Reduction in Vehicle Temperatures and Fuel Use from Cabin Ventilation, Solar-Reflective Paint, and a New Solar-Reflective Glazing

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Outline

- Improved Mobile Air Conditioning Cooperative Research Program
- Vehicle Thermal Soak Test
- Thermal and Vehicle Fuel Use Analysis
Improved Mobile Air Conditioning Cooperative Research Program

- Demonstrate technologies to reduce direct (leakage) and indirect (tailpipe) HFC-134a refrigerant emissions
- Government/Industry partnership
- 28 Industry Sponsors
- Administered by Society of Automotive Engineers (SAE)
- Four Teams
  - Reduce leakage during operation
  - Improved COP
  - Reduce vehicle thermal load
  - Reduce leakage during service
2006 I-MAC Reduced Thermal Load Vehicle

Select the most promising technologies and test in a final configuration

- Solar Reflective Glazings
- Solar Powered Parked Car Ventilation
- Solar Reflective Paint
Solar Reflective Glazings: Sungate EP

- Manufacturer: PPG Industries
- Reflects IR portion of solar spectrum
  - Meets 70% transmittance requirement
  - Greater than 50% solar energy reflected
- Reduces solar heat gain
- Windshield, sidelites, backlite

<table>
<thead>
<tr>
<th></th>
<th>Solargreen® glass</th>
<th>Sungate® windshield</th>
<th>Sungate® EP</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTa</td>
<td>72%</td>
<td>72</td>
<td>71</td>
</tr>
<tr>
<td>TSET</td>
<td>44%</td>
<td>39</td>
<td>33</td>
</tr>
<tr>
<td>TSER</td>
<td>6%</td>
<td>31</td>
<td>47</td>
</tr>
</tbody>
</table>
Solar Powered Parked Car Ventilation

- Manufacturer: Webasto
- 24 cell, 17 W PV panel in sunroof
- Six ~ 1.6 W fans
- Current configuration: Extracts hot air from cabin interior
- Since STS already had a sunroof, a unique test install was required
Solar Reflective Paint

- Manufacturer: PPG Industries
- Prototype S2X
- Maintains color while reflecting IR portion of solar spectrum
- Standard clearcoat over IR reflective basecoat
- Cooler skin temperatures reduce cabin heat gain
- NREL measured absorptance
  - Baseline 89.4%
  - Solar reflective 82.1%
I-MAC Vehicle Soak Test Procedure

- Two nearly identical vehicles parked facing 160º, front/back
- Evaluate technologies that reduce thermal load
  - Modify test vehicle
  - Start data acquisition system ~ 8:30 am
  - Stop data acquisition system ~ 16:30 am
- Data analysis
  - Report time-averaged temperature difference between identical locations between 12:30 and 13:30
  - Eliminate cloudy days
  - Average results with multiple “good” test days
Cadillac STS & NREL Test Facility

Modified

Baseline
Reduction in Air Temperatures

Solar reflective glazings all locations
Solar powered ventilation
Solar reflective paint
Solar Reflective Glass (All Locations), Paint, and Ventilation

Reduction in Temperature (oC):
- Air-Foot: 5.6
- Air-Breath: 12.0
- Air: 8.8
- Dashboard: 16.8
- Roof Exterior: 6.0
- Front Driver Seat: 10.3
- Front Pass Seat: 11.9
- Windshield: 20.4

Reduction in Temperature (°F):
- Air-Foot: 9
- Air-Breath: 21.6
- Air: 15.4
- Dashboard: 32.2
- Roof Exterior: 10.8
- Front Driver Seat: 18.5
- Front Pass Seat: 21.6
- Windshield: 36.7
Comparison to Solar Reflective Glass only Data

- Solar Reflective Glass-all locations, Parked Car Ventilation
- Solar Reflective Glass-all locations
- Solar Reflective Windshield-Backlite
- Solar Reflective Windshield

Reduction in Temperature (°C)

- Air-Foot
- Air-Breath
- Air
- Dashboard
- Roof Exterior
- Front Driver Seat
- Front Pass Seat
- Windshield

Reduction in Temperature (°F)

Solar Reflective Paint-all tests
Solar Powered Ventilation Only

- Air Foot: -2.9
- Air Breath: 7.1
- Air: 8.3
- Dashboard: 8.3
- Roof Exterior: 1.5
- Front Driver Seat: 1.0
- Front Pass Seat: 0.7
- Windshield: 0.3
- Air blown into vehicle: 2.3
- Air pulled out of vehicle: 2.3

Reduction in Temperature (°C)
Solar Reflective Roof Film Only

Reduction in Temperature (°C)

- Air-Foot: 0.5
- Air-Breath: 1.2
- Air: 0.8
- Dashboard: 0.9
- Roof Exterior: 6.7
- Front Driver Seat: 0.4
- Front Pass Seat: 0.4
- Windshield: -0.6
Integrated Modeling

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

CAD

Cabin Thermal/Fluid

RadTherm

Air Conditioning

Vehicle

Thermal Comfort

Fuel Economy

Tailpipe Emissions

Occupant Thermal Comfort

SAE 2007 World Congress

2007-01-1194
Integrated Modeling

Model temperatures and airflow in the cabin

CAD

Cabin Thermal/Fluid

RadTherm

Air Conditioning

Vehicle

Thermal Comfort

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Tailpipe Emissions

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SAE 2007 World Congress

2007-01-1194
Baseline Soak Results Comparison to Test Data
Soak Results Temperature Contours

Baseline

Reduced Thermal Load
- Solar Reflective Glazings
- Solar Reflective Paint
- Solar Powered Parked Car Ventilation

Contours of Static Temperature (°C) Jan 29, 2007
FLUENT 6.3 (3d, dp, pbns, rngkel)
Simplified Thermal Model
RadTherm

136,000 Elements

Full CFD model
900,000 Fluid Nodes

136,000 Elements

Simplified model
8 Fluid Nodes
Baseline Cool Down Results

- Driver Seat (Simulation)
- Driver Seat (Data)
- Pass. Seat (Simulation)
- Pass. Seat (Data)

Temperature (°C)

Time (Minutes)
Adjust A/C Load in RadTherm to Achieve Equal 30 min. Cooldown

30% Reduction in cooling load
30 minute cool down

- **Heat Balance:**

\[
\sum_{t=0}^{t=30} (mC_p \Delta T)_{Air,Baseline} - \sum_{t=0}^{t=30} \Delta Q_{Solar,Soak} - \sum_{t=0}^{t=30} \Delta Q_{Solar,Soak} = \sum_{t=0}^{t=30} (mC_p \Delta T)_{Air,ReducedThermalLoad}
\]

\[
\Delta T = T_{AirExit} - T_{AirInlet}
\]

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

- **Balanced with:**

Baseline – 5.7 kW cooling

Reduced Thermal Load – 4.0 kW cooling

- **29.8% Reduction in cooling load**
Model the STS over a drive cycle and find the fuel use.

Integrated Modeling

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.

<table>
<thead>
<tr>
<th></th>
<th>City</th>
<th>Highway</th>
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<tbody>
<tr>
<td>FTP</td>
<td>16</td>
<td>24</td>
</tr>
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</table>

**Fuel Economy (mpg)**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>FTP Drive Cycle</th>
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</thead>
<tbody>
<tr>
<td>Fuel Economy no AC</td>
<td>18.5</td>
</tr>
<tr>
<td>Fuel Economy with Baseline AC</td>
<td>15.4</td>
</tr>
<tr>
<td>Fuel Economy with 70% Baseline AC</td>
<td>16.1</td>
</tr>
</tbody>
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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)

<table>
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<tr>
<th>FTP Drive Cycle</th>
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</tr>
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<tbody>
<tr>
<td>Fuel Used with Baseline AC</td>
<td>42.6</td>
</tr>
<tr>
<td>Fuel Used with 70% Baseline AC</td>
<td>31.4</td>
</tr>
<tr>
<td>Fuel Savings per Vehicle</td>
<td>11.2</td>
</tr>
</tbody>
</table>

26% Reduction in AC fuel use for this vehicle
Conclusions

- Significant reduction in cabin interior temperatures demonstrated
- 30% reduction in thermal load
- Potential for lower power A/C system or A/C used less often
- Reducing fuel use of vehicle air conditioning is within reach with current technology
Acknowledgements

- **DOE**
  - Lee Slezak
  - Ed Wall
- **NREL**
  - Charlie King
  - Matt Keyser
  - Aaron Oakley
  - Sean Gooding
- **EPA**
  - Stephen Andersen
  - Karen Thundiyil
  - Kris Taddonio
- **Nissan**
  - David Barwin
- **GM**
  - Greg Major
  - Bill Hill
  - David Drapkin
- **Webasto**
  - James Cowen
- **I-MAC Team 3**
  - Gary Pollak, SAE
  - Paul Hoke, Ford
  - Al Reginaldo, Toyota
  - Hashem Akbari, LBNL
- **AVL**
  - Reinhard Tatschel
- **ThermoAnalytics, Inc.**
  - Craig Makens
  - Craig Cless
- **BETA CAE Systems**
  - George Galaitis