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# Mobile A/C System Energy Requirements

Consumers continue to be concerned about the fuel consumption of their vehicles. Many are not aware of the impact of accessories on this fuel consumption. Vehicle air conditioning (A/C) is one of the highest energy consuming accessories and has become standard equipment for vehicles.

The energy required to provide comfort in a vehicle depends on many factors. The load on the A/C system is a function of the fan setting, the outside ambient and humidity, and the speed of the vehicle among other variables. The fuel consumption of the A/C will vary greatly depending on the weather conditions that prevail in a given area and also on the traffic patterns that are typical of a given city. Following, we will provide some background information on various factors that affect A/C fuel consumption and then some pointers on how to operate the vehicle air conditioning system to minimize energy consumption while still providing comfort.

Comparing the use of a vehicle A/C system to a home air conditioning system may help consumers to understand why vehicle A/C can have such a large impact on fuel consumption. Consumers expect the vehicle A/C system to provide nearly instant relief after a hot soak in the summer sun. Home air conditioning usually runs continuously during the day, even if it may be set back at times to save energy. The demand and expectations of the consumer of the vehicle air conditioning system to provide comfort and maintain driver's alertness may require increasing the system cooling capacity resulting in larger energy demands.

If you turn off a home air conditioning system for a few hours on a sunny 90°F degree day, by the time you get back the room air temperature may reach 90°F degrees, but most of the surfaces will still be cooler. When you turn the A/C system on it will take some time for it to reach some initial level of comfort and longer to reduce the room air temperature to a comfortable 75°. However, leave your vehicle parked in the sun for minutes and the interior breath air temperature and various interior surface temperatures can warm to well over 100°F. But with the vehicle, you expect the temperature to be reduced to a comfortable level in a matter of minutes.

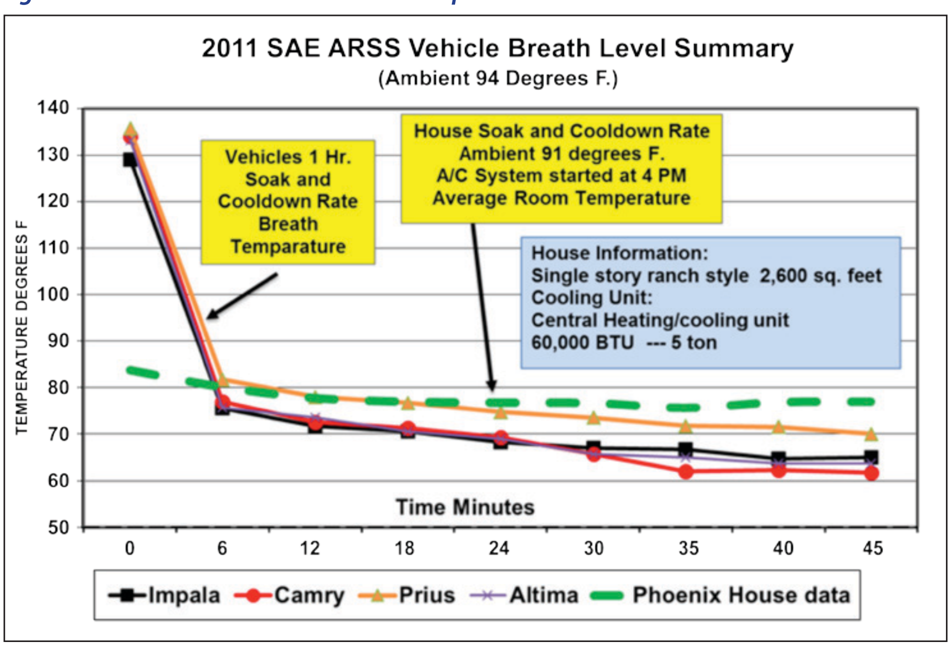
*The Transportation Energy Data Book* (Edition 33 – 2014) notes that the average commute time was 25.4 minutes in 2012 and two thirds of workers traveled less than 30 minutes. The commute time was less than 15 minutes for 28.1% of workers. Soak vehicle times are 8 hours or more for the normal work day.

*The IPCC/TEAP Special Report:* Safeguarding the Ozone Layer and the Global Climate System reports that studies have shown that mechanical power required to operate the vehicle A/C ranges from 1,365 to 11,600 BTU/h depending on ambient temperature and engine speed. One ton of cooling is defined as delivering 12,000 BTU/h of cooling. A typical home window air conditioner is less than one ton. A small home central air conditioner would be about two tons (24,000 BTU/h) and a large one about five tons (60,000 BTU/h).

Figure 1 compares cool-down rates of three vehicles to a single-story ranch house, which has an interior volume to be cooled over 138 times greater than the average vehicle being cooled. The cool-down of the vehicle requires a much faster rate than that of the home. This home has a 5 ton unit, typical of cooling capacity in the desert Southwest area. The cool-down rate of a home is more likely to be in the range of 2 to 3 degrees per hour as the more typical home unit is close to 2 tons, sometimes taking hours to achieve the desired temperature, while a vehicle has to achieve the comfort level within minutes.

Humidity is another factor to consider in the cooling capacity of home A/C. Under some weather conditions, home systems may not provide satisfactory comfort since it will cool the

***Figure 1 - Vehicle and house interior temperature cool-down rates***



### TABLE 1 - COMPARISON OF HOUSE AND VEHICLE SOAK TEMPERATURE OVER TIME

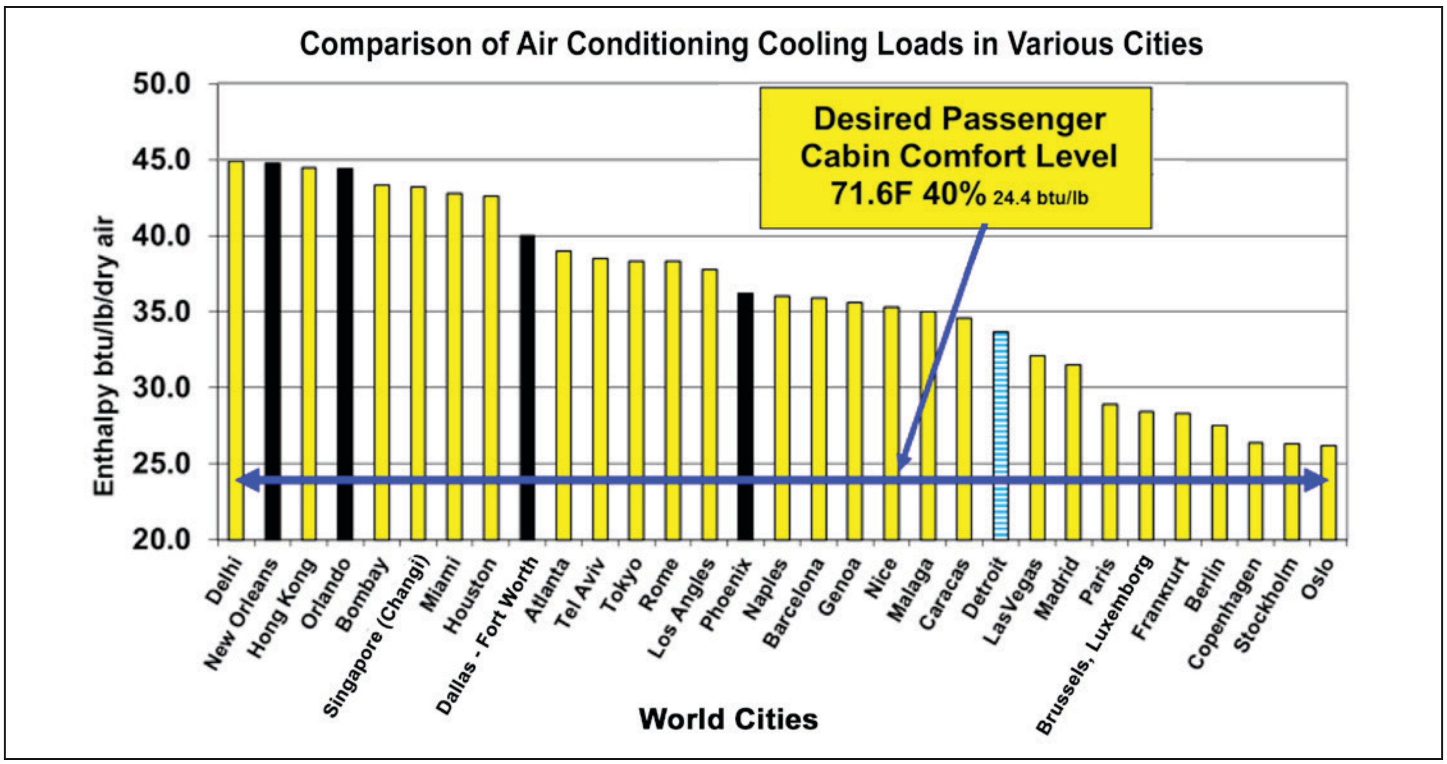
| House | 8:00 AM | 10:35 AM | 12:00 PM | 4 PM | | Vehicle - Black Coupe, All Day Soak Full Sun, SAE Technical Paper 860591 | 8 AM | 10:35 AM | 12:00 PM | 4 PM |
|---|---|---|---|---|---|---|---|---|---|---|
| Ambient Weather | 72°F | 83°F | 86°F | 89°F | | Ambient Weather | 85°F | 92°F | 97°F | 101°F |
| House Average Air Temperature | 75.6°F | 76.9°F | 79.4°F | 80.9°F | | Vehicle Breath Temperature | 93°F | 140°F | 160°F | 154°F |
| Living Room Inside Seat Cushion | 75.2°F | 75.9°F | 75.8°F | 74.2°F | | Vehicle Interior Seat Material | 93°F | 110°F | 120°F | 130°F |
| Bed Mattress Surface | 75.6°F | 76°F | 78.4°F | 82.8°F | | Instrument Panel Surface Black | 115°F | 18°F | 212°F | 189°F |

air but not reduce the humidity level to a comfortable range, resulting in the occupants being uncomfortable. Today, some vehicle A/C systems have added the consideration of humidity control to minimize energy consumption and provide an optimal humidity level inside the vehicle.

Higher air velocity is required in a vehicle as compared to the indirect low velocity airflow in a house air conditioning system. In a vehicle, the air is directed to the body, but in a home, it is a diffuse or indirect airflow. After the occupants have reached some reasonable level of comfort in a vehicle, the system must be adjusted to then provide a level of comfort that is acceptable for longer travel times with diffuse airflow.

Table 1 compares the cool-down rate of four vehicles on a 94°F day, which, in 1 hour, have reached an interior average air temperature of 132°F. at 12:15 PM, and a home having no cooling system operation from 7 AM until 4 PM on a 90°F day. You can see from this data that the house warmed up by only 8°F as compared to 60-70°F for the vehicle during a soak.

*Figure 2*



## Windows Open Versus Operating Air Conditioning System

The use of the A/C system can reduce driver fatigue, a major safety issue, and may result in reduced energy requirements when comparing A/C operation versus vehicle windows open. Rolling the windows down on a vehicle impacts the vehicle drag and increasing drag increases vehicle fuel consumption.

Figure 3 and 4 compare four different vehicle operating conditions: maximum cooling load (outside air, high fan), minimal cooling system load (recirculated air, low fan) and A/C system off with vehicle windows open to A/C system off and windows closed. When the cabin becomes comfortable, and is not operating at full cooling capacity, there are reduced energy requirements when compared to the windows open with A/C off. Obtaining comfort by operating with closed windows, A/C on, low fan speed and the selection of recirculated air may result in the use of less fuel.

## Vehicle Fuel Consumption

This comparison of two luxury four-door sedans (“A”–“B”) and a large SUV (“I”) was conducted on a test track with weather conditions of a sunny 90°F (32°C) day with 20% relative humidly. This resulted in the same fuel use for vehicles “I” and “B”. Vehicle “A” used more fuel with windows open and the A/C off.

There are many factors that affect the amount of fuel that will be required to operate the vehicle air conditioning system. The vehicle MPG rating is the result of many factors. The resistance to airflow over the vehicle on the highway is called drag. The effect of operating the vehicle with the windows open or closed can change the drag and fuel consumed. These factors and other climate related considerations affect the amount of fuel consumed for operation of the A/C system. Estimates have varied from as low as 4% to as high as 30% for the impact of vehicle A/C usage on fuel consumption over an annual period of time.

With the weather conditions of this test, it would be difficult for comfort or safety reasons to operate the vehicles with all windows closed and no cooling. When operating with vehicle windows open and no A/C operation, occupant comfort and fatigue become factors.

*Figure 3*

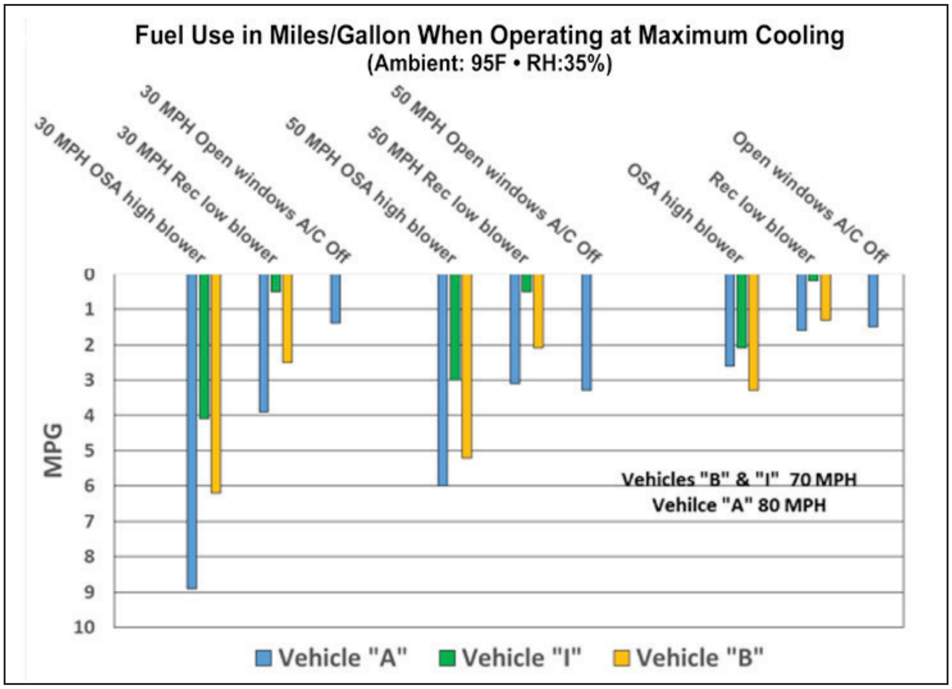
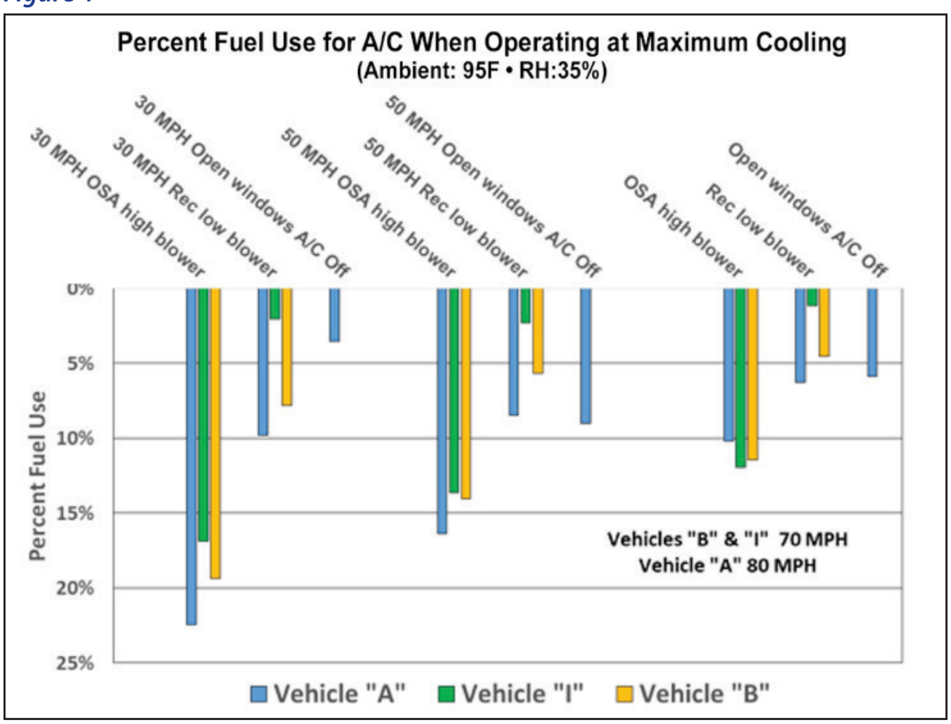



*Figure 4*



Vehicles having high MPG ratings operated with open windows and closed with no A/C operation and operation of the A/C system, at road speeds, may result in higher MPG fuel consumption.

Having windows up or down during vehicle operation has little bearing on the amount of energy used in city traffic, since most of the energy is consumed to reduce the temperature in the vehicle when the vehicle speeds are low. Operating the A/C system in outside (normal) or recirculated air (max) for short cool down trips can result in different fuel consumption. However, operating the A/C system after initial cool down during extended highway operation requires less energy than the initial cool-down phase.

The comparison, in Figure 3, of the three production vehicles, when operating at 30 MPH with the air conditioning system set for high blower, outside air (max cooling load) resulted in fuel consumption ranging from 4.1 to 8.9 miles per gallon. With the system selection set for minimum cooling, (low fan speed, recirculated air), the A/C fuel consumption was reduced to a range of 0.5 to 3.9 miles per gallon.

When comparing A/C operation at 50 MPH the maximum A/C load fuel use ranged from 3 to 6 MPG and low A/C load was 0.5 to 3.1 MPG.

Some reports for A/C system fuel have been conducted at cooler weather conditions and with the A/C system operating continuously on high blower. This is not comparing a realistic operating condition for vehicle occupant comfort.

The SAE Cross Country data below provides a consumer use comparison for full system cooling performance, high fan speed and reduced fan speeds allowing for a level of occupant comfort.

When traveling for an extended period of time, after the vehicle interior has reached some level of comfort, the A/C system cooling requirements can be reduced by operating on recirculated air (max) and reduced fan speed.

## SAE Technical Paper 2009-01-540 SAE Cross Country A/C Comfort Evaluation

### RIDE OVERVIEW

The comfort ride evaluation program included four ride teams representing different world regions including Europe, Asia Pacific, and North America. The purpose was to determine if regional occupant comfort requirements, riding in the same type of vehicle, at the same time and climatic conditions, would dictate different system performance requirements.

The ride route selected allowed a wide ambient temperature change within a short period of time providing changing occupant comfort requirements and A/C system cooling requirements. The data in figures 5 and 6 compares the cooling requirements for a two-day trip between Phoenix, AZ and Flagstaff AZ and return.

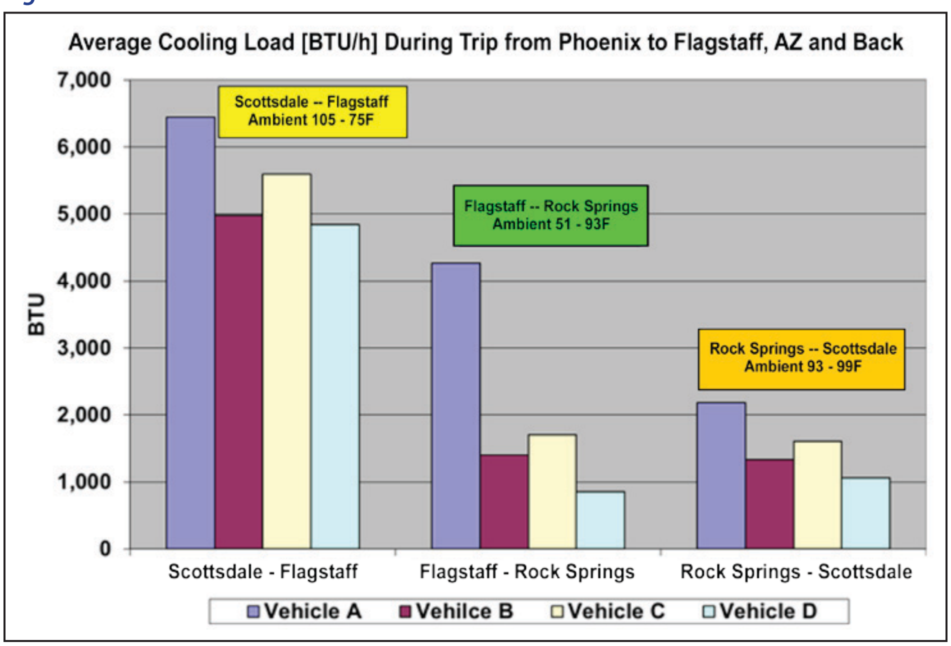
The travel route selected provided weather conditions from low desert to mountain terrain and an ambient temperature over the driving period ranged from 104°F to 76°F. The second day return travel encountered an ambient range of 40°F to 99°F. The daytime travel periods had clear skies with full sun load. The relative humidity ranged from 15% in the Scottsdale area to 40% at Flagstaff. The test vehicles were four identical 2008 Silver Chevrolet four-door Impala production vehicles.

### COOLING REQUIREMENTS

Capacity Analysis: Vehicle airflow was used to estimate the system capacity. Since there was not the capability to measure real time cooling requirements for the entire ride segment, capacity was calculated only at the predetermined time intervals where data was taken. The data compares each travel segment cooling capacity used to acquire the average recorded comfort level.

Figure 5 (BTU/h) compares the different average cooling energy ratings required for cooling these vehi-

*Figure 5*



cles traveling different travel segments with varying weather conditions. Comparing the three travel sectors with the vehicle's cabin occupants being comfortable resulted in the A/C cooling demand being reduced. The four vehicles' average cooling capacity ranged from 5,467 BTU/h to 2,055 BTU/h.

As indicated by the temperature of the various travel sectors, occupants were comfortable with reduced A/C system control setting, and the energy (fuel use) was greatly reduced.

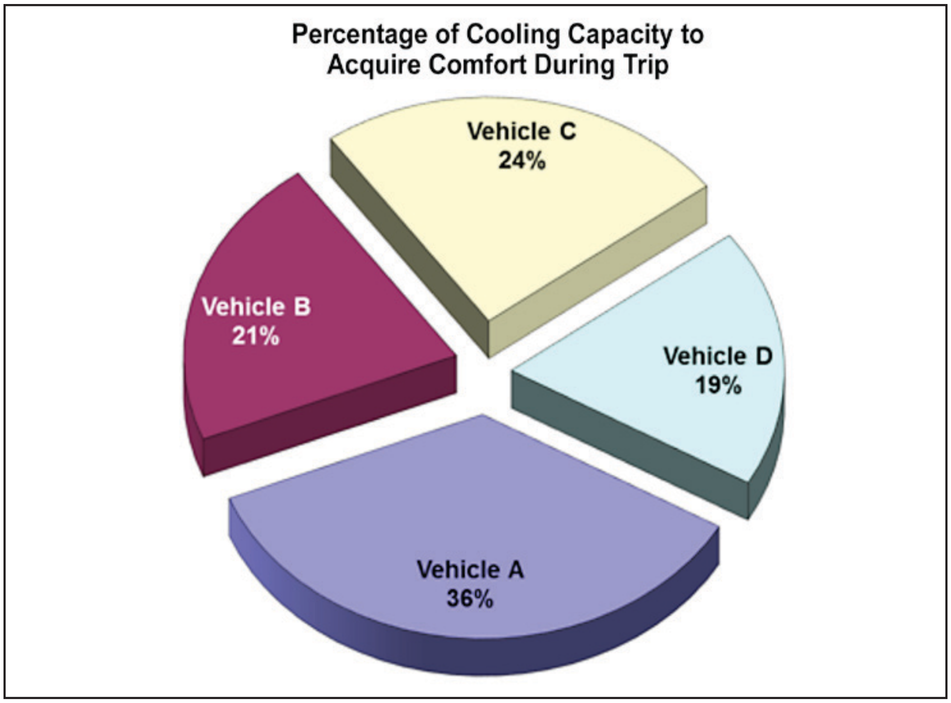
Figure 6 shows how these diverse groups of people from different regions of the world chose to operate their system with significantly different energy consumption patterns.

## EPA Credits Offered for Efficient A/C Operation

Beginning in 2017, the USEPA has introduced a new ruling that allows vehicle OEMs to get credits against their overall vehicle mileage requirements. Below are tables 2 and 3 showing a list of the air condition system and other credit options. Included here is an option for the addition of shutters at the front grille of the vehicle that close when cooling loads are low so that vehicle drag is decreased.

A program was sponsored by the USCAR group in cooperation with the USEPA to evaluate a series of vehicles for the impact of different variations of the A/C system on fuel economy. This was reported out at the SAE TMSS in 2012 in Troy Michigan. In this series of tests, a number of domes-

*Figure 6 - Trip Cooling Comparison Between Vehicles*




### TABLE 2 - A/C EFFICIENCY CREDITS & FUEL CONSUMPTION IMPROVEMENT VALUES

| Technology description | Estimated reduction in A/C $CO_2$ emissions and fuel consumption (percent) | Car A/C efficiency credit (g/mi $CO_2$) | Truck A/C efficiency credit (g/mi $CO_2$) | Car A/C efficiency fuel consumption improvement (gallon/mi) | Truck A/C efficiency fuel consumption improvement (gallon/mi) |
|---|---|---|---|---|---|
| Reduced reheat, with externally-controlled, variable-displacement compressor | 30 | 1.5 | 2.2 | 0.000169 | 0.000248 |
| Reduced reheat, with externally-controlled, fixed-displacement or pneumatic variable displacement compressor | 20 | 1.0 | 1.4 | 0.000113 | 0.000158 |
| Default to recirculated air with closed-loop control of the air supply (sensor feedback to control interior air quality) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed based on additional analysis) | 30 | 1.5 | 2.2 | 0.000169 | 0.000248 |
| Default to recirculated air with open-loop control of the air supply (no sensor feedback) whenever the outside ambient temperature is 75 °F or higher (although deviations from this temperature are allowed if accompanied by an engineering analysis) | 20 | 1.0 | 1.4 | 0.000113 | 0.000158 |
| Blower motor controls that limit wasted electrical energy (e.g. pulse width modulated power controller) | 15 | 0.8 | 1.1 | 0.000090 | 0.000124 |
| Internal heat exchanger (or suction line heat exchanger) | 20 | 1.0 | 1.4 | 0.000113 | 0.000158 |
| Improved evaporators and condensers (with engineering analysis on each component indicating a COP improvement greater than 10%, when compared to previous design) | 20 | 1.0 | 1.4 | 0.000113 | 0.000158 |
| Oil Separator (internal or external to compressor) | 10 | 0.5 | 0.7 | 0.000056 | 0.000079 |

### TABLE 3 - OFF-CYCLE TECHNOLOGIES & CREDITS & EQUIVALENT FUEL CONSUMPTION INPROVEMENT VALUES FOR CARS AND LIGHT TRUCKS

| Technology | Adjustments for cars | | Adjustments for trucks | |
|---|---|---|---|---|
| | g/mi | gallons/mi | g/mi | gallons/mi |
| +High Efficiency Exterior Lights* (at 100 watt savings) | 1.0 | 0.000113 | 1.0 | 0.000113 |
| +Waste Heat Recovery (at 100W) | 0.7 | 0.000079 | 0.7 | 0.000079 |
| +Solar Panels (based on a 75 watt solar panel)**; | | | | |
| Battery Charging Only | 3.3 | 0.000372 | 3.3 | 0.000372 |
| Active Cabin Ventilation and Battery Charging | 2.5 | 0.000282 | 2.5 | 0.000282 |
| +Active Aerodynamic Improvements (for a 3% aerodynamic drag or Cd reduction) | 0.6 | 0.000068 | 1.0 | 0.000113 |
| Engine Idle Start-Stop; | | | | |
| w/ heater circulation system# | 2.5 | 0.000282 | 4.4 | 0.000496 |
| w/o heater circulation system | 1.5 | 0.000169 | 2.9 | 0.000327 |
| Active Transmission Warm-Up | 1.5 | 0.000169 | 3.2 | 0.000361 |
| Active Engine Warm-up | 1.5 | 0.000169 | 3.2 | 0.000361 |
| Solar/Thermal Control | Up to 3.0 | 0.000338 | Up to 4.3 | 0.000484 |

*High efficiency exterior lighting credit is scalable based on lighting components selected from high efficiency exterior lighting list (see Joint TSD Section 5.2.3, Table 5–21).

**Solar Panel credit is scalable based on solar panel rated power, (see Joint TSD Section 5.2.4). This credit can be combined with active cabin ventilation credits.

#In order to receive the maximum engine idle start stop, the heater circulation system must be calibrated to keep the engine off for 1 minute or more when the external ambient temperature is 30 deg F and when cabin heat is demanded (see Joint TSD Section 5.2.8.1).

+This credit is scalable; however, only a minimum credit of 0.05 g/mi $CO_2$ can be granted.

tic vehicles were evaluated using the new EPA drive schedule titled AC17 (Figure 7) and were conducted in a climatic test facility that simulates a typical U.S. average summer air conditioning cooling requirement and sun load. This performance test does not reflect the higher air conditioning cooling loads experienced in the U.S. As an example, cooling requirements for Phoenix are 7% and New Orleans 33% higher than Detroit (Figure 2).

The fuel economy penalty for A/C operation on this schedule ranged as follows for the vehicles in this study (Figure 8).

## General Pointers for Vehicle A/C System Operation

Since the user has many options in operating the vehicle A/C system, it is important to have an understanding of how some of the operating functions affect fuel consumption. The use of recirculated air and reduced fan speed modes results in the lowest cooling energy requirements. Selection of outside air and higher fan speed will generally require more energy than using lower fan speeds and selecting recirculated (max) air.

The greatest amount of energy (fuel use) generally occurs when the A/C system is operated after the vehicle has been heat soaked.

Setting the temperature control for full cold, and operating the system for the first few minutes on outside air (OSA - normal), will help purge the hot cabin air. Then switching and using recirculated air (max), after the first few minutes can help reduce the cabin heat load.

The second important control is the fan or blower speed. This is generally adjusted for both the amount of air movement and fan noise level.

When traveling at highway speeds and being in the vehicle for extended periods, the use of outside air and a selected fan speed will provide a more desirable air exchange and air quality within the passenger cabin.

When comfort is achieved, the selection of these controls settings can have an effect on the vehicle air quality and energy requirements.

## City Traffic After Vehicle Hot Soak

Upon initial entry, open vehicle windows for a few minutes to exchange the hotter vehicle air with the cooler outside air.

After closing the vehicle windows and it is extremely hot in the vehicle,

*Figure 7 - AC17 Test Cycle*

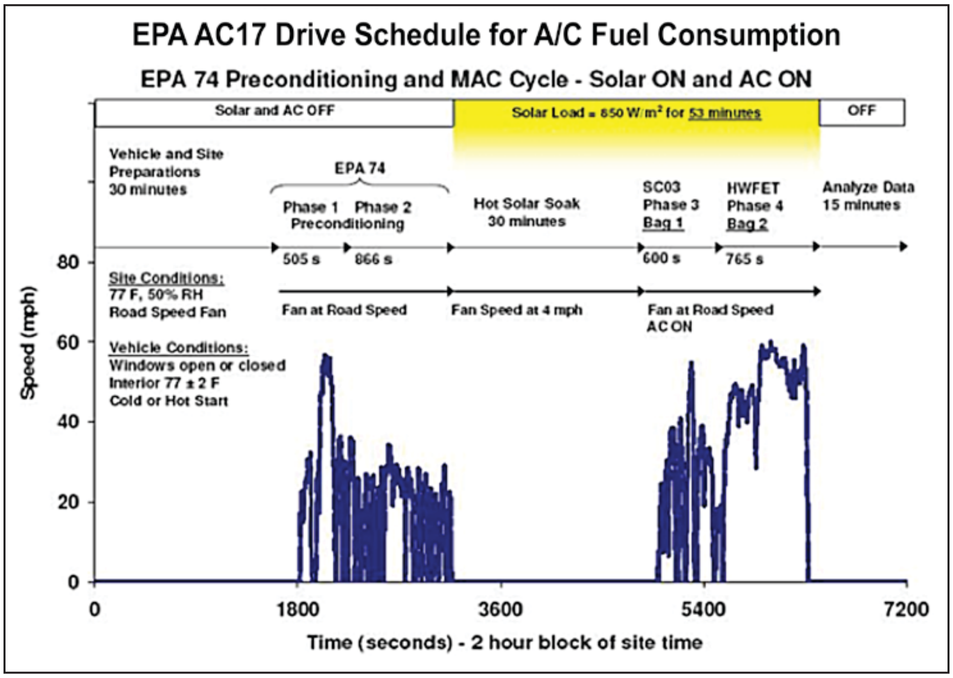
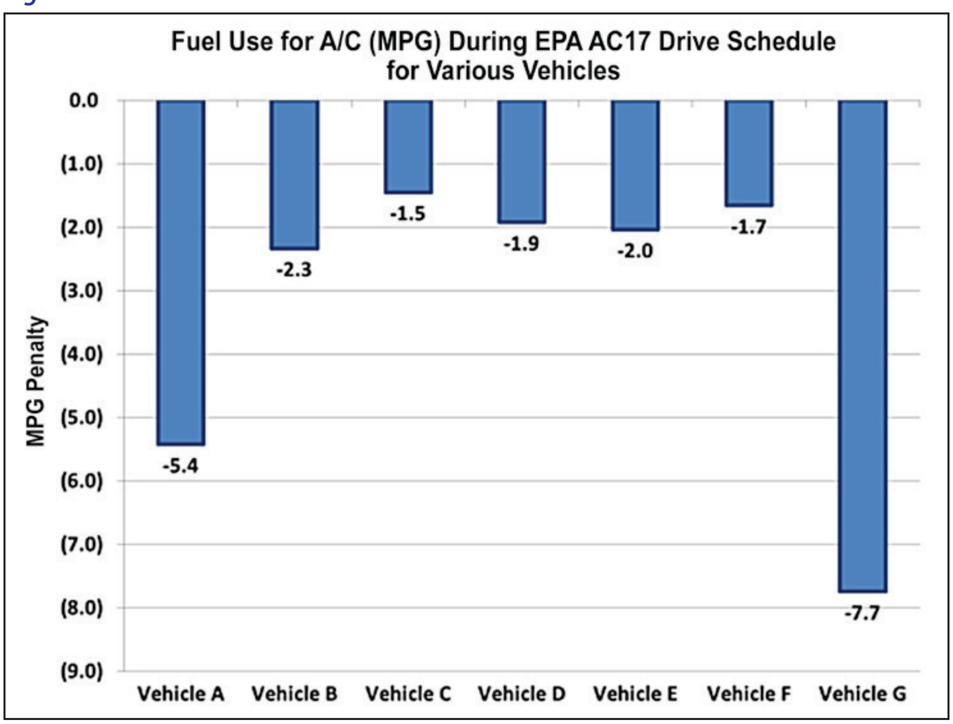



*Figure 8*



options include operating the system on normal or outside air for a few minutes. Most vehicles have a body exit vent that will allow the outside air to purge the cabin of hot air. After this, set the A/C system control to max (or in some vehicles, just using the recirculated air symbol). This will provide the best cooling performance. As the interior of the cabin begins to reach some level of comfort, reduce the fan speed to the desired comfort and noise level.

## Highway

Highway driving impacts A/C compressor performance, resulting in increased cooling capacity.

Initially the A/C should be set for max full cold, highest fan speed. As the interior of the cabin begins to reach some level of comfort, reduce the fan speed to the desired comfort and noise level.

When driving for extended periods of time, to improve air quality within the passenger cabin, changing the A/C air selection to outside air for 5 to 10 minutes each hour is recommended. When the system is operated on max it is continually recirculating 100% of the cabin air. When operating in outside air mode, air enters into the air inlet at the base of the windshield and exits outside the cabin on vehicles equipped with body exit vent systems. This results in improved air exchange within the vehicle cabin.

## Windows Open Versus Closed

When operating at low speed city traffic conditions, setting the A/C system on max and adjusting the fan speed for desired comfort requires energy as compared with no A/C with windows open.

## Summary

The choice involves your, and your passenger's comfort and driver fatigue issues. There are many factors that impact how much fuel is used, including the specific vehicle fuel use (MPG rating) for the type of driving and the temperature and humidity conditions. Depending upon many factors, as noted above, including the vehicle drag value, the energy requirements can be very slightly different to being the same to operate the A/C system versus shutting off the A/C system and opening the vehicle's windows.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## Technical Papers and References

### *SAE International Web Site*

For the SAE CRP reports and some of the ARSS presentations: http://www.sae.org/standardsdev/tsb/cooperative/altrefrig.htm

For the majority of the AARS, ARSS and ARSES presentations: http://www.sae.org/events/aars/presentations/

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http://www.macsw.org/imis15/MACS

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- Effects of Air Conditioner Use on Real-World Fuel Economy 2013-01-0551. Published 04/08/2013, Shean Huff, Brian West and John Thomas Oak Ridge National Laboratory