Mobile Air Conditioning: Issues

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K.G. DULEEP
Energy and Environmental Analysis, Inc.
www.eea-inc.com

Mobile A/C Systems

- Presentation overview:
  - Overview of basic current Air Conditioning (A/C) systems.
  - A/C impact on Fuel Economy (FE) and Green House Gas (GHG) emissions.
  - Ways to mitigate the indirect GHG emissions.
  - Ways to mitigate refrigerant leakage.
  - Alternative refrigerants.
  - Direct and indirect emissions reduction potential and estimated costs.
  - The A/C contribution to vehicle FE.
  - Laboratory test correlation to real world.

Overview of Mobile A/C Systems

- A current basic mobile A/C system consists of engine powered compressor activated by an electrical clutch. The device compresses and heats up the refrigerant. The condenser heat exchanger rejects the heat to outside air. The refrigerant leaves the condenser in liquid phase.
- The refrigerant then is directed through series of control valves/switches and fluid reservoir to an expansion valve. The expansion valve sprays the refrigerant into the evaporator coil. The refrigerant vaporizes and cools, thereby cooling the vehicle interior.
- R-134a is the only new vehicle refrigerant currently used in the U.S. The previous generation refrigerant, R12, was banned and phased out in early 90s due to ozone layer depletion concerns.

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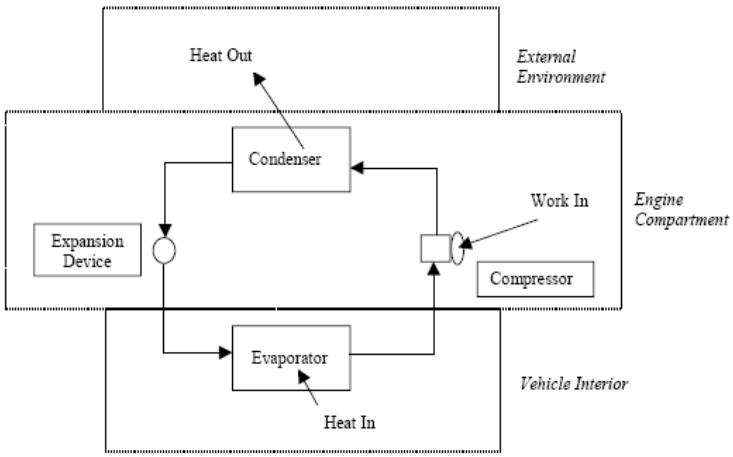
Mobile A/C Basic Schematic



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A/C Contribution to FE and GHG Impact

- Mobile A/C impacts GHG emissions through two factors labeled direct and indirect. Indirect emissions are due to increased tailpipe emissions which affect fuel economy.
  - When operating, the A/C place an additional load on vehicle engine and electrical system.
  - Components are heavy and influence FE through increased weight.
- The A/C system contributes to direct GHG emissions through refrigerant leakage during operation, accidents, maintenance and end-of-life.

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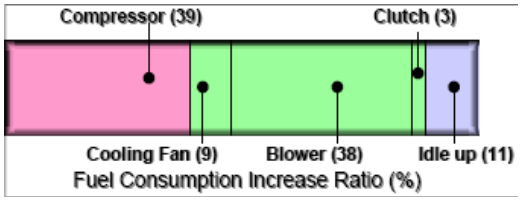
Fuel Consumption Increase

- During operation, power absorbed by the compressor accounts for less than half of total energy requirement. Other major energy losses are from the blower and the need to increase idle speed to provide adequate cooling.



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A/C Usage Effect on FE Laboratory Analysis

- The most recent large-scale analysis was performed by the US EPA. The "A/C on" effect cycle is represented by SC03 test, which is a standard EPA cycle run at 95˚F with A/C at max setting.
- "No A/C" test represented by the standard FTP test, modified to remove the "Bag 1" (cold start portion) to make the cycle more comparable to SC3 (hot soak start).
- The re-weighted FTP Bag 2 and 3 data (to match SC03 average speed) was used as the "no AC" baseline for analysis of fuel consumption impact on SCO3 cycle,

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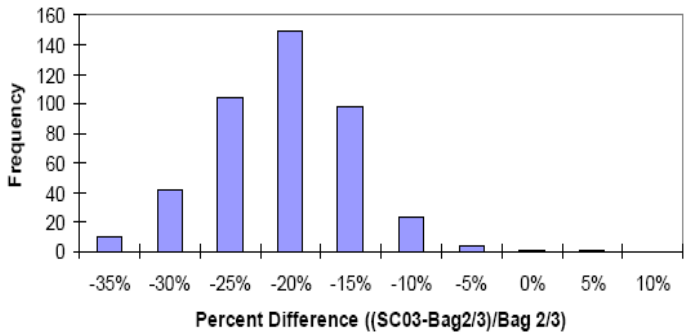
Laboratory Work - Results

- EPA analysis showed that, on average, A/C operation at 95˚F reduced FE of conventional gasoline vehicle by 20% .
- The standard deviation of the percentage difference was 5.9%, but hybrid vehicles had greatest FE loss



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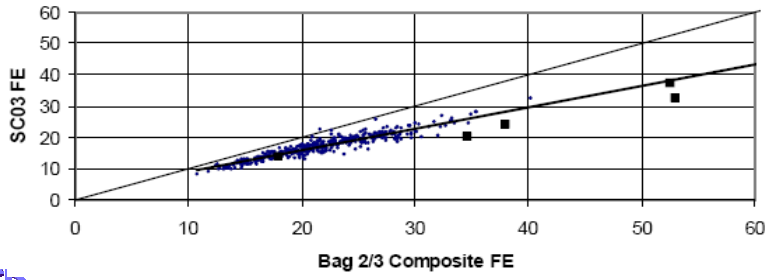
Results - continued

- Linear fit was found to be good representation of FE difference:
  SC03 FE = 0.681 * (FTP Bag2/3 Composite FE) + 2.343
- Hybrids showed higher difference (30.7%, squares on the plot), due to A/C operation higher absolute contribution to reduced fuel economy



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Indirect GHG Emissions Reduction Potential

- Lower indirect A/C GHG emissions can be achieved by component redesign and cycle efficiency improvements, as well as general weight reduction techniques.
- Examples:
  - **Variable displacement compressor.** Engine load can be optimized by adjusting compressor output, as oppose to on/off cycling.
  - **Electrical compressor.** Eliminates clutch and drive belt losses. Substitutes the belt drive with direct drive electric motor. Allows engine-off at idle, while the A/C continues operating.

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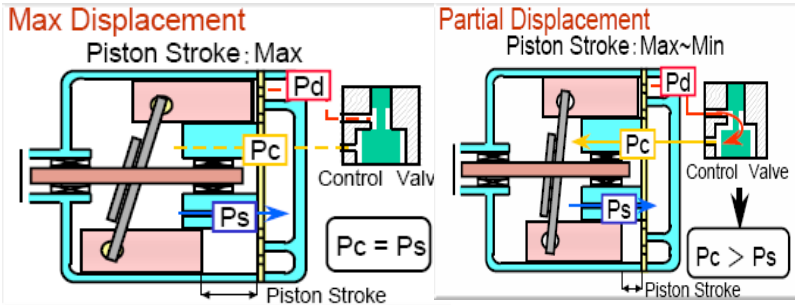
Variable Displacement Compressor



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Indirect GHG Emissions - Continued

- Improved air conditioner technology examples:
  - **Condenser Redesign.** High performance subcool-type condenser can reduce engine load by 10% for equivalent performance.
  - **A/C Control Integration.** A/C load can be coordinated with powertrain demand to reduce A/C load during acceleration, for example. Run A/C at max during deceleration and store cold air for later demand.
  - **Air Inlet Mixture Control**. Mix fresh and re-circulated cabin air to reduce cooling load

Source: Toyota/Denso

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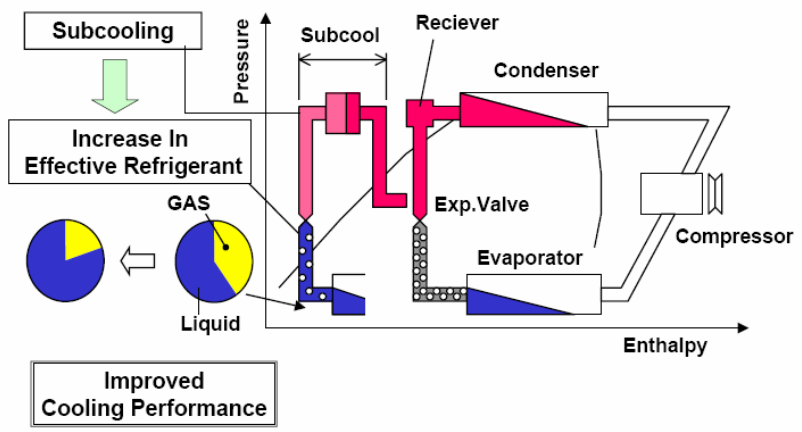
Denso Sub-cool Cycle



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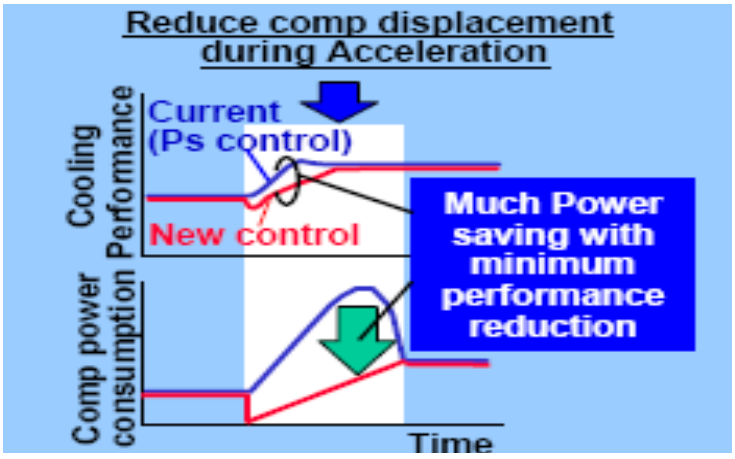
Effect of Control Strategy



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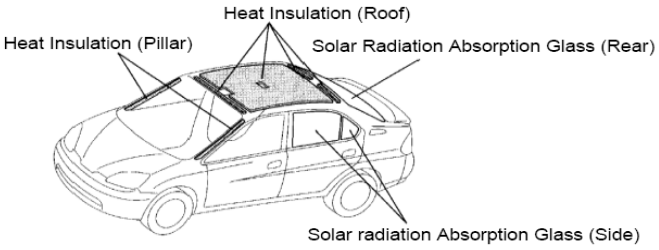
Indirect GHG Emissions - Continued

- Vehicle-based heat load reduction measures:
  - Solar reflective glass and roof surface, body insulation.
  - Hot soak ventilation such as solar powered fan.
  - Ventilated or climate controlled seats
  - Increased use of re-circulated air.



Source: Toyota/Denso

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Direct GHG Emissions Reduction Measures

- Reduced leakage R-134a systems:
  - Low-permeability hoses and seals, Improved connectors.
- Alternative refrigerants:
  - HFC-152a has GWP of 120. Overall similar to R-134a, therefore, adaptable to existing A/C components.
  - CO_2 (R744) by definition has GWP of 1. Existing components can not be used due to higher pressure requirements (7-10 times higher compared to R-134a).
  - In addition to technical and safety issues, all alternative refrigerants are forecast to increase system costs.

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Mobile A/C GHG Emissions Reduction Future Potential

Refrigerant	Direct Leakage Reduction [%]	Direct Leakage [g/mi CO_2]	Direct Leakage Reduction [%CO_2]	Indirect Emissions Reduction [%CO_2]	Additional Cost [$]
R-134a	Baseline	Baseline = 6	Baseline	Baseline	Baseline
R-134a Enhanced	50	3	50	30	25 to 40 (RPE 38 to 60)
R-152a	50	0.3	95	5 to 20	About 70 (RPE 105)
CO_2	N/A	~0	N/A	9 to 20	50 to 180 (RPE 75 to 270)

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Laboratory Testing Correlation to Real World

In addition to SC03 and FTP (Bag 2 and 3) data, the following factors must be taken into consideration:

- A/C compressor operation fraction (EPA derived multiplier of 0.133) to represent the US estimated average ambient conditions and use
- A factor to adjust the laboratory test FTP and SC03 average speeds (21.5 mpg) to more realistic city and highway average speeds (19.9 and 57.1 mpg).

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Developing Country Issues

- As incomes increase in developing countries, demand for air-conditioning in vehicles will increase.
- Demand for AC already showing sharp increases in India and China, but is still small as a percent of light vehicle sales.
- Combined effect of vehicle sales growth + increased AC penetration will be very large

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Developing Country Issues

- Percent impact of AC on indirect emissions and Fuel Economy will be much larger because 1) engine sizes are smaller and 2) tropical weather will require AC operation for most of the year.
- Direct GHG emissions may be huge due to lack of refrigerant recapture during service and **no** end-of-life recycling.

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Summary

- MAC is a critical area for fuel consumption and total GHG emissions.
- Impact of increased MAC usage in developing countries will be very large unless effective solutions and enforcement of refrigerant re-cylcing occurs.
- Fortunately, a number of technical solutions appear possible and need encouragement.

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