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Impact of Sungate EP on PHEV Performance

Results of a Simulated Solar Reflective Glass PHEV Dynamometer Test

John Rugh

Final Report in Support of Technical Services Agreement TSA-08-206

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PGW Project Monitor: Mukesh Rustagi

Technical Report
NREL/TP-540-45908
June 2009

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Executive Summary

The objective of the project was to assess the impact of a solar reflective windshield and backlite on PHEV range and fuel economy. The effect of Sungate® EP on PHEV performance was evaluated on NREL's PHEV test bed, a 2006 Toyota Prius modified with a 5 kWh Hymotion Li-ion Energy Storage System. The tests, performed at Environmental Testing Corporation in Aurora, Colorado, used portable electric heaters installed in the passenger compartment to simulate the solar heat gain through the glazings. A vehicle thermal analysis determined the thermal loads from the glazings (including transmitted, re-radiated, and convective loads) which were simulated with the electric heaters. The thermal load for Solargreen® glazings installed in all positions was 1629 W. For Sungate EP in the windshield and backlite and Solargreen in the sidelites, the thermal load was 1264 W.

Three configurations were run over a UDDS and a USO6 drive cycle.

- A/C off
- A/C on with Solargreen heat load
- A/C on with Sungate EP heat load

The air conditioning system used automatic control with a temperature setpoint of 68ºF and 100% recirculation. This resulted in maximum blower air flow rate.

The test sequence was:

- Soak overnight at 100ºF air temperature and charge ESS to 100%
- Start interior heater 1.5 hours prior to start of drive cycle to approximate increased interior cabin temperatures due to a solar soak
- Initiate drive cycle and cabin cooldown
- Repeat drive cycles to the end of the drive cycle in which the vehicle was in charge-sustaining mode for the entire cycle.

<u>UDDS Drive Cycle</u>

Over repeated UDDS drive cycles, the Sungate EP glazing reduced the A/C compressor power and resulted in an increase in fuel economy compared to Solargreen. The A/C compressor power dropped from 1509 W to 1403 W during charge-depletion mode and from 1431 W to 1236 W during charge-sustaining mode. The adjusted, utility factor-weighted fuel economy increased from 36.8 to 42.9 mpg for the Sungate EP thermal load case while the adjusted, utility factor-weighted electrical energy consumption was roughly equivalent. The charge-depletion range turned out to be a poor metric because in some of the tests the current out of the ESS was limited due to temperature control limits of the power electronics and energy storage systems. When this situation occurred, the ESS provided power for a longer period of time and the charge-depletion range was greater.

In addition to the lower A/C compressor power, the cabin air temperature was also lower for the Sungate EP case compared to the Solargreen case. The lower solar load (heater

power) due to the Sungate EP resulted in a 15ºF reduction in cabin air temperature at the end of the soak. At the end of charge depletion, the cabin air temperature was 87.2ºF for Solargreen and 82.7ºF for Sungate EP. Although the time to charge depletion varied for each test, the temperature vs. time plots show the Sungate EP cabin air temperature is less than the Solargreen at all points during the test.

USO6 Drive Cycle

Over USO6 drive cycles, the impact of the Sungate EP displayed similar trends compared to the UDDS drive cycles except for fuel economy. During charge depletion, the A/C power decreased from 1562 W to 1481 W due to Sungate EP. For charge-sustaining operation, the A/C power dropped from 1487 W to 1435 W. The adjusted, utility factor-weighted fuel economy decreased from 40.4 to 40.0 mpg while the electrical energy consumption was the same. The $< 1\%$ reduction in fuel economy is thought to be due to test variation or differences in powertrain control strategy. In addition to the lower A/C compressor power, the cabin air temperature was also lower for the Sungate EP configuration compared to the Solargreen configuration. Prior to the cooldown, the cabin air temperature was 13ºF cooler due to the reduced thermal load of the Sungate EP. At the end of charge depletion, the cabin air temperature was 93.2ºF for Solargreen and 84.0ºF for Sungate EP.

Conclusion

The UDDS/USO6 composite fuel economy increased 8% from 38.4 mpg to 41.6 mpg due to the reduction in thermal loads from Sungate EP glazings installed in the windshield and backlite. The electrical energy consumption was essentially equivalent with a less than 0.2% increase.

In conclusion, Sungate EP resulted in lower A/C compressor power and lower interior cabin air temperature, which would result in improved occupant comfort. The lower A/C power resulted in improved UDDS/USO6 composite fuel economy.

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1.0 Introduction

1.1 Background

Fuel used for vehicle climate control significantly affects our nation's energy security by decreasing the fuel economy of the 230 million light-duty conventional vehicles in the United States. To address this issue, NREL works closely with industry to develop techniques to reduce the ancillary loads, such as climate control, in vehicles. We are conducting research to improve vehicle efficiency and fuel economy by controlling the climate in the vehicle, while still keeping the passengers comfortable. As part of this effort, we are conducting research to reduce the thermal load on the vehicle interior.

As powertrains become electrified, climate control loads reduce range or cause the gasoline engine to operate more frequently. The operation of the A/C system in a cooldown situation for a PHEV40 reduces the electric range 18% to 30% depending on the drive cycle. If the thermal loads of the vehicle can be reduced and subsequently the A/C usage and compressor power, the PHEV range with A/C on can be increased. If the battery is sized to account for the energy to operate the A/C system, reducing the thermal loads will decrease the battery size and cost.

PGW has 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.

1.2 Objective

The objective of the test program was to determine the impact of solar reflective glass on PHEV range and fuel economy.

1.3 Evaluation Approach

The approach of this test was to drive a PHEV over a drive cycle in a controlled environment with the A/C off and A/C on. Since the dynamometer cell did not have solar lamps, portable electric heaters were installed in the passenger compartment to simulate the solar heat gain through the glazings. A vehicle thermal analysis determined the thermal loads from the glazings (including transmitted, re-radiated, and convective loads) which were simulated with the electric heaters.

Three configurations were run over a UDDS and a USO6 drive cycle.

- A/C off
- A/C on with Solargreen heat load
- A/C on with Sungate EP heat load

The air conditioning system used automatic control with a temperature setpoint of 68ºF and 100% recirculation. This resulted in maximum blower air flow rate.

The test sequence was:

- Soak overnight at 100ºF air temperature and charge ESS to 100%
- Start interior heater 1.5 hours prior to start of drive cycle to approximate increased interior cabin temperatures due to a solar soak
- Initiate drive cycle and cabin cooldown
- Repeat drive cycles to the end of the drive cycle in which the vehicle was in charge-sustaining mode for the entire cycle.

Cabin air temperature, air conditioning power, and vehicle fuel use were measured during the test.

2.0 Test Setup

2.1 Vehicle

The test vehicle was NREL's PHEV which is a 2006 Toyota Prius modified with a 5 kWh Hymotion Li-ion Energy Storage System (ESS or battery). The vehicle is shown in Figure 1. The OEM installed hybrid battery was still installed in the vehicle. The PHEV ESS was controlled to provide an electric assist during the initial portion of a trip. This is called the charge-depletion portion of the trip. Figure 2 shows the state of charge (SOC) of the PHEV ESS during one of the tests. Note the ESS starts fully charged and the SOC is 100%. When the SOC drops to ~5%, the ESS is discharged and the vehicle begins to operate like a regular hybrid Prius (charge sustaining). The charge-depletion fuel economy and A/C compressor power are defined as the average of the data from cycle 1, cycle 2, and cycle 3 up to the point of SOC=5%. The charge-sustaining fuel economy and A/C compressor power are calculated using the data from cycle 4. The charge-depletion and charge-sustaining cabin air temperatures are defined as the average of the 5 minutes before SOC reaches 5% and the end of cycle 4 respectively.

Figure 1. Test Vehicle - NREL PHEV

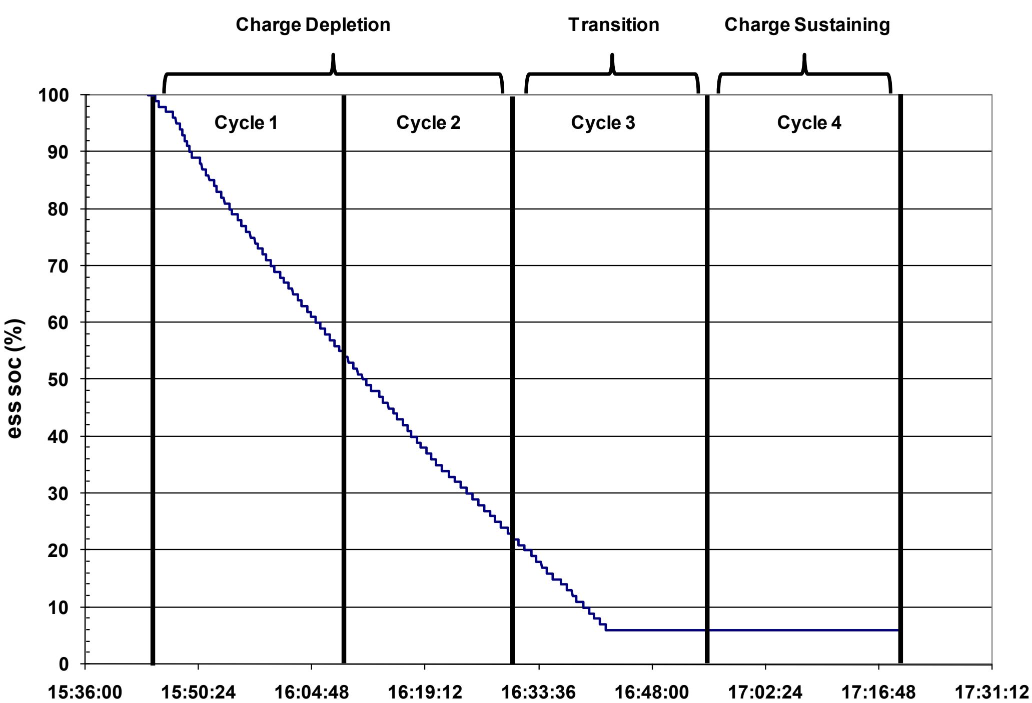

Figure 2. PHEV ESS SOC for 12/18/08 UDDS Solargreen Test

2.2 Test Location

The testing was performed at Environmental Testing Corporation (ETC) in Aurora Colorado. (http://www.etclab.com) The elevation of the facility is approximately 5437 feet above sea level. Since the Prius has regenerative breaking, the tests were performed using a 4-wheel dynamometer (Figure 3). The vehicle was either soaked overnight at 100ºF in that chamber or a neighboring chamber and moved to the 4-wheel dynamometer chamber prior to the 1.5 hour soak with the heaters.

Figure 3. NREL PHEV on 4-Wheel Dynamometer at ETC

2.3 Data Acquisition

The bulk of the data from the test was recorded using a V2Green system that was installed with the Hymotion ESS. Data logged by this system included

- Vehicle speed
- Distance
- Fuel consumption
- Electrical energy consumption
- OEM hybrid battery (SOC, volts, current)
- Hymotion ESS (SOC, volts, current)

The data were automatically uploaded to the V2Green web site and manually downloaded after the test for processing.

Additional temperature data were recorded using a small Hobo data acquisition system installed in the vehicle. The passenger compartment air temperature measurement location was at the left rear seat to the right and above the headrest. Resistance Temperature Detectors (RTD) were used at the locations shown in Figure 4.

Figure 4. Temperature Measurement Locations for Hobo Data Acquisition System

In order to measure the air conditioning compressor power, an AVIT data logger was connected to the CAN bus and controlled using Snap-Master software.

2.4 Heater Configuration

Since the dynamometer cell did not have solar lamps, two portable 1500 W ceramic electric heaters were installed in the passenger compartment to simulate the solar heat gain through the glazings. The right rear seat was folded down and the heaters were placed on the resulting surface facing forward as shown in Figure 5. Each heater was plugged into a wattsup?Pro watt meter to measure and record the power usage. Each watt meter was plugged into a variable transformer to control the power. Figure 6 shows the variable transformers and watt meters on the equipment cart.

The heater power had to be monitored closely and adjusted during the test since the heater resistance was a function of the passenger compartment air temperature. This was extremely important at the start of 1.5 hr soak and the start of cooldown.

Figure 5. Passenger Compartment Portable Heaters on the Right Rear Seat

Figure 6. Equipment Cart with Variable Transformers and Watt Meters

2.5 Heater Power Analysis

2.5.1 Vehicle Solar Load Estimator

Prior to testing, a thermal analysis was conducted to determine the heater settings. The first step was to calculate the transmitted, absorbed, and reflective solar power at each glazing using NREL's vehicle solar load estimator (VSOLE). The program takes into account the angle of incidence and calculates the transmitted, reflected, and absorbed power based on the radiation source, vehicle geometry, vehicle orientation, and glazing type. All glazing surfaces are assumed flat, and to have constant thickness, uniform properties, and regular shape. The calculation of the optical properties as a function of wavelength and angle uses a single-pane approximation for glass.

The properties of Sungate EP were provided by PGW and are shown in Figure 7.

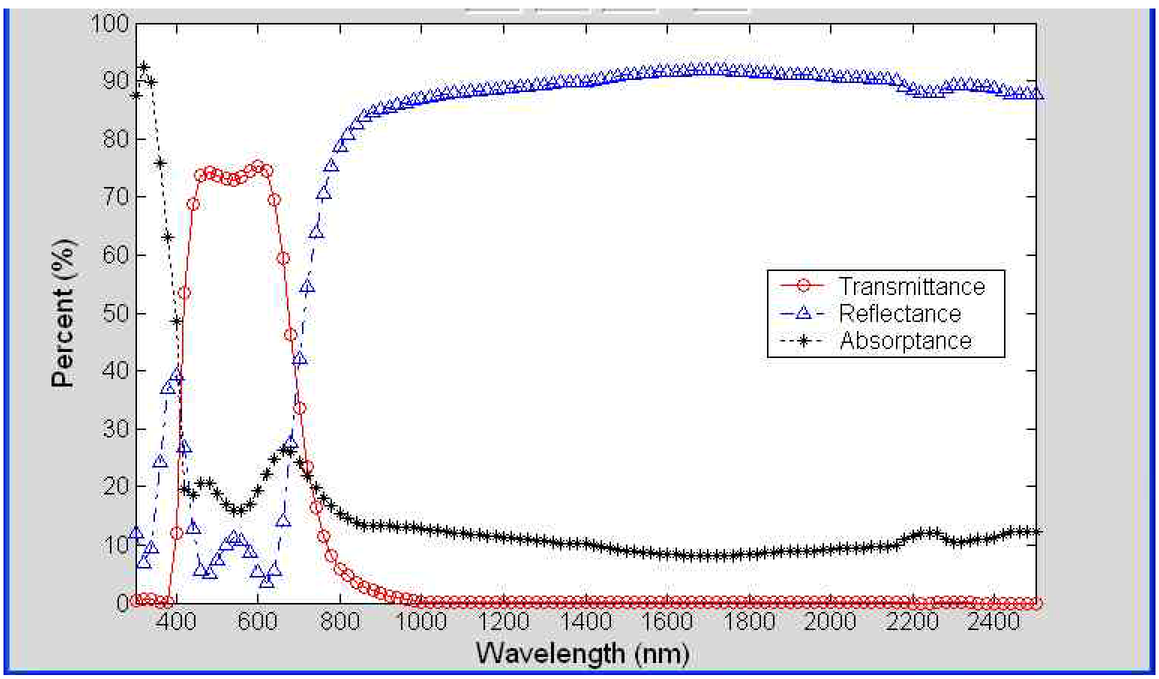

Figure 7. Sungate EP Spectral Properties

The glazing areas and angles were measured on the NREL PHEV. A Phoenix incident solar radiation on July 6 at 12:30 pm was used. The VSOLE results for the Solargreen and Sungate EP configurations are shown in Figures 8 and 9 respectively. The sidelites were Solargreen in both cases.

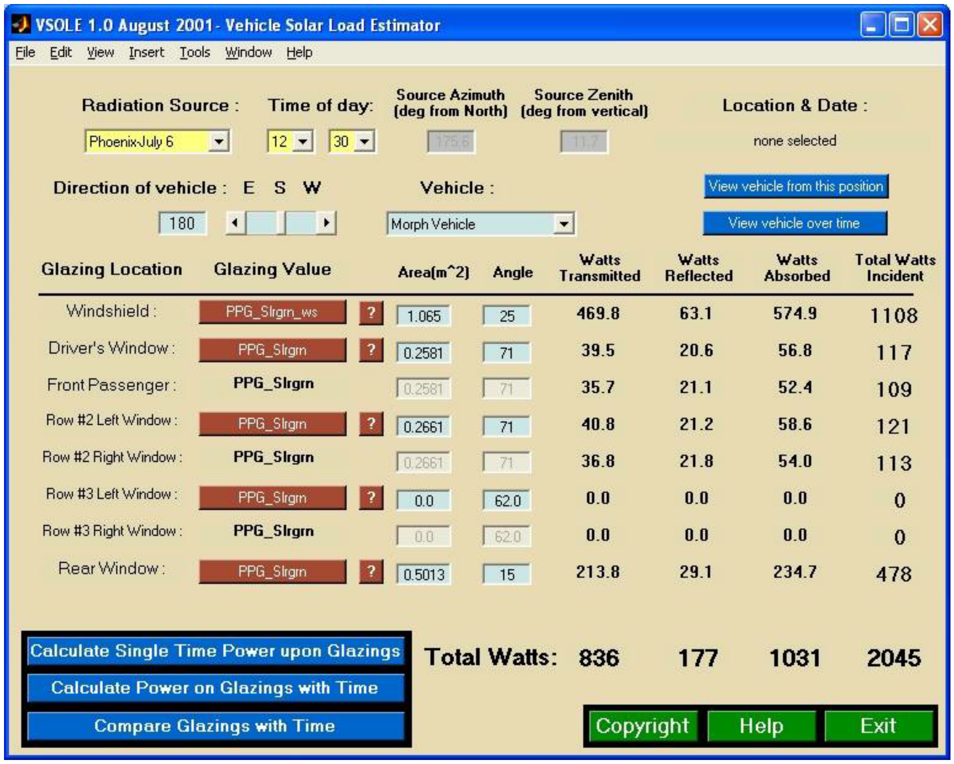

Figure 8. Solargreen VSOLE Results

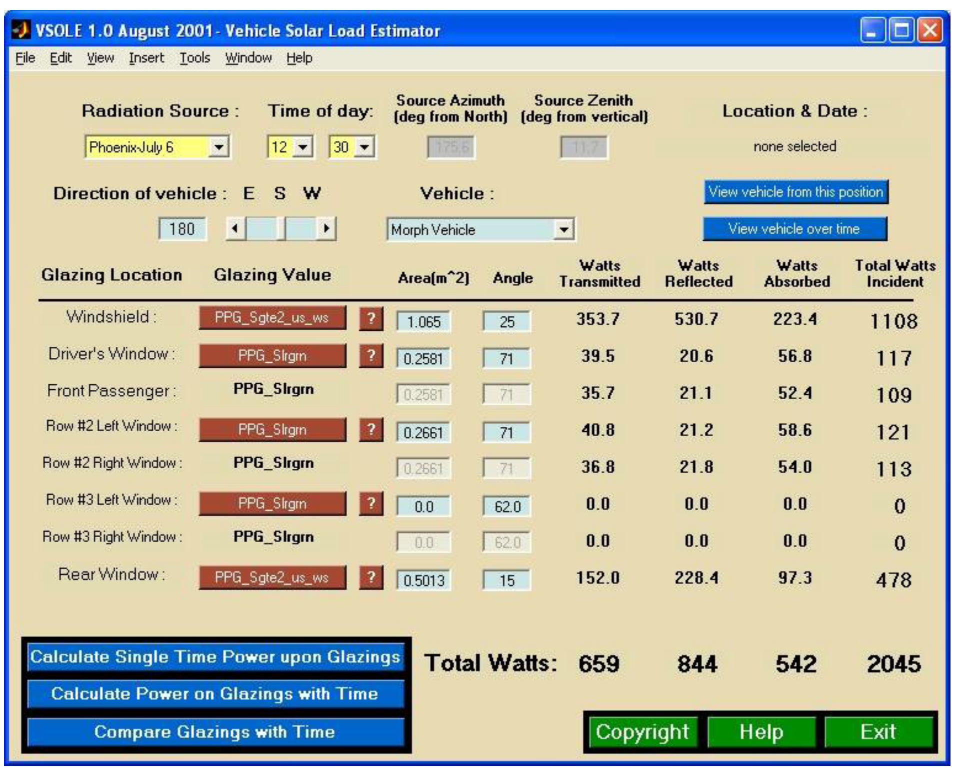

Figure 9. Sungate EP VSOLE Results

2.5.2 Thermal Analysis to Determine Heater Power

Although the transmitted solar power can be obtained directly from VSOLE, the portion of the sun's energy that would be absorbed and convected/reradiated to the interior adds to the heat load of the passenger compartment.

A spreadsheet, included in Appendix B, was used to calculate the total heat load through the glazings. The heat transfer through opaque surfaces was not considered. For the analysis, the windshield and backlite were represented as a single glazing. The sidelites were also represented as a single piece of glazing with a uniform temperature. This seems reasonable since the sun is essentially overhead as shown in Figure 10.

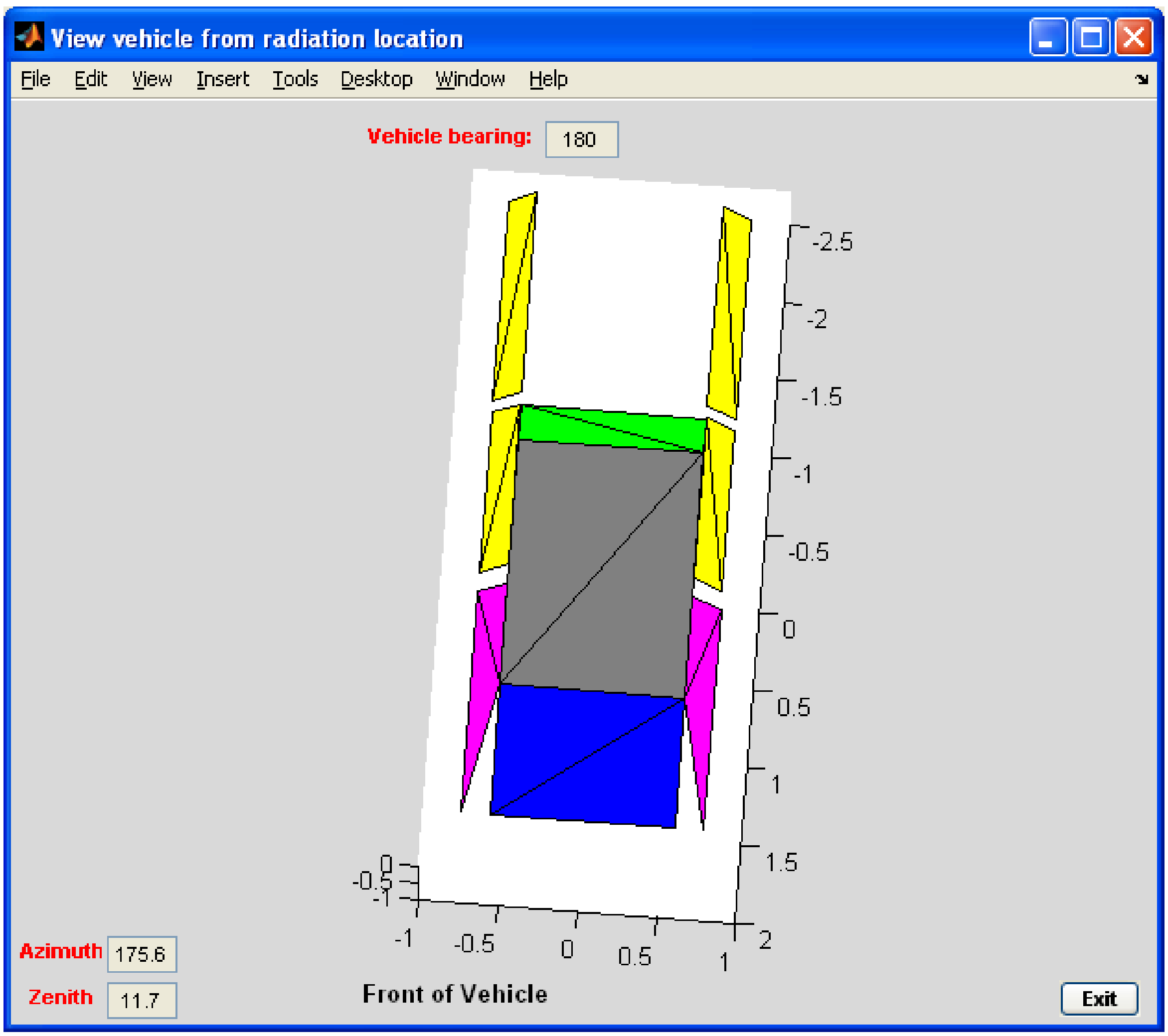

Figure 10. Vehicle from Sun's Perspective

The simplified thermal network is shown in Figure 11.

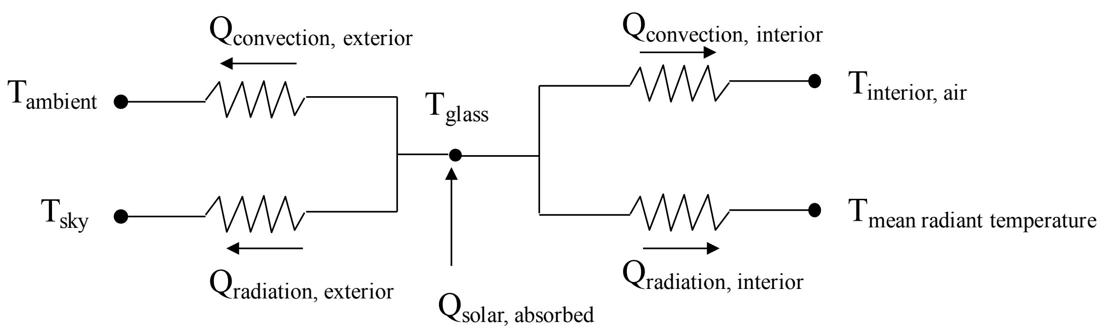

Figure 11. Thermal Analysis Network Diagram

The unknown in Figure 11 is T_{glass} and it is solved for iteratively.

$$Q_{solar,\ absorbed} = Q_{convection,interior} + Q_{radiation,\ interior} + Q_{convection,\ exterior} + Q_{radiation,\ exterior} \quad (1)$$

where

$$Q_{solar,\ absorbed} = \text{from VSOLE} \quad (2)$$

$$Q_{convection,\ exterior} = h_{exterior}\,(T_{glass} - T_{ambient}) \quad (3)$$

$$Q_{radiation,\ exterior} = \varepsilon\,\sigma\,(T^4_{glass} - T^4_{sky}) \quad (4)$$

$$Q_{convection,\ interior} = h_{interior}\,(T_{glass} - T_{interior,\ air}) \quad (5)$$

$$Q_{radiation,\ interior} = \varepsilon\,\sigma\,(T^4_{glass} - T^4_{mean\ radiant\ temperature}) \quad (6)$$

Table 1 includes the environmental assumptions.

Table 1. Exterior Velocity and Ambient Temperature

Measurement	Value	Units
UDDS average wind velocity (v)	8.76	m/s
USO6 average wind velocity (v)	21.64	m/s
$T_{ambient}$	37.8	^{o}C

The air properties were calculated at 315 K. The values used as well as other important parameters are identified in Table 2.

Table 2. Air properties and constants for thermal analysis

Parameter	Value	Units
density (ρ)	1.111	kg/m^3
specific heat (cp)	1.007	kJ/kg K
thermal conductivity (k)	0.0274	W/m K
dynamic viscosity (μ)	1.9168E-05	Ns/m^2
prandtl number (Pr)	0.705	
thermal diffusivity (α)	2.47E-05	m^2/s
characteristic length (l)	0.5	m
surface emissivity (ε)	0.9	
Steph Boltz constant (σ)	5.67E-08	W/m^2K^4
absorptivity baseline (α)	0.793	
absorptivity SRF (α)	0.641	
Interior Velocity	3	m/s
Interior Air Temperature	20	^oC
Area (windshield & backlite)	1.5663	m^2
Area (sidelites)	1.0484	m^2

Other equations used are

$$T_{sky} = 0.0552\ T^{1.5}_{ambient} \tag{7}$$

$$h = \frac{Nu\ k}{l} \tag{8}$$

The Reynolds number of the exterior flow was calculated and then the appropriate Nu correlation was selected based on comparing the Re to the $Re_{critical}$.

$$Re = \frac{\rho\ V\ l}{\mu} \tag{9}$$

$$Nu_{laminar} = 0.644\ Re^{0.5}\ Pr^{0.33333} \tag{10}$$

$$Nu_{mixed} = (0.037\ Re^{0.8} - 871)\ Pr^{0.33333} \tag{11}$$

The passenger compartment solar load from the glazings for the UDDS and USO6 drive cycles are shown in Table 3.

Table 3. Heater Power Settings

	Heater Power (W)	
Drive Cycle	**Solargreen**	**Sungate EP**
UDDS	1649	1270
USO6	1608	1298
aveage	1629	1284

For Solargreen glazings installed in the windshield and backlite, the solar load transmitted and reradiated/convected was 1629 W; therefore, the heaters were set to this level. An error was made adjusting the Sungate EP heaters during the test and they were 20 W low. In order to be consistent throughout the test, the heater setting was kept at 1264 W for Sungate EP.

2.6 Calculation Procedure for mpg and Wh/mi

The actual fuel economy and electrical energy consumption were adjusted to take into account how people drive and distance driven between charging events. The roadmap to the calculation is shown in Figure 12.

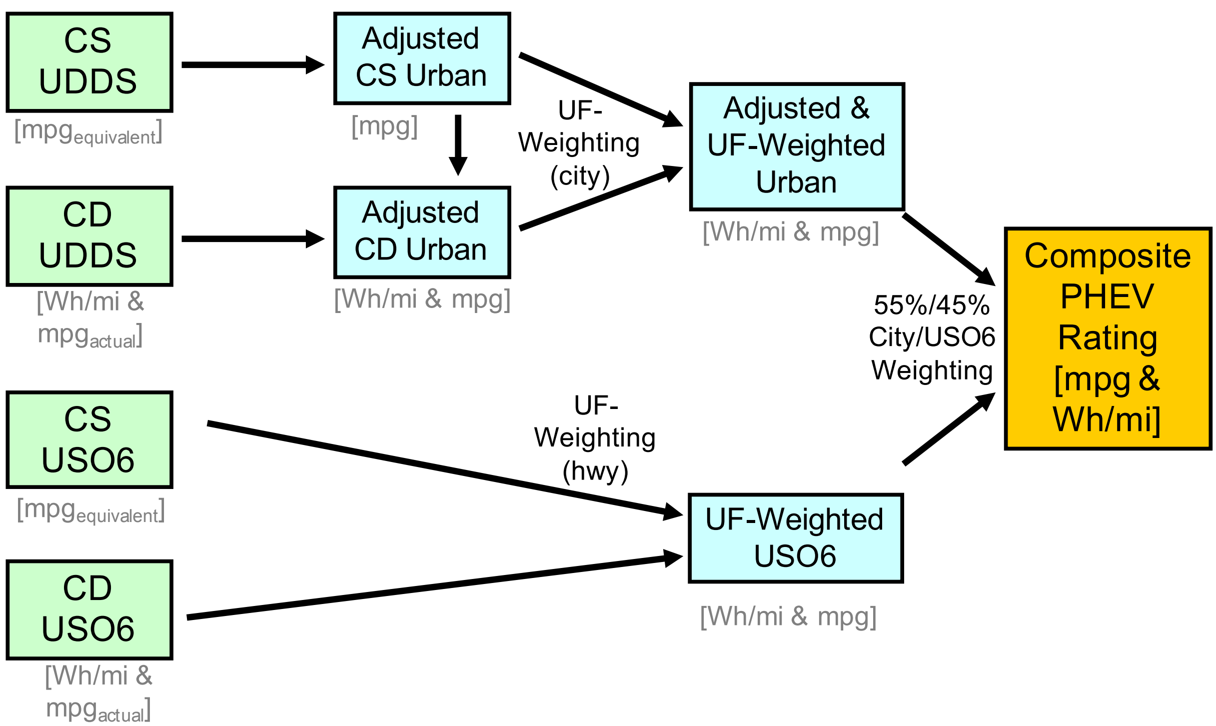

Figure 12. Roadmap of mpg and Electrical Energy Consumption Calculations

Since the SOCs during the charge-sustaining portion of the tests were not constant, the mpg was slightly adjusted using Equation 12.

$$mpg_{gasoline\,equivalent} = \frac{D}{V_{fuel} + \frac{E_{\text{charge}}}{E_{gasoline}}} \tag{12}$$

- D = Distance
- V_{fuel} = volume of fuel used
- E_{charge} = Battery energy used (OEM and Hymotion pack)
- E_{gasoline} = constant, 33.44 kWh/gal

$$mpg_{adjusted,CS,UDDS} = \frac{1}{0.003259 + \frac{1.1805}{mpg_{gasoline\,equivalent}}} \tag{13}$$

$$\Delta consumption_{adjusted,CS,UDDS} = \frac{1}{mpg_{adjusted,CS,UDDS}} - \frac{1}{mpg_{gasoline\,equivalent,CS,UDDS}} \tag{14}$$

$$mpg_{adjusted,CD,UDDS} = \frac{1}{\frac{1}{mpg_{actual,CD,UDDS}} + \Delta consumption_{adjusted,CS,UDDS}} \tag{15}$$

The utility factors (UF) were calculated from SAE J 2841 using the CD mileage from the respective tests. Separate UF curves were used for the respective drive cycles.

$$mpg_{adjusted,UF-Weighted,UDDS} = \frac{1}{\frac{UF_{UDDS}}{mpg_{adjusted,CD,UDDS}} + \frac{1-UF_{UDDS}}{mpg_{adjusted,CS,UDDS}}} \tag{16}$$

$$E_{adjusted,UF-Weighted,UDDS} = UF_{UDDS}(E_{actual,CD,UDDS}) \tag{17}$$

$$mpg_{UF-Weighted,US06} = \frac{1}{\frac{UF_{HWFET}}{mpg_{actual,CD,US06}} + \frac{1-UF_{HWFET}}{mpg_{gasoline\,equivalent,CS,US06}}} \tag{18}$$

$$E_{UF-Weighted,US06} = UF_{HWFET}(E_{actual,CD,US06}) \tag{19}$$

$$mpg_{composite} = \frac{1}{\frac{0.55}{mpg_{adjusted,UF-Weighted,UDDS}} + \frac{0.45}{mpg_{UF-Weighted,USO6}}} \quad (20)$$

$$E_{composite} = 0.55E_{adjusted,UF-Weighted,UDDS} + 0.45E_{UF-Weighted,USO6}) \quad (21)$$

3.0 Results

3.1 UDDS Results

Figure 13 shows the A/C compressor power is lower for the Sungate EP case at all times during the test. Figure 14 shows the average A/C compressor power during charge depletion decreases from 1509 W to 1403 W due to Sungate EP. With the average charge-depletion time of 56 minutes over repeated UDDS cycles, the reduction in A/C power equates to a 100 Wh increase in energy available for the powertrain. During charge sustaining, the A/C compressor power decreases from 1431 W to 1236 W for the Sungate EP case.

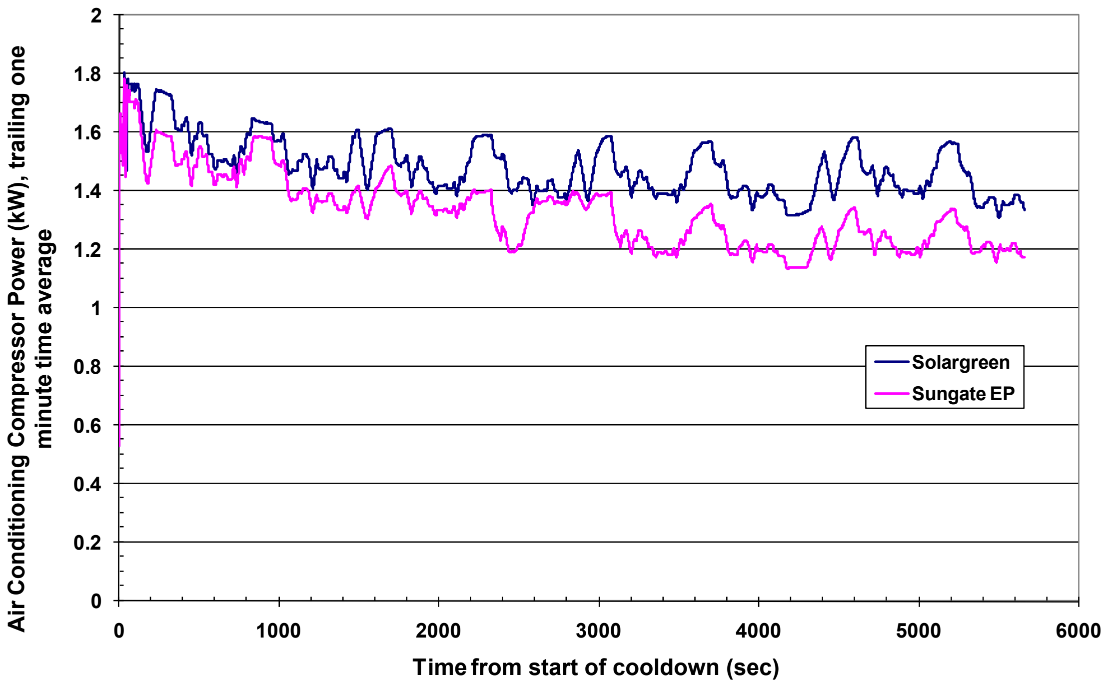

Figure 13. A/C Power vs time over UDDS Drive Cycles

Figure 14. Average A/C Power – UDDS Drive Cycles

The cabin air temperature vs time is shown in Figure 15. The lower simulated solar load of the Sungate EP results in lower cabin temperatures at every time point. During charge depletion, Figure 16 shows the cabin temperature for the Solargreen case is 87.2°F and 82.7°F for Sungate EP case. During charge sustaining, the cabin temperature is 82.7°F for Solargreen and 80.0°F for Sungate EP.

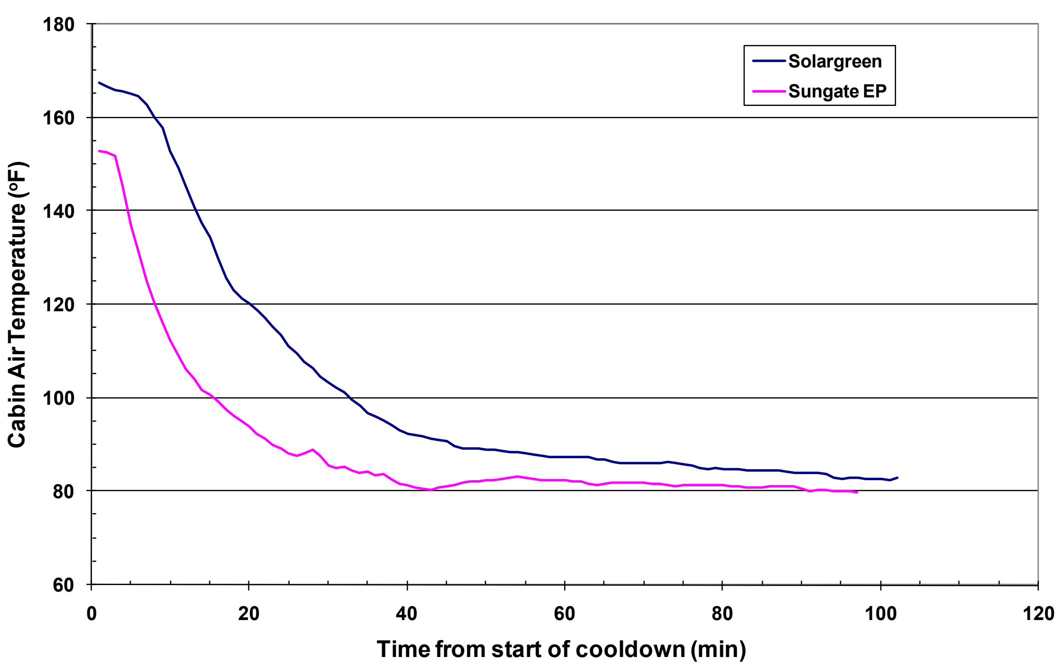

Figure 15. Cabin Air Temperature vs Time over UDDS Drive Cycles

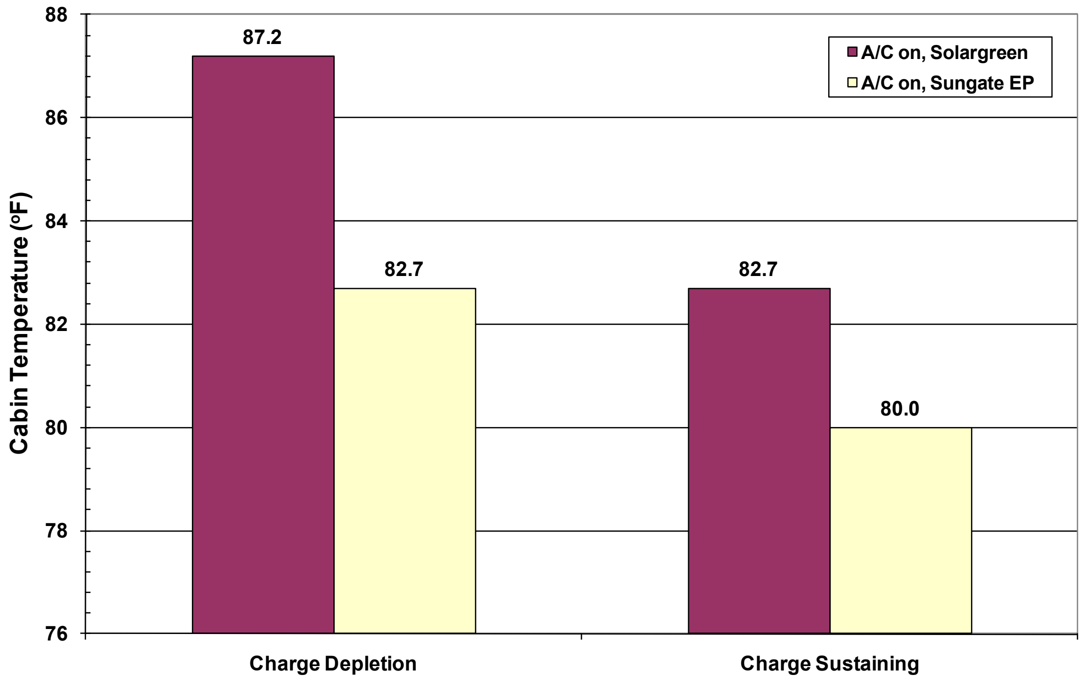

Figure 16. Average Cabin Air Temperature over UDDS Drive Cycles

The actual measured fuel economy and electrical energy consumption during the charge-depletion and charge-sustaining phases of the test are shown in Figures 17 and 18. These results need to be interpreted carefully because in-use performance will be different. For example, a driver will not get 233.7 mpg in city driving as implied by the UDDS A/C off test. Also a driver will not be start every trip fully charged and will sometimes drive beyond the charge-depletion range.

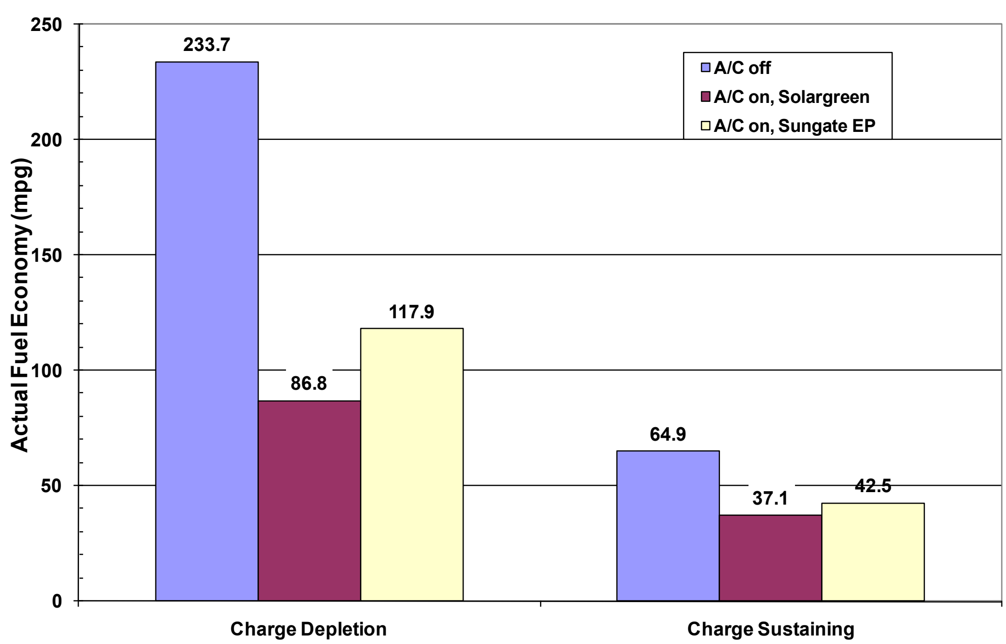

Figure 17. Actual Fuel Economy, UDDS

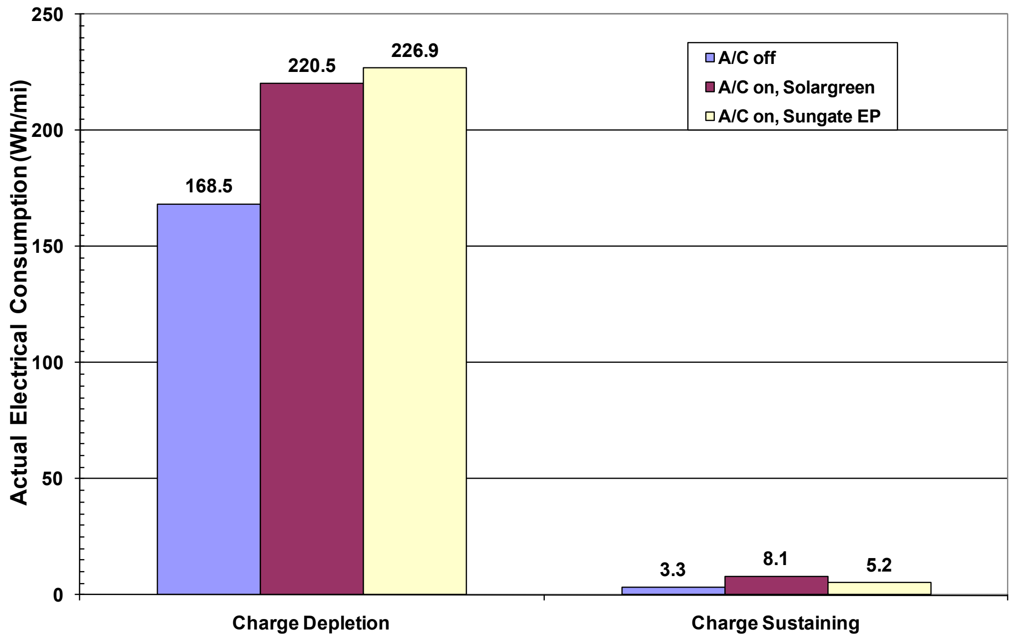

Figure 18. Actual Electrical Energy Consumption, UDDS

Using the equations in Section 2.6, the fuel economy and electrical energy consumption were adjusted to reflect real world usage. When the A/C is operated, the fuel economy drops from 68.5 mpg to 36.8 mpg (Figure 19). Reducing the thermal load due to Sungate EP improves the A/C on fuel economy to 42.9 mpg which is a 17% increase. Figure 20 shows that the electrical energy consumption increases from 104.5 Wh/mi to 114.7 Wh/mi when the A/C is operated. The electrical energy consumption increased slightly (1%) to 115.7 Wh/mi for the Sungate EP thermal load.

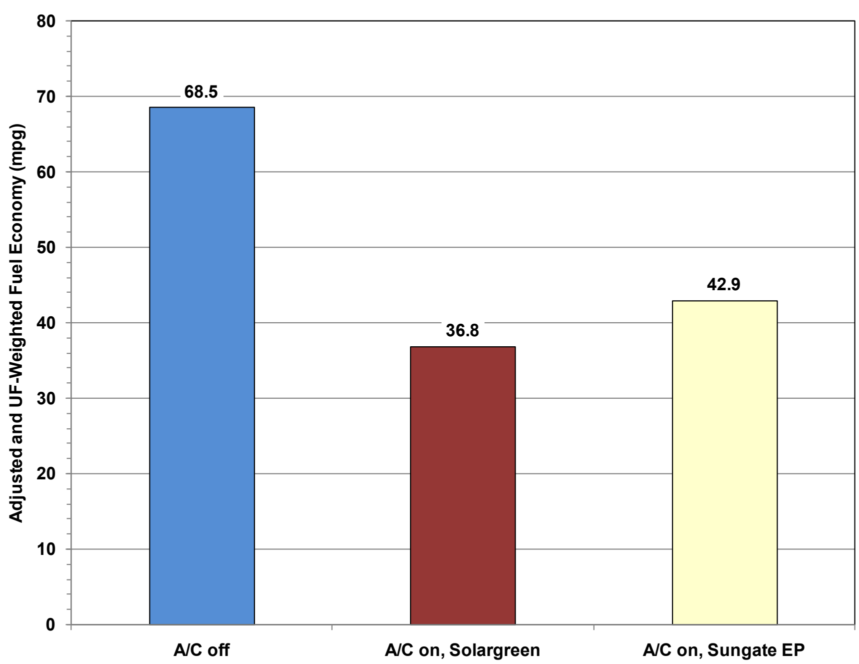

Figure 19. Adjusted and UF-Weighted Fuel Economy, UDDS

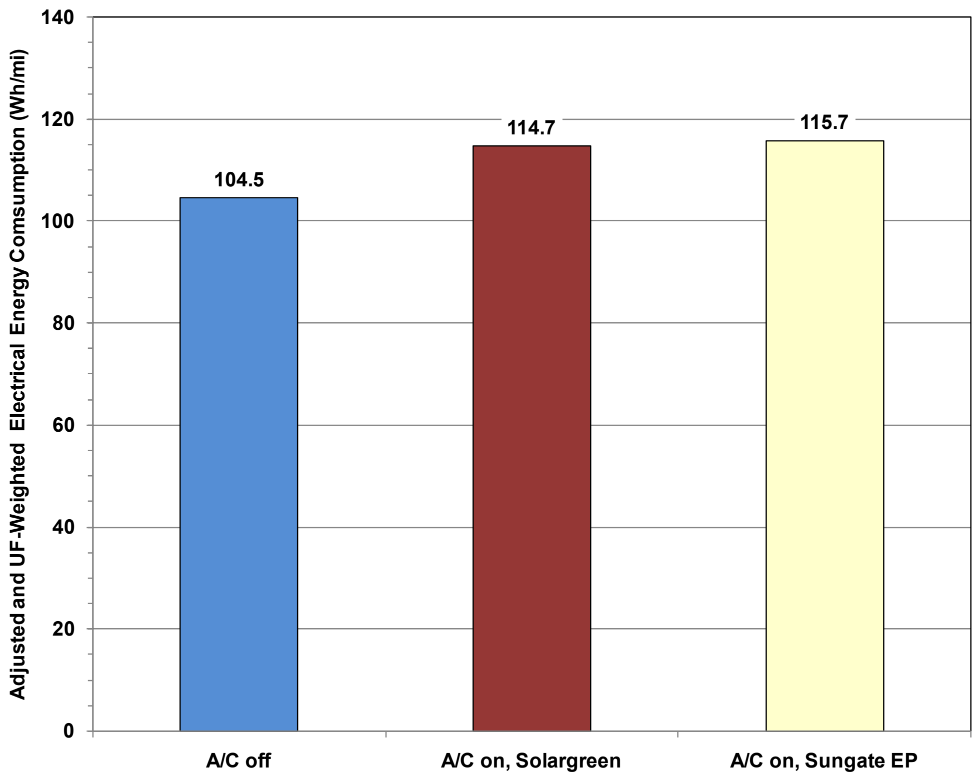

Figure 20. Adjusted and UF-Weighted Electrical Energy Consumption, UDDS

3.2 USO6 Results

Figure 21 shows the difference in A/C compressor power between the Solargreen and Sungate EP thermal loads was not as large over the USO6 drive cycles. In Figure 22, the average A/C compressor power during charge depletion is 1562 W for Solargreen and 1481 W for Sungate EP. During charge sustaining, the average A/C compressor power is 1487 W for Solargreen and 1435 W for Sungate EP. The USO6 drive cycle has more aggressive accelerations than the UDDS. In the non-averaged A/C power data, it was noted the A/C compressor was clutched out during the hard accelerations. This did not happen during the UDDS drive cycles.

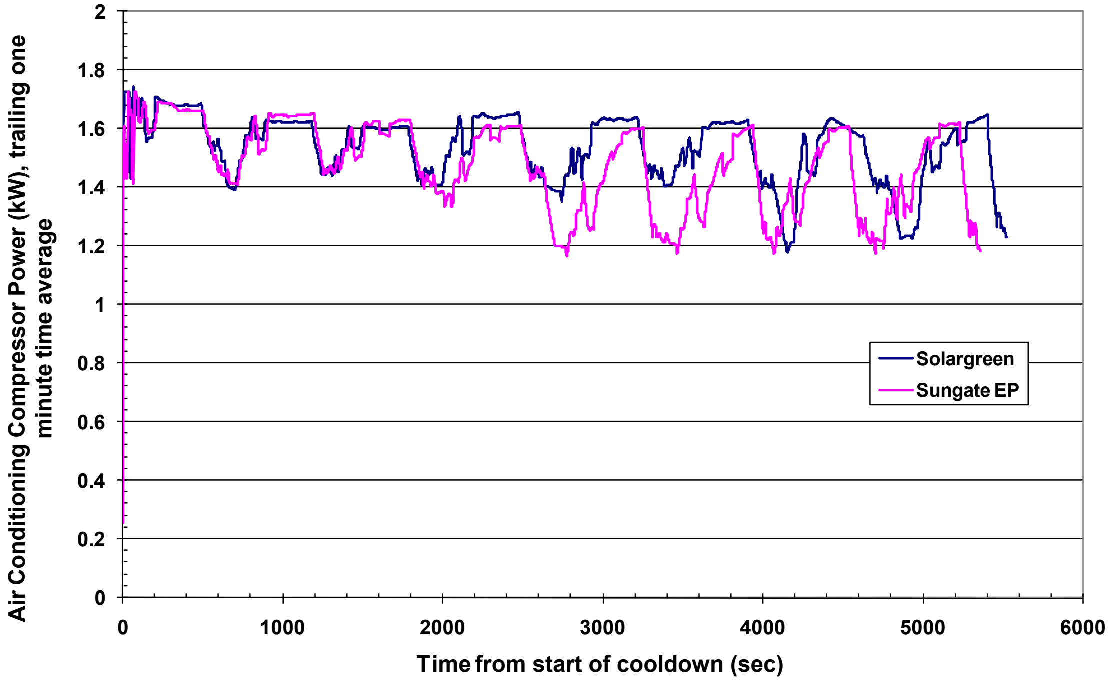

Figure 21. A/C Compressor Power vs time over USO6 Drive Cycles

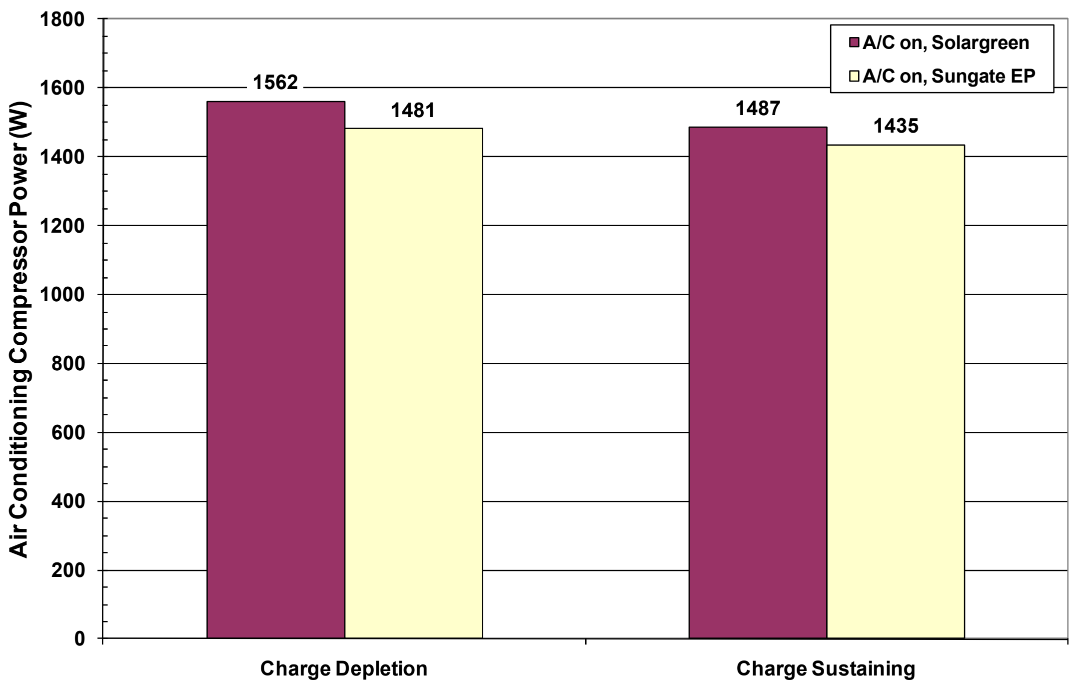

Figure 22. Average A/C Compressor Power over USO6 Drive Cycles

Figure 23 shows the Sungate EP cabin temperature was lower than the Solargreen cabin temperature at every time point. In Figure 24, the average cabin temperature is 93.2 °F for Solargreen and 84.0 °F for Sungate EP during charge depletion. During charge sustaining, the cabin temperatures are 93.6 °F and 84.7 °F for Solargreen and Sungate EP respectively.

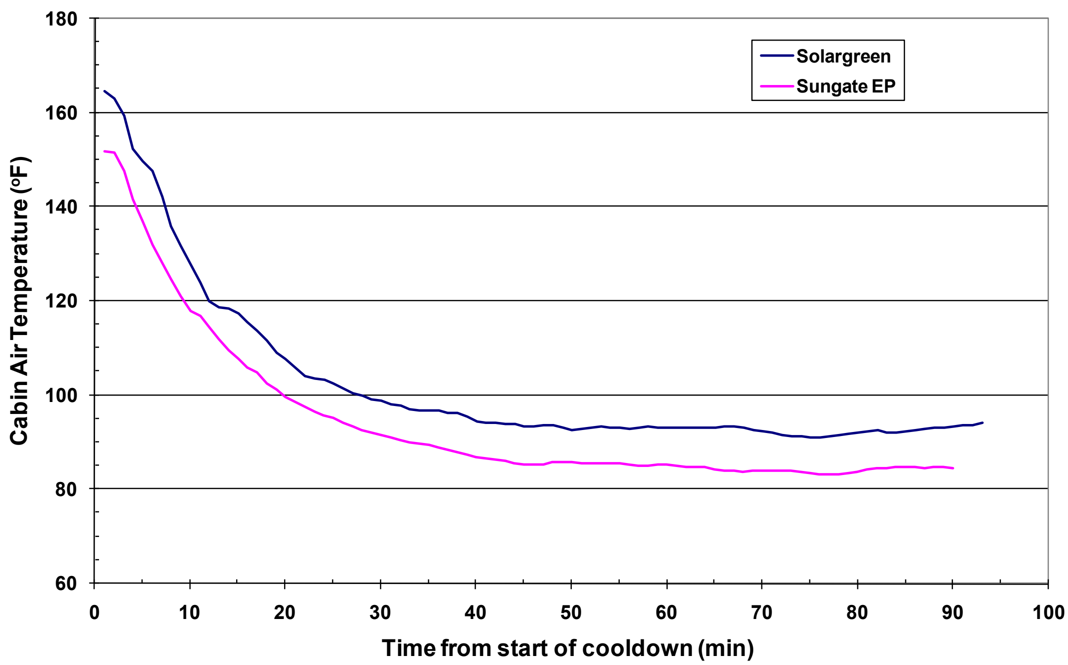

Figure 23. Cabin Air Temperature vs Time over USO6 Drive Cycles

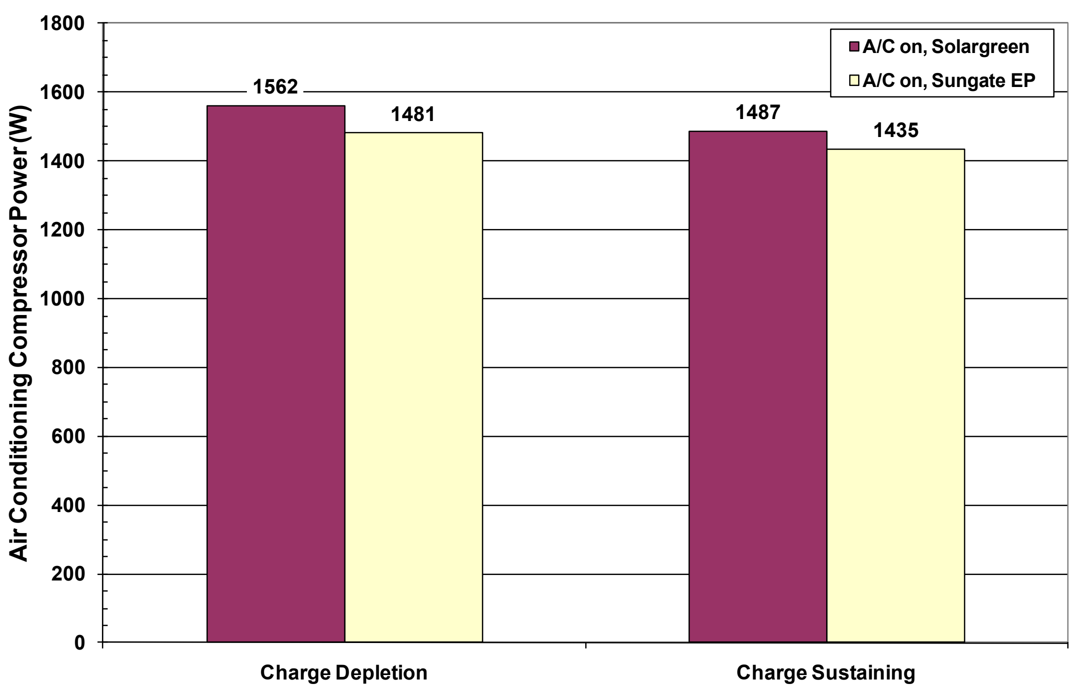

Figure 24. Average Cabin Air Temperature over USO6 Drive Cycles

The actual fuel economy and electrical energy consumption data are shown in Figures 25 and 26. Using a methodology similar to the UDDS, the raw data were adjusted to reflect real usage of a PHEV, and the results are shown in Figures 27 and 28.

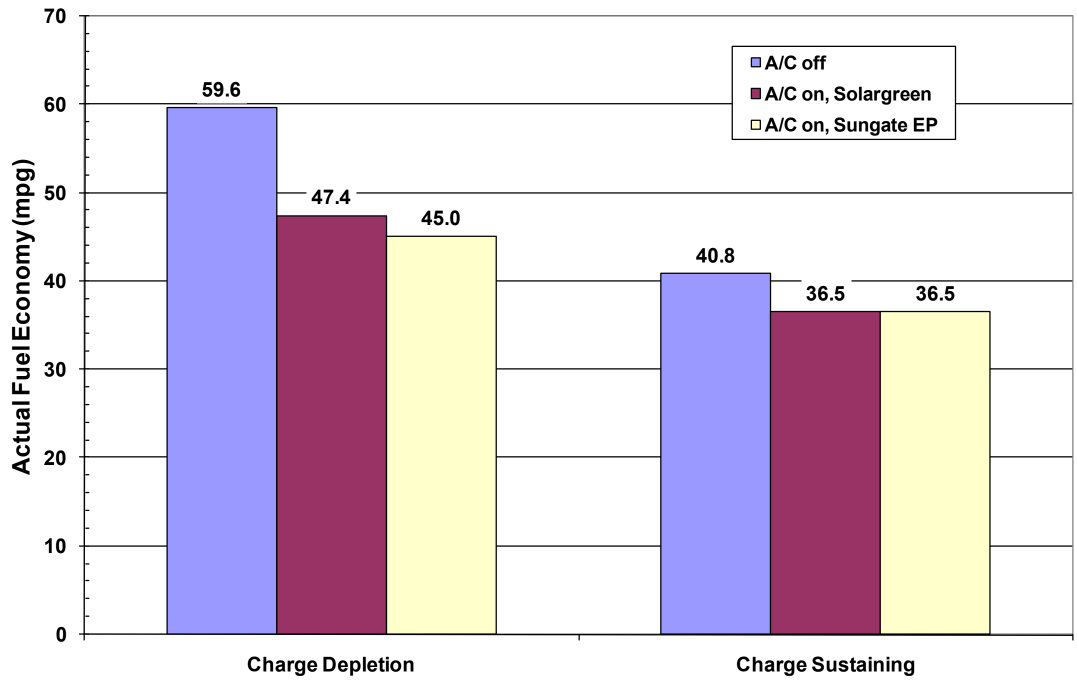

Figure 25. Actual Fuel Economy, USO6

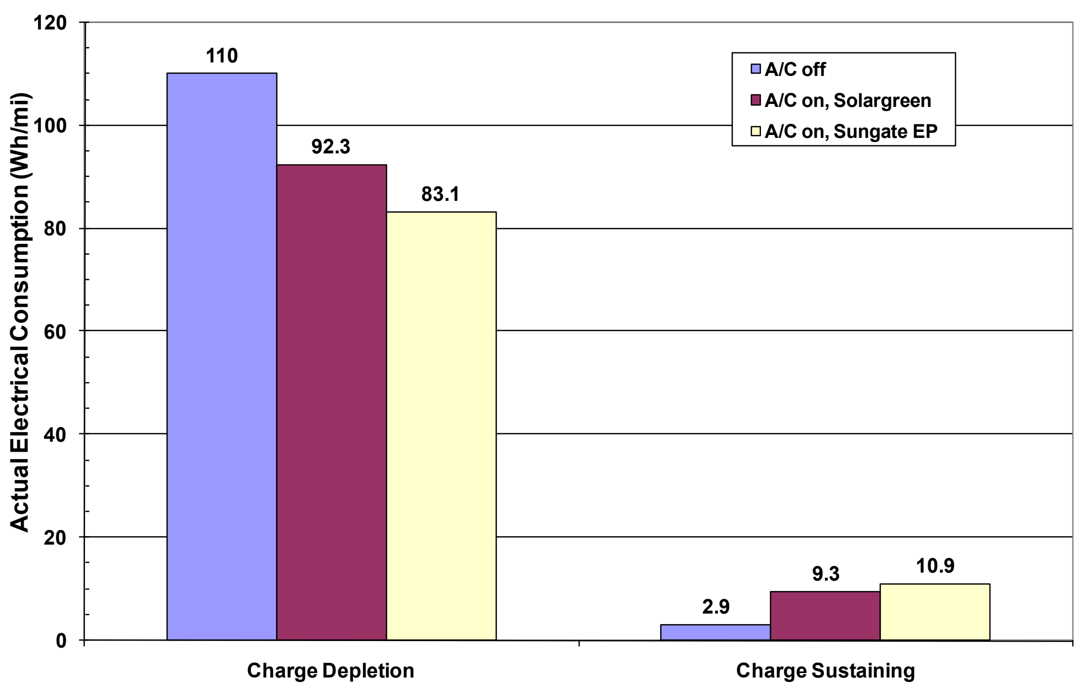

Figure 26. Actual Electrical Energy Consumption, USO6

When the A/C was not operated, the fuel economy was 46.3 mpg. The Solargreen thermal loads and A/C on resulted in 40.4 mpg. It was expected that the lower thermal loads for the Sungate EP would improve the fuel economy but that did not happen. Figure 27 shows the fuel economy dropped slightly to 40.0 mpg (1%) despite the lower A/C compressor power noted in Figure 22. Figure 28 shows that the electrical energy consumption increased slightly from 41.5 Wh/mi to 41.6 Wh/mi (0.2% increase) when the Sungate EP thermal load was applied. While the exact reason for this is not known, it is probably within the test to test variation.

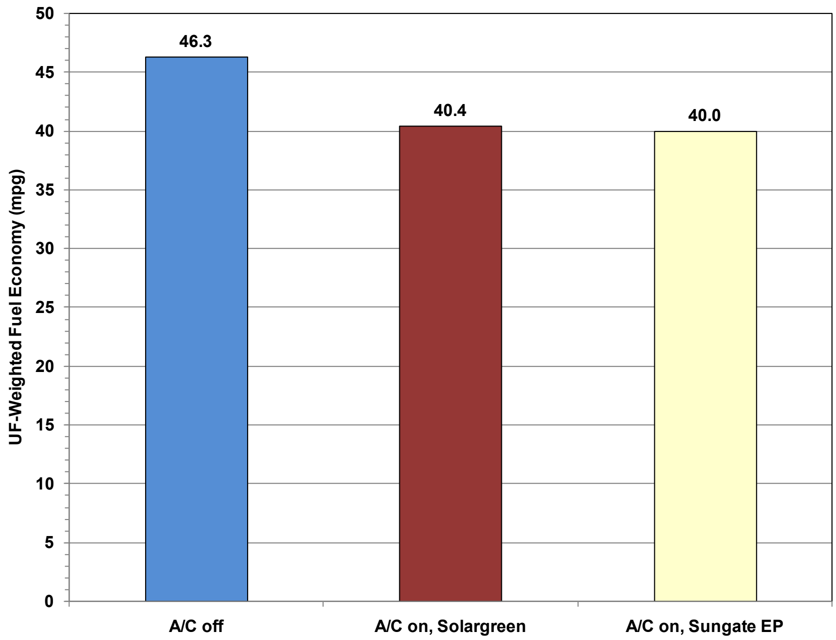

Figure 27. UF-Weighted Fuel Economy, USO6

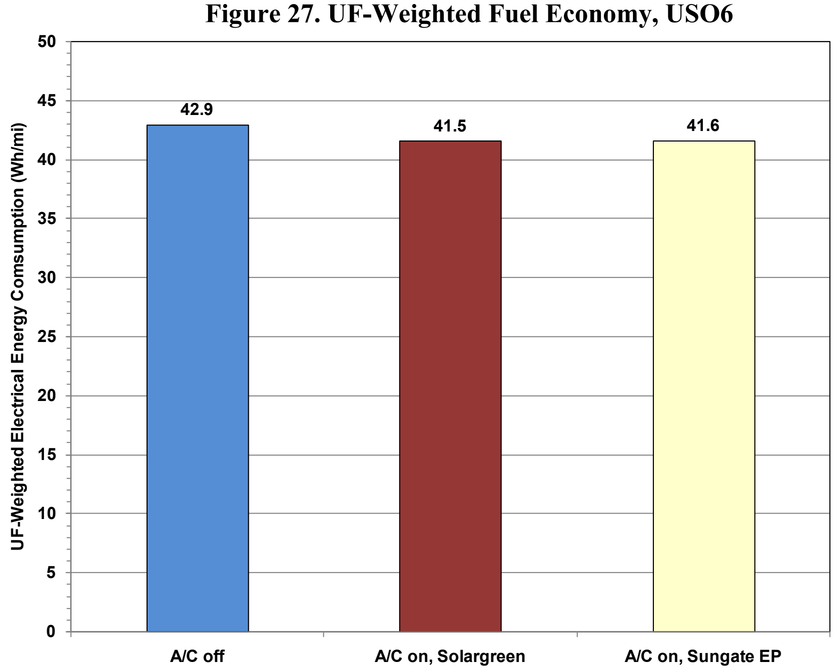

Figure 28. UF-Weighted Electrical Energy Consumption, USO6

3.3 UDDS/USO6 Composite Results

To combine the data from the two drive cycles into a composite value, the standard EPA split of 55% city and 45% highway was used. Using equations 20 and 21 from Section 2.6, the fuel economy and electrical energy consumption were combined using the USO6 as a surrogate for the HWFET. Figure 29 shows the A/C off fuel economy is 56.4 mpg and the A/C on Solargreen fuel economy is 38.4 mpg. The Sungate EP thermal load results in an 8% increase in fuel economy to 41.6 mpg. The electrical consumption with A/C off is 76.8 Wh/mi while the A/C on and Solargreen thermal load electrical consumption is 81.8 Wh/mi. The electrical energy consumption for the Sungate EP thermal load increased < 1% to 82.3 Wh/mi which is probably within the test-to-test variation.

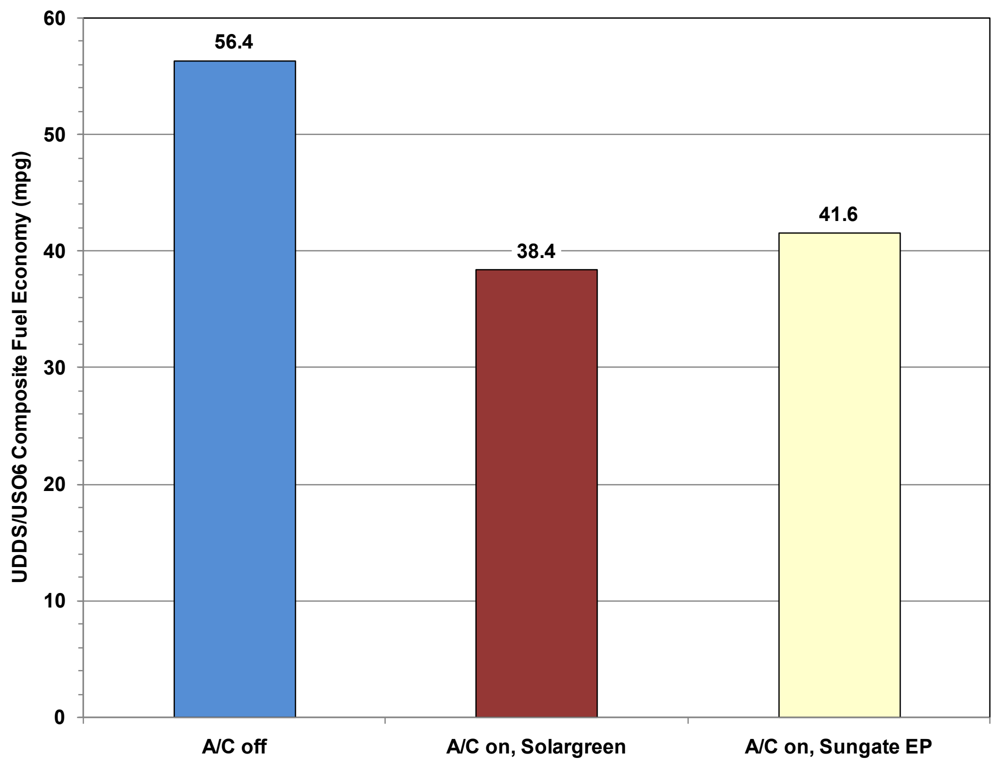

Figure 29. UDDS/USO6 Composite Fuel Economy

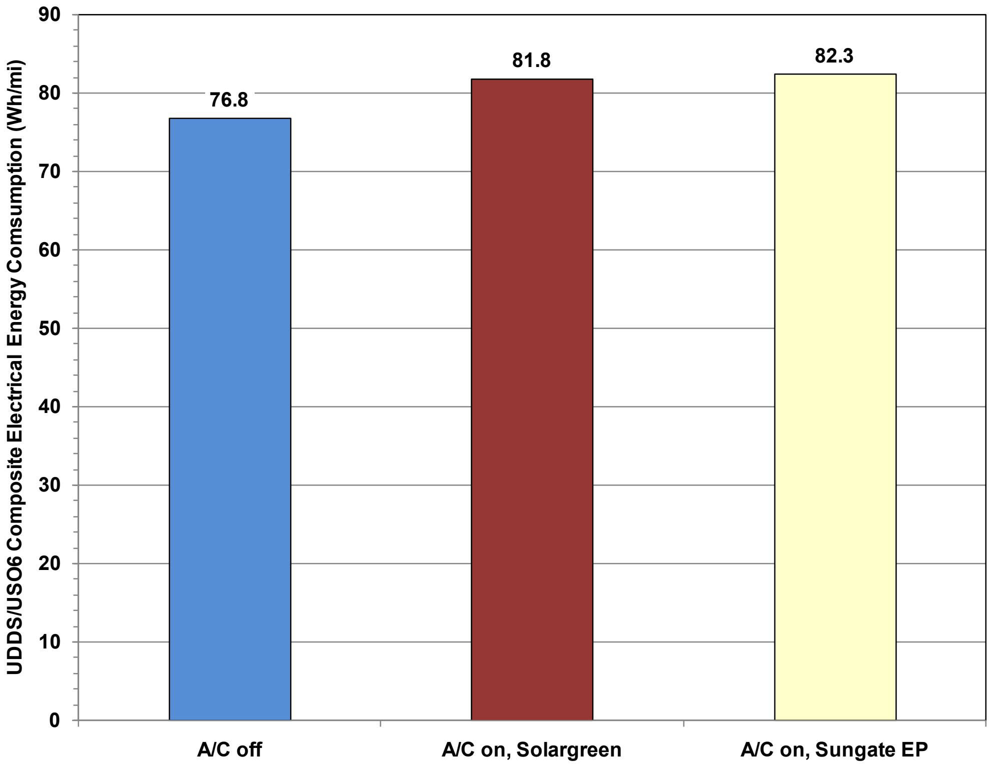

Figure 30. UDDS/USO6 Composite Electrical Energy Consumption

4.0 Conclusions

Using Sungate EP solar reflective glazing in the windshield and backlite reduced the passenger compartment thermal load from 1629 W to 1264 W in a Toyota Prius. The reduced thermal load due to Sungate EP in the windshield and backlite resulted in lower A/C compressor power and lower interior cabin air temperature (improved occupant comfort) compared to Solargreen. The lower compressor power yielded an 8% increase in the UDDS/USO6 composite fuel economy from 38.4 to 41.6 mpg while the UDDS/USO6 composite electrical energy consumption was equivalent.

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14. ABSTRACT *(Maximum 200 Words)*
The project assessed the impact of a solar reflective windshield and backlite on plug-in hybrid electric vehicle (PHEV) range and fuel economy. The effect of Sungate® EP on PHEV performance was evaluated on NREL's PHEV test bed, a 2006 Toyota Prius modified with a 5 kWh Hymotion Li-ion Energy Storage System. The tests, performed at Environmental Testing Corporation in Colorado, used portable electric heaters installed in the passenger compartment to simulate the solar heat gain through the glazings.The UDDS/USO6 composite fuel economy increased 8% from 38.4 mpg to 41.6 mpg due to the reduction in thermal loads from Sungate EP glazings installed in the windshield and backlite. The electrical energy consumption was essentially equivalent with a less than 0.2% increase. Using the Sungate EP resulted in lower A/C compressor power and lower interior cabin air temperature, which would improve occupants' comfort. The lower A/C power improved UDDS/USO6 composite fuel economy.

15. SUBJECT TERMS
advanced vehicle systems; fuel economy; plug-in hybrid electric vehicles; solar reflective glazings

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