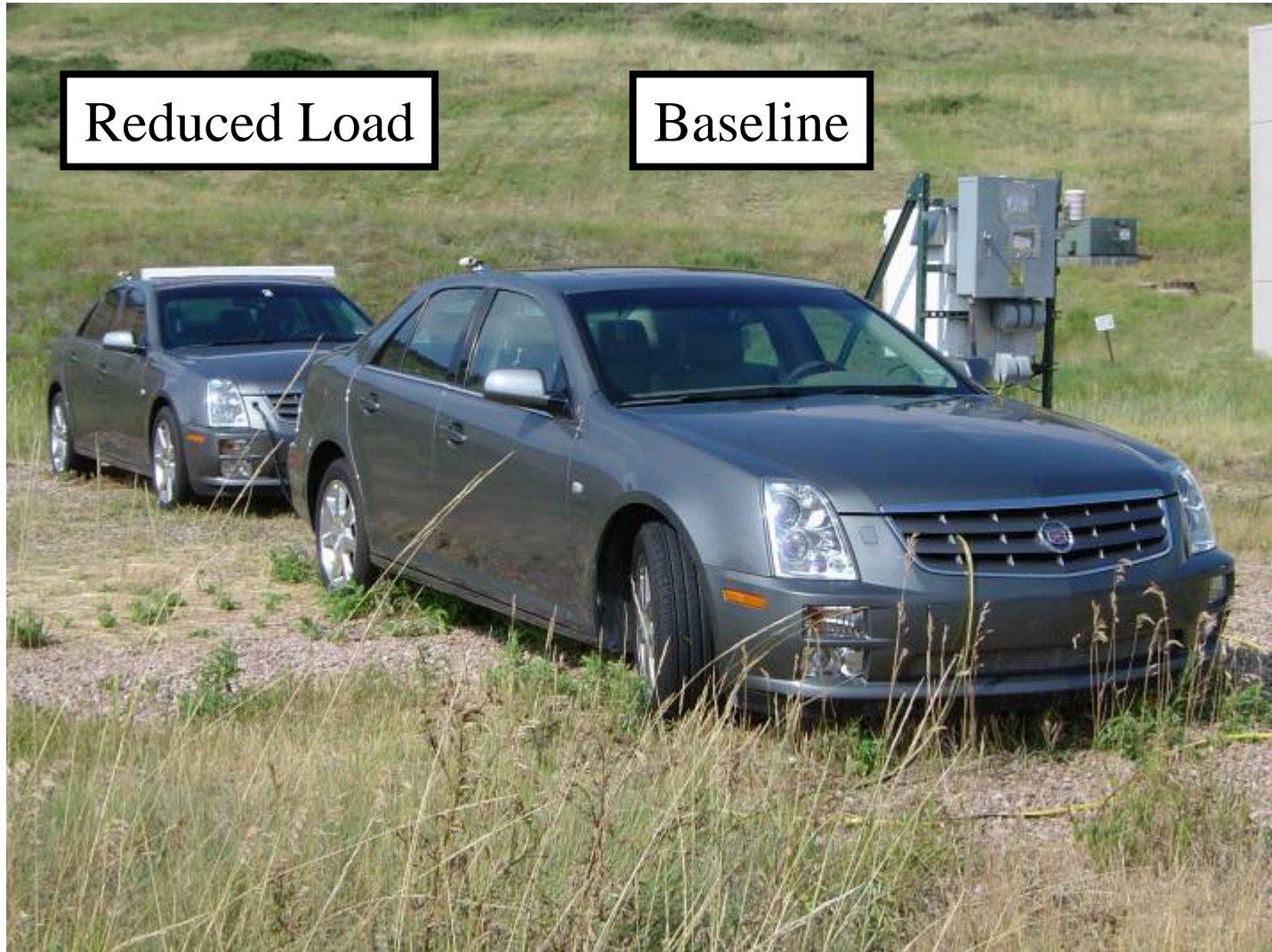


**3M headliner  
insulation**

**3M IR reflective  
film on roof skin**

**3M IR reflective  
film in glazing  
interior**

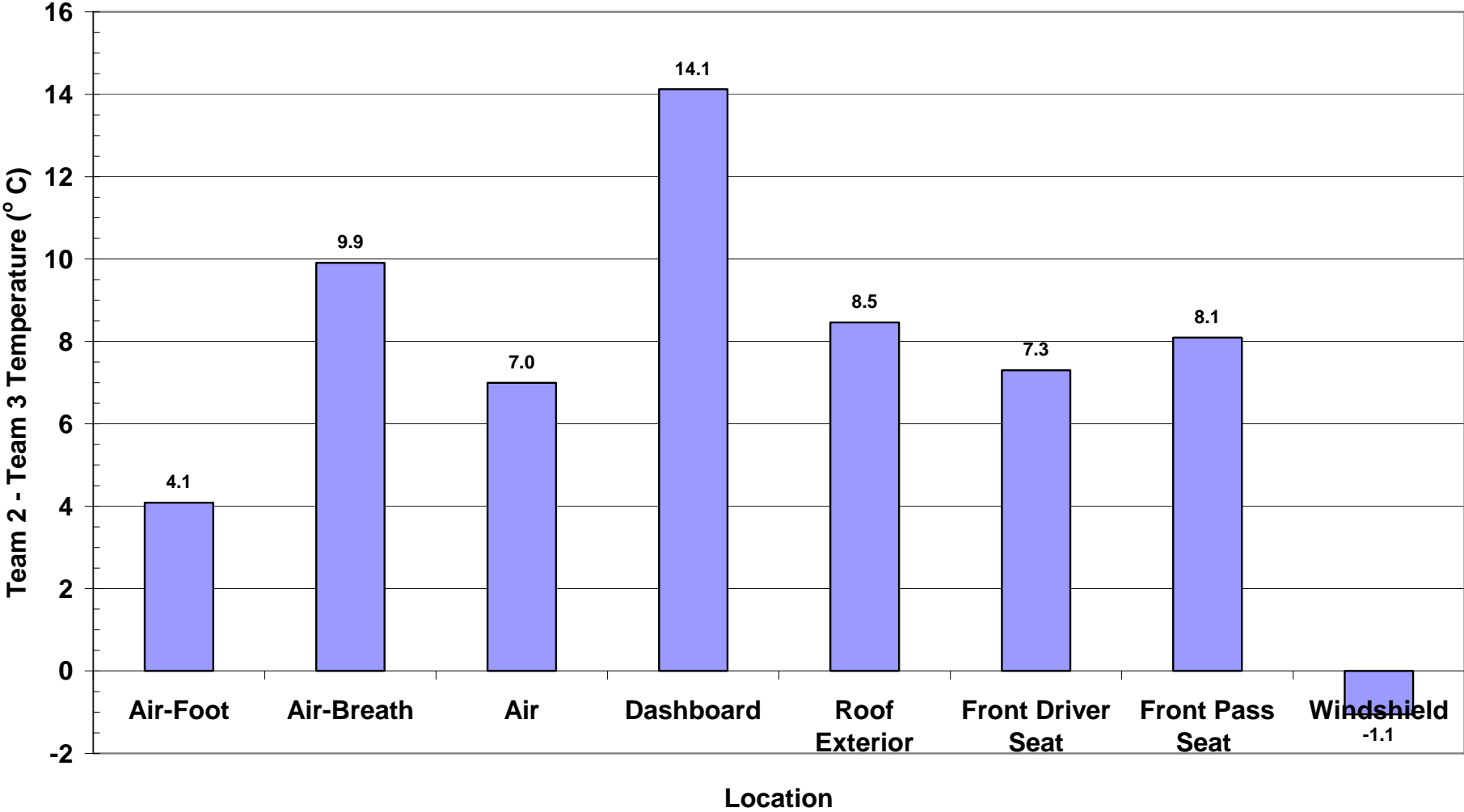
# Side-by-Side Vehicle Soak Test of Cadillac STS, Golden CO



Reduced Load

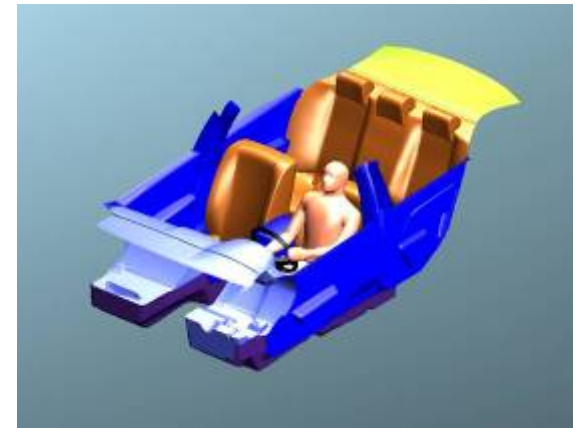
Baseline

# Reduction in Soak Temperatures



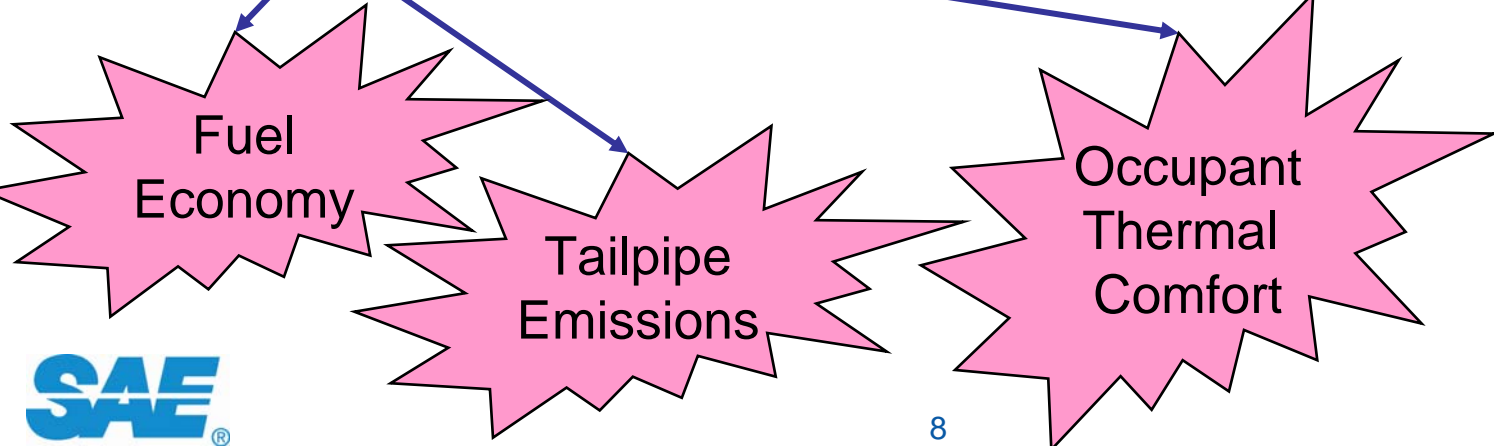
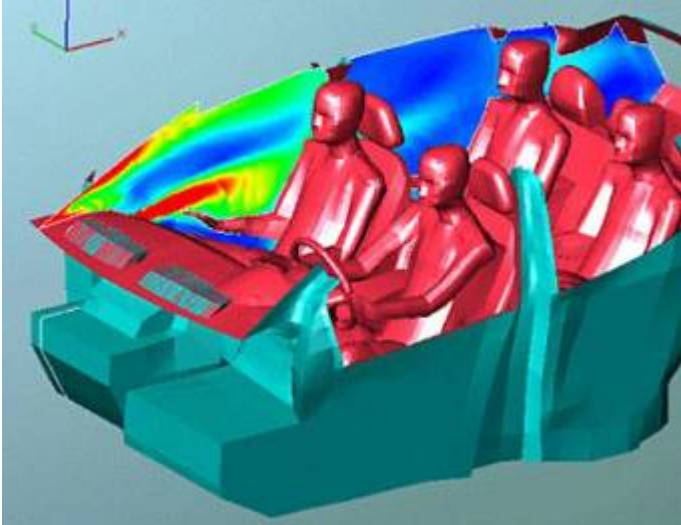
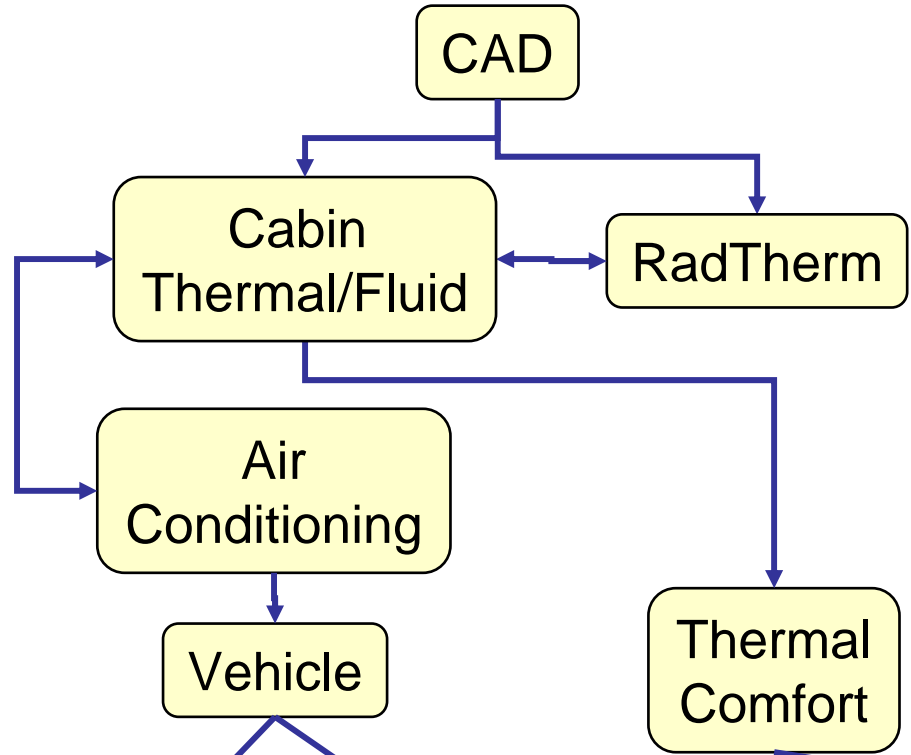
# Assessing the Impact of the Temperature Reduction

- Thermal Comfort
  - Use NREL thermal comfort tools
  - Cooldown testing with ADAM
- Fuel Use
  - NREL integrated modeling process
  - Analysis



# Integrated Modeling

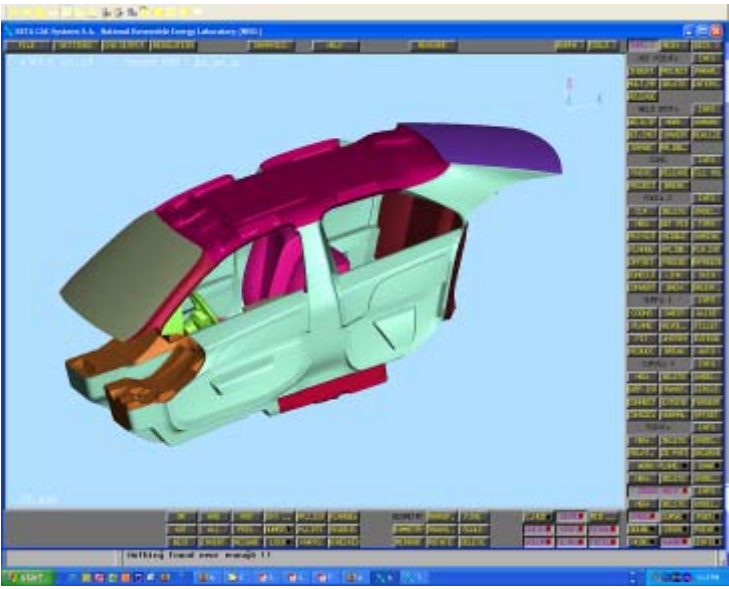
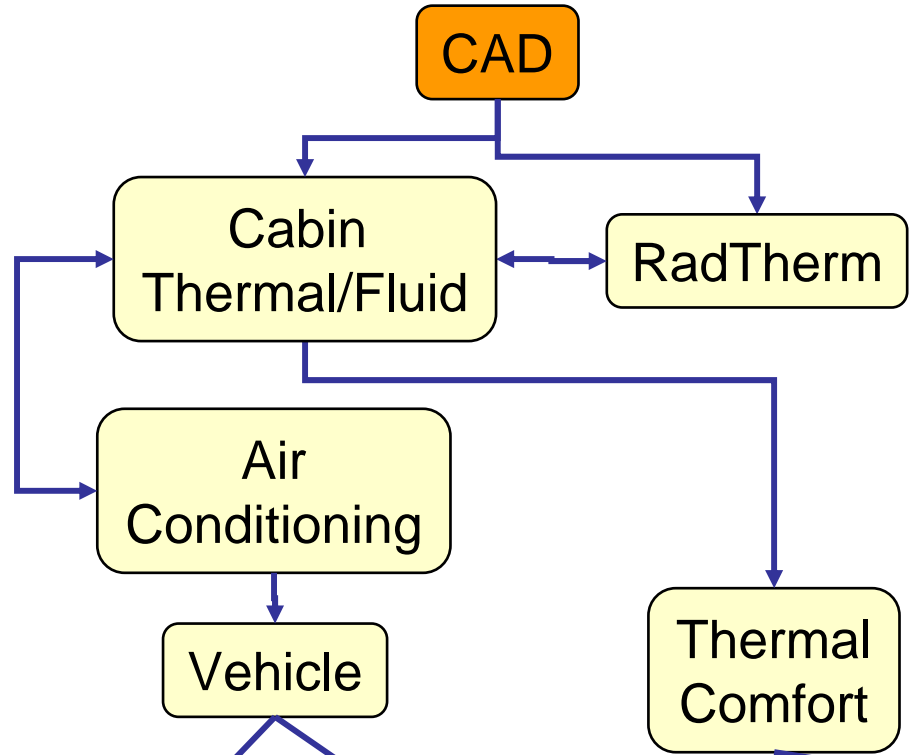
Assessing the impact of advanced climate control systems on vehicle fuel use and human thermal comfort in a Cadillac STS





# Integrated Modeling

Mesh the geometry of the STS



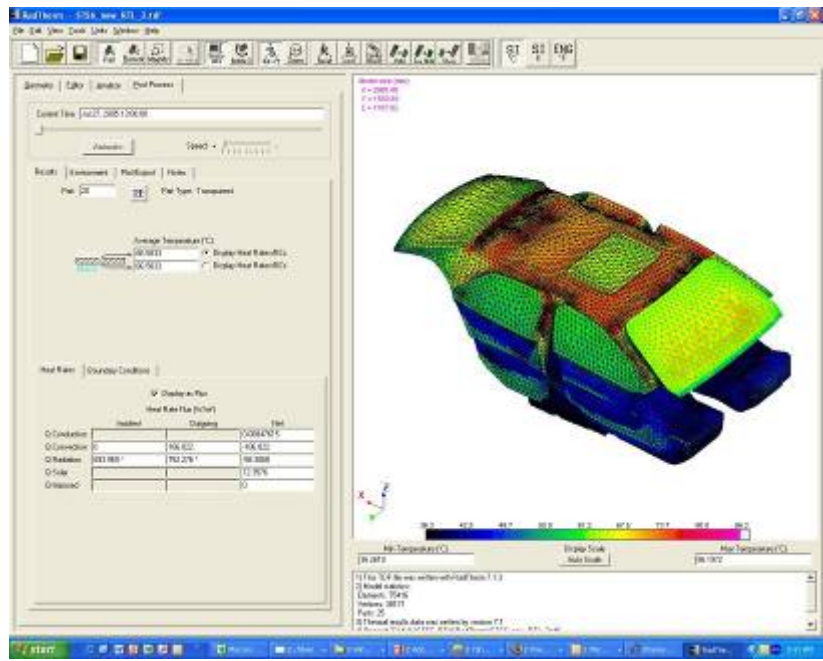
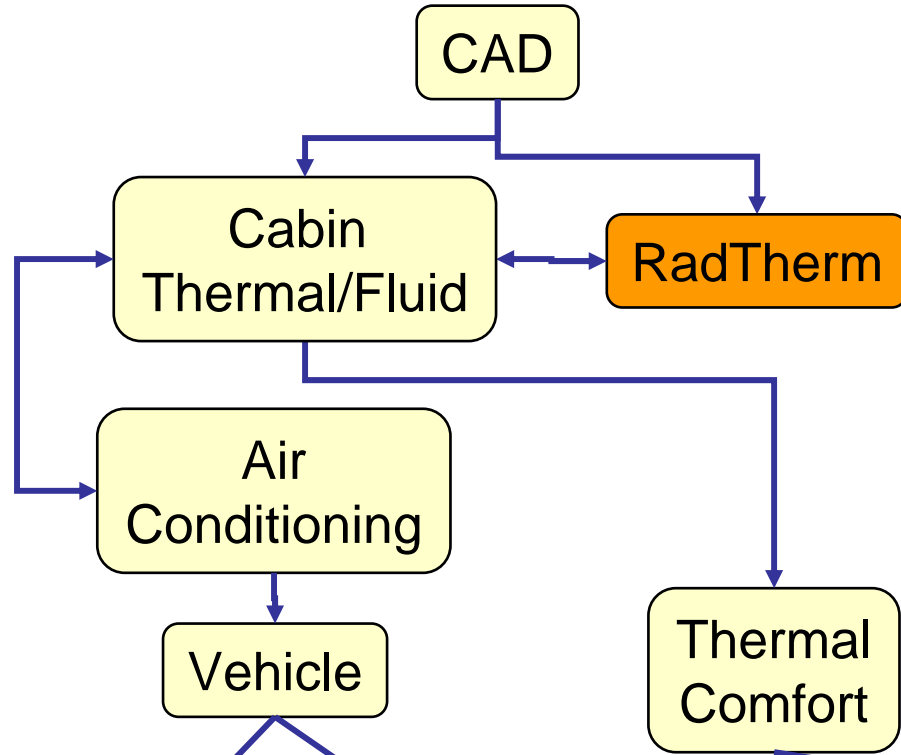
Fuel Economy

Tailpipe Emissions

Occupant Thermal Comfort

# Integrated Modeling

Determine the solar load into the STS



Fuel Economy

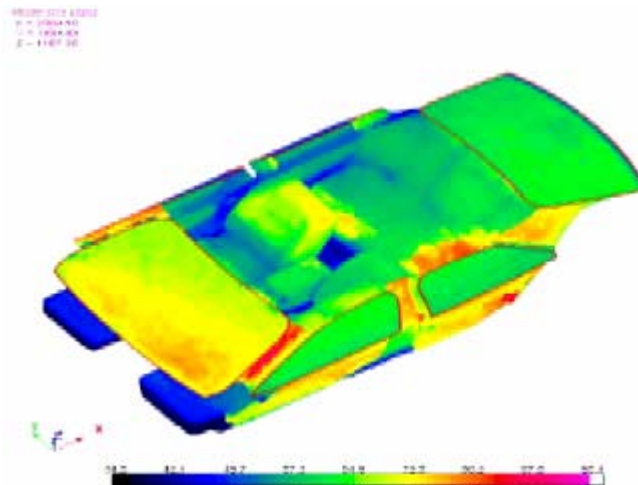
Tailpipe Emissions

Occupant Thermal Comfort



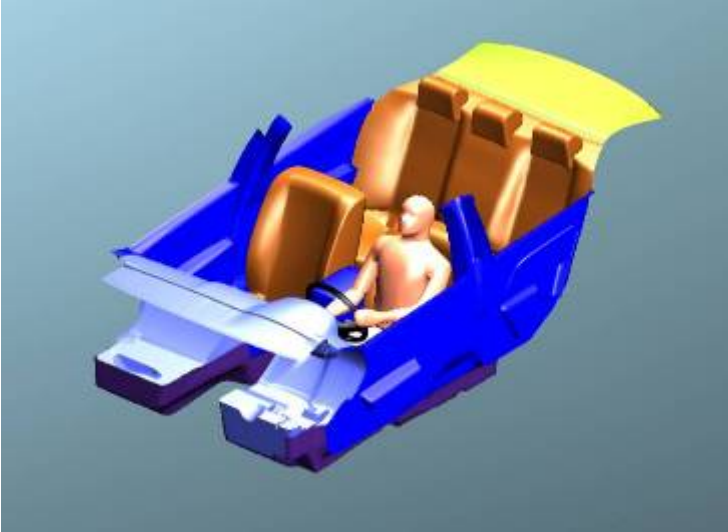
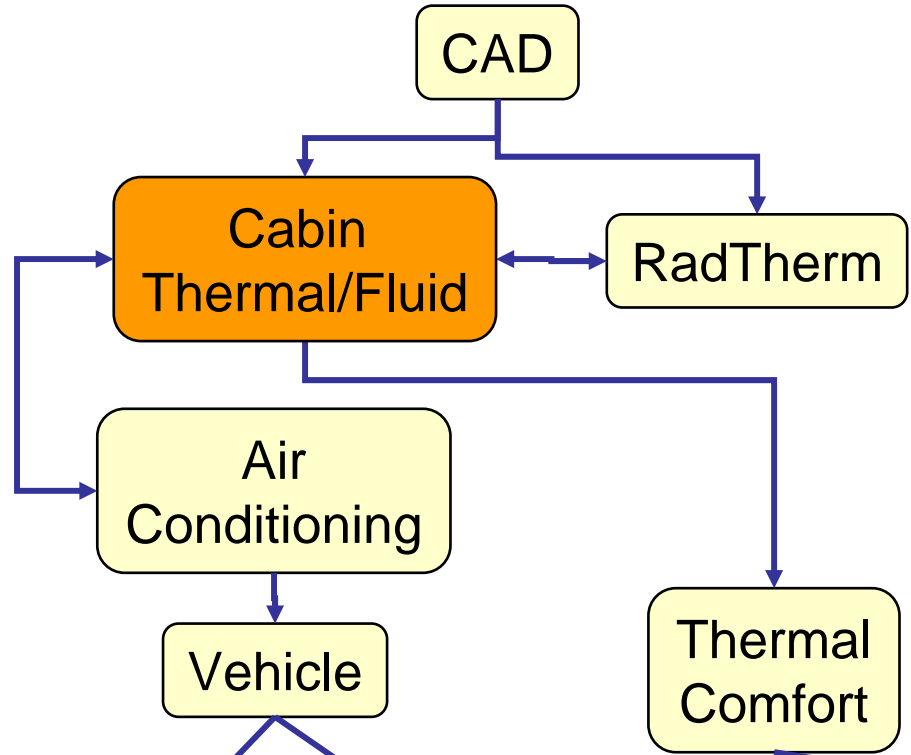
# CFD Linking to RadTherm

- RadTherm software (version 8.0.0) used for simulating heat transfer at surfaces
  - Radiation
  - Convection
  - Conduction
- Linked with CFD

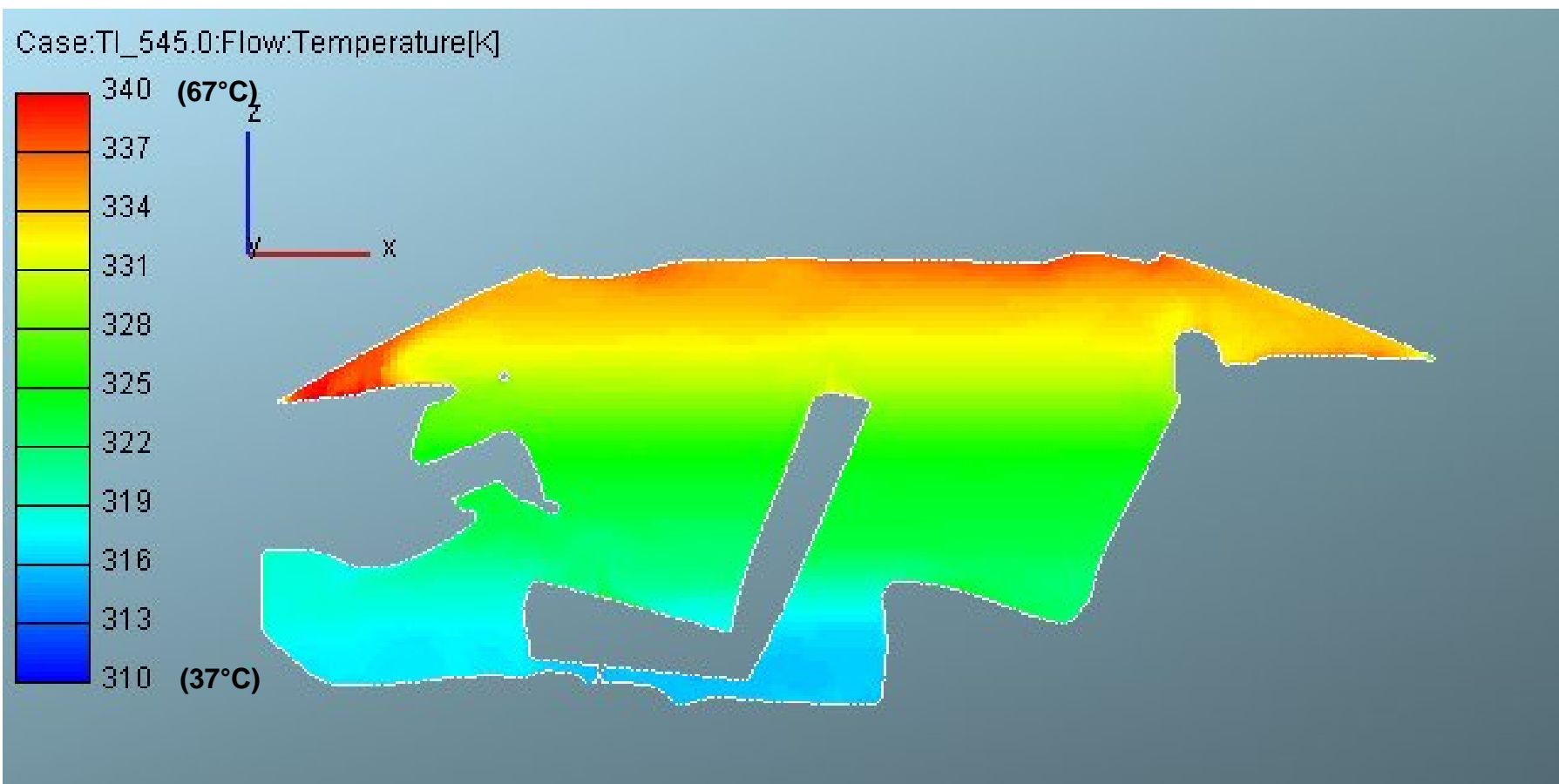


# Integrated Modeling

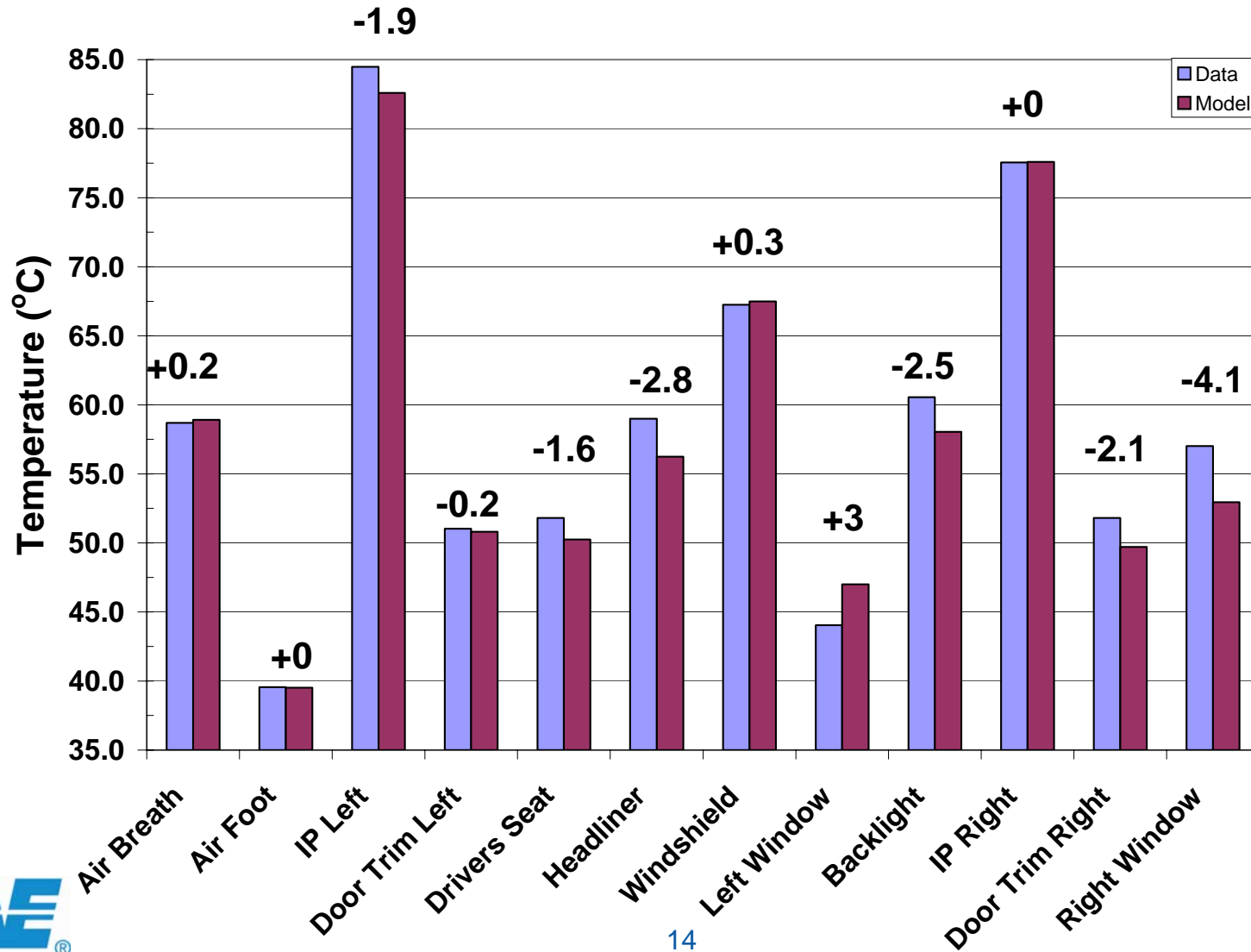
Model temperatures and airflow in the cabin



# Baseline Soak Results Temperature Contours

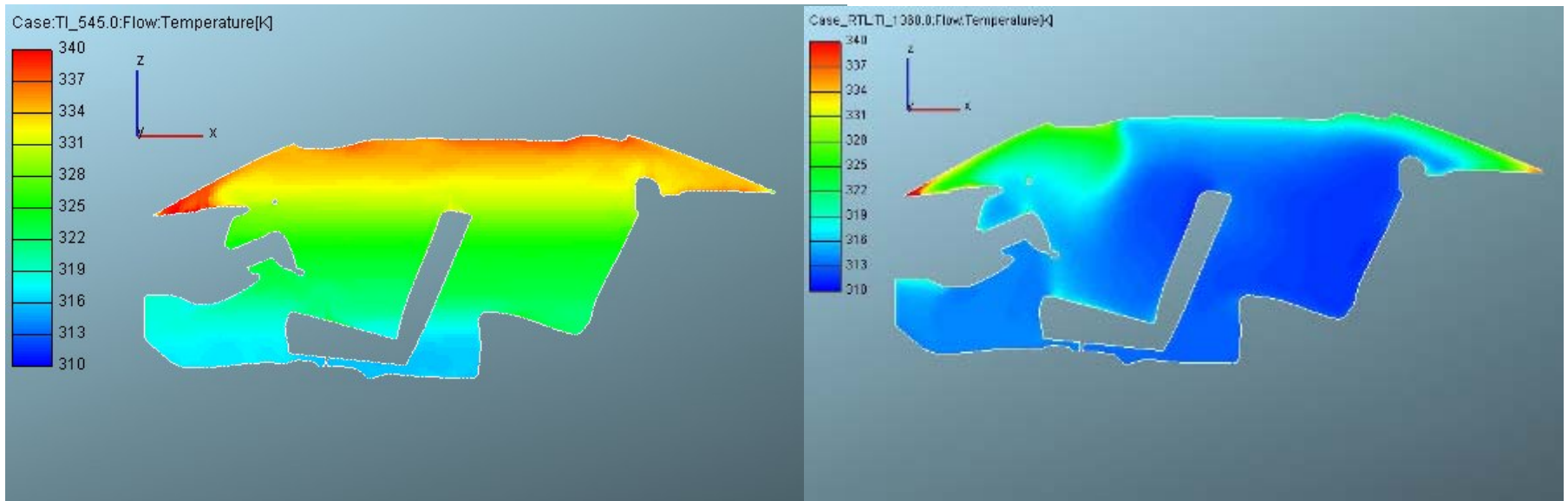


# Baseline Soak Results Comparison to Test Data



# Soak Results

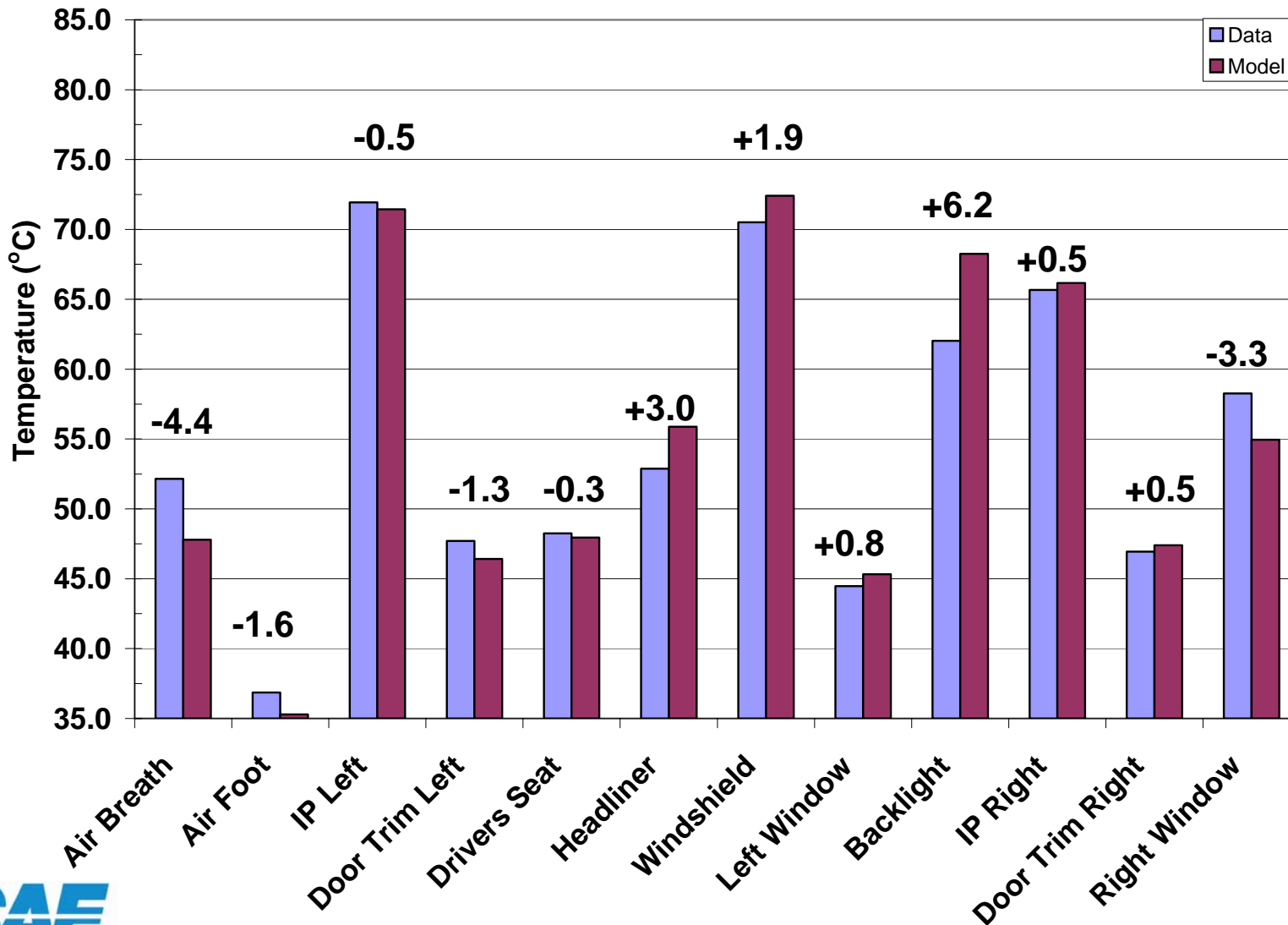
## Temperature Contours



Baseline

Reduced Thermal Load

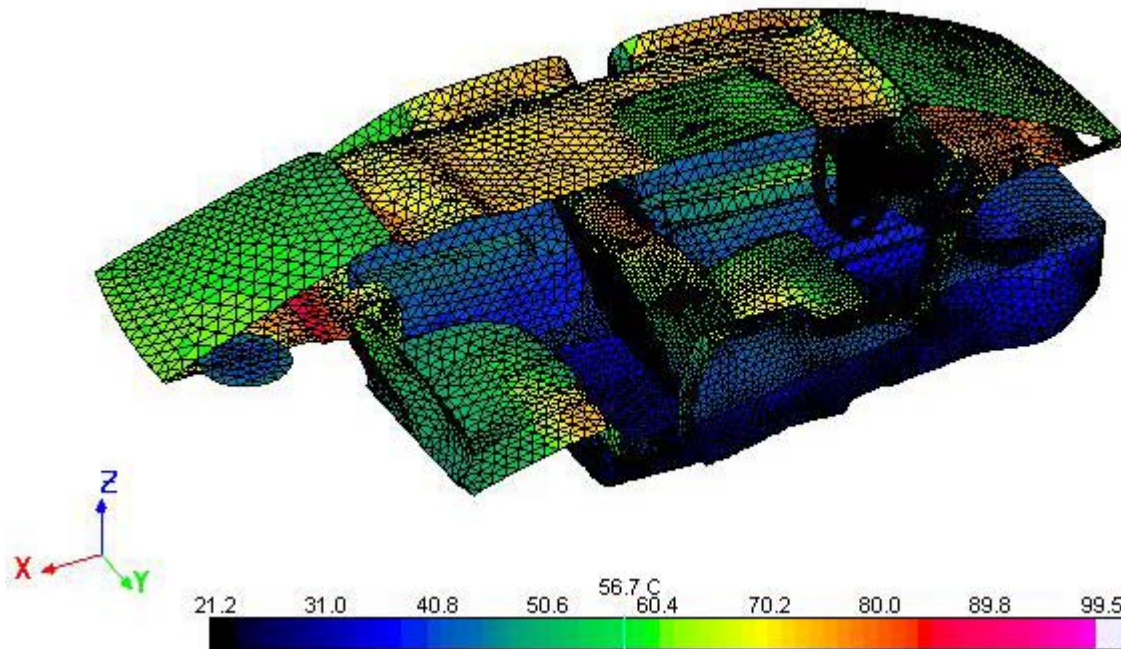
# Reduced Load Soak Results Comparison to Test Data





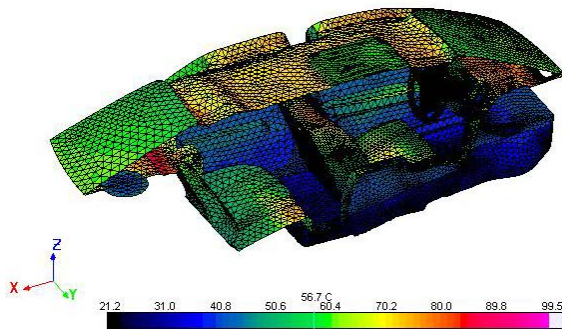
# Impact on Thermal Load

- RadTherm used to determine the difference in AC load to achieve equal cool down

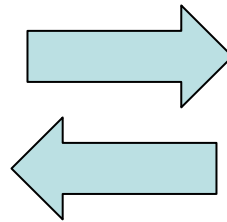


# Simplified Thermal Model

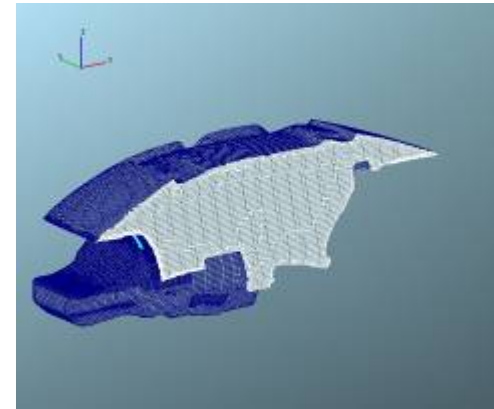
RadTherm



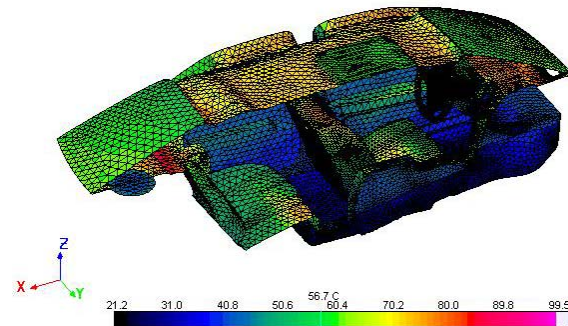
136,000 Elements



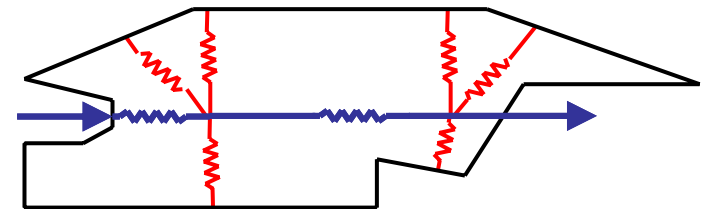
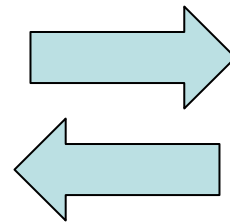
FIRE



**Full CFD model** 900,000 Fluid Nodes



136,000 Elements

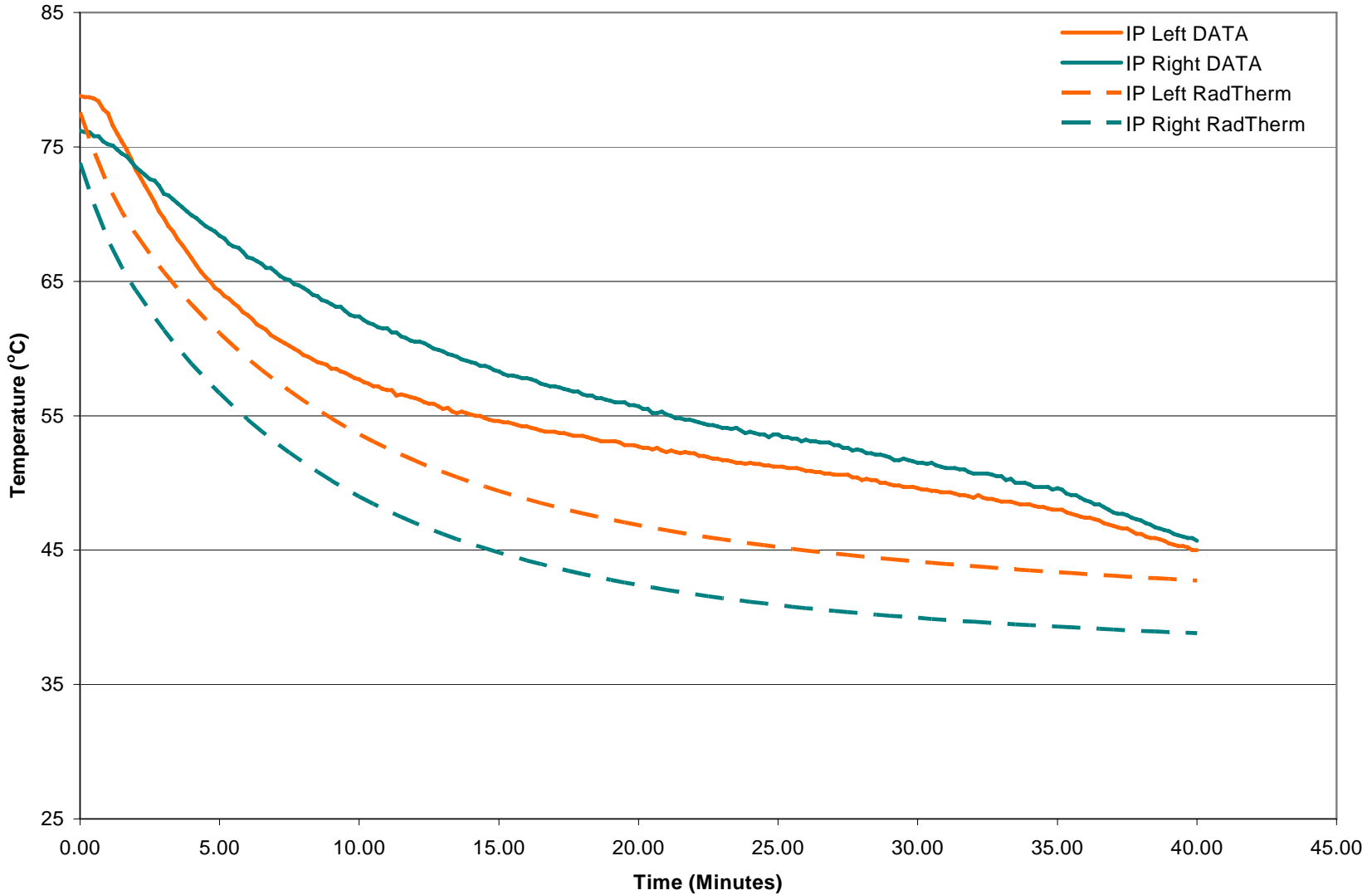


**Simplified model** 8 Fluid Nodes

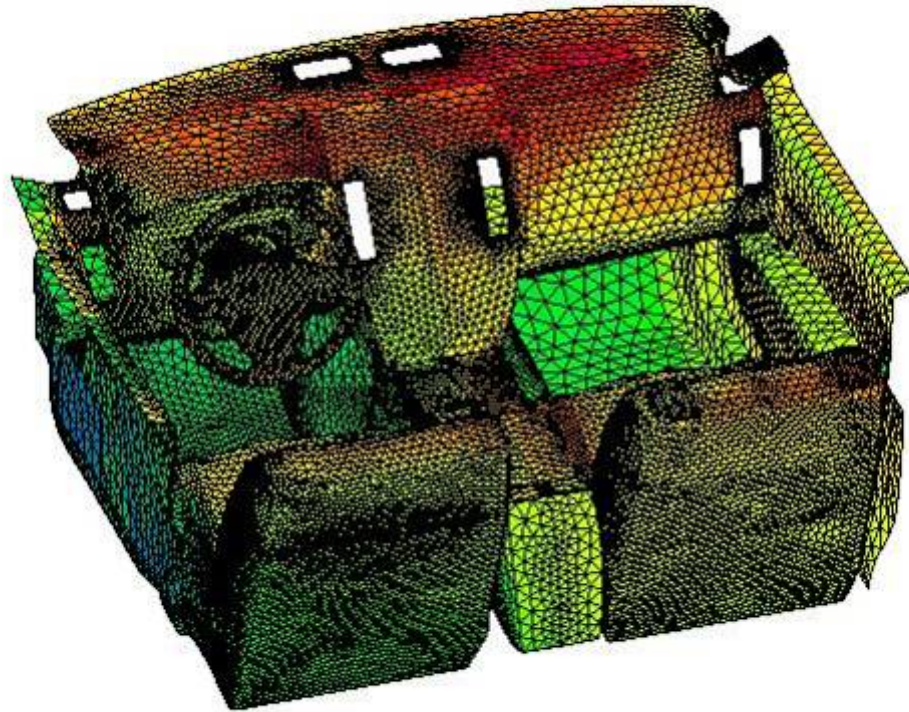
# Cool Down Assumptions

- Cool down data taken with vehicle at idle
- AC air flow 0.11 kg/s, 183 scfm
- Determine equal cool down at 30 min.

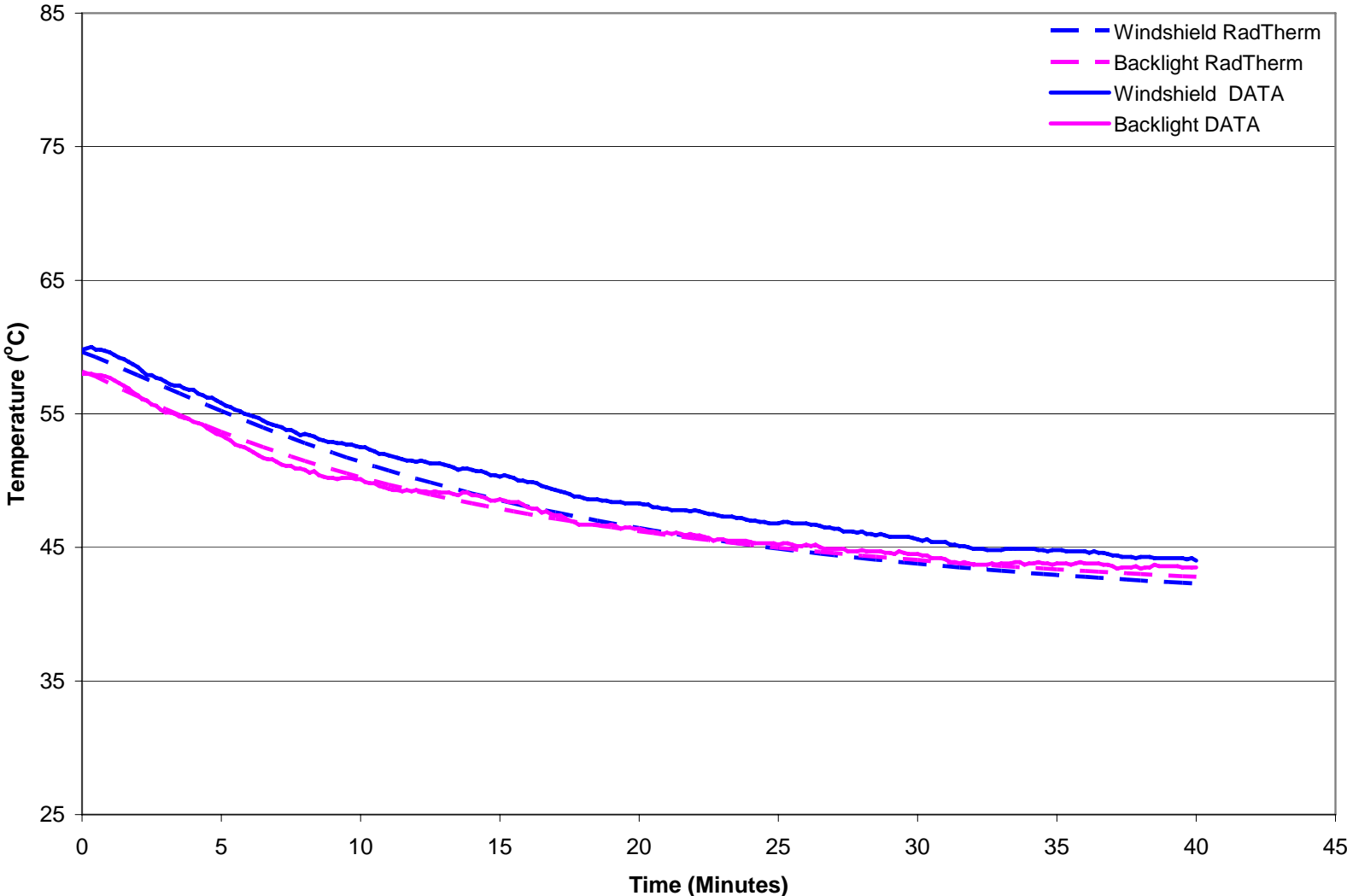
# Baseline Cool Down Results



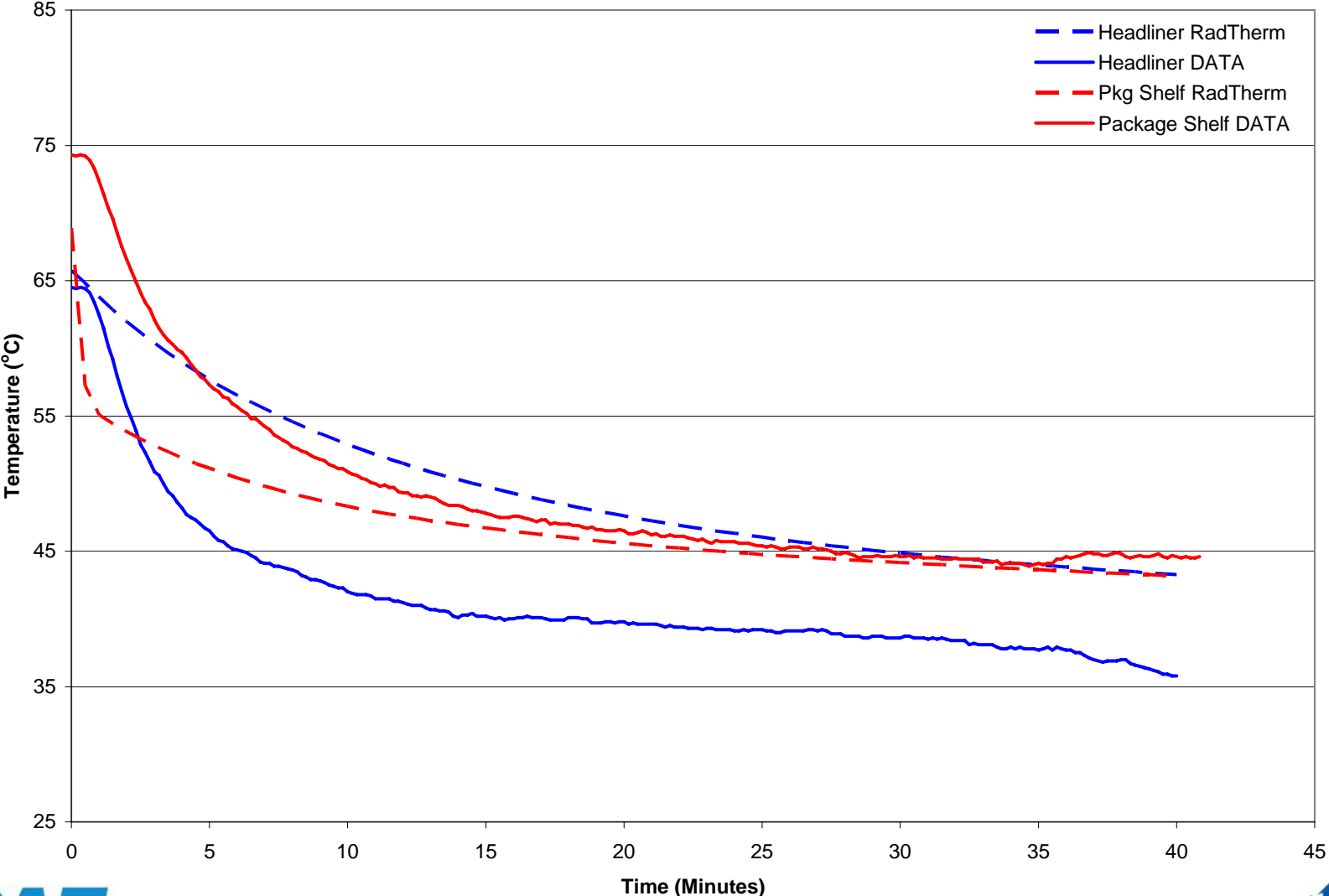
# Baseline Cool Down Results



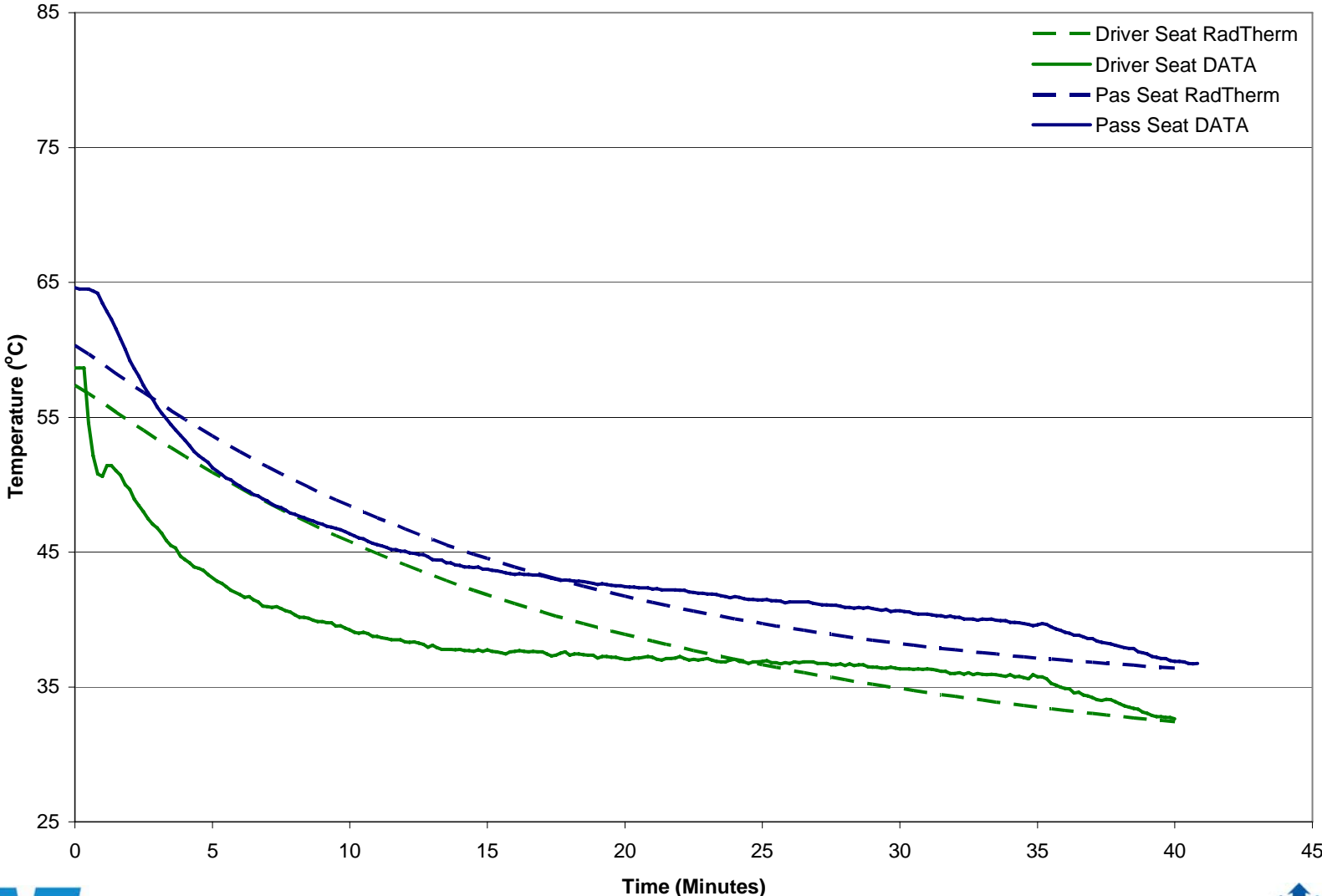
# Baseline Cool Down Results



# Baseline Cool Down Results



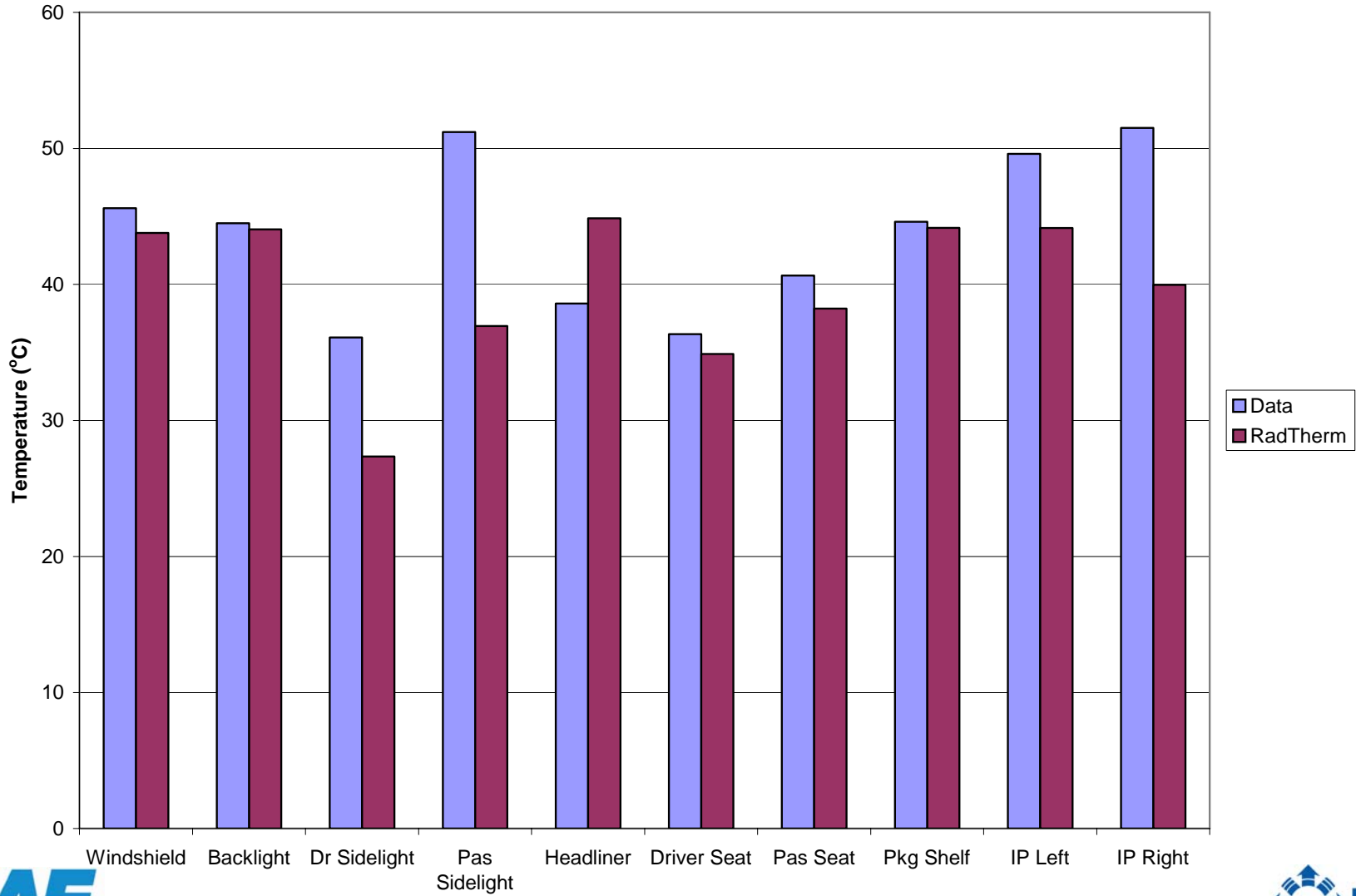
# Baseline Cool Down Results





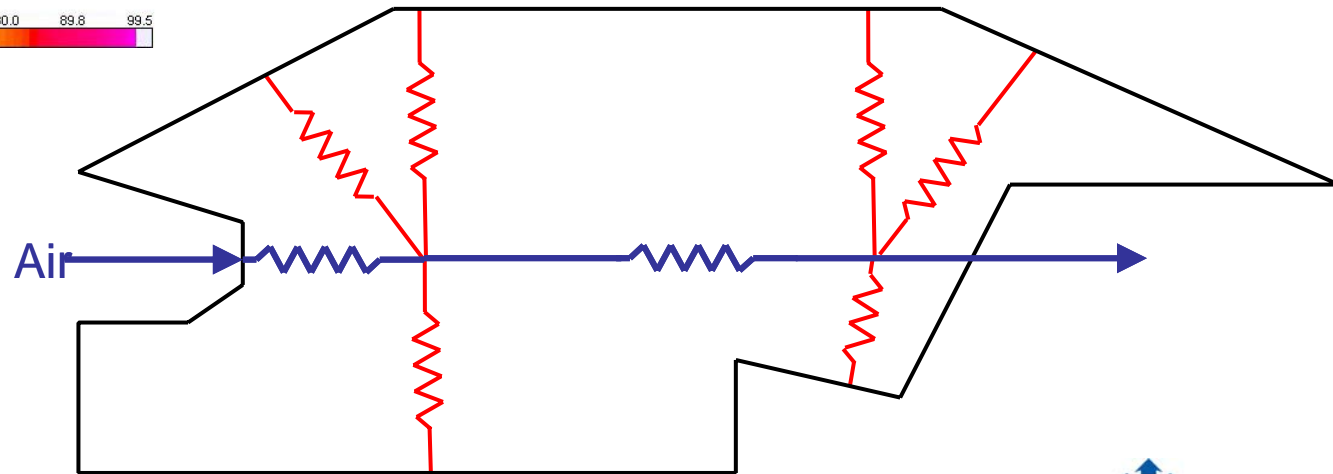
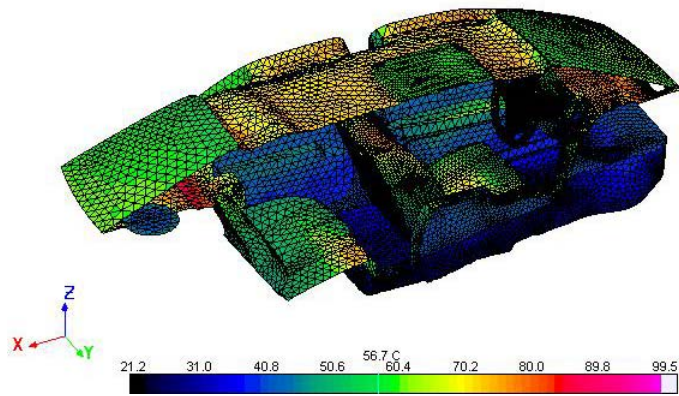
# Baseline Cool Down Results

## (4 kW Cooling)

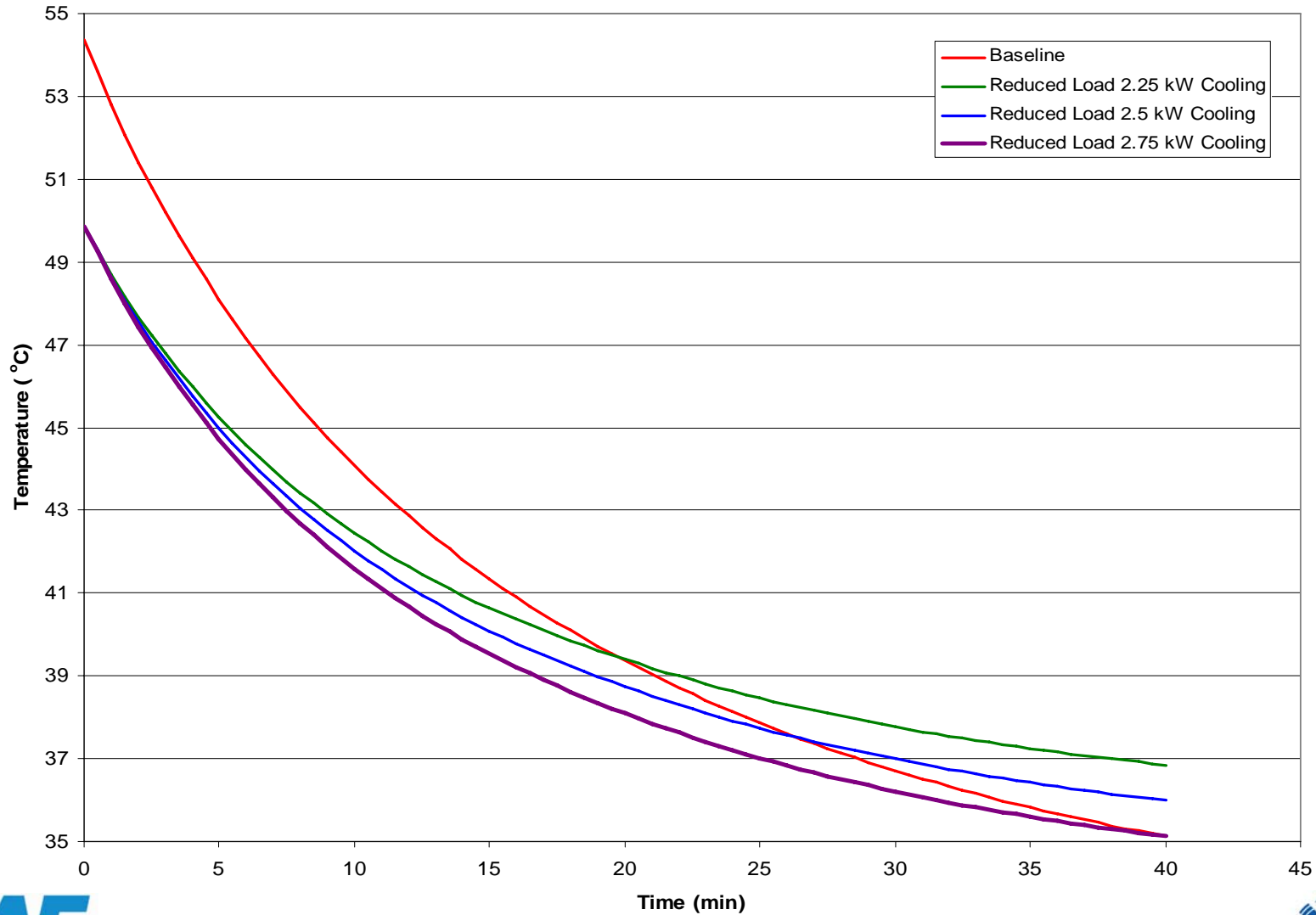


# Impact on Thermal Load

- Adjust AC load in RadTherm to achieve equal 30 min. cool down



# Mass Average Temperature



# 30 minute cool down

- Heat Balance:

$$\sum_{t=0}^{t=30} \left( \dot{m} C_p \Delta T \right)_{Air, Baseline} - \sum_{t=0}^{t=30} \Delta Q_{Solar} - \sum_{Soak} \Delta Q_{Solar} = \sum_{t=0}^{t=30} \left( \dot{m} C_p \Delta T \right)_{Air, ReducedThermalLoad}$$

$$\Delta T = T_{AirExit} - T_{AirInlet}$$

$$\Delta Q_{Solar} = Q_{Solar, Net_{Baseline}} - Q_{Solar, Net_{ReducedLoad}}$$

- Balanced with:

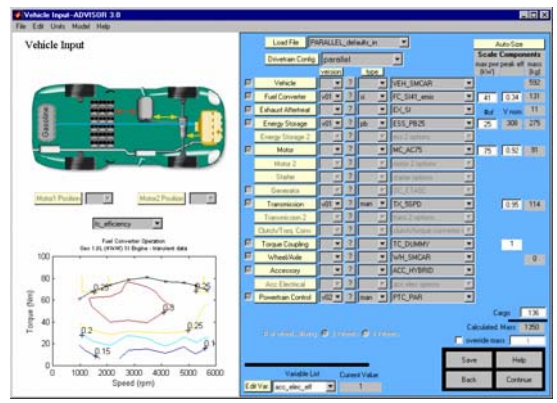
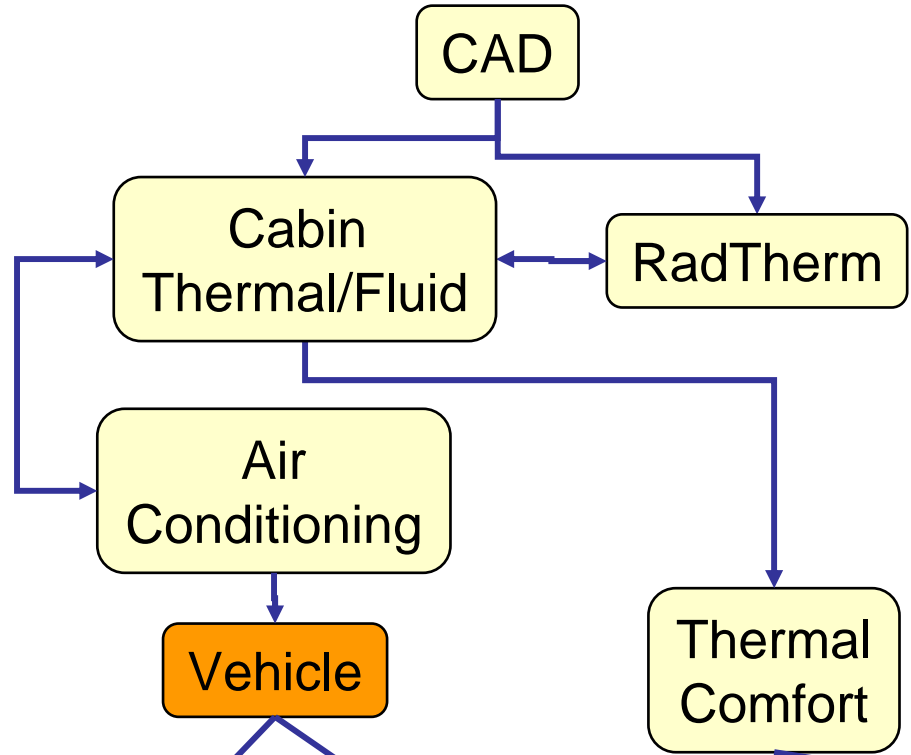
Baseline – 4 kW cooling

Reduced Thermal Load – 2.8 kW cooling

- 29.8% Reduction in cooling load

# Integrated Modeling

Model the STS over a drive cycle and find the fuel use



# Impact on Fuel Economy

- Vehicle simulator used to assess impact of reduced AC load.



City  
**16**

Highway  
**24**

| Fuel Economy (mpg)                |                 |
|-----------------------------------|-----------------|
|                                   | FTP Drive Cycle |
| Fuel Economy no AC                | 18.5            |
| Fuel Economy with Baseline AC     | 15.4            |
| Fuel Economy with 70% Baseline AC | 16.1            |

# Impact on Fuel Use

- US Average AC use - 32.6% (MAC Summit 2004)
- US Vehicle Miles Traveled - 11,998 (Wards 2005)

| <b>Annual Fuel Used per Vehicle for AC (gal)</b> |                        |
|--|------------------------|
|  | <b>FTP Drive Cycle</b> |
| <b>Fuel Used with Baseline AC</b>                | <b>42.6</b>            |
| <b>Fuel Used with 70% Baseline AC</b>            | <b>31.4</b>            |
| <b>Fuel Savings per Vehicle</b>                  | <b>11.2</b>            |

26 % Reduction in AC fuel use for this vehicle

# Summary

## NREL thermal management modeling tools used to assess impact of load reduction technologies

- Cadillac STS test results - soak temperatures reduced
- Validated thermal/fluid model
- Results indicate the thermal load is reduced 29.8 %
- Fuel used for AC reduced 26 %
- Future work
  - A/C model → A/C power
  - Linking models



# Acknowledgements

- **DOE**
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