Mexico City Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning

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First International Conference on Carbon Management at Urban and Regional Levels: Connecting Development Decisions to Global Issues
September 7, 2006
Situation and Opportunity

• Situation
  – Global motor vehicle market is growing rapidly
  – Most vehicles will be air conditioned
  – Air conditioning could be 30% of total fuel use
  – Refrigerant emissions are greenhouse gases

• Opportunity for government and industry
  – MAC emission reduction partnership
  – Secure International financing to jump-start transformation
  – Select new mobile AC technology, satisfying customer demand for comfort, fuel-efficiency and environmental quality
Predicting Fuel Used for AC

Fuel use increased up to 30%
Even more with hybrid vehicles!

A/C Cooling 3-6 kW_{th}
Predicting Mexico City Fuel Used for AC

- Use Multiple Models/Inputs/Data Sets
  - Environmental Conditions (Temperature, Humidity, W/m² Solar)
  - Thermal Comfort Model
  - Vehicle Simulations (Fuel Economy Reduction with AC)
Environmental Conditions: Mexico City: Temperature

IWEC Data Base
International Weather for Energy Calculations
Temperature, humidity, solar radiation
Mean Radiant Temperature Model

- MRT varies with vehicle type
- Vehicle data used to generate models

Model

\[ \text{MRT(car, time)} = 27^\circ \text{C} \times \frac{\text{Radiation(t)}}{1000 \text{W/m}^2} + T_{\text{ambient(t)}} \]

MRT represents average surface temperature

Reference: SAE 2002-01-1957
Mean Radiant Temperature

Mean Radiant Temperature (C) in Mexico City, Mexico

Month

Time of Day

12-6am
6-9am
9am-1pm
1-4pm
4-7pm
7-10pm
10pm-12am

Jan
Feb
Mar
Apr
May
June
July
Aug
Sept
Oct
Nov
Dec

10
15
20
25
30
35
40
45
50
Thermal Comfort Model Inputs & Outputs

Thermal Comfort Model

**Energy Balance:**
- Internal heat production
- Water vapor diffusion through skin heat loss
- Sweating heat loss
- Respiration latent and dry heat loss
- Convection heat loss
- Radiation heat loss

**Inputs**
- Air Temperature
- Mean Radiant Temperature
- Humidity Ratio
- Air Velocity
- Activity (met)
- Clothing (clo)

**Outputs**
- Predicted Mean Vote (PMV)
- Predicted Percent Dissatisfied (PPD)

Source: International Standards Organization (ISO) 7730 “Moderate thermal environments—Determination of the PMV and PPD indices and specification of the conditions for thermal comfort”
Thermal Comfort Model: Percent of People Using AC

Thermal Sensation Vote
- 3 Cold
- 2 Cool
- 1 Slightly Cool
0 Neutral
+ 1 Slightly Warm
+ 2 Warm
+ 3 Hot

PMV
- 3
- 2
- 1
0
+ 1
+ 2
+ 3

PMV from PMV

Mexico City

TMY
T
H
TC
PPD
Time
Month
City A
City X

PPD

VMT w/AC
MPG w/AC
MPG w/o AC
Gal for AC/veh
Reg
Tot Gal /State

VMT
w/AC
MPG
w/AC

Gal for
AC/veh
Reg
Tot Gal
/State

NREL National Renewable Energy Laboratory
AC Usage for Cooling

Predicted Percent Dissatisfied (%) in Mexico City, Mexico
Clothing: 0.6, Velocity: 0.1, MRT: Ambient+Rise

100% of People Have AC On
Vehicle Usage with Time of Day, Month

Mexico City

70% Daily Travel

Hour of the Day

Percentage of Travel Occurring during that Time

Summer Months: May - September

Assumed the same as U.S.
Fuel Economy Impact: Vehicle Simulations

Mexico City

Typical Mexico City Car: Simulated Nissan Tsuru
AC system: 130cc R134a compressor, 120W blower
Drive Cycle

![Graph of Drive Cycle]

**CYC_MEXICO_CITY**

- **key on**
- **speed**
- **elevation**

**Speed/Elevation vs. Time**

- **Description**
- **Statistics**

- **time:** 1394 s
- **distance:** 5.5 miles
- **max speed:** 47.16 mph
- **avg speed:** 14.21 mph
- **max accel:** 6.66 ft/s²
- **max decel:** -6.66 ft/s²
- **avg accel:** 1.53 ft/s²
- **avg decel:** -1.32 ft/s²
- **idle time:** 358 s
- **no of stops:** 14
- **max up grade:** 0 %
- **avg up grade:** 0 %
- **max down grade:** 0 %
- **avg down grade:** 0 %

**Percentage (%)**

- **Speed (mph):**
  - 0%
  - 10%
  - 20%
  - 30%
  - 40%

**Elevation (feet):**

- 0
- 0.2
- 0.4
- 0.6
- 0.8
- 1
Fuel Economy Impact: Vehicle Simulations

Mexico City

Fuel Economy (km/liter)

<table>
<thead>
<tr>
<th>Drive Cycle</th>
<th>Mexico City</th>
<th>ECE EUDC</th>
<th>FTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Economy no AC</td>
<td>11.55</td>
<td>14.81</td>
<td>14.31</td>
</tr>
<tr>
<td>Fuel Economy with AC</td>
<td>9.09</td>
<td>11.39</td>
<td>11.50</td>
</tr>
<tr>
<td>FE % drop with AC</td>
<td>21.28</td>
<td>23.08</td>
<td>19.66</td>
</tr>
</tbody>
</table>

Hot initial conditions

Typical Mexican Car: Simulated Nissan Tsuru

FTP: U.S. Standard Drive Cycle

NREL National Renewable Energy Laboratory
Vehicle Registrations
Cars, Jeeps, and Taxis

Mexico City

- 3.5% Average Annual Growth
- 2.2 million automobiles in 2000
  World Bank

> Graph showing automobile registrations (millions) from 2004 to 2016 with a linear trend line.

- TMY
- T
- H
- City A
- City B
- PPD
- Time
- Month
- PPD
- VMT w/AC
- MPG w/AC
- MPG w/o AC
- Gal for AC/veh
- Reg
- Tot Gal /State

World Bank
Distance Traveled per Year

Mexico:
• Car: 14,484 km (9,000 miles)

U.S.:
• Car: 19,214 km (11,939 miles)

Sources:
• Centro Mario Molina
• Ward’s Automotive Yearbook, 2005
Fuel Used for AC

Projected AC Fuel Use

- Billion liters
- Registered Vehicles
- Automobile Registrations (millions)

Graph showing projected AC fuel use from 2004 to 2020 with lines for Mexico City Cycle and Registered Vehicles.
Potential Fuel & CO₂ Savings in Mexico City

Baseline and 3 Scenarios:
In 2015, annual fuel savings of 38 to 77 million liters
annual CO₂ savings of 90 to 178 million kg
equal to 19,000 to 39,000 cars off the road!
Assumptions: 20 to 40% of new cars sold with A/C
I-MAC implementation by 2008 or 2010
20% of A/Cs are I-MAC
Per Vehicle Fuel Saved by Reducing AC Consumption

Assuming 30% efficiency improvement, almost 60 liters saved per vehicle.

Equivalent to 15 gal/veh/yr

At $2.30 per US gal

AC system up grade would pay for itself in 1.2 years.

30% improvement is achievable now!

I-MAC program
Conclusions

• Fuel use & CO$_2$ emissions depend on MAC design
• Technology is available to improve MAC fuel efficiency
• Mexico City can save millions of liters of fuel annually
• The cost to vehicle owners is paid back rapidly
• Collaboration is key to success
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CO₂ Reduction across the World

Billion kg CO₂: Reduction with 30% Drop in AC Power (2002)
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