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

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ABSTRACT

A new type of solar-reflective glass that improves reflection of the near-infrared (NIR) portion of the solar spectrum has been developed. Also developed was a prototype solar-reflective paint that increases the NIR reflection of opaque vehicle surfaces while maintaining desired colors in the visible portion of the spectrum. Both of these technologies, as well as solar-powered parked car ventilation, were tested on a Cadillac STS as part of the Improved Mobile Air Conditioning Cooperative Research Program (I-MAC). Significant reductions in interior and vehicle skin temperatures were measured.

The National Renewable Energy Laboratory (NREL) performed an analysis to determine the impact of reducing the thermal load on the vehicle. A simplified cabin thermal/fluid model was run to predict the potential reduction in A/C system capacity. The potential reduction in fuel use was calculated using a vehicle simulation tool developed by the U.S. Department of Energy (DOE).

INTRODUCTION

When operating, the A/C system is the largest ancillary load on an automobile's engine. This increases the in-use fuel consumption experienced by a consumer. An NREL study[1] showed that the United States uses 7 billion gal (26.4 billion L) of fuel per year for light-duty vehicle A/C, which is equivalent to 5.5% of the total national light-duty vehicle fuel use. It takes 9.5% of the imported crude oil to produce this much gasoline. The fuel-use percentages are based on a total annual light-duty vehicle fuel use of 125.9 billion gal (477 billion L)[2] and imported oil of 73 billion gal (276 billion L)[3].

The A/C system in a vehicle is sized to reduce the interior temperature to an acceptable level after a hot soak. Technologies, such as solar-reflective glass and paint, can reduce the thermal load on a vehicle, interior temperatures, and fuel use.

The Society of Automotive Engineers (SAE) I-MAC Cooperative Research Program[4] was announced in April of 2004, with the first full meeting taking place July 1 during the SAE-sponsored 2004 Alternate Refrigerant System Symposium. The goal of the program is to make significant reductions in all aspects of emissions resulting from the operation of an R134a vehicle A/C system. Specific targets for reductions were:

1. Refrigerant leakage during operation and service
2. Tailpipe emissions resulting from powering the system
3. Thermal load on the vehicle after the vehicle is parked in the sun to minimize cooling requirements.

The SAE I-MAC Cooperative Research Program is a joint effort funded by DOE, the U.S. Environmental Protection Agency (EPA), SAE, and 28 industry partners.

The Thermal Load Reduction Team goal is to demonstrate advanced technologies that reduce cooling loads by 30% after a vehicle is parked in the sun.

LOAD-REDUCTION TECHNOLOGIES

During the summer of 2005, the I-MAC Thermal Load Reduction Team evaluated technologies to reduce the thermal load on the A/C system. The team picked the most promising technologies and continued testing in 2006. The technologies incorporated into the Cadillac STS test vehicle are solar-reflective glazings, solar-powered parked car ventilation, and solar-reflective paint.

SOLAR-REFLECTIVE GLAZINGS

As vehicle design trends increase glazing surface area, a greater portion of the thermal load on vehicles enters through the glazings. Developing vehicle glazings that reflect the incident solar radiation is a critical step to making significant reductions in the thermal loads. The solar-reflective glazings used in the test vehicle were developed with the goal of reducing the solar heat load to the maximum extent possible given the Cadillac STS glazing area and transmissivity requirements. Since the infrared portion of the solar spectrum provides the highest amount of solar energy, the objective was to reflect as much of that energy away from the vehicle as possible, so that it is neither absorbed in the glass nor transmitted through the glass.

PPG Industries' glass technology group developed a technology, called Sungate® EP, that allows only 3% of the infrared (IR) energy to be transmitted through the glass. With this technology, only 33% of the total solar energy is transmitted through the glass, most of it in the visible spectrum. Since the federal requirements for visibility dictate a minimum of 70% visible light transmission, the Sungate EP glass is close to the highest performance possible within the constraints of the visibility requirements.

SOLAR-POWERED PARKED CAR VENTILATION

When the solar energy enters the vehicle, it goes into heating the interior mass of the passenger compartment including the air. Venting the warm air and pulling in cooler ambient air can reduce the temperature of the interior and reduce climate control thermal loads.

Solar cells are integrated in the sunroof glass to provide power to the electric blower system that is integrated in the sunshade. Depending on the design requirements, the blowers can either vent hot air or pull in cool air through the roof while the car is parked. Opening the sunroof and pressing an ON/OFF switch activates the "solar ventilation." As soon as the sun shines, the blowers system turns on.

The solar panel consists of 24 cells over an area of 0.13 m^2 which provides 12 V and 17 W in the system manufactured by Webasto. The solar panel can be linked to the electrical system of the car if desired. The blower system consists of six 1.7 W fans. By measuring the exit velocity at the fans, we estimated the blower assembly flow rate to be approximately 0.077 kg/s (137 cfm).

Since the Cadillac STS already had a sunroof, we were unable to perform a professional installation due to structural limitations. Instead, a bracket was built and secured to the roof around the existing opening. Shown in Figure 1, the sunroof with the solar cells was then installed above the existing sunroof. The fan assembly was installed in the existing Cadillac STS sunshade. A production installation would work just like a regular sunroof.

Figure 1. Test (Non-Production) Installation of the Solar-Powered Parked Car Ventilation System

SOLAR-REFLECTIVE PAINT

The solar-reflective coating was made in the PPG Industries coatings research center in Allison Park, Pennsylvania. IR reflective pigments (available from Ferro Corporation) were incorporated into a commercial automotive refinish basecoat composition. The IR reflective black, yellow, and brown pigments were added to the basecoat at a total level of 22% by weight of the dry film. Other pigments, such as TiO_2, were also added at a level of 22% by weight of the dry film. The thermoplastic-polymeric binder system used to make the basecoat consisted of acrylic copolymers and cellulose acetate butyrate.

The basecoat was over-coated with a commercial refinish clearcoat available from PPG Industries (Low

VOC Performance Clear D8-93). Basecoat film thickness was approximately 20-25µ. Clearcoat film thickness was about 45-55µ. The clearcoat consisted of acrylic polyols cross-linked with isocyanate functional resins. The basecoat pigmentation was chosen based on experience with commercial IR reflective roofing coatings, which are sold by PPG under the trade name of Duranar® SPF. The coatings were applied in a commercial body shop via standard spray techniques, which are well known in the industry. Further optimization of the IR reflectance properties of practical coatings systems continues to be a research interest within PPG.

The control basecoat contained conventional pigments, such as iron oxide, carbon black, and TiO_2. The TiO_2 level in the control basecoat was the same as in the experimental basecoat. The visual color was approximately the same as the experimental basecoat. The binder systems in the two basecoats were the same, as were the compositions of the clearcoats on both cars.

Laboratory testing with a sun lamp yielded a 9-10°C difference in equilibrium panel temperature between experimental and control coatings. The measured solar absorptivity of the solar reflective and control coatings was 82% and 89% respectively.

The control basecoat/clearcoat were applied to the control vehicle while the solar reflective basecoat/clearcoat were applied to the modified vehicle.

VEHICLE SOAK TEST SETUP

From July 23, 2006, to September 7, 2006, outdoor thermal soak tests were performed on a pair of Cadillac STSs. One vehicle was modified with the load-reduction technologies while the other vehicle was not modified except for the control paint that color-matched the solar-reflective paint. The advantage of using two vehicles is that the impact of day-to-day environmental differences is minimized, although we still needed a high solar load and light winds. We measured the temperature difference at various locations between the vehicles. Table 1 outlines the four configurations we tested.

Table 1. 2006 I-MAC Thermal Load Reduction Team Cadillac STS Test Matrix

Config.	Ventilation	Solar-Ref. Windshield	Solar-Ref. Backlite	Solar-Ref. Sidelites	Solar-Ref. Paint
1	X	X	X	X	X
2		X	X	X	X
3		X	X		X
4		X			X

The tests were performed in Golden Colorado, at NREL's South Table Mesa site (Figure 2). The ground surface was a mixture of crushed rock and dirt. The vehicles were oriented to 160º and were leveled to approximately the same tilt angle. The seats were adjusted to the same position. The Sungate EP windshield did not have a shade band, so the shade band region on both vehicles was covered with an opaque material. The windows were cleaned frequently to eliminate dust accumulation.

Figure 2. Cadillac STSs at NREL Test Site

General Motors (GM) provided the data acquisition system in both vehicles, and Nissan instrumented the vehicles. For the soak test, 41 type K thermocouples were used to measure surface and air temperatures. NREL radiation shields were added to the breath air temperature thermocouples. Adhesive thermocouples reinforced with metallic tape were used on most surfaces. The exterior roof surface thermocouple was secured using thermally conductive Omega epoxy.

Environmental conditions were measured by a weather station at a nearby building. The parameters of interest were ambient temperature, global horizontal solar radiation, and wind speed/direction. The test day was determined to be good if the average wind speed was less than 2.5 m/s and if there were no significant clouds between 10:00 and 13:30.

To determine the inherent temperature difference between the vehicles, data were gathered during the night. The ventilation system was not operating and there was no solar load. We assumed these offsets would apply during the day, and the daytime temperature differences were adjusted accordingly. The offsets were small, ranging from 0ºC at the front passenger seat to 0.7ºC at the dashboard.

The body leakage during the thermal soak was measured to determine if the vehicles had similar leak rates. A tracer gas decay method was implemented using two Bruel & Kjaer Multi-Gas Type 1302 Monitors. A small amount of SF_6 was injected into both vehicles, and the concentrations were monitored for 2 hours. The air changes per hour were 0.59 and 0.69 for the control and modified vehicles respectively. This infiltration is equivalent to approximately 1.2 cfm, a fairly low leak rate.

VEHICLE SOAK TEST RESULTS

The data system was typically started around 8:00 a.m., and data were recorded every minute throughout the day. The reduction in temperature (Baseline Vehicle – Modified Vehicle) was then computed for each location. The time period 12:30 to 13:30 was determined to be the critical period because the temperature differences between the vehicles were fairly constant during this time. Figure 3 shows the temperature reductions versus. time for the solar-reflective glass in all locations and solar-reflective paint. The larger temperature reductions at 11:00 for the driver seat and 15:00 for the passenger seat are when the IR portion of sun load on the respective seat is being reflected by the solar-reflective sidelites in the modified vehicle. The larger variation in the roof skin temperature difference is due to changes in the wind speed and the associated changes in heat loss from the roof. Table 2 defines which thermocouples were used to calculate the average temperatures.

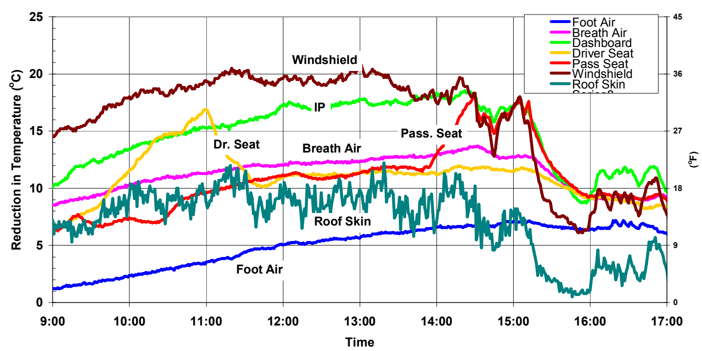

Figure 3. Temperature Reduction vs. Time for Ventilation, Solar-Reflective Glass in All Locations, and Solar-Reflective Paint

Table 2. Definition of Temperature Averages

Location	Description
Air-Foot	Average of driver, passenger, left rear and right rear air temperature in the footwell
Air-Breath	Average of driver, passenger, left rear and right rear air temperature at breath level
Air	Average of air-foot and air-breath
Dashboard	Average of 2 surface thermocouples on the instrument panel
Roof Exterior	Exterior surface of the roof
Driver Seat & Pass Seat	Average of internal and surface temperature of the seat cushion and seat back
Windshield	Interior surface temperature

The average reduction in temperature for a given day is the time average from 12:30-13:30. For most of the configurations, we had multiple good test days, and these data were averaged. Only configuration 3 had a single day of good data, but it was an optimum day.

Figure 4 shows the reduction in temperature for the four configurations. The numerical temperate reduction data are in Table 3.

CONFIGURATION 1: SOLAR-REFLECTIVE GLASS (ALL LOCATIONS), SOLAR-POWERED VENTILATION, SOLAR-REFLECTIVE PAINT

The combination of solar-reflective glass (all locations), solar-powered ventilation, and solar-reflective paint resulted in significant temperature reductions. Upon entering a vehicle, an occupant first makes contact with the air and seat. The breath air temperature was reduced 12.0ºC, and the seats were reduced 10-12ºC. Thermal radiation from the dashboard and windshield also impacts thermal comfort. The dashboard temperature was reduced 16.8ºC and the windshield was reduced 20.4ºC. The temperature of the vehicles with solar-reflective glass, parked car ventilation, and solar-reflective paint is located in Table 4.

During the solar-soak tests, the difference in windshield temperature was easy to detect by touch. While the control windshield felt very hot, the Sungate EP windshield felt cool in comparison. Although the lower paint temperature was measurable, it was not as easy to detect by touching the surface.

We found that the operation of the solar-powered ventilation affected the roof skin temperature. The roof temperature was reduced 9.8ºC when the ventilation was on and 6.0ºC on average when the ventilation was off. The flow exiting the vehicle entrained cool ambient air and caused increased convective heat loss from the roof skin. Since the roof skin thermocouple was located within a foot of the ventilation outlet (see Figure 1), we think the 6.0 average temperature reduction is a better estimate of the reduction in roof skin temperature due to solar-reflective paint.

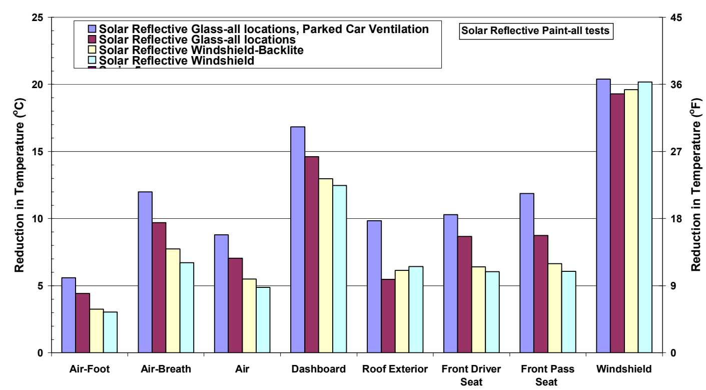

Figure 4. Reductions in Temperature (ºC)

Table 3. Reductions in Temperature (ºC)

	Air-Foot	Air-Breath	Air	Dashboard	Roof Exterior	Front Driver Seat	Front Pass Seat	Windshield
Solar Reflective Glass-all locations, Ventilation	5.6	12.0	8.8	16.8	9.8 / 6.0	10.3	11.9	20.4
Solar Reflective Glass-all locations	4.4	9.7	7.1	14.6	5.5	8.7	8.7	19.3
Solar Reflective Glass-Windshield-Backlite	3.3	7.7	5.5	13.0	6.1	6.4	6.6	19.6
Solar Reflective Glass-Windshield	3.0	6.7	4.9	12.5	6.4	6.0	6.1	20.2

Table 4. Temperatures for Configuration 1 (ºC, except where noted)

	Air-Foot	Air-Breath	Air	Dashboard	Seat Driver	Seat Pass	Windshield	Ambient	Wind Speed (m/s)
Control	36.4	57.0	46.7	77.0	51.1	54.2	68.7	27.7	2.0
Modified	30.8	44.9	37.9	60.1	40.6	42.5	48.3		

CONFIGURATION 2: SOLAR-REFLECTIVE GLASS (ALL LOCATIONS), SOLAR-REFLECTIVE PAINT

Without the solar-powered ventilation, the vehicle interior temperatures still were dramatically cooler. The average air temperature and seat temperature were reduced 9.7ºC and 8.7ºC respectively. The windshield was 19.7ºC cooler, and the dashboard was 14.6ºC cooler.

CONFIGURATIONS 3 & 4: SOLAR-REFLECTIVE GLASS (WINDSHIELD & BACKLITE AND WINDSHIELD ONLY), SOLAR-REFLECTIVE PAINT

Temperature reductions with the windshield/backlite and the windshield only were similar to each other. This is because the vehicles were oriented towards the sun and the solar load on the backlight was small. If the vehicles had been oriented away from the sun, the modified vehicle air temperatures would have been essentially the same as the control vehicle because the solar load on the north-facing windshields would have been lower. The windshield/IP/seats would have been cooler in both vehicles because there would have been shading from the roof and less direct sun load.

SOLAR-POWERED VENTILATION ONLY

During the summer of 2005, we tested the solar-powered ventilation by itself. With air being pulled out of the vehicle, the reduction in temperatures in Figure 5 was significant. The air temperature was reduced 5.6ºC, and the seat temperatures were reduced 5-6ºC. Because the glass was not solar reflective, the solar load was still high on the windshield and dashboard; therefore, the temperature reductions were due to convection heat loss driven by the interior airflow. Air was being pulled in through the HVAC heater/defroster ducts and any other natural body leakage areas. Figure 5 also shows the reductions in temperature with air being blown into the vehicle. For the Cadillac STS, this was not an effective way to cool the vehicle, and the temperature reductions were significantly lower.

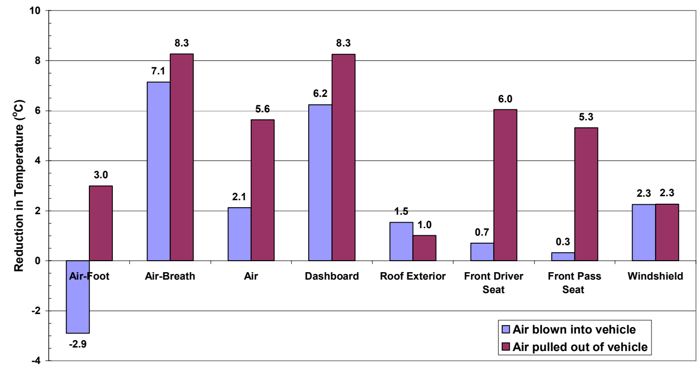

Figure 5. Reduction in Temperature for Solar-Powered Ventilation Only (2005 Test Program)

SOLAR-REFLECTIVE ROOF ONLY

During the summer of 2005, we also tested the Cadillac STS with a solar-reflective film on the roof. The film was an IR reflecting product (CI-100T) manufactured by 3M. The 6.7ºC cooler roof temperature did not have a significant impact on the interior temperatures. Although we were not able to test the solar-reflective paint by itself in 2006, we think the reduction in interior temperatures would be similar to 2005 solar-reflective roof film results.

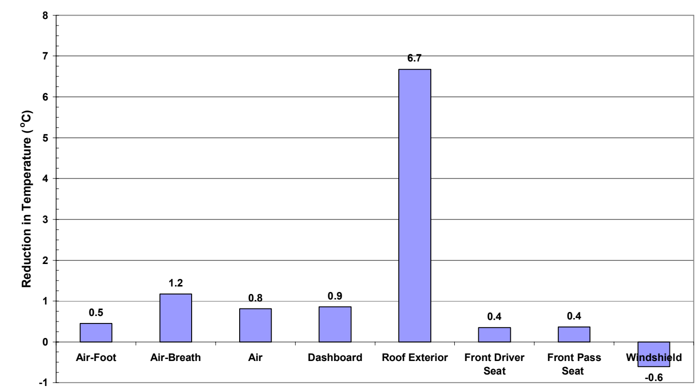

Figure 6. Reduction in Temperature for Solar-Reflective Film on Roof Only (2005 Test Program)

VEHICLE THERMAL ANALYSIS

A numerical model of the STS test vehicle was developed using Fluent CFD software and RadTherm thermal analysis software. The CAD files of the vehicle interior geometry were obtained from GM. The CAD was imported into ANSA software where it was cleaned up, details were removed, and surface meshed. The model volume mesh was created using the Fluent TGrid hexcore mesh tool. The resulting volume mesh was approximately 1,300,000 cells; the surface mesh in RadTherm was approximately 209,000 elements. RadTherm models the solar load on the vehicle, convection losses on the interior and exterior surfaces, and conduction through the surfaces. Fluent CFD software was used to model the convective heat transfer and fluid flow in the cabin. During the analysis RadTherm and Fluent interact in the following way. RadTherm provides surface temperature boundary conditions to Fluent, and Fluent provides heat transfer coefficients and fluid temperatures to RadTherm. Several exchanges between RadTherm and Fluent were needed to achieve a consistent solution.

The model was first validated against quasi steady-state soak data from the Cadillac STS test. Figure 7 compares the model prediction to test data for the baseline vehicle. Several factors—such as the uncertainty in temperature measurement locations, material properties, and vehicle orientation—could contribute to the differences between measured temperatures and the model-predicted temperatures. Overall, the results show excellent agreement. Figure 8 compares the model prediction to test data for the reduced load vehicle. In the reduced load model, uncertainty in the ventilation airflow rate, as well as the same factors cited in the baseline model, contribute to the differences between predicted and measured temperatures. The results for the reduced load vehicle also show good agreement. The validated model was then used to simulate the vehicle cooldown.

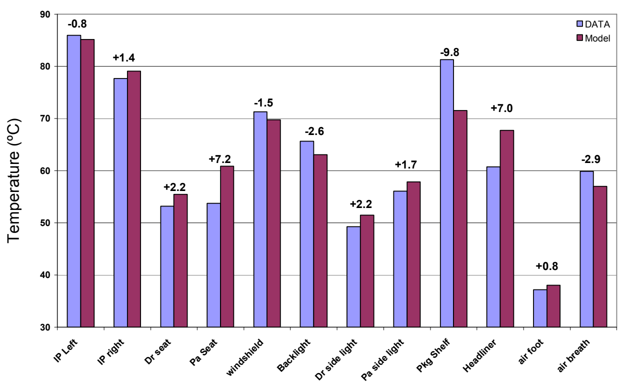

Figure 7. Baseline Soak Results Comparison to Test Data

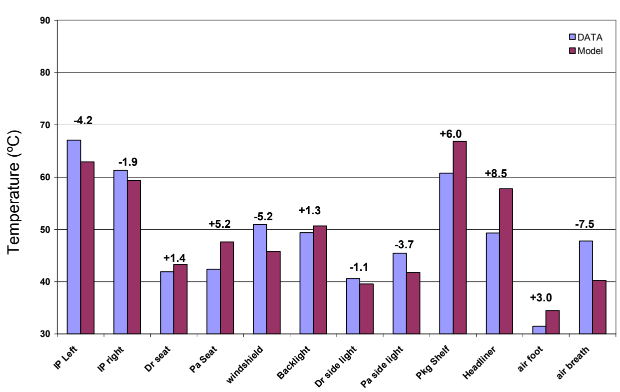

Figure 8. Reduced Load Soak Results Comparison to Test Data

It was found that excessive run times were needed to achieve a cool-down simulation using the full Fluent/RadTherm model. Therefore, a simplified model was created for the cool-down simulations, which used only RadTherm. In the full Fluent/RadTherm simulation, the heat transfer coefficients and fluid temperatures are mapped to the RadTherm mesh. In the simplified model, the heat transfer coefficients are mapped to the RadTherm mesh and held constant during the cooldown. The fluid temperatures are now simulated by eight fluid nodes, making use of the advection capabilities in RadTherm. In essence the model was bisected in each plane into eight fluid volumes, in contrast to the 1,300,000 fluid volumes in the Fluent model. This simplified model was validated to vehicle cool-down data. A typical baseline cool-down comparison is shown in Figure 9. As expected the results of the simplified model are not an exact match to the data, but the model has captured the overall behavior of the thermal environment. Some of the factors contributing to the data/model differences are the same as those already discussed under the steady-state model validation. In addition, the initial conditions were not an exact match to the data. This is not of great concern as the main focus of the cool-down model is to predict differences in cooling load required between the baseline and reduced load configurations.

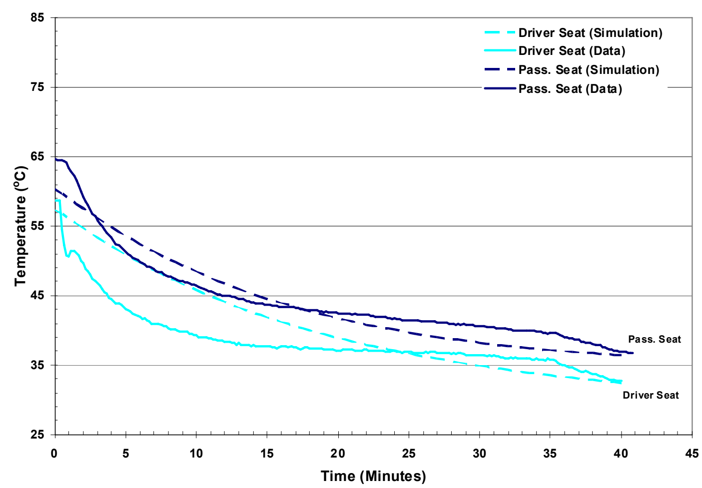

Figure 9. Baseline Cool-Down Comparison

A cool-down time of 30 minutes was chosen. That is the vehicle cabin was assumed to be at a comfortable temperature in 30 minutes. The approach that was used was to fix the cooling load in the baseline vehicle at 5.7 kW. This results in a realistic cooldown with the interior mass average temperature reaching 30ºC in 30 minutes. The cooling load in the reduced thermal load vehicle was then decreased until the vehicles had an equal cooldown, which was determined in two ways. The first method was to use a mass average temperature, and then determine at what cooling load the two vehicles achieved an equal mass average temperature of 30ºC in 30 minutes. The second method calculated a heat balance for each vehicle.

The mass average temperature calculation shows an equal cool-down time with a 4.0 kW A/C system, as is shown in Figure 10. This is a 30% reduction in cooling load. The heat balance calculation shows equal time to 30ºC with a 31% lower A/C load. To be conservative, the 30% lower load (4.0 kW) was used in the fuel-use calculations.

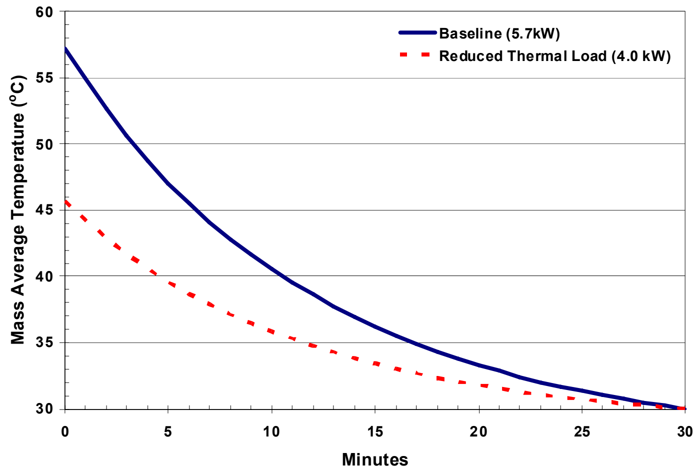

Figure 10. Mass Average Temperature

The A/C fuel-use calculation followed the procedure used in References 1 and 5. The ADVISOR vehicle simulator was used to determine the effect of the reduced A/C load on fuel use. The Cadillac STS was simulated on standard city and highway drive cycles, and the results were compared to published window sticker values. The A/C load on the vehicle was modeled by using a curve of compressor power as a function of compressor rpm obtained from the OEM. The vehicle fuel economy was then calculated in the simulator over the FTP cycle for the vehicle without A/C, baseline A/C, and 30% reduced A/C. The Vehicle Miles Traveled with A/C on (VMTAC) are the average miles traveled by a passenger car in the United States (11,998 miles[6]) multiplied by the average percent of A/C use in the United States (32.6%[1]). The VMTAC are 3,911 miles. Fuel used per vehicle is calculated by dividing the miles traveled by the fuel economy (miles per gallon). Fuel used for A/C is then the difference between fuel used with A/C on and fuel used with A/C off. For the Cadillac STS, the baseline A/C fuel use is 42.6 gal per year while the reduced thermal load vehicle A/C fuel use is 31.4 gal. These data show that reducing the A/C load by 30% results in a 26% reduction in A/C fuel use.

CADILLAC STS VENTILATED SEATS

Improving the delivery methods for conditioned air in an automobile is an effective way to increase thermal comfort with little energy cost. This reduces A/C needs and thus fuel use. Automotive seats are well suited for effective delivery of conditioned air due to their large contact area with and close proximity to the occupants. Normally a seat acts as a thermal insulator, increasing skin temperatures and reducing evaporative cooling of sweat. Ventilating a seat has low energy costs and eliminates this insulating effect while increasing evaporative cooling. W.E.T. Automotive Systems manufactures a ventilated seat used in the Cadillac STS that pulls air through the seat cushion and back. We assessed one of these seats using ADAM, NREL's thermal comfort manikin[7].

The Vehicle Climate Control Lab at NREL was developed to simulate the soak and cooldown of a vehicle passenger compartment[8]. The passenger compartment from a compact car, A to C pillar, was heat soaked using a 963 W/m^2 ± 23% full-spectrum solar simulator for 3.5 hours. During this time, the average room environment was controlled to 31.6°C ± 0.4°C and 30% ± 5% RH. ADAM and the subjects were conditioned in an office environment. The subject entered the heat-soaked room, stood for 30 seconds, and then did step exercises for one minute to simulate walking to the car. The subject entered the heat-soaked car, and took a pre-cool-down thermal comfort and sensation vote. The A/C system was started 45 seconds after the subject entered the vehicle, at which time the first cool-down vote was taken. Thermal comfort and sensation votes followed every two minutes for the duration of the test. ADAM predicted warmer overall thermal sensations than the subjects, but the trends were similar. Both showed a cooler sensation due to the operation of the ventilated seat.

Figure 11 shows an operating ventilated seat increased the heat loss from ADAM's back and bottom by ~ 60 W/m^2 (25-35 minutes into the cool-down) compared to no ventilation (baseline). The seat contact temperature was reduced by ~ 4.7ºC resulting in an overall thermal sensation improvement of 0.28 (on a +4 to –4 scale) shown in Figure 12. We determined that if the A/C system capacity was reduced by 7%, and the ventilated seat was used, the same thermal sensation and comfort as the baseline seat would result. Using NREL's A/C fuel-use model[1], an estimated 522 million gal/year or 7.5% reduction in U.S. A/C fuel use could be achieved.

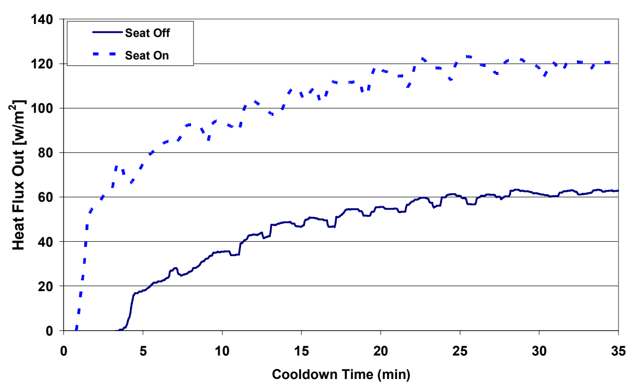

Figure 11. Heat Loss from ADAM's Back and Bottom

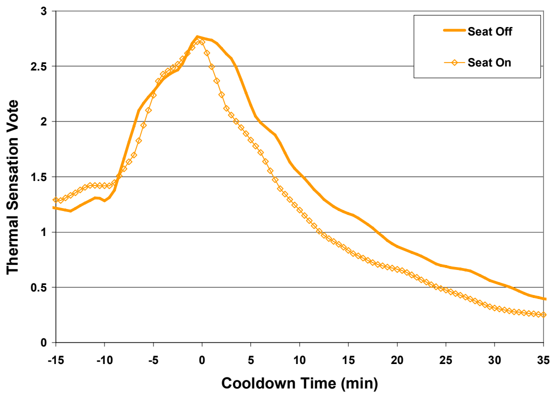

Figure 12. ADAM Thermal Sensation

CONCLUSION

NREL completed testing of technologies to reduce the thermal load on a Cadillac STS as part of the I-MAC Cooperative Research Program. Among the technologies tested were PPG Sungate EP solar-reflective glass, PPG prototype solar reflective paint, and a Webasto solar-powered parked car ventilation system. A combination of these technologies reduced breath air temperature by 12°C (22°F), seat temperatures by 11°C (20°F), windshield temperature by 20.4°C (37°F), and the instrument panel surface temperature by 16.8°C (30°F).

NREL also completed an analysis to estimate the impact of reducing the thermal load on A/C system capacity of a Cadillac STS. The integrated modeling process started with CAD data of the STS. The CAD data was cleaned up, and then meshed for RadTherm and CFD analysis. The models were benchmarked against test data and showed excellent agreement. A transient cool-down simulation of both the baseline and reduced load vehicles was performed. By maintaining an equivalent cool-down time in the baseline as compared to the reduced load vehicle, results show that the A/C load can be reduced by over 30%. Vehicle simulations show that the 30% reduction in thermal load results in a 26% reduction in fuel used for A/C.

The load-reduction technologies we tested, as well as climate-control seating, are available for today's vehicles and are representative of techniques to reduce the thermal load on the passenger compartment. Other technologies could also be used to reduce the thermal loads and improve thermal comfort with similar results. If incorporated in conjunction with a smaller A/C system or if the A/C is used less often, the reduced A/C fuel use will save drivers money at the pump, and the reduced temperatures will improve thermal comfort immediately after a hot soak. The reduced fuel use translates directly to reduced CO_2 emissions, which is good for the environment.

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