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

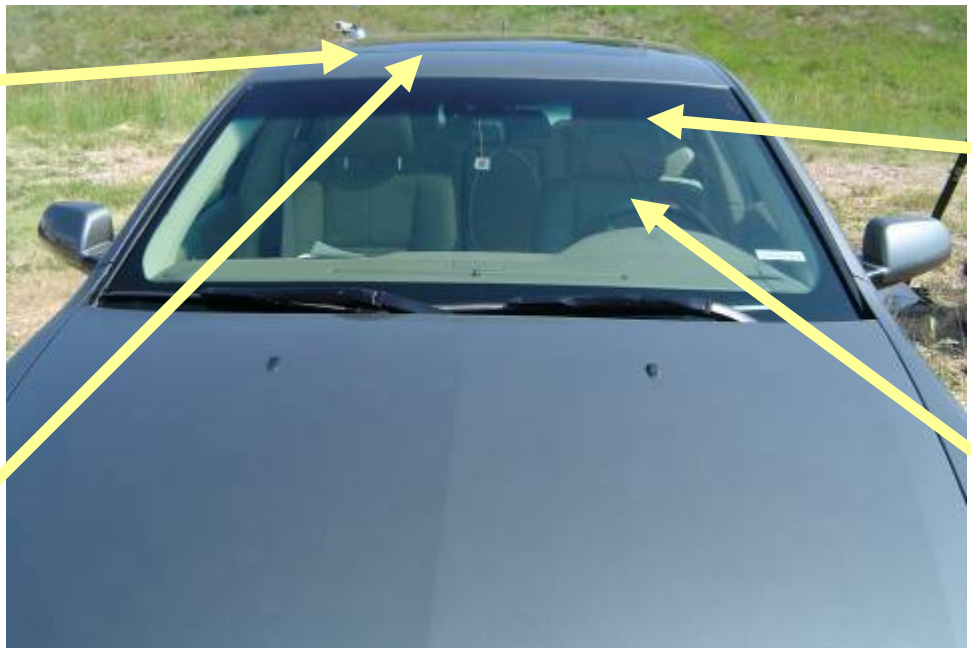
- ~$3 million budget (2005 and 2006)
- Government/Industry partnership
- Demonstrate technologies to reduce direct (leakage) and indirect (tailpipe) HFC-134a refrigerant emissions
- Administered by Society of Automotive Engineers (SAE)

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

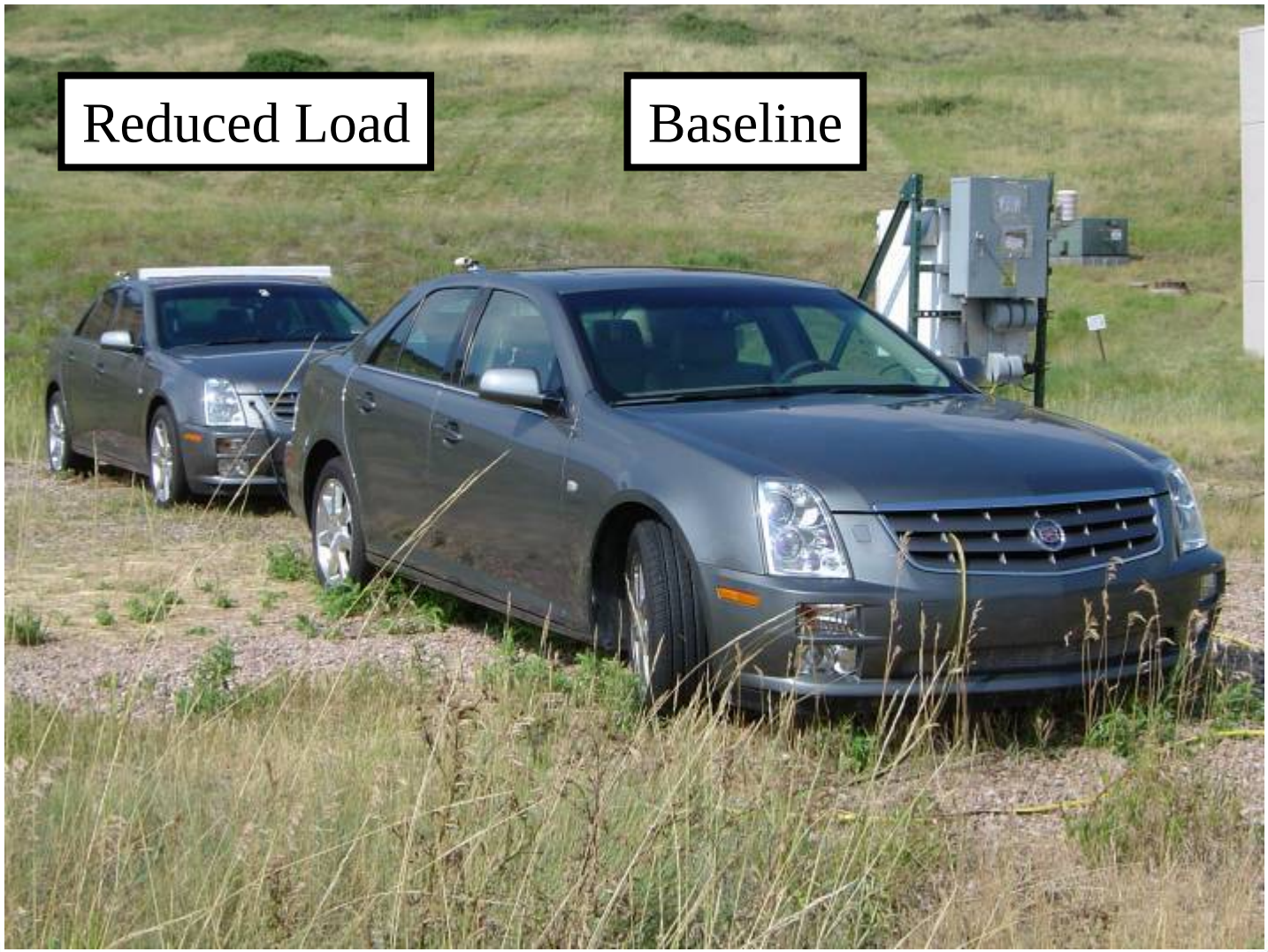


3M IR reflective film on roof skin

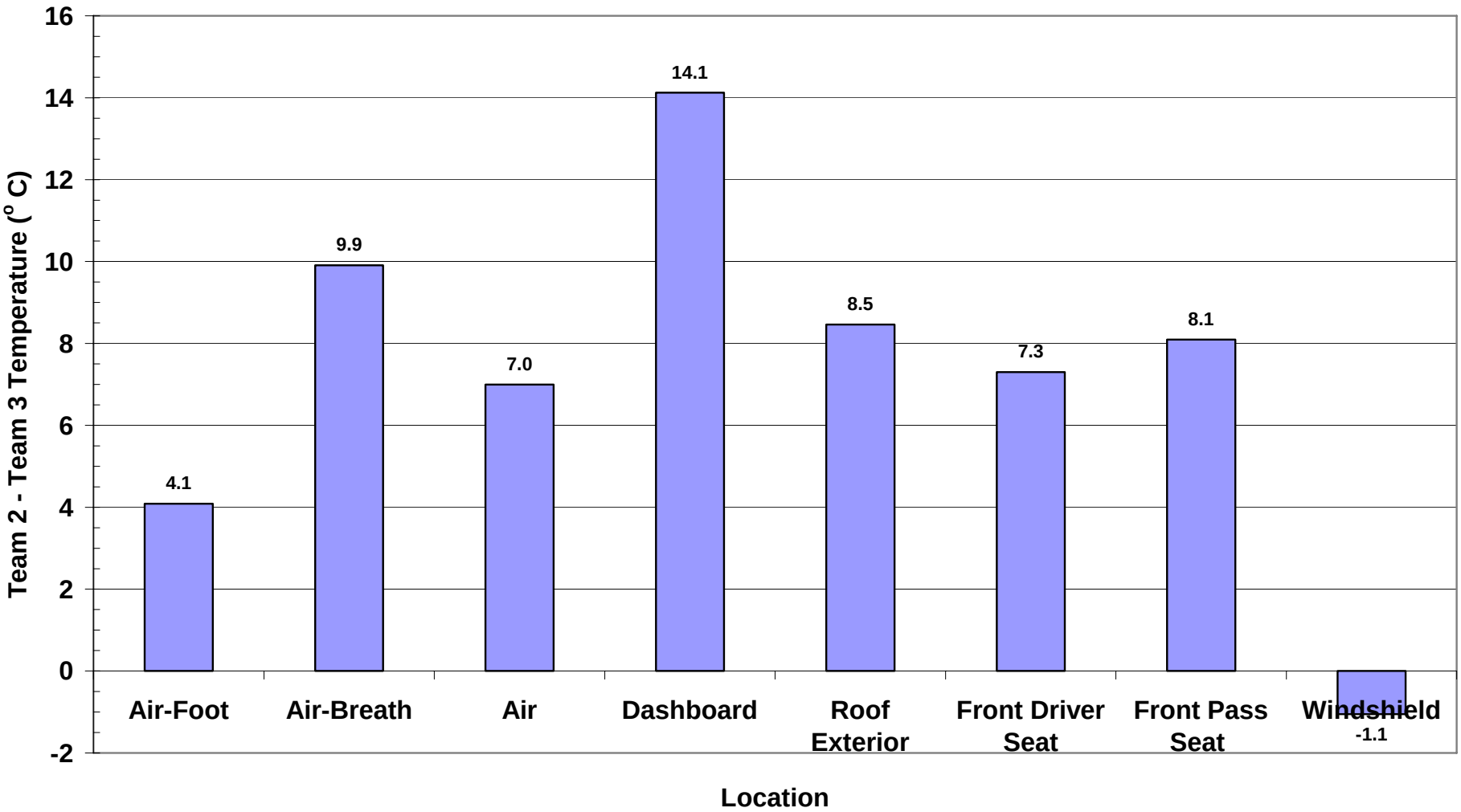
3M headliner insulation

3M IR reflective film in glazing interior

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



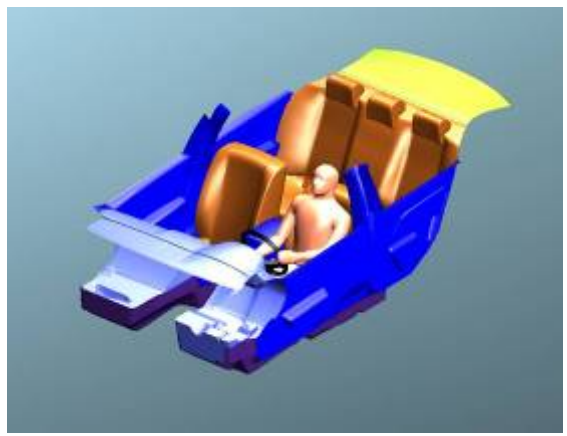
Reduction in Soak Temperatures



Assessing the Impact of the Temperature Reduction

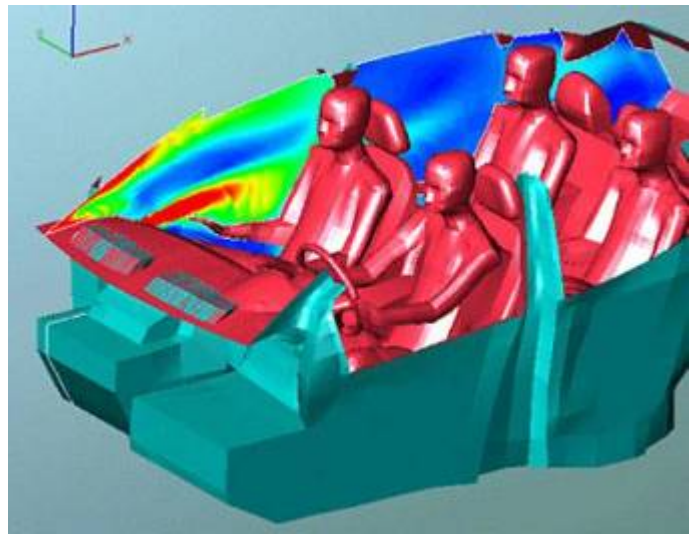
- Thermal Comfort
  - Use NREL thermal comfort tools
  - Cooldown testing with ADAM

- Fuel Use
  - NREL integrated modeling process
  - Analysis

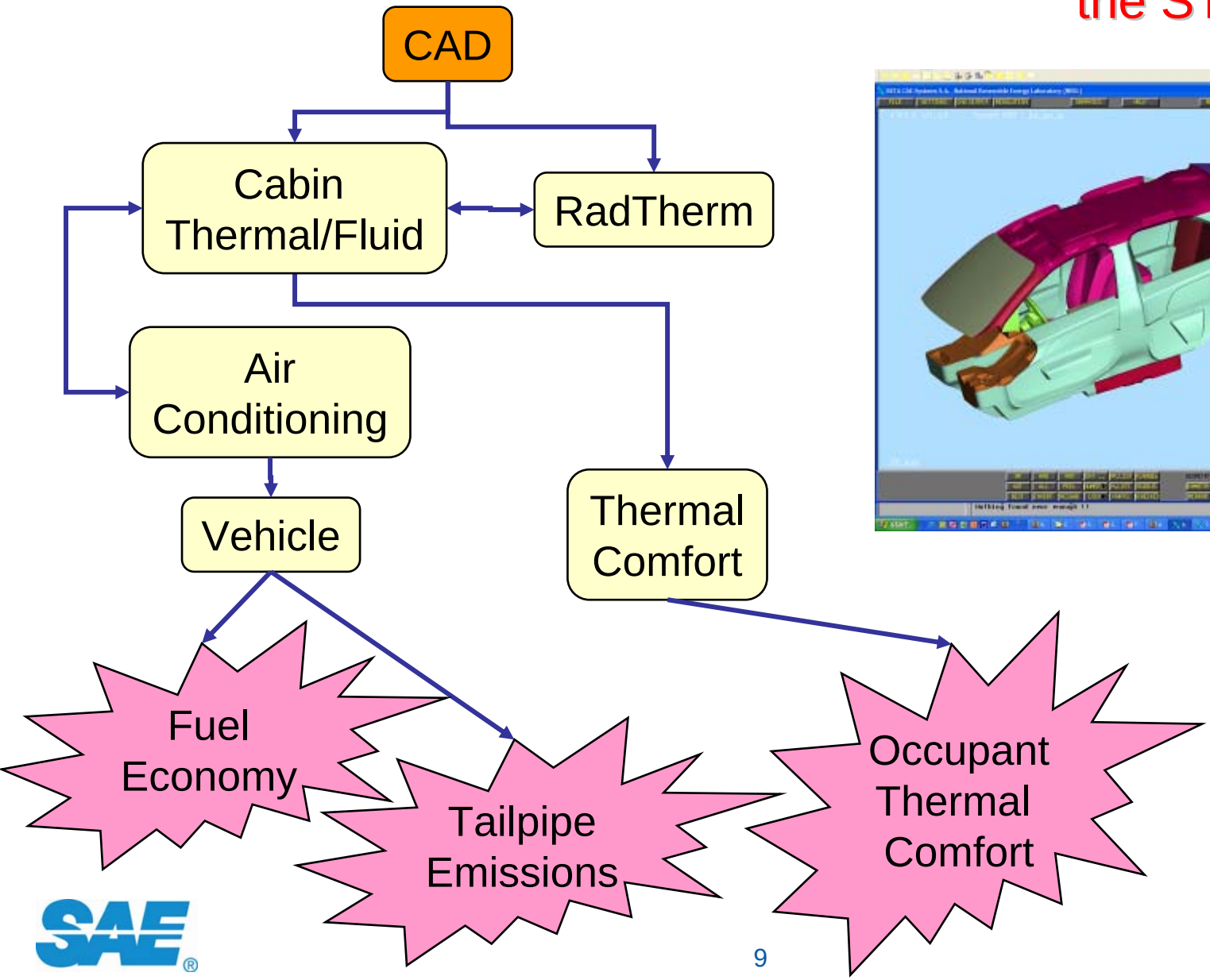


Integrated Modeling

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



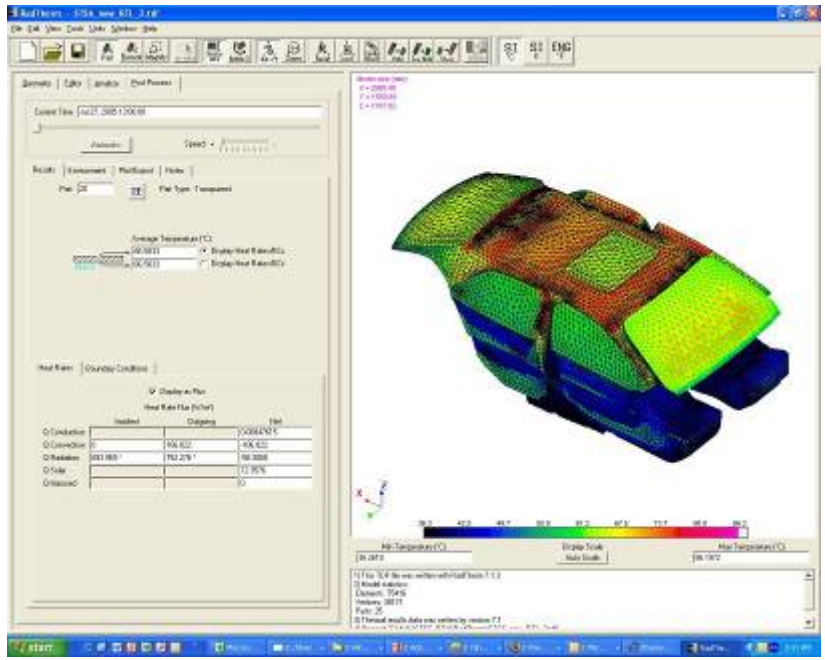
Integrated Modeling



Mesh the geometry of the STS

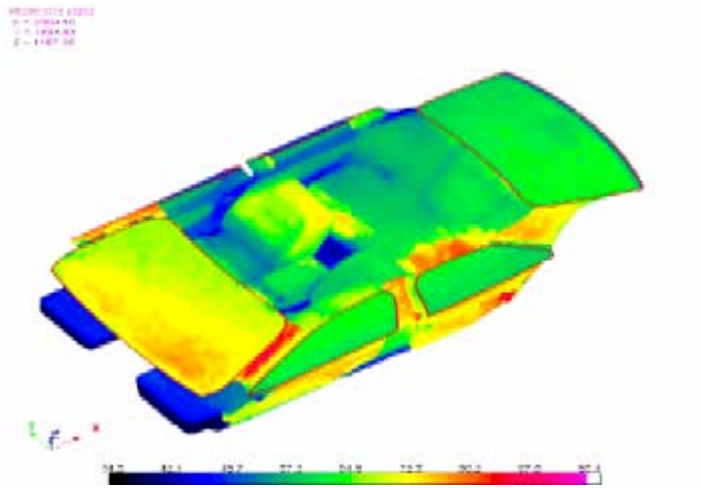
Integrated Modeling

Determine the solar load into the STS



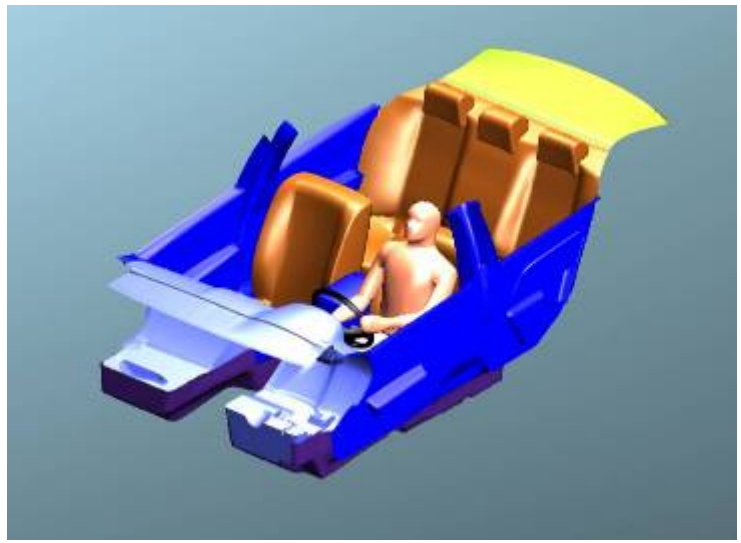
CFD Linking to RadTherm

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

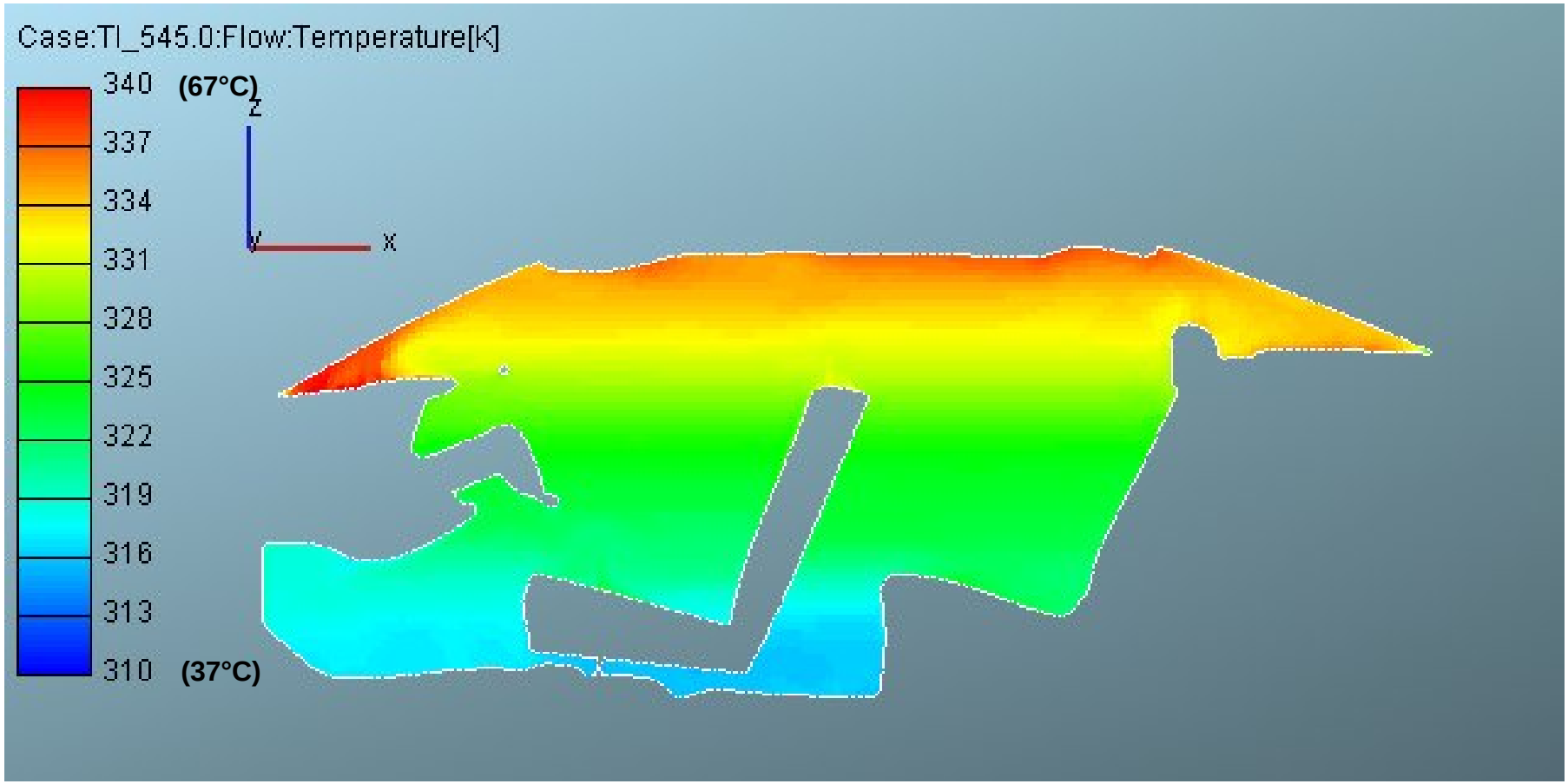


Integrated Modeling

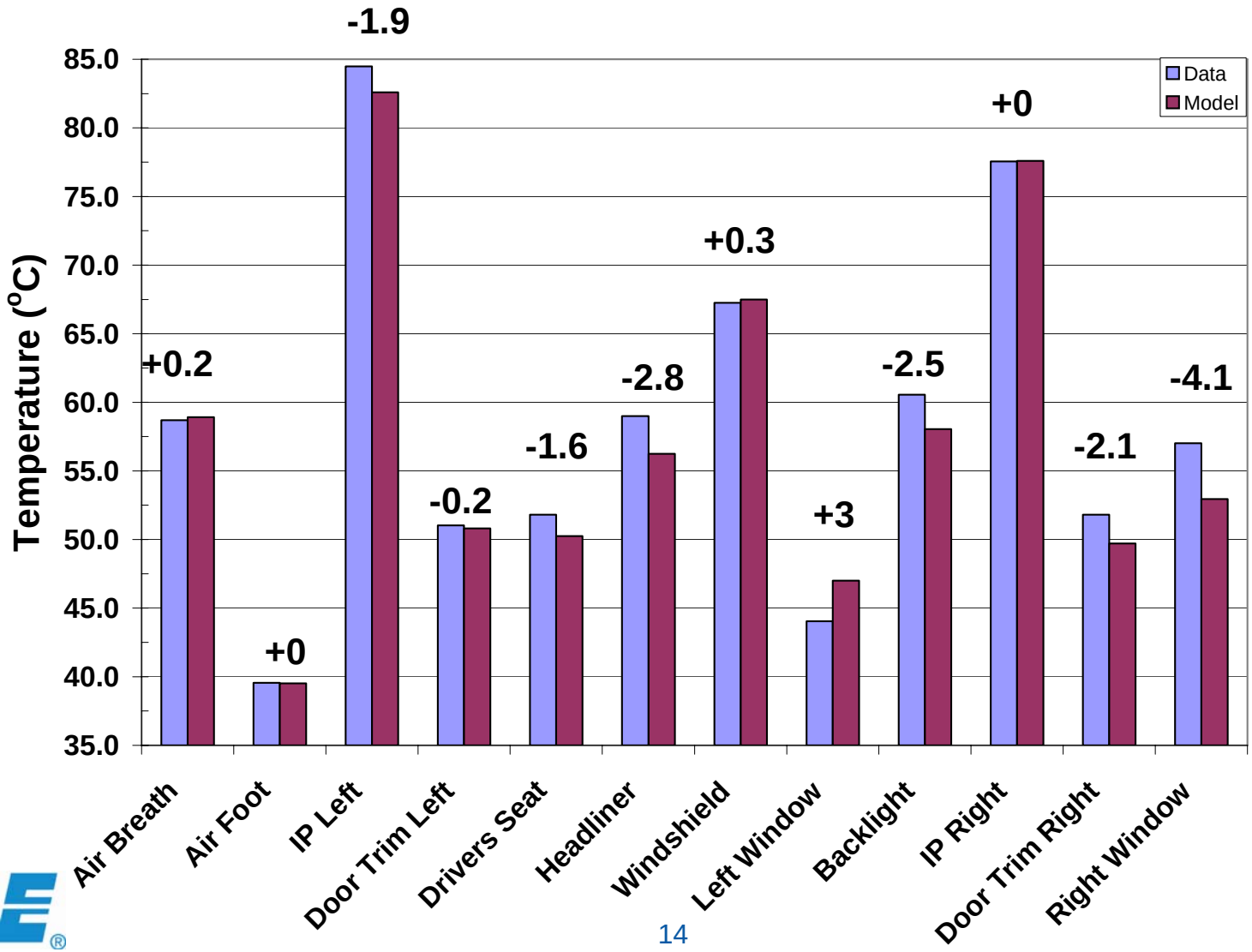
Model temperatures and airflow in the cabin



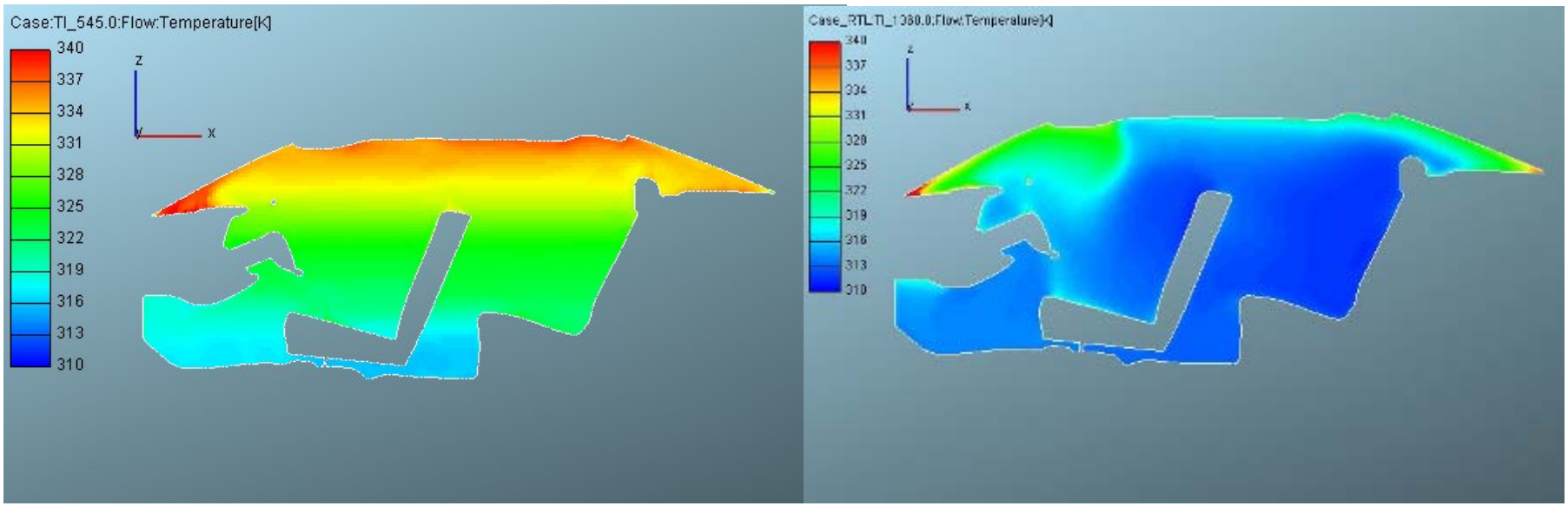
Baseline Soak Results Temperature Contours



Baseline Soak Results Comparison to Test Data



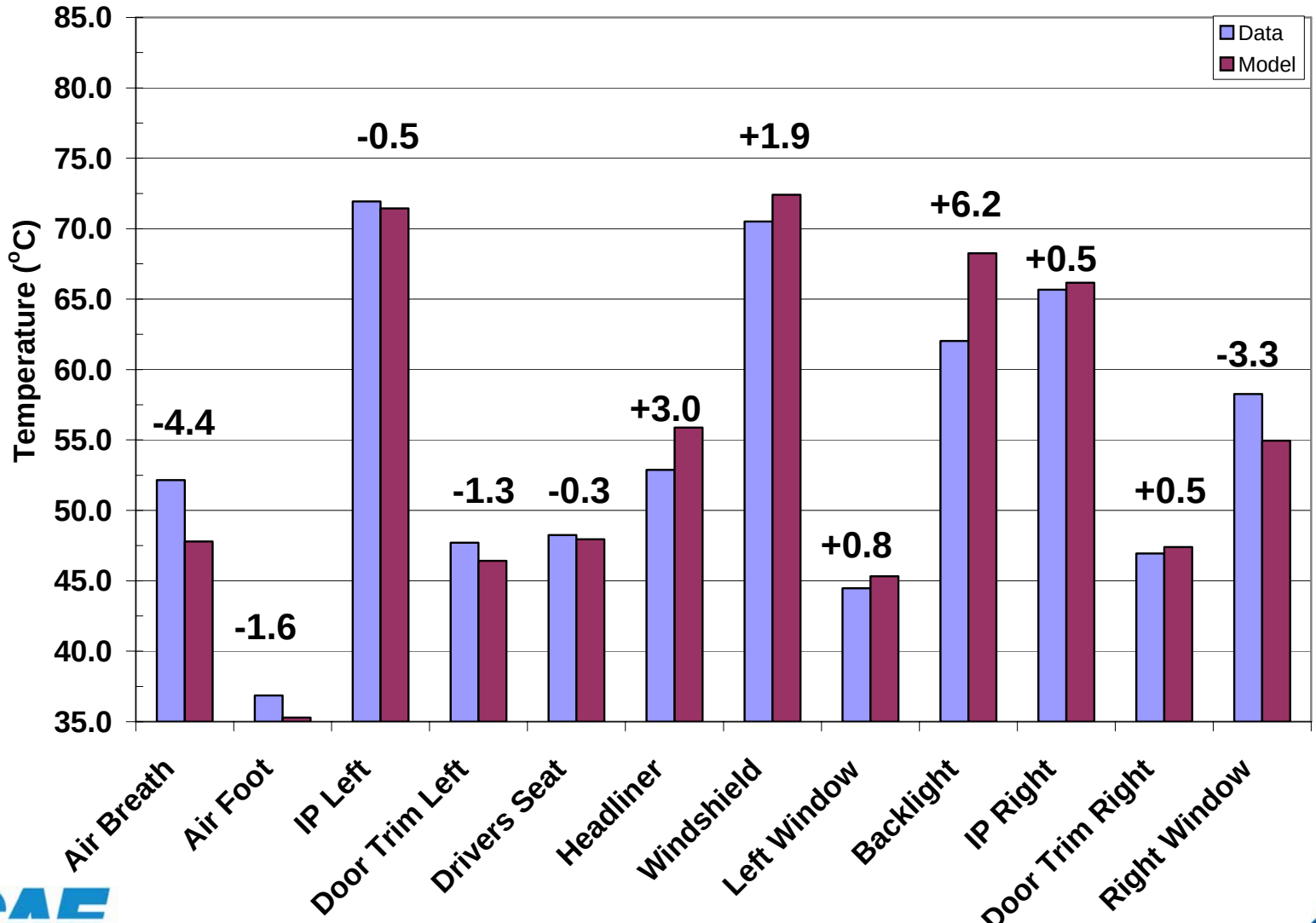
Soak Results
Temperature Contours



Baseline

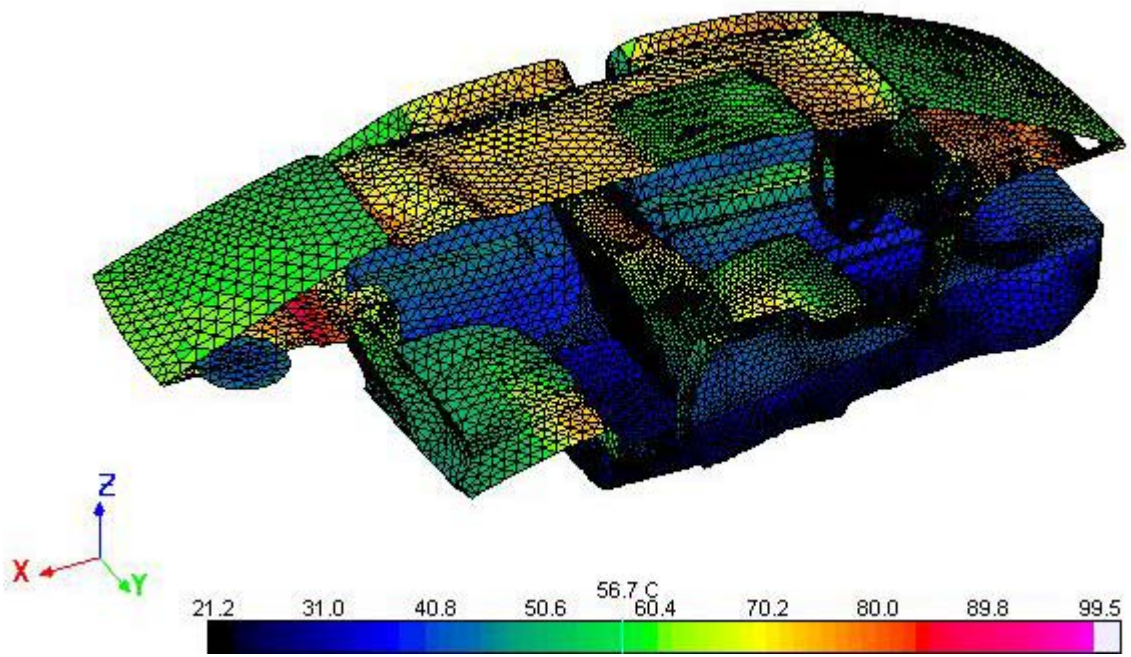
Reduced Thermal Load

Reduced Load Soak Results Comparison to Test Data



Impact on Thermal Load

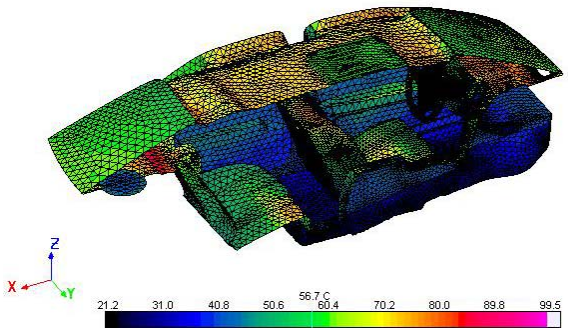
- RadTherm used to determine the difference in AC load to achieve equal cool down

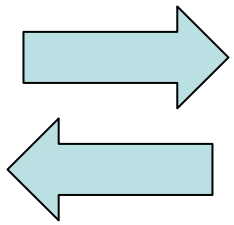


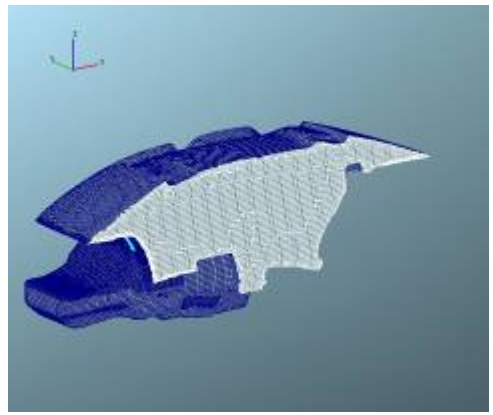
Simplified Thermal Model

RadTherm

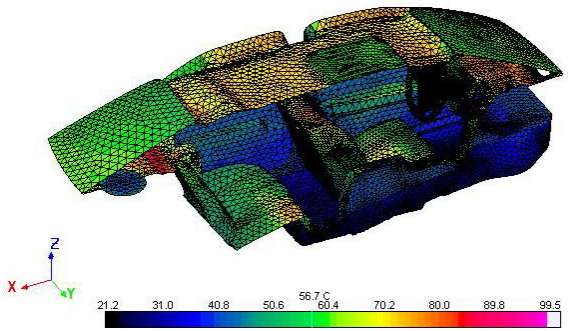
FIRE

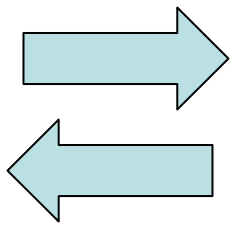


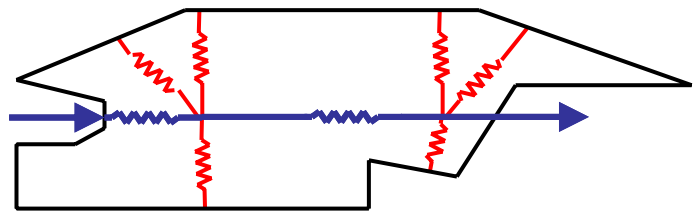




136,000 Elements **Full CFD model** 900,000 Fluid Nodes





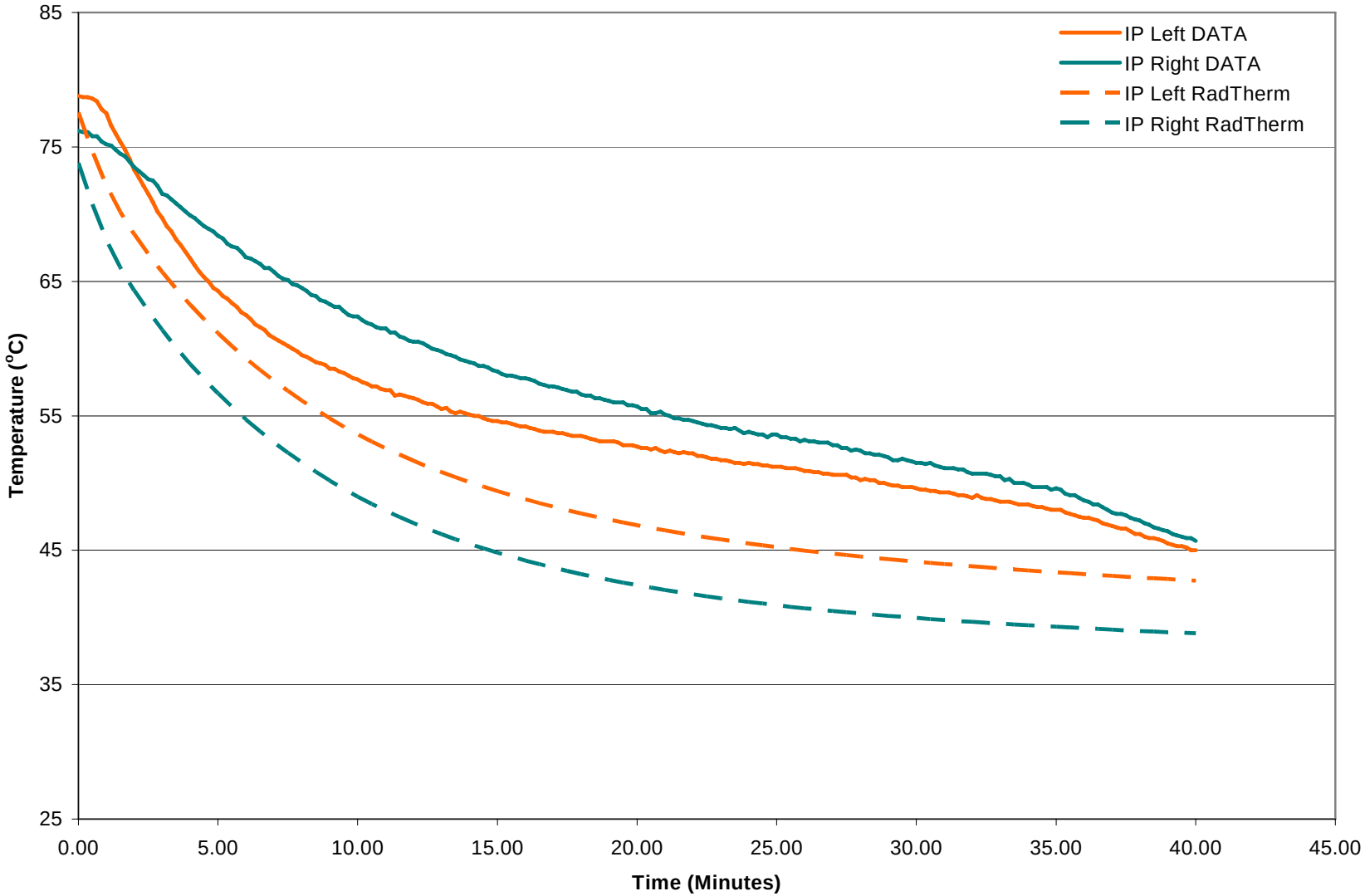


136,000 Elements **Simplified model** 8 Fluid Nodes

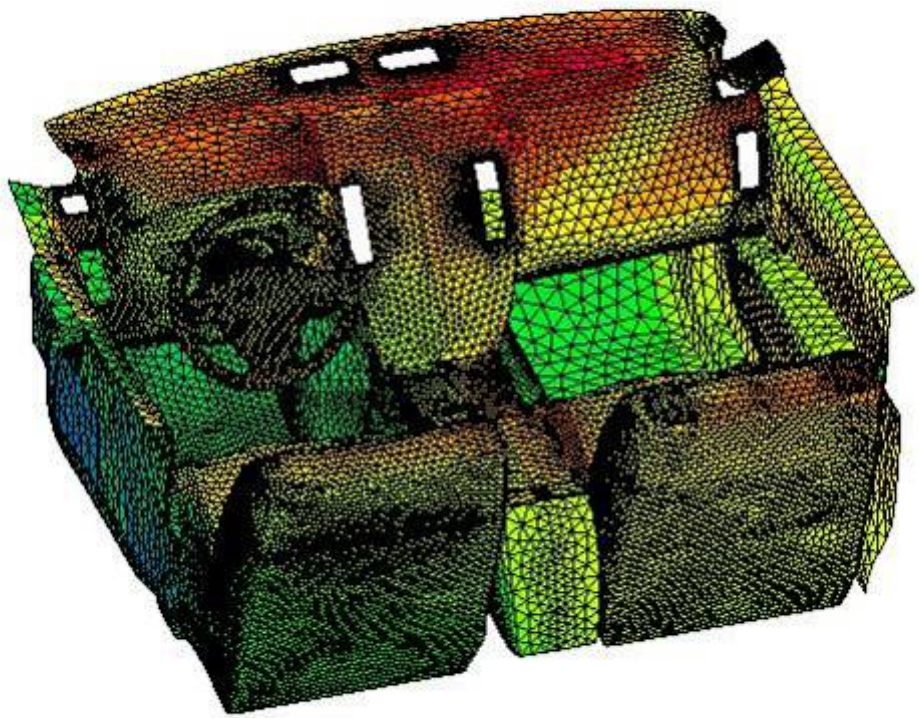
Cool Down Assumptions

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

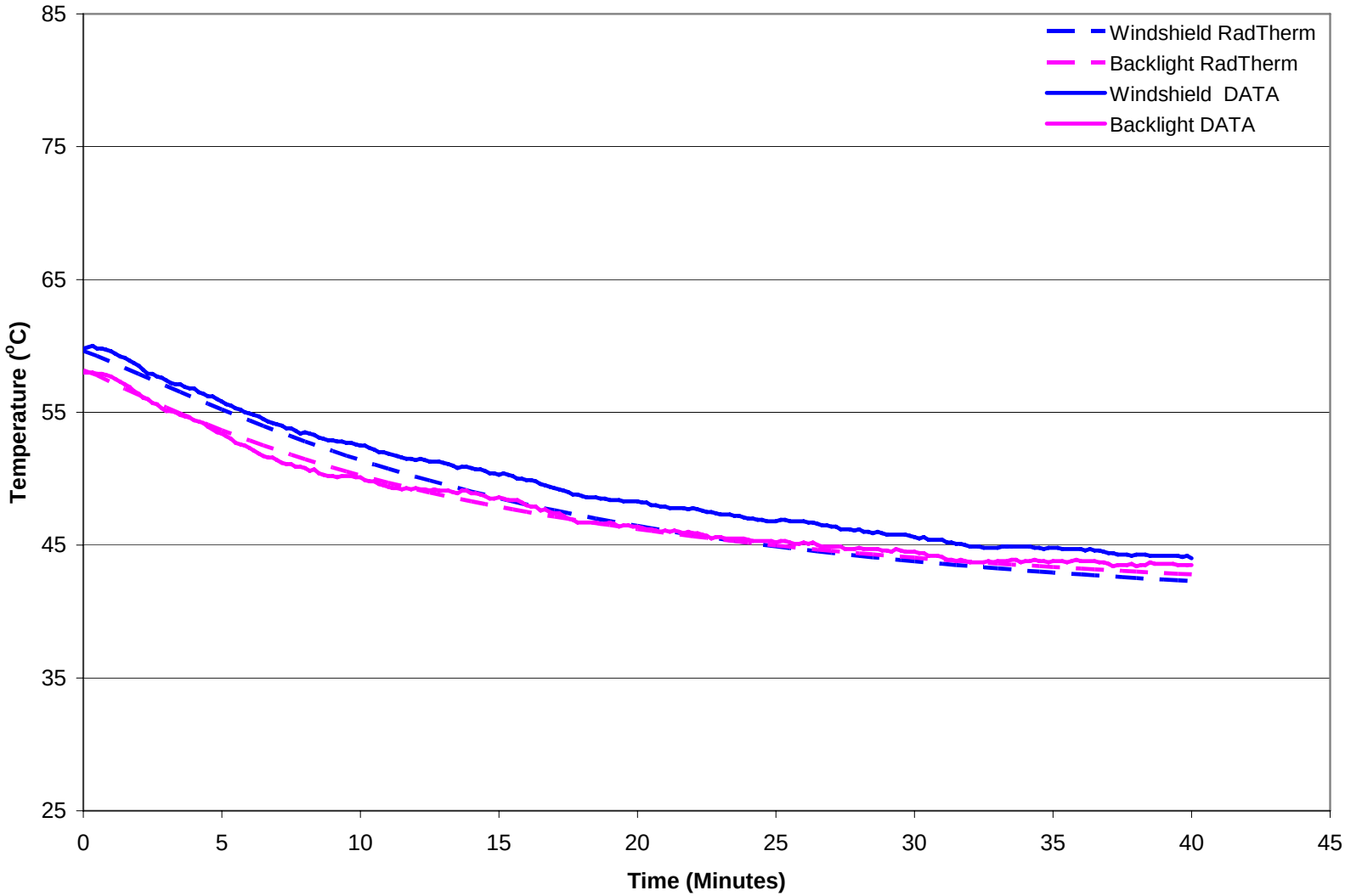
Baseline Cool Down Results



Baseline Cool Down Results



Baseline Cool Down Results



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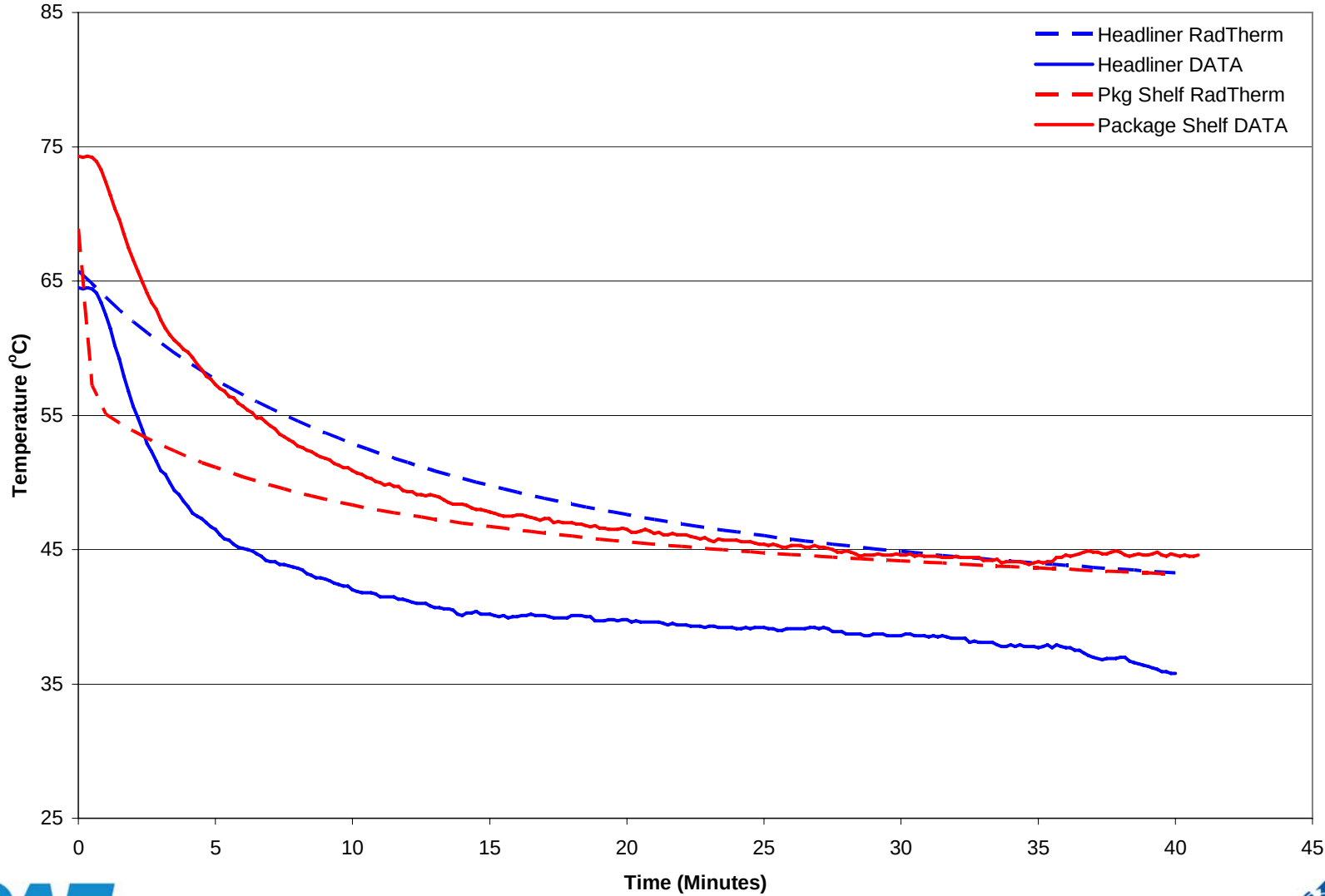
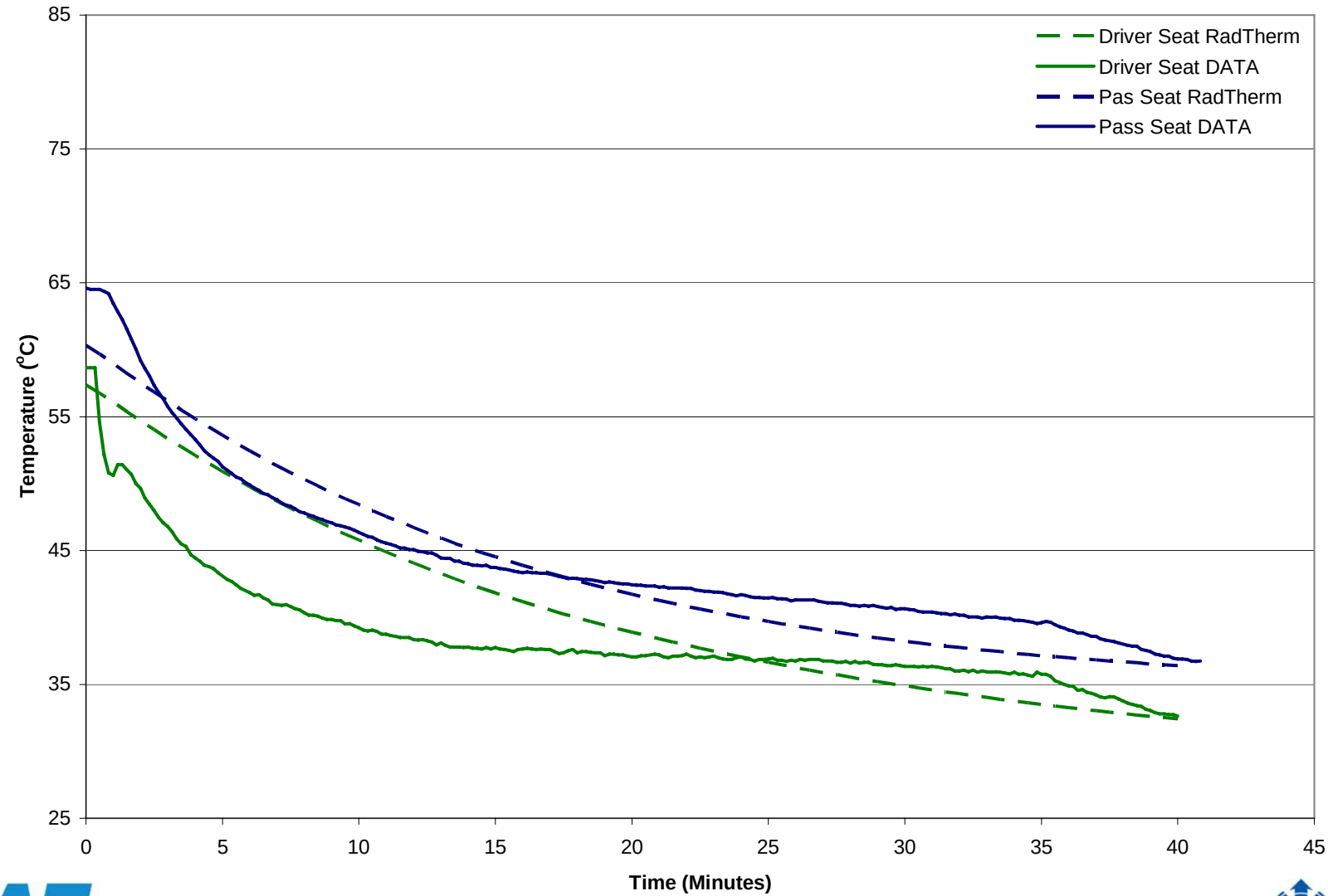
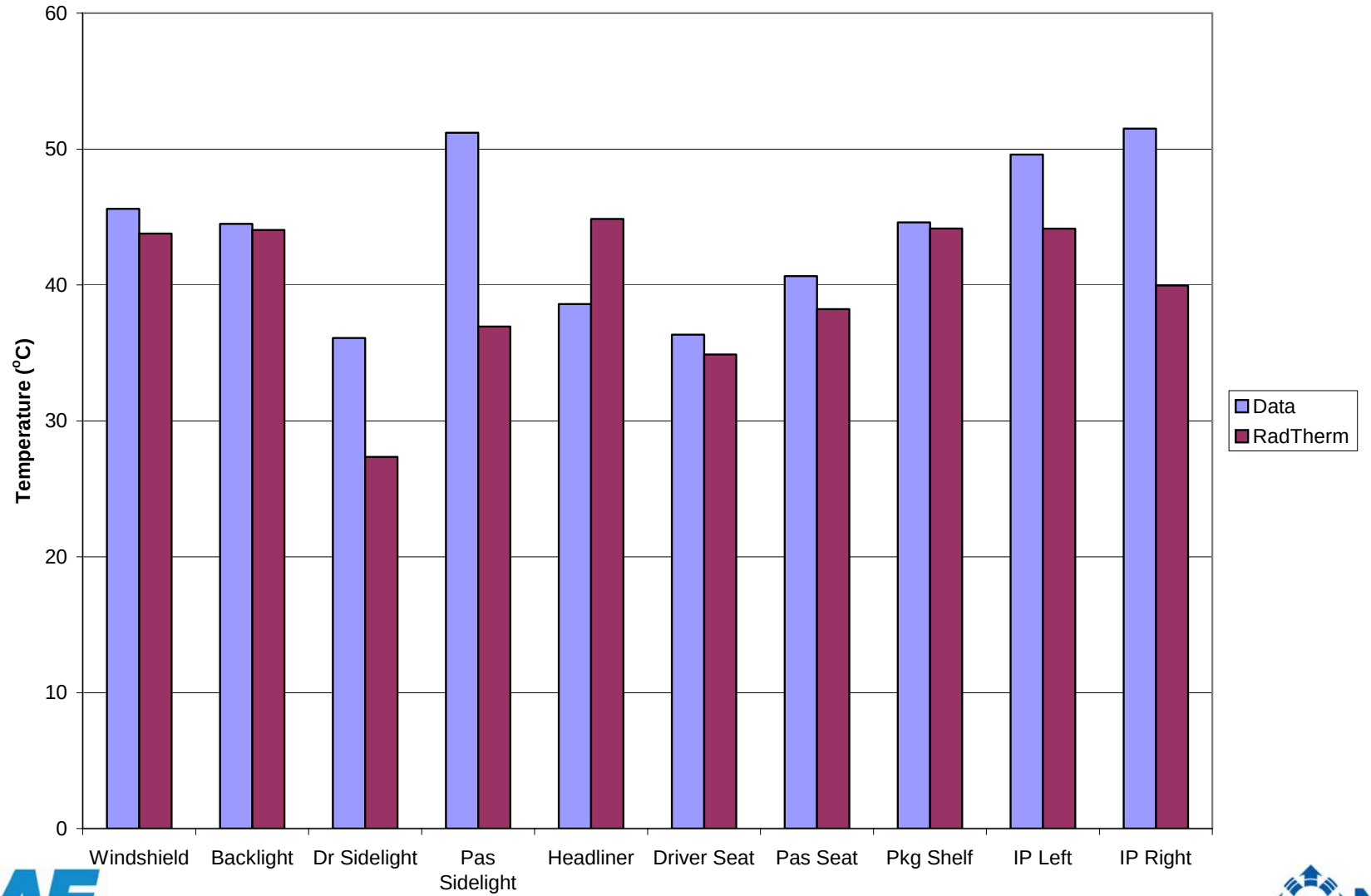


Baseline Cool Down Results



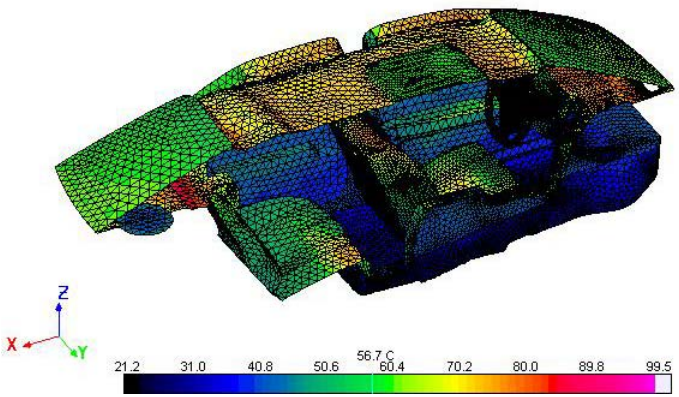
Baseline Cool Down Results

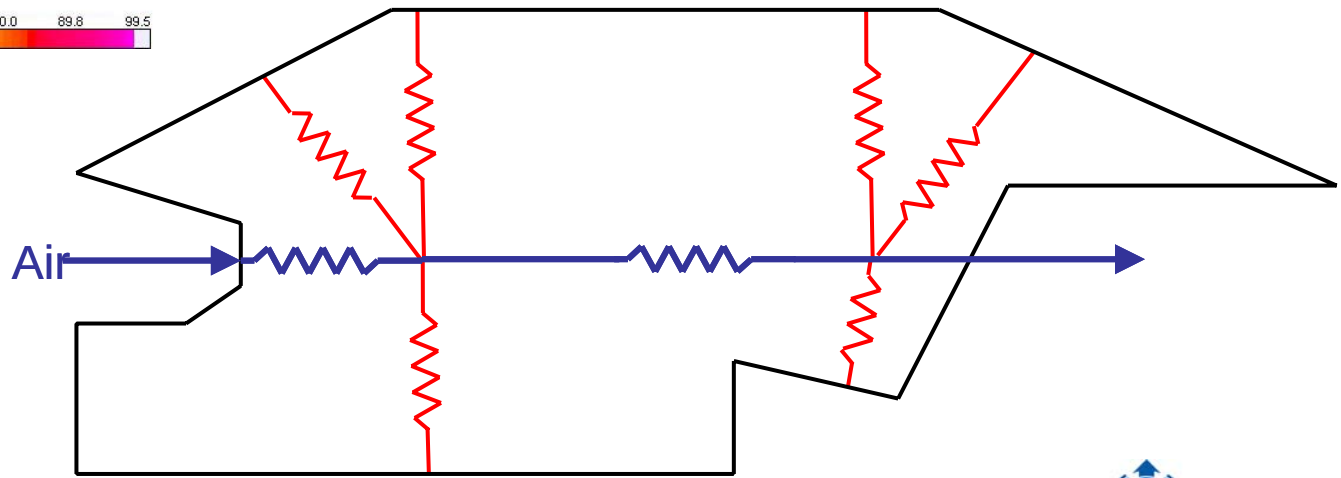
(4 kW Cooling)



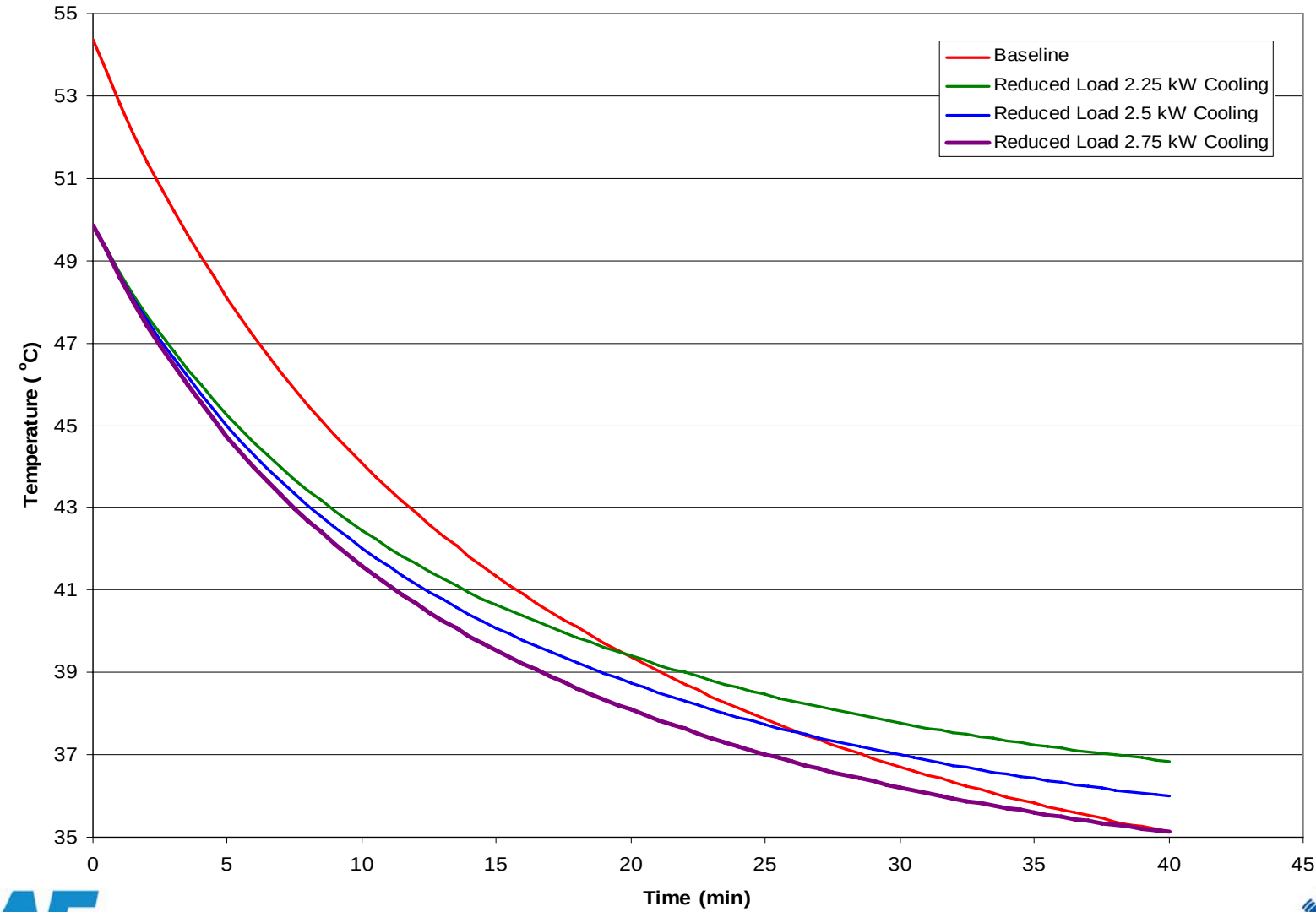
Impact on Thermal Load

- 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:

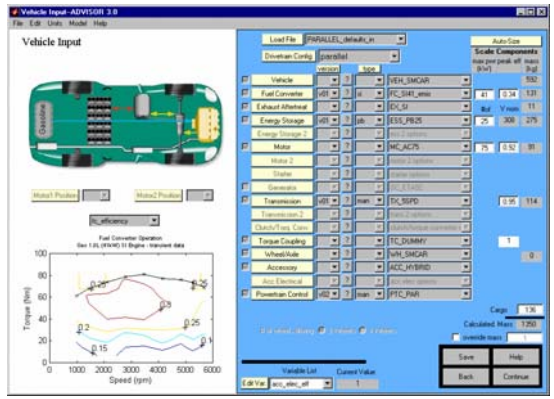
  Baseline – 4 kW cooling

  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



ADVISOR

CAD

Cabin Thermal/Fluid

RadTherm

Air Conditioning

Vehicle

Thermal Comfort

Fuel Economy

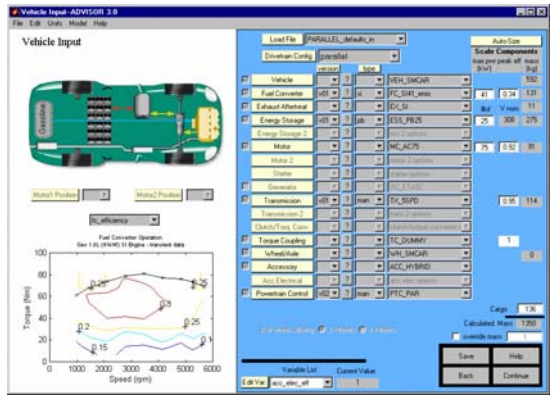
Tailpipe Emissions

Occupant Thermal Comfort

Impact on Fuel Economy

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

City	Highway
16	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)

Annual Fuel Used per Vehicle for AC (gal)	FTP Drive Cycle
Fuel Used with Baseline AC	42.6
Fuel Used with 70% Baseline AC	31.4
Fuel Savings per Vehicle	11.2

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

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  - Reinhard Tatschl
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  - Craig Cless
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