Significant Fuel Savings and Emission Reductions by Improving Vehicle Air Conditioning

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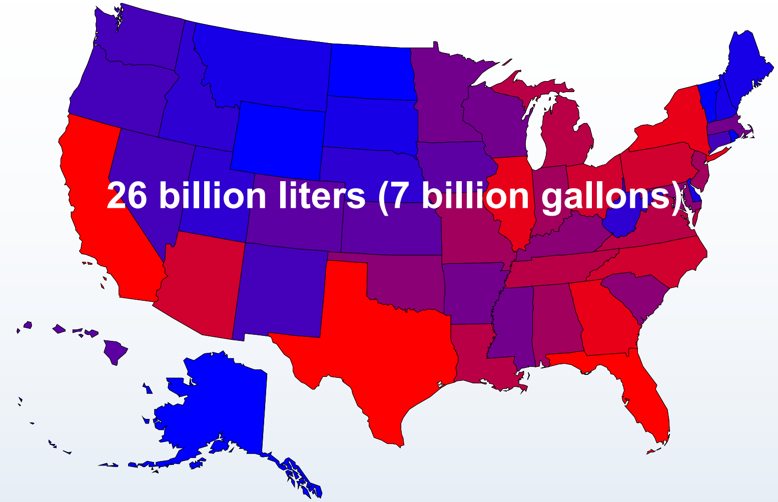
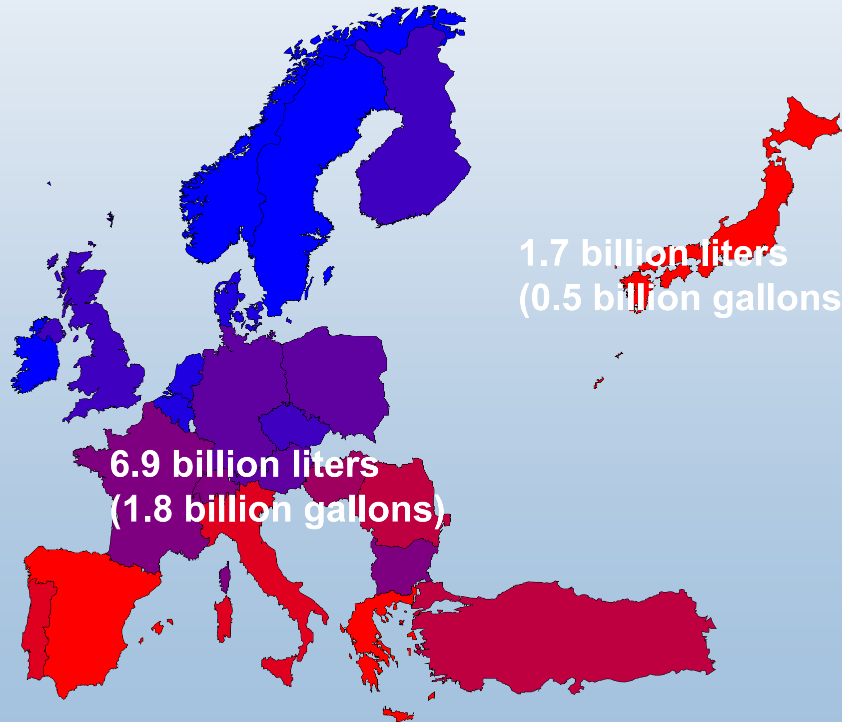
Outline

- Modeling approach
  - Thermal comfort-based AC fuel use prediction
  - Model updates

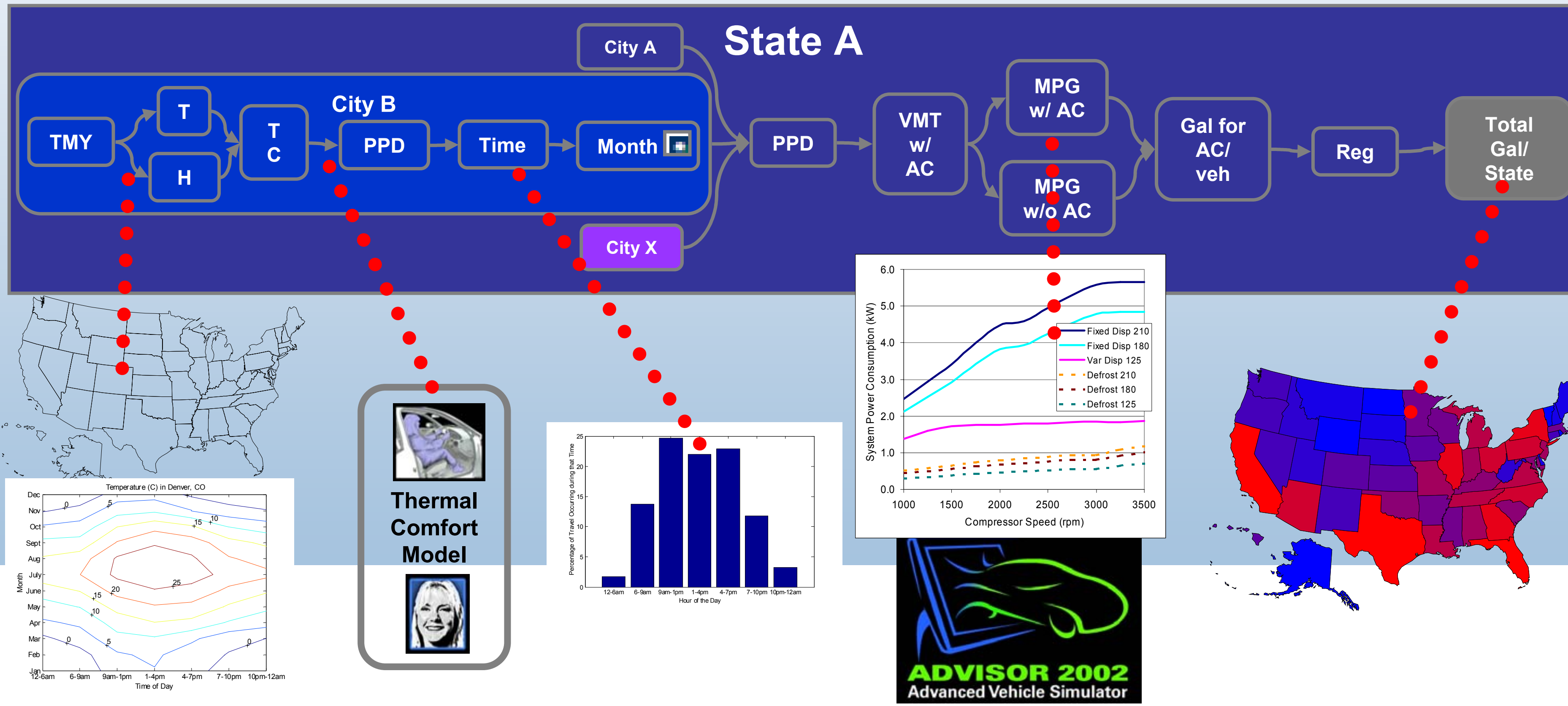
- Fuel saved for *up to 30%* drop in AC power (equal to a 43% increase in COP)
  - Per vehicle (cars, light trucks)
  - By climate
  - Total savings and CO_2 reductions across California, U.S., EU, and Japan





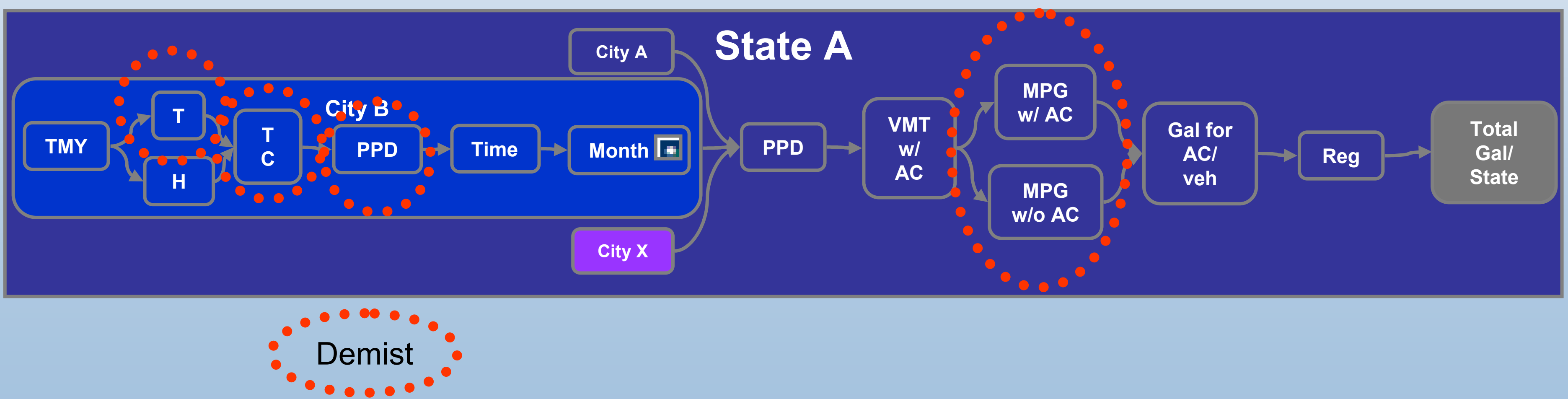
Predicting Fuel Used for AC

- Use Multiple Models/Inputs/Data Sets
  - Environmental Conditions (Temp, RH, W/m²)
  - Thermal Comfort Model
  - Vehicle Simulations (Fuel Economy Reduction with AC)

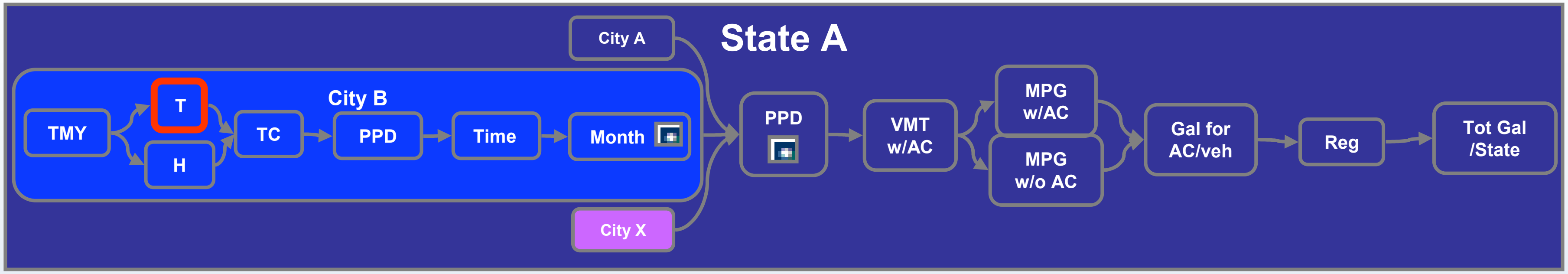


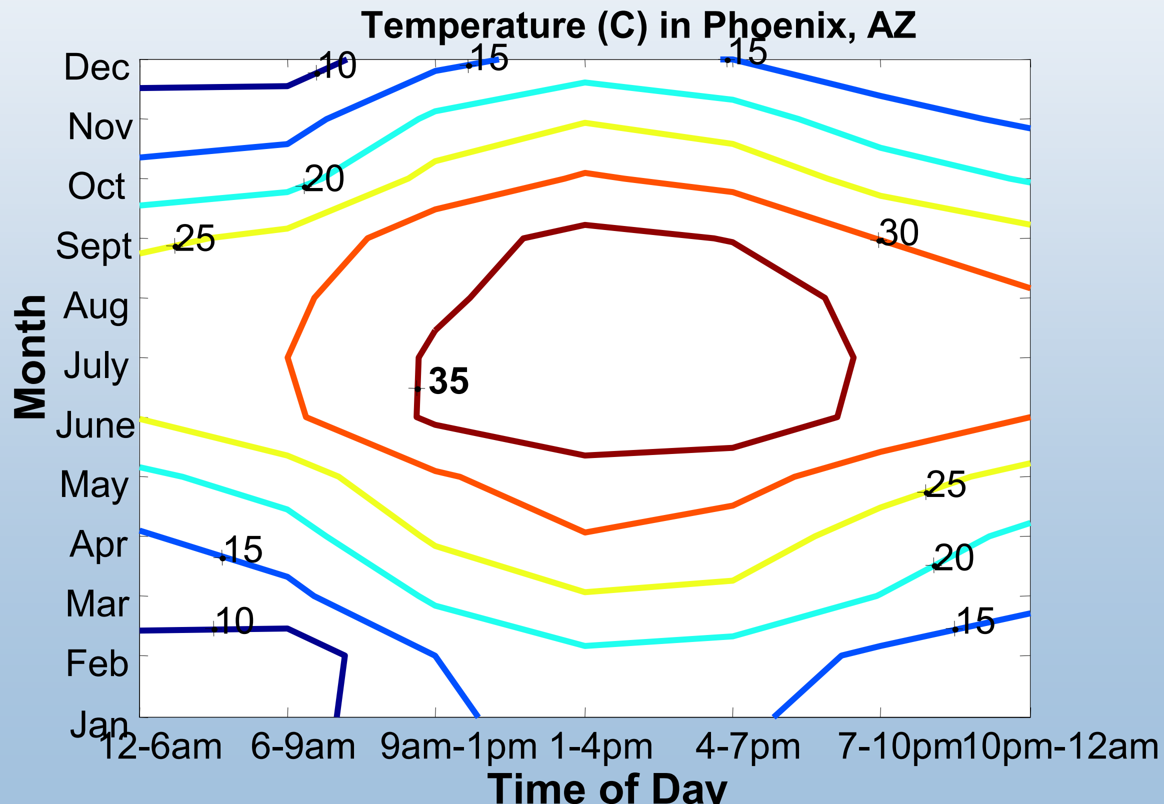
Model Updates

- Updates to U.S. study, Summer 2003
  - Mean Radiant Temperature varies with vehicle type (car, truck)
    - Therefore usage PPD varies with type
  - Thermal comfort: use one assumption for clothing and soak (MRT)
  - Include demisting
  - AC power consumption = f(type, compressor speed)



Environmental Conditions: Phoenix, AZ: Temperature





Temperature, humidity, solar radiation

Mean Radiant Temperature Models

- MRT varies with vehicle type (car, truck)
- Vehicle data used to generate models

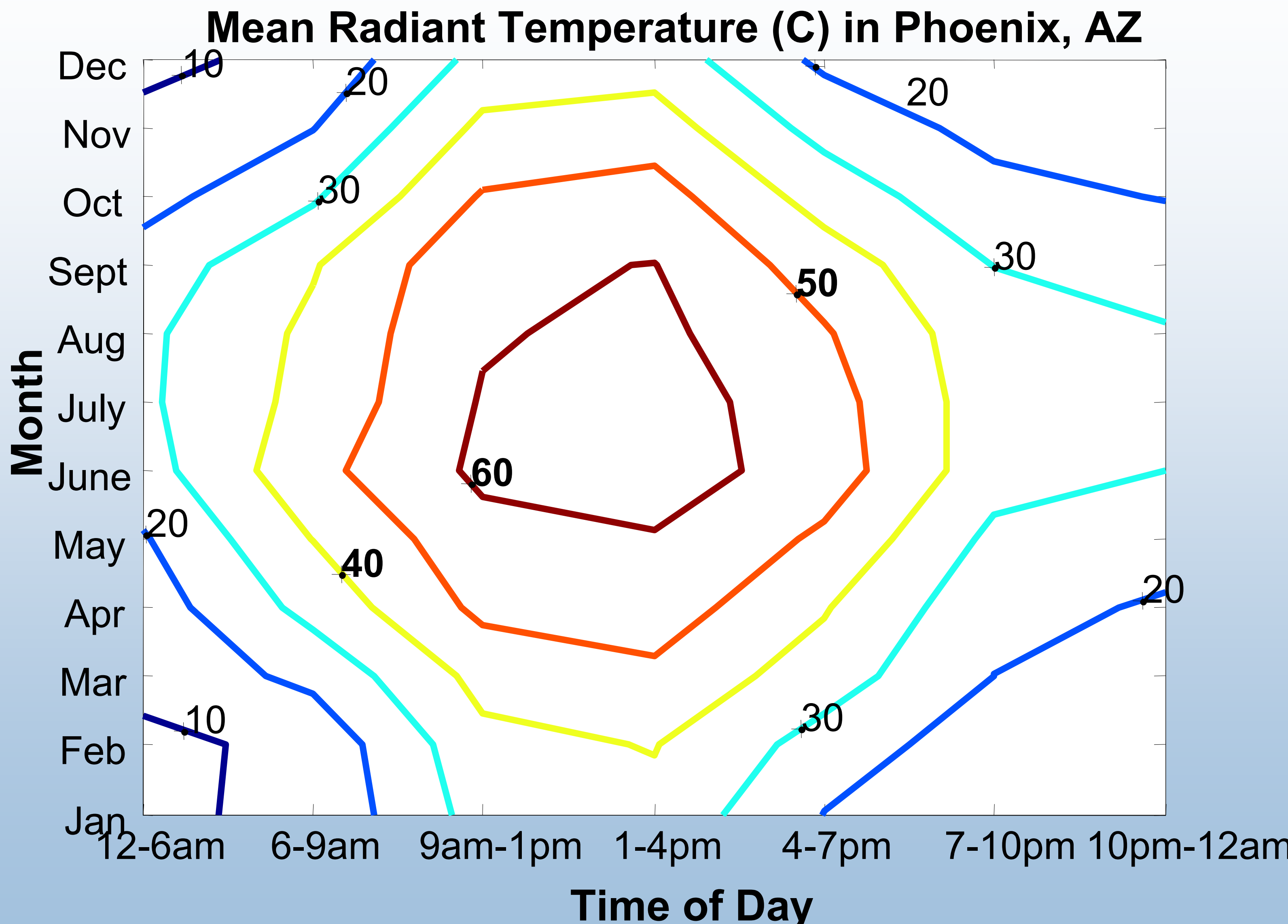
- Ford Crown Victoria
- Plymouth Breeze
- Jeep Grand Cherokee
- Ford Explorer (White)
- Ford Explorer (Black)
- Lincoln Navigator
- Dodge Grand Caravan
- Ward Atkinson – Phoenix 2002
- Bill Hill – GM Data

Models

$$MRT(car, time) = \mathbf{27°C} * Radiation(t)/1000W/m^2 + T_{ambient}(t)$$

$$MRT(truck, time) = \mathbf{24°C} * Radiation(t)/1000W/m^2 + T_{ambient}(t)$$

Mean Radiant Temperature by City



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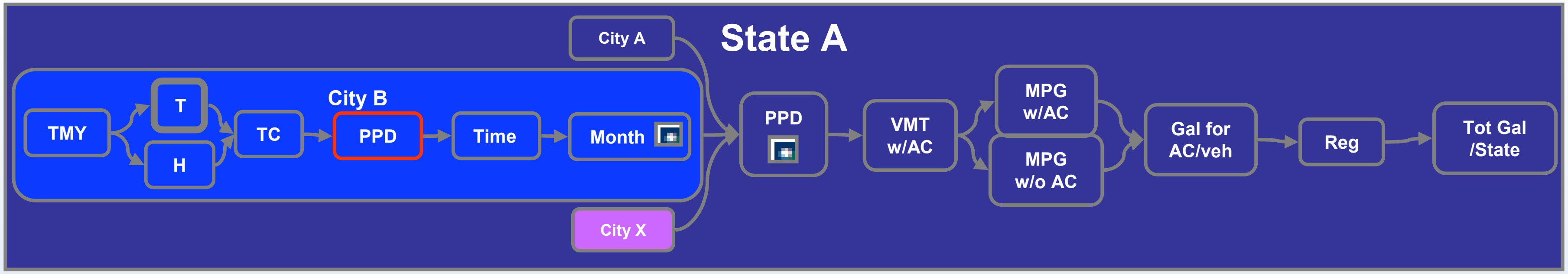
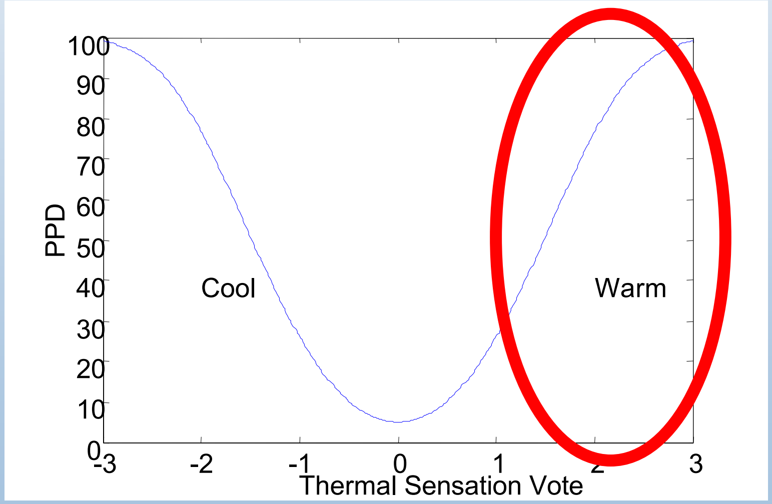
Thermal Comfort Model: Percent of People Using AC

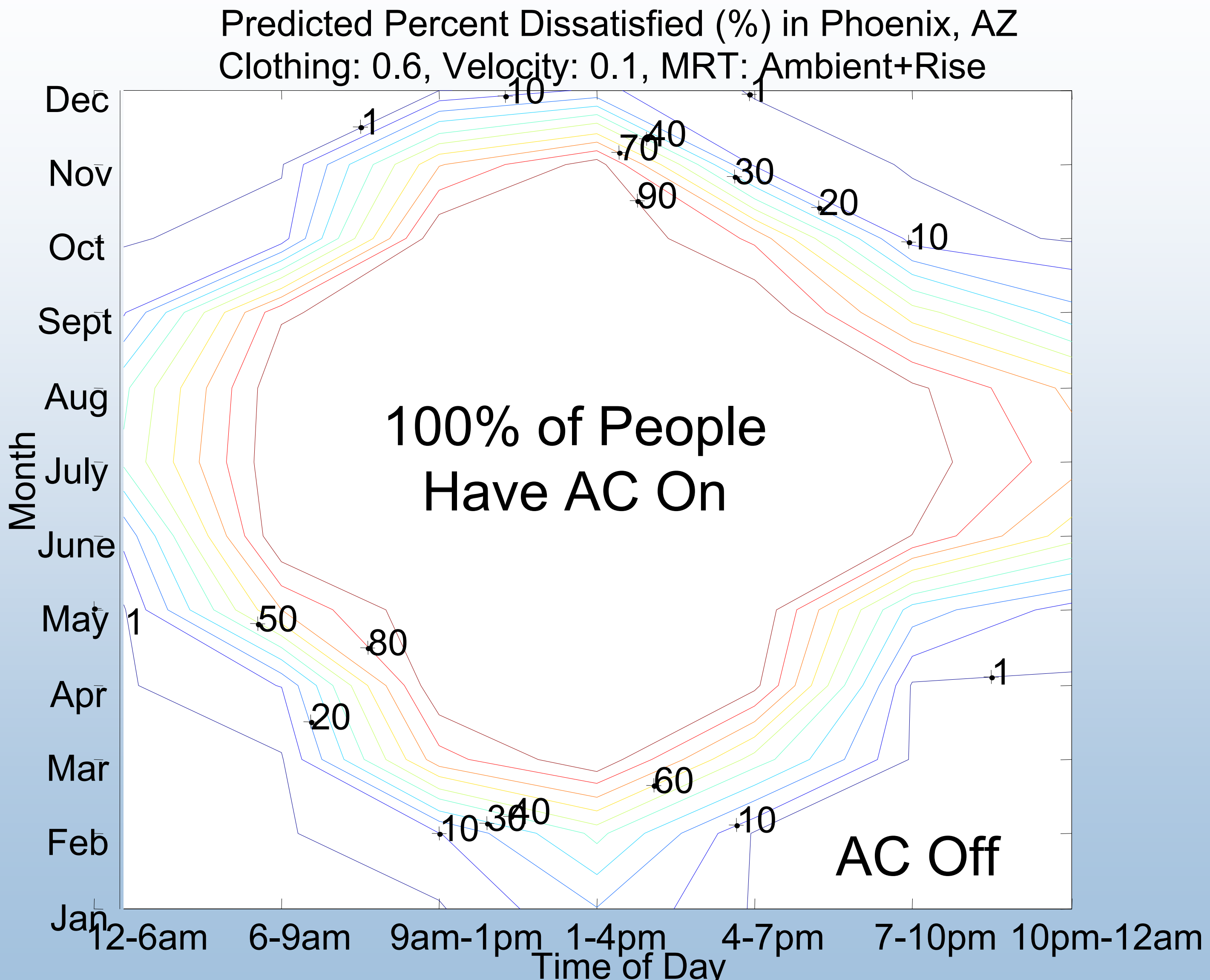


Thermal Comfort Model, *PPD from PMV*

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



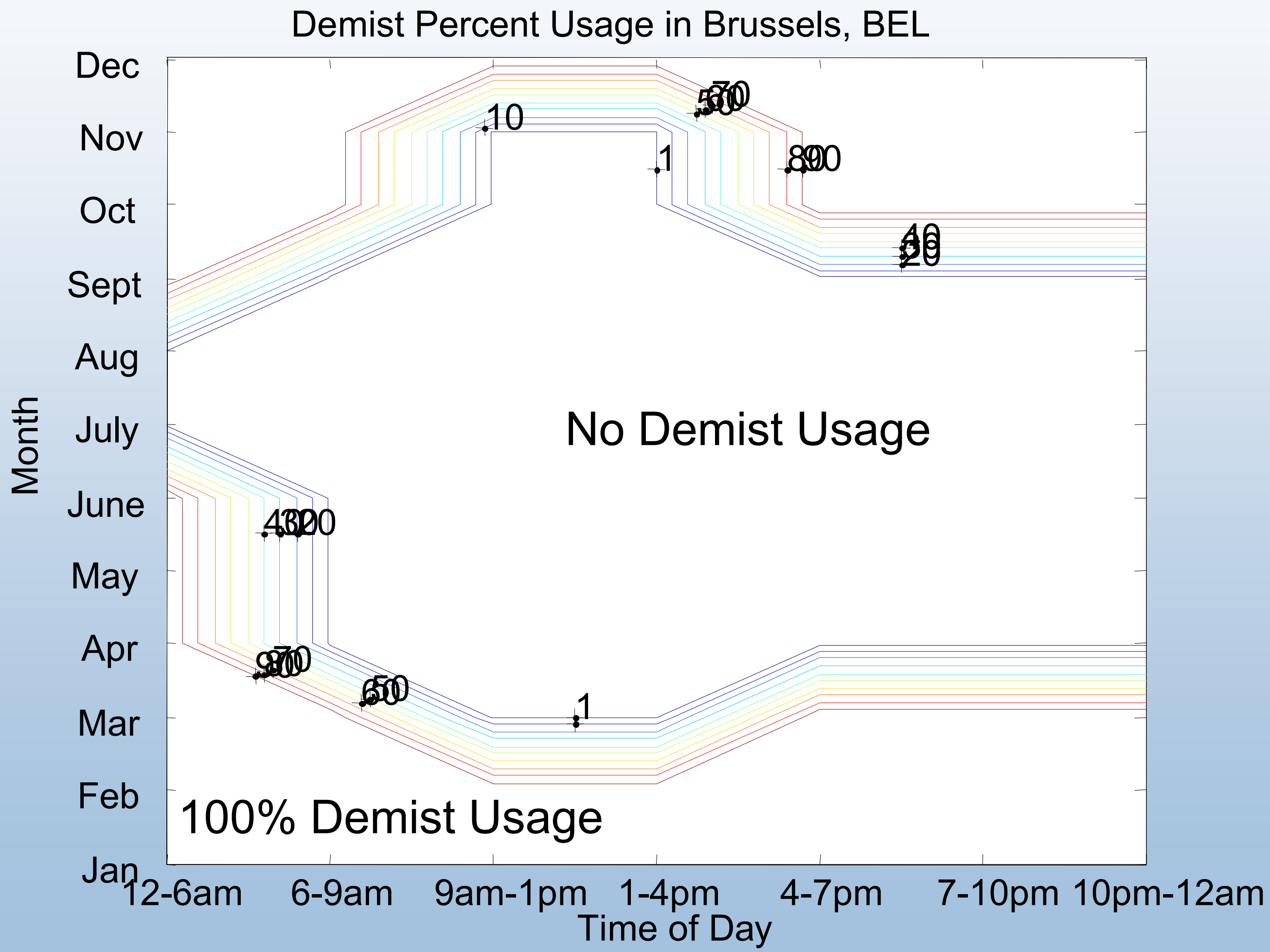
AC Usage for Cooling



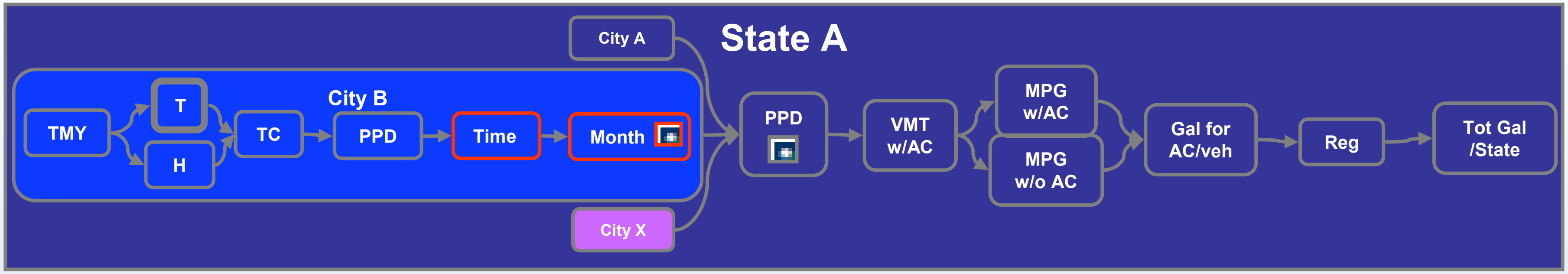
AC Usage for Demisting

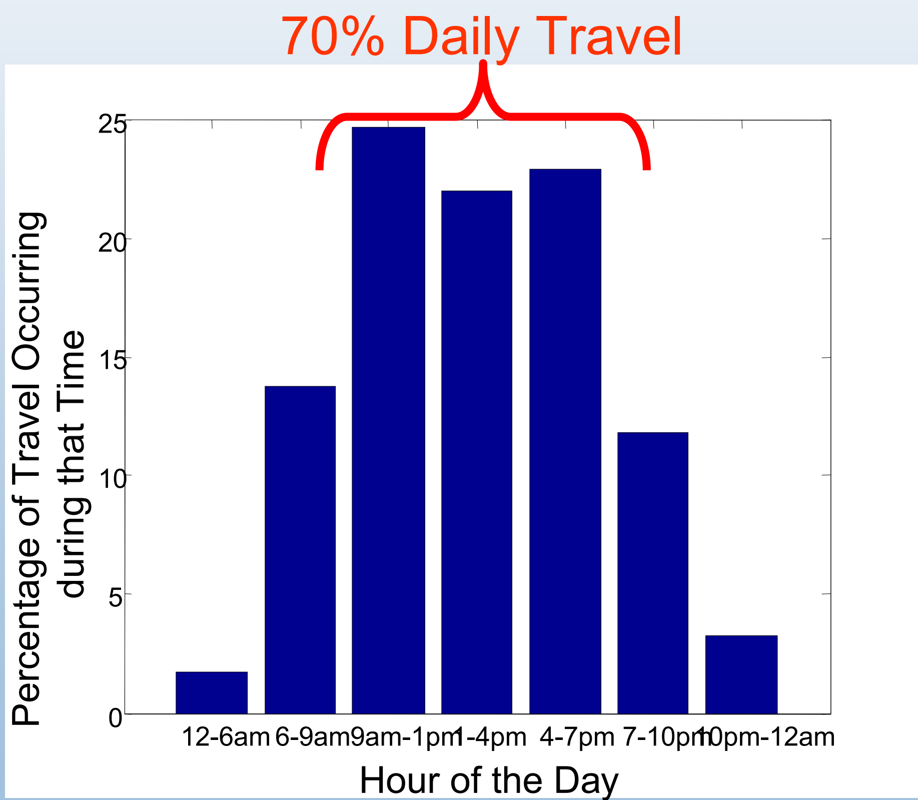
AC used for demist if:

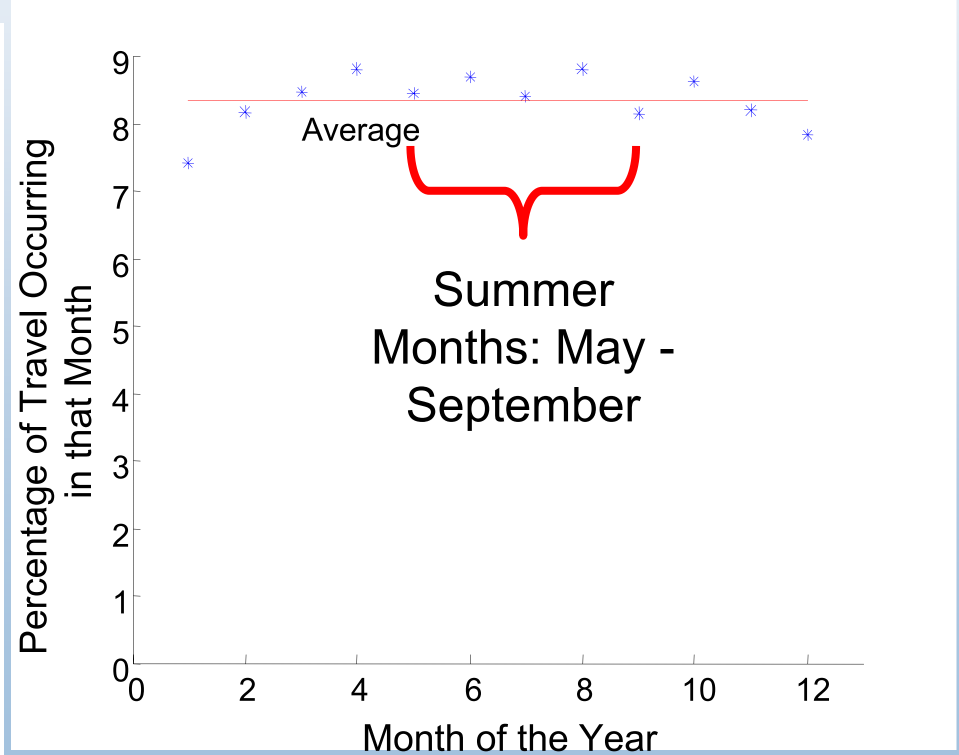
Temperature is between 1.7-12.8°C (35-55°F), and Relative Humidity > 80%



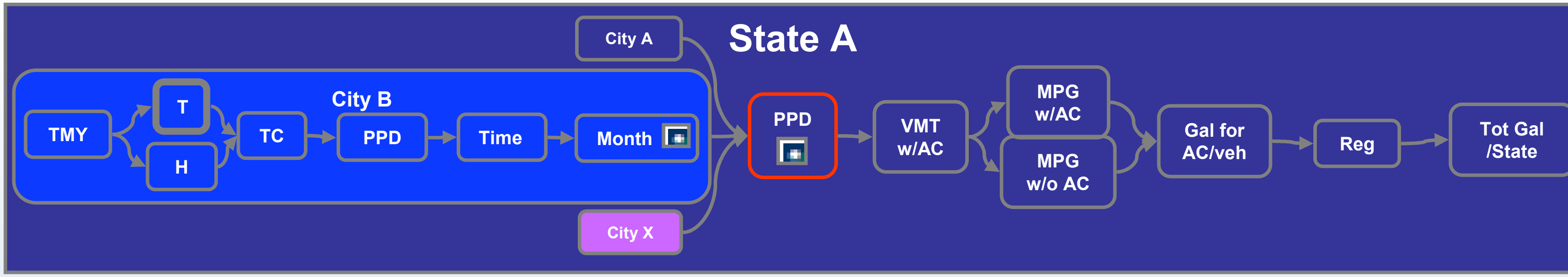
Vehicle Usage with Time of Day, Month

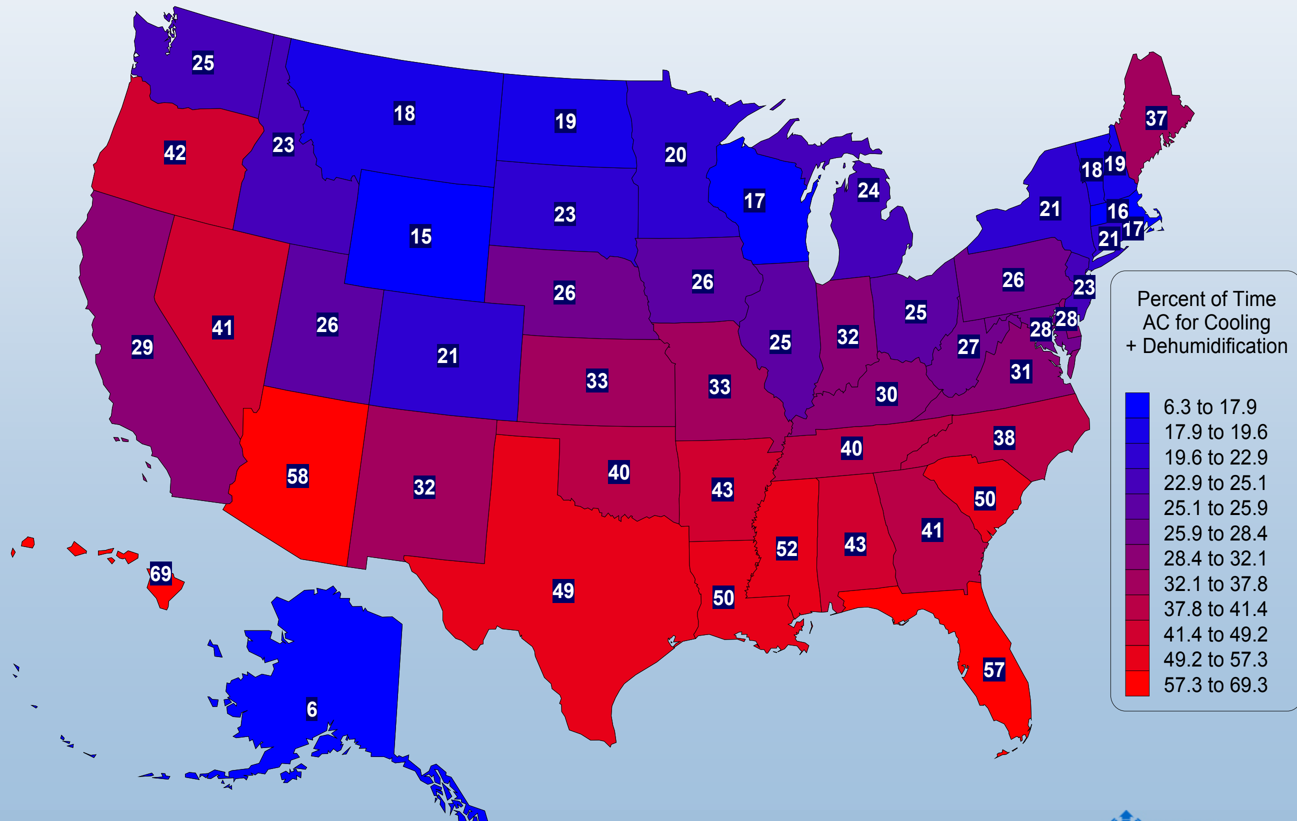






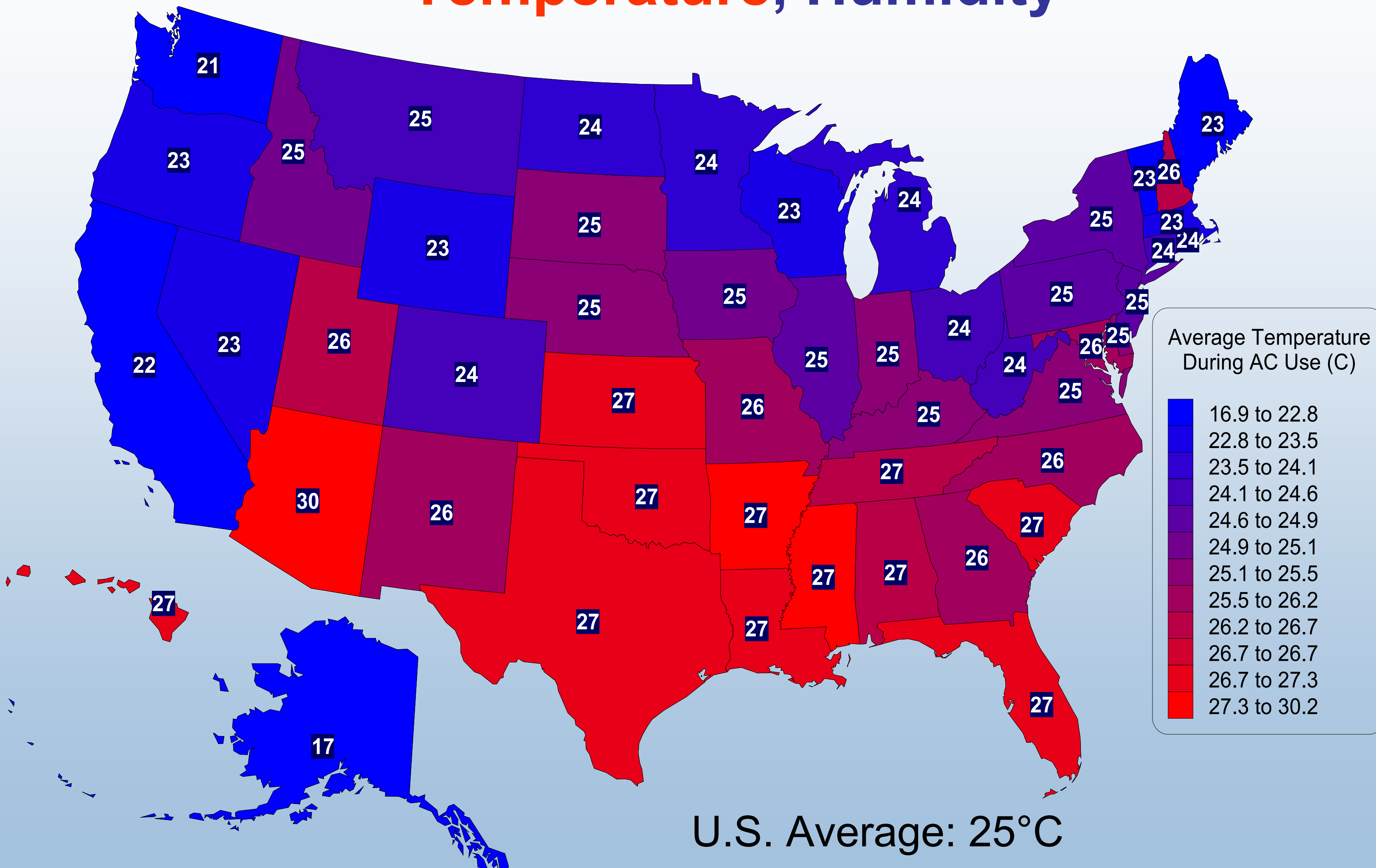
Percent of Time AC is On: Cooling + Demist





Climate during AC Use

Temperature, Humidity



Climate during AC Use

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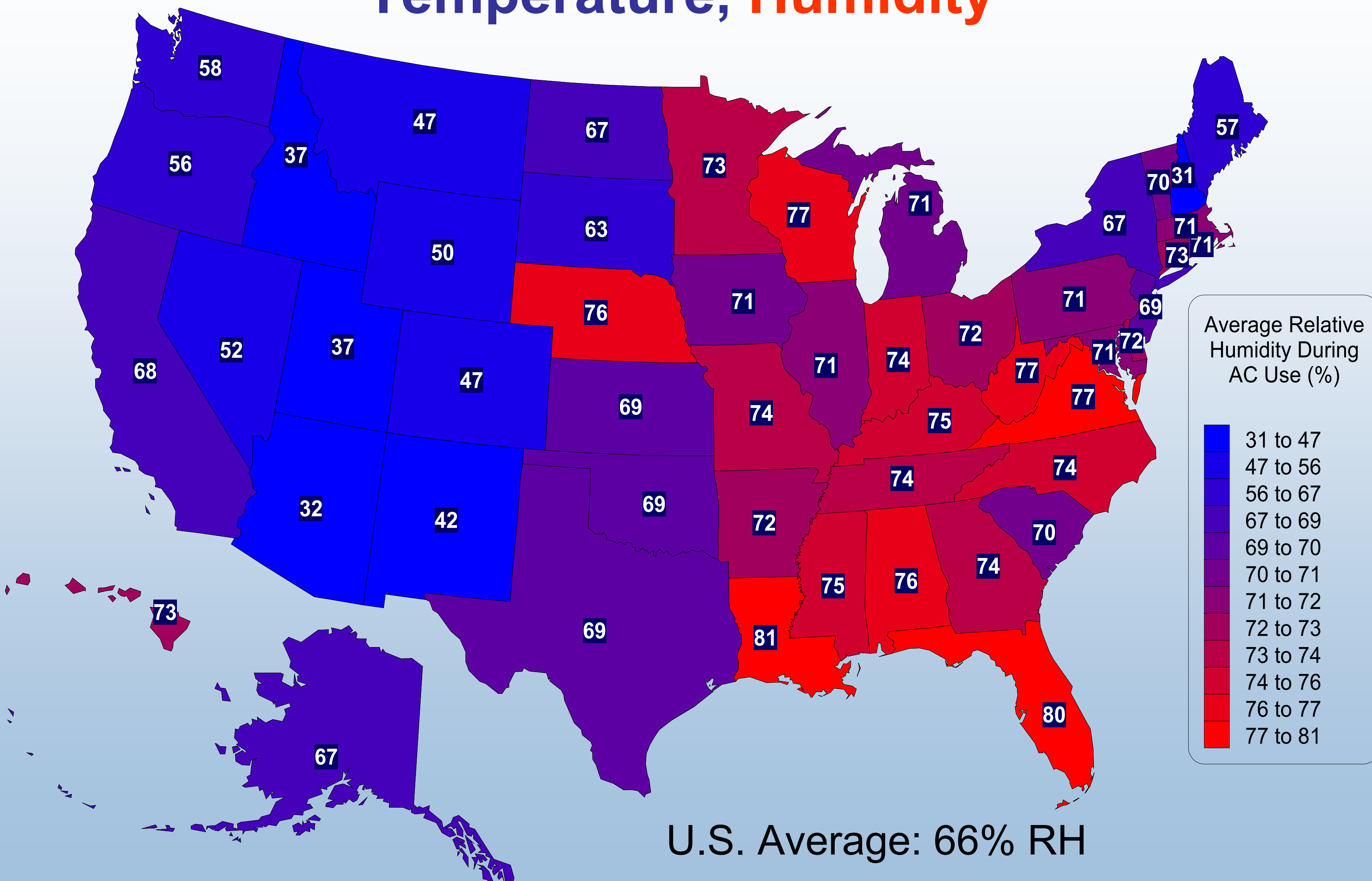
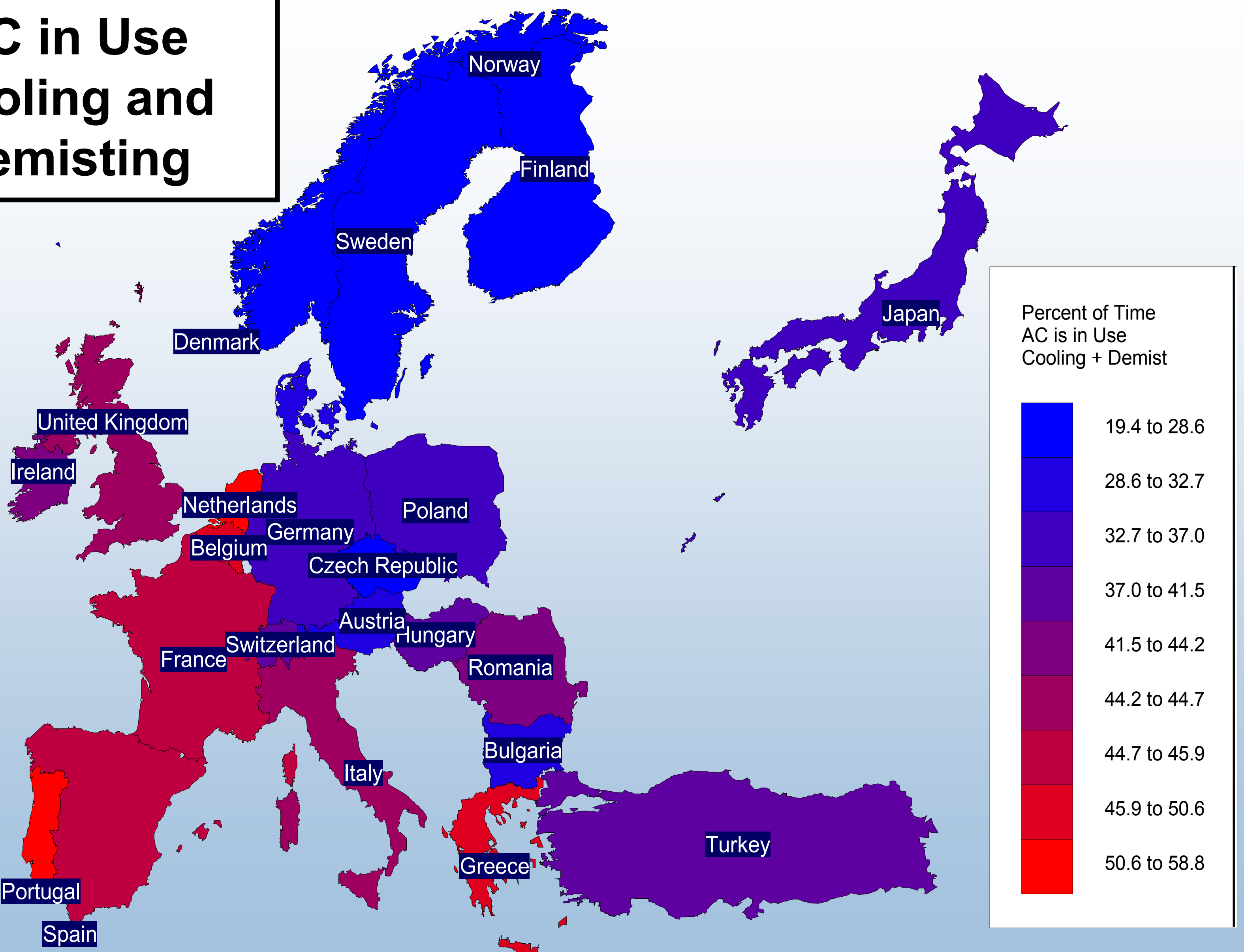
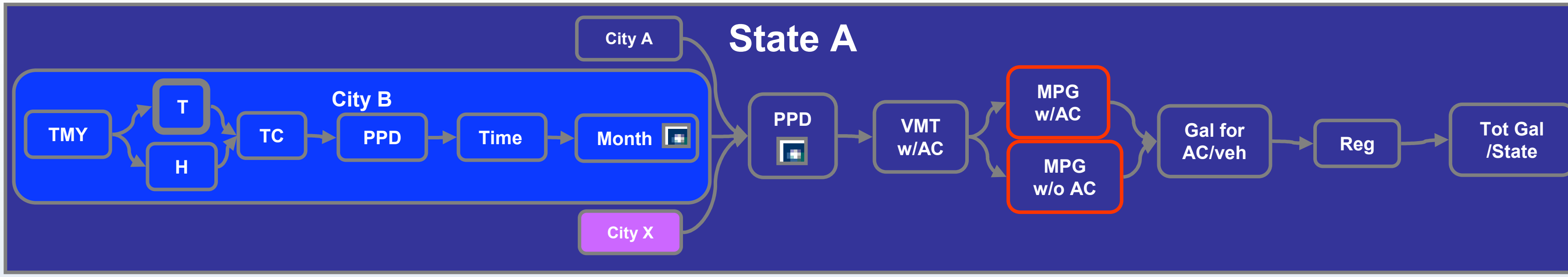


Percent of Time AC in Use Cooling and Demisting



Fuel Economy Impact: Vehicle Simulations



ADVISOR 2002
Advanced Vehicle Simulator

	US Car	US Truck	EU Vehicle
Fuel Economy no AC	22.0	18.8	30.4
Fuel Economy with AC	18.0	16.2	27.3
Fuel Economy defrost	21.1	18.1	29.0

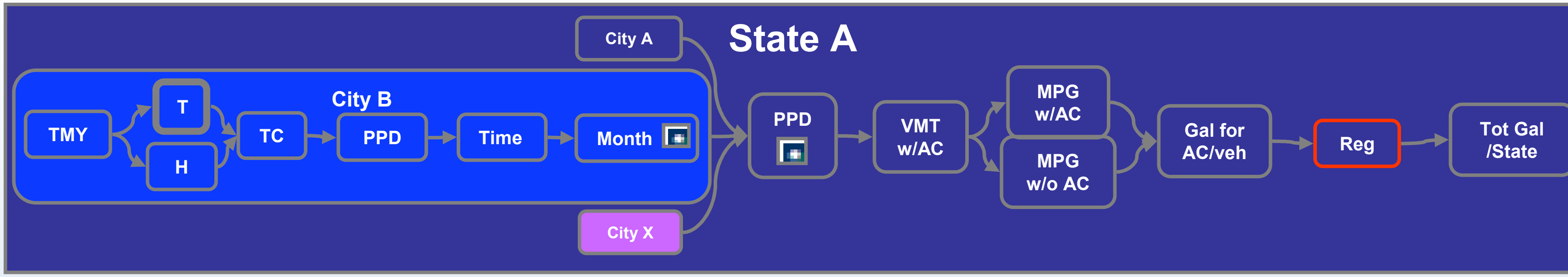
	US Car	US Truck	EU Vehicle
FE Drop with AC	18%	14%	10%
FE Drop with defrost	4%	4%	4%

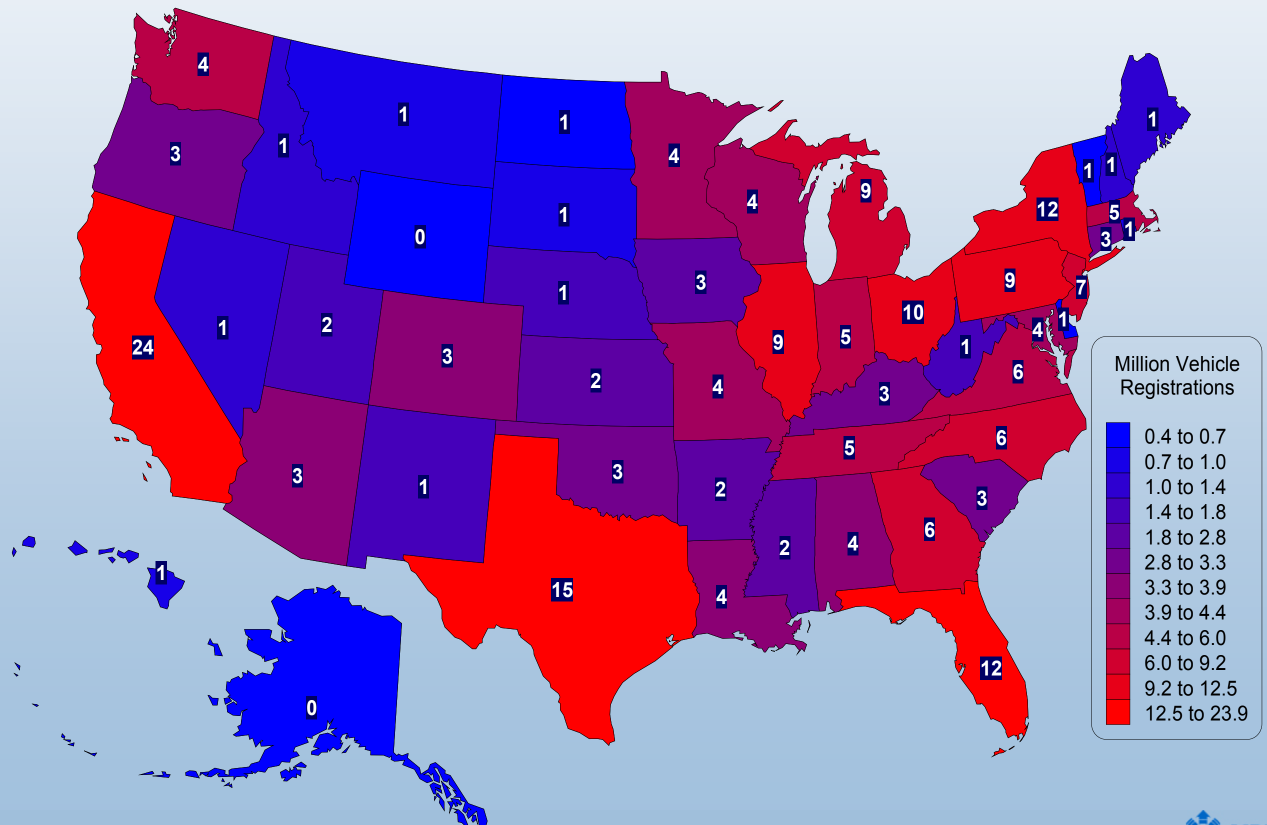
FTP drive cycle

Hot initial conditions

US car and truck based on existing fleet

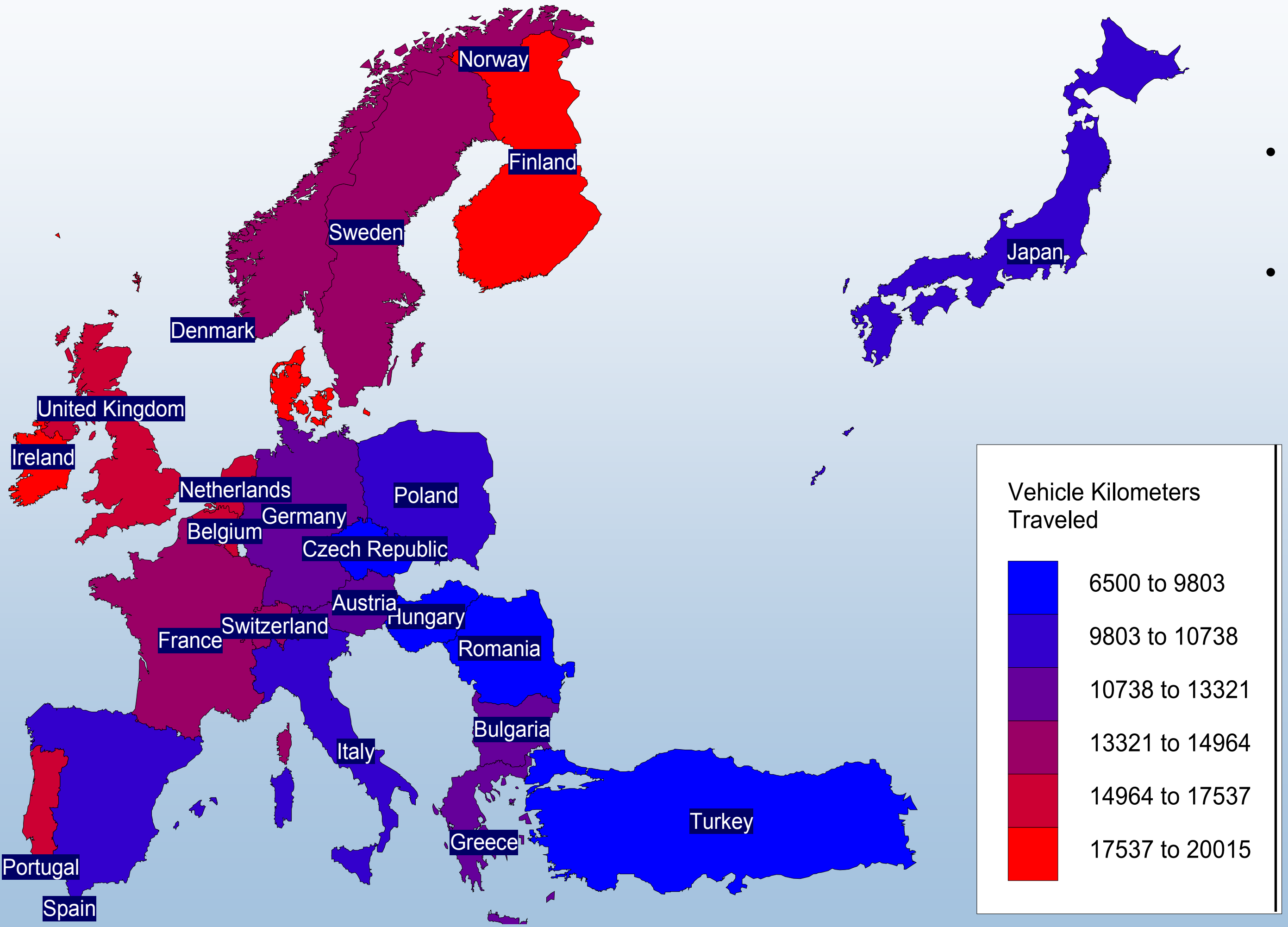
Vehicle Registrations





Total	Million Vehicles
US	213.0

Distance Traveled per Year EU and Japan



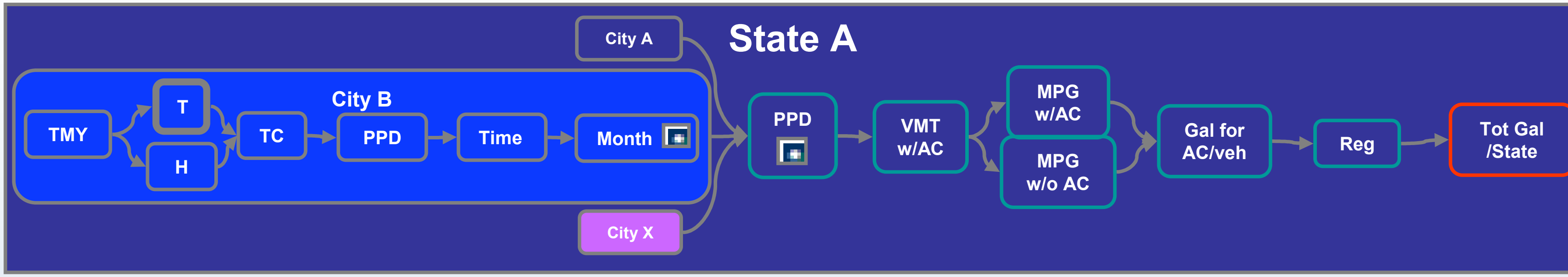
Sources:

- 2002 World Road Statistics from the International Road Federation
- International Road Traffic and Accident Database
- Ward's Automotive Yearbook, 2001

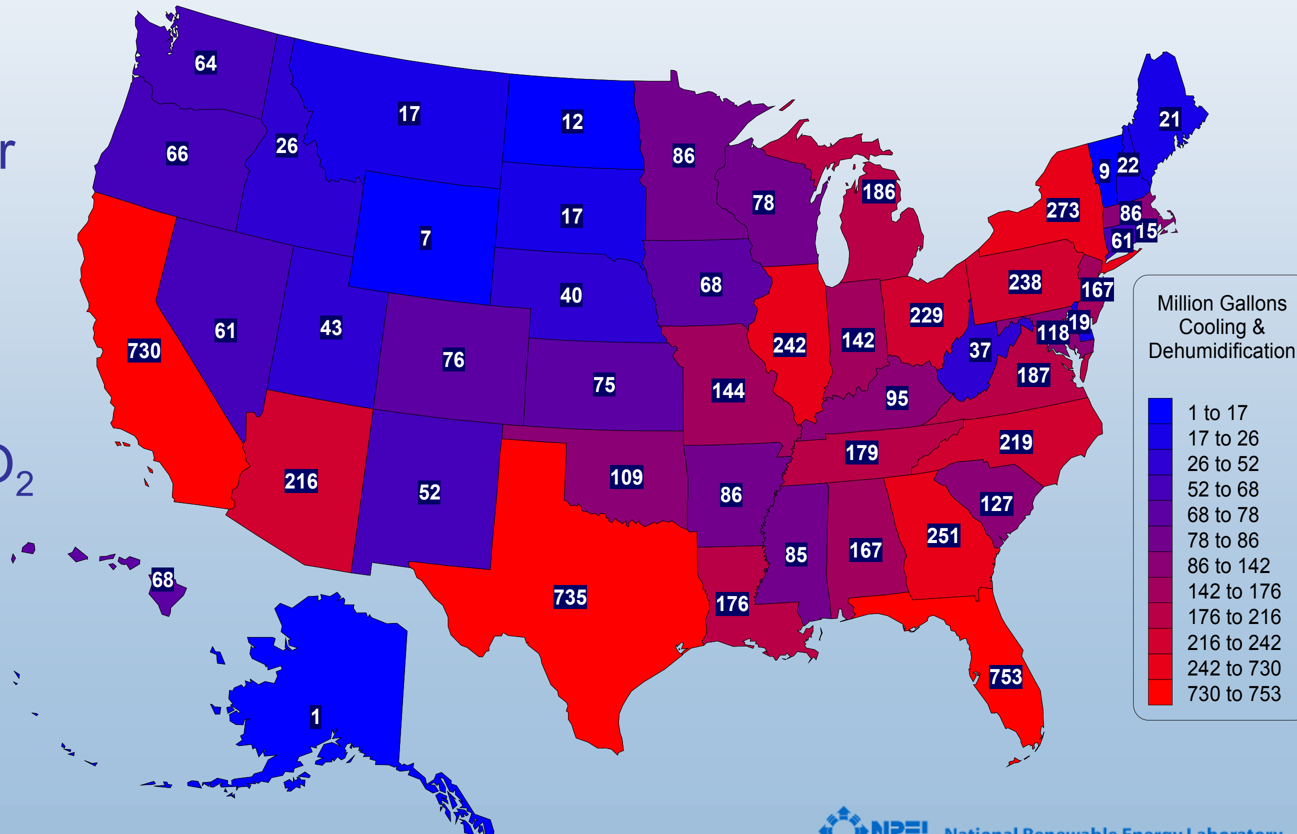
U.S.:

- Car: 11,850 miles (19,070 km)
- Truck: 11,958 miles (19,244 km)

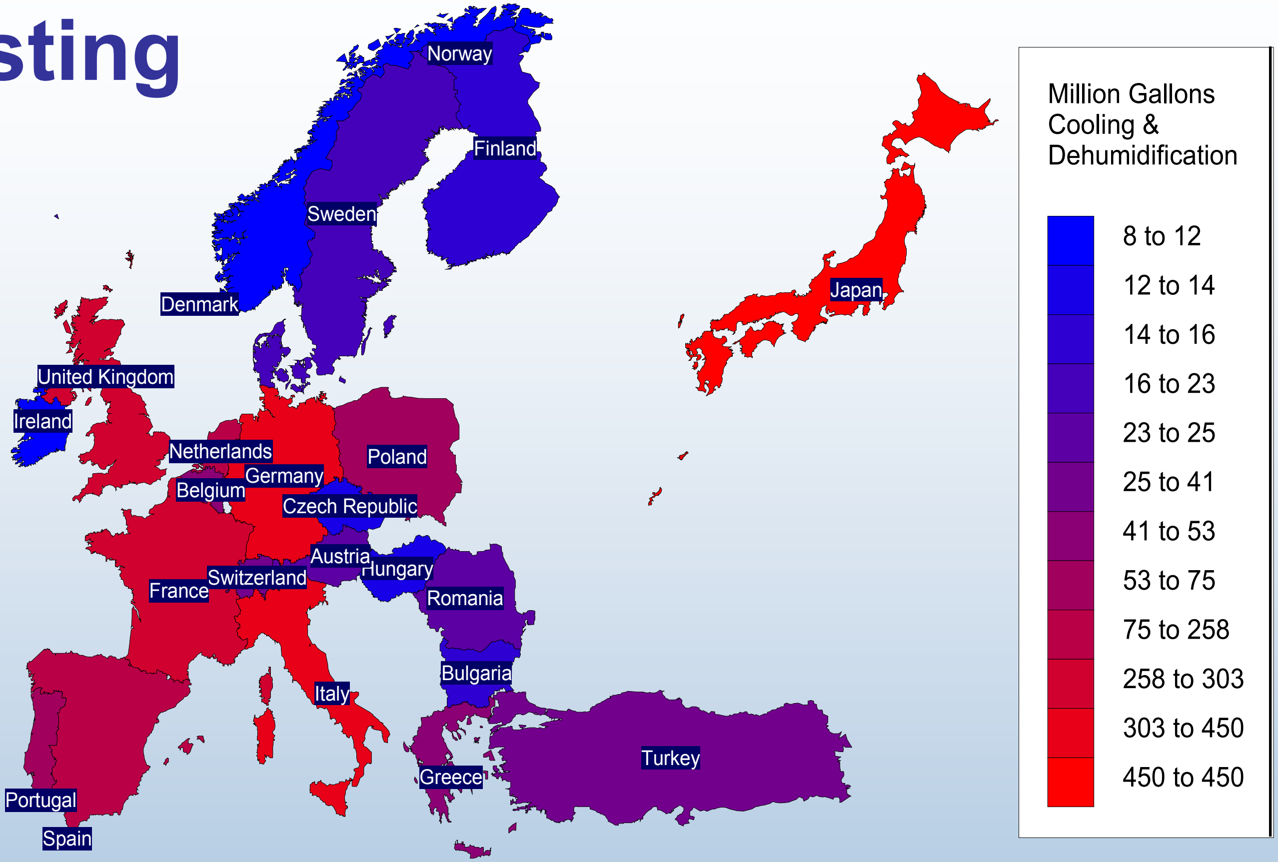
National Fuel Used for AC



- 7.0 billion gallons used for air conditioning annually
- 5.5% total fuel consumption
- 62 billion kg CO_2
- 9.5% imported crude oil

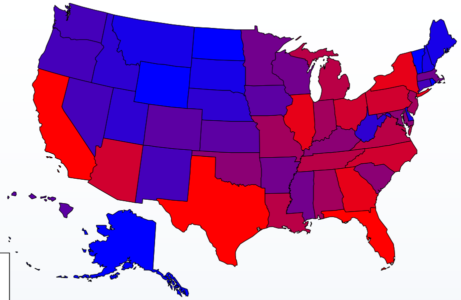


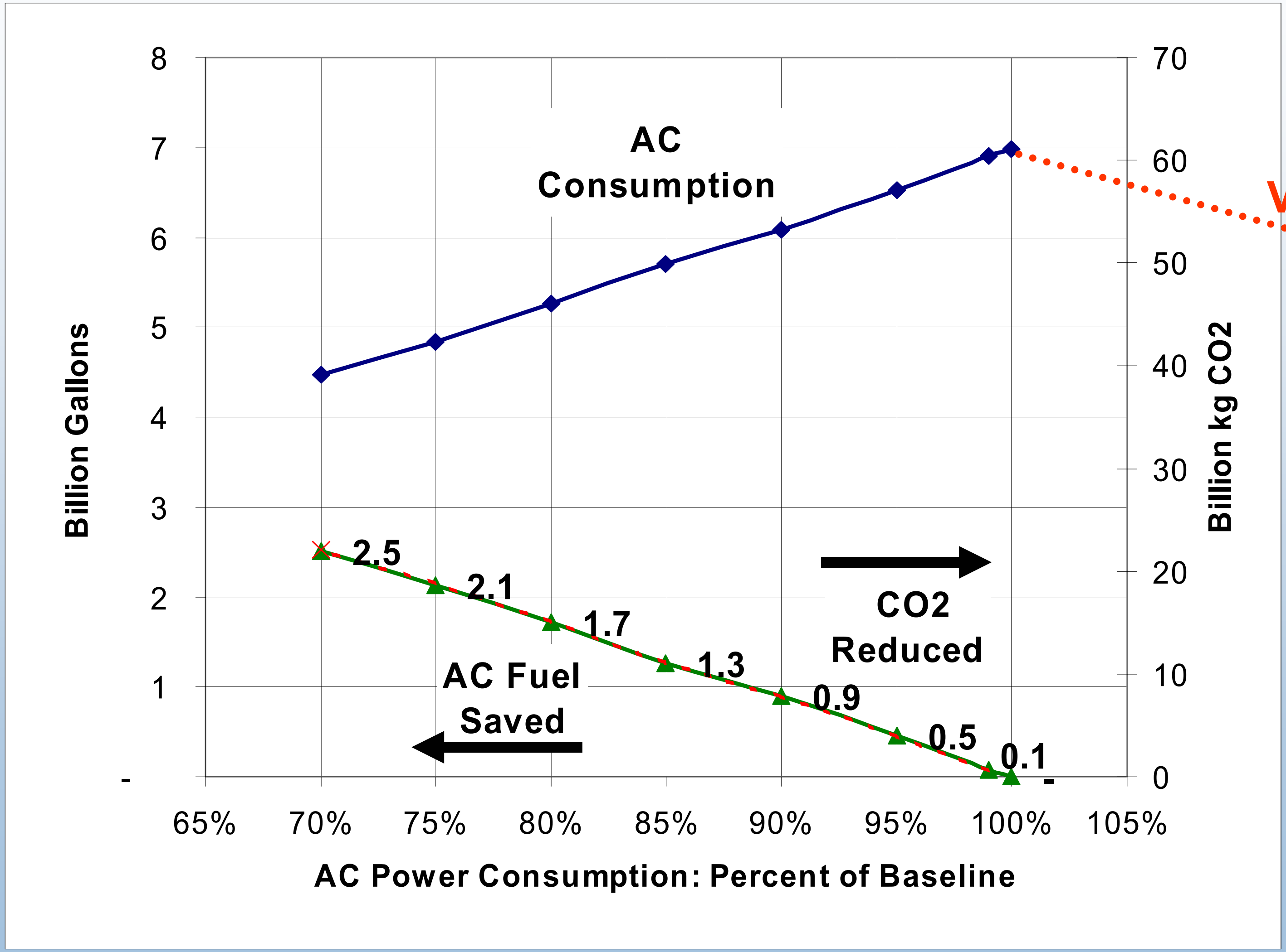
Total Fuel Use for AC for Cooling and Demisting



	Totals Dehumid + Cooling	Billion Gallons	Billion Liters	Billion kg CO2	Percent of Total Consumption
EU	100% Market	1.8	6.9	16.0	3.2%
Japan	100% Market	0.45	1.7	4.0	3.5%

U.S. Fuel Saved & CO_2 Reduced by Reducing AC Consumption





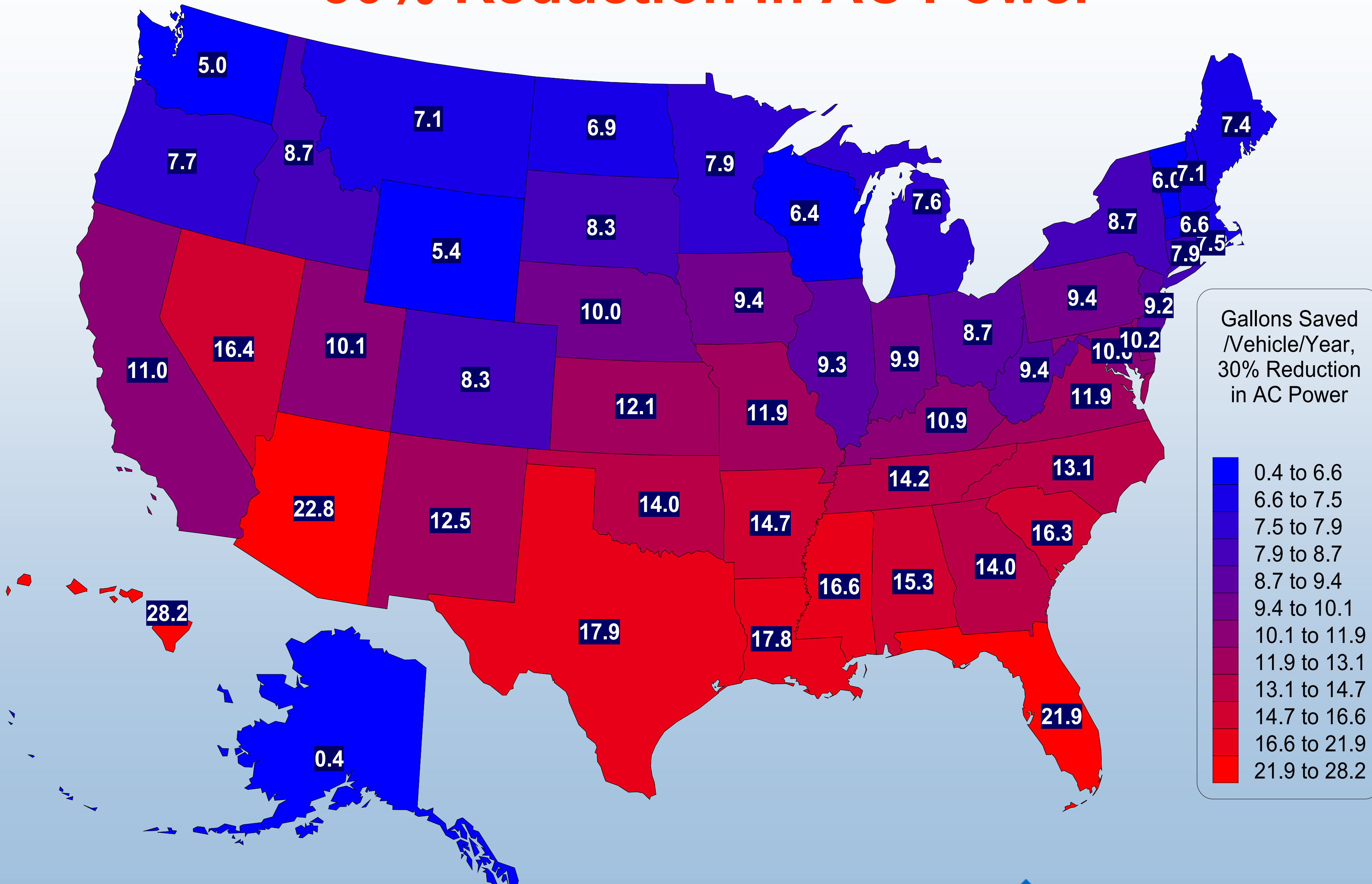
Vs. Total Consump.

5.5%

3.6%

Fuel Saved per Vehicle by Climate

30% Reduction in AC Power



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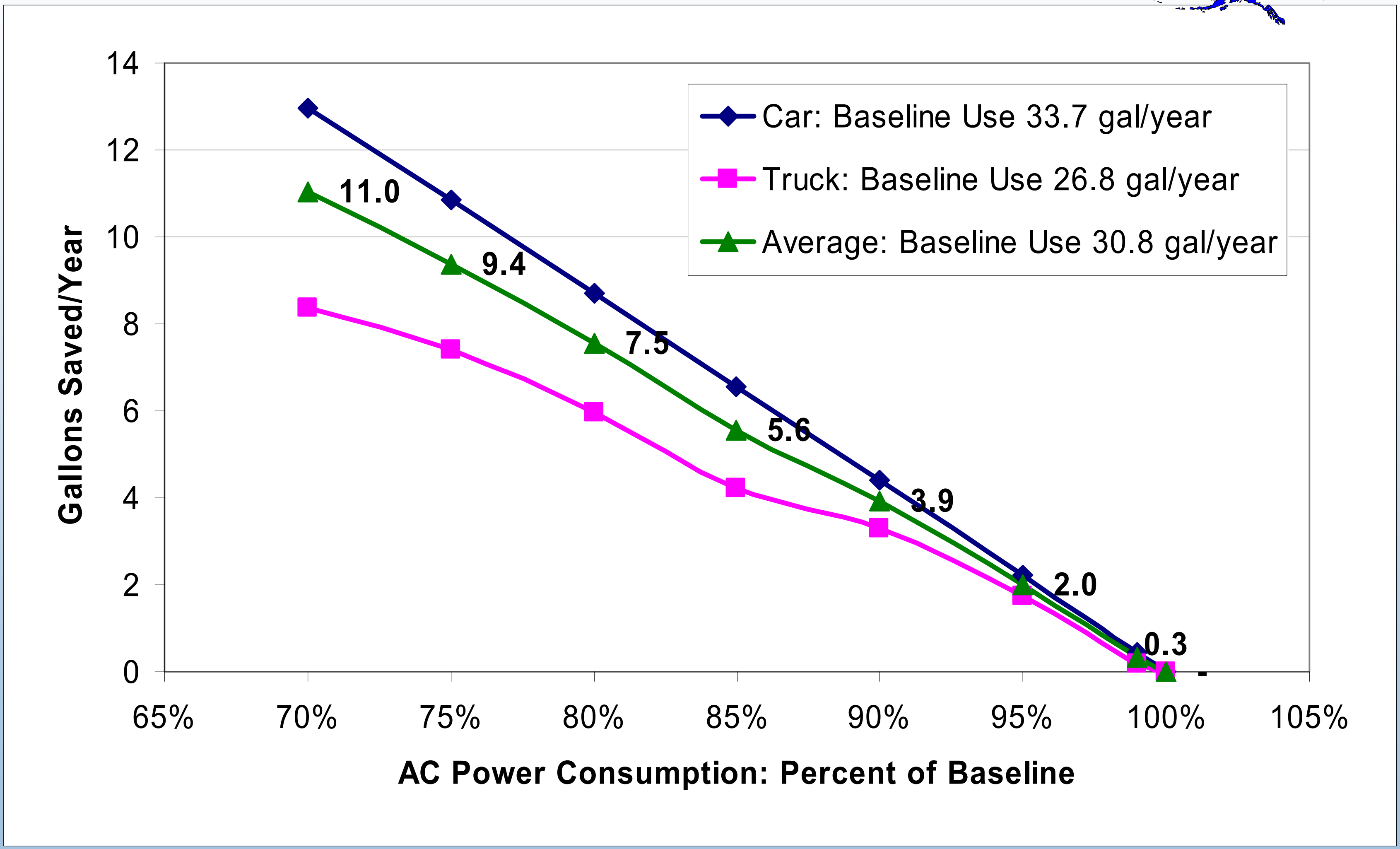
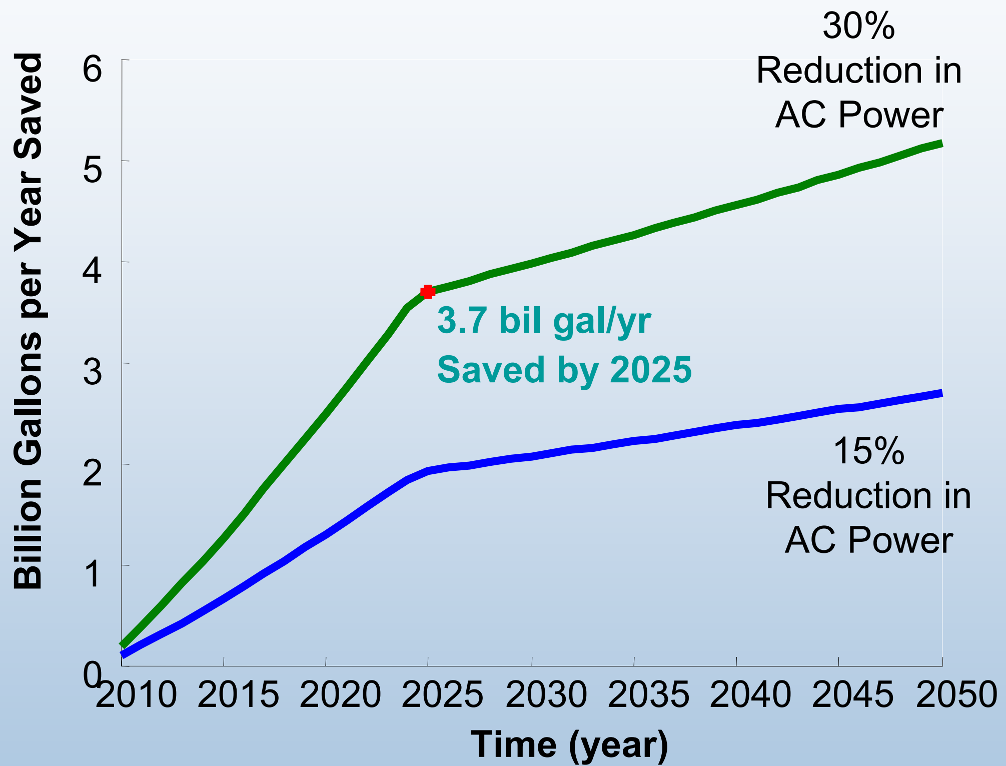
Per Vehicle Fuel Saved by Reducing AC Consumption

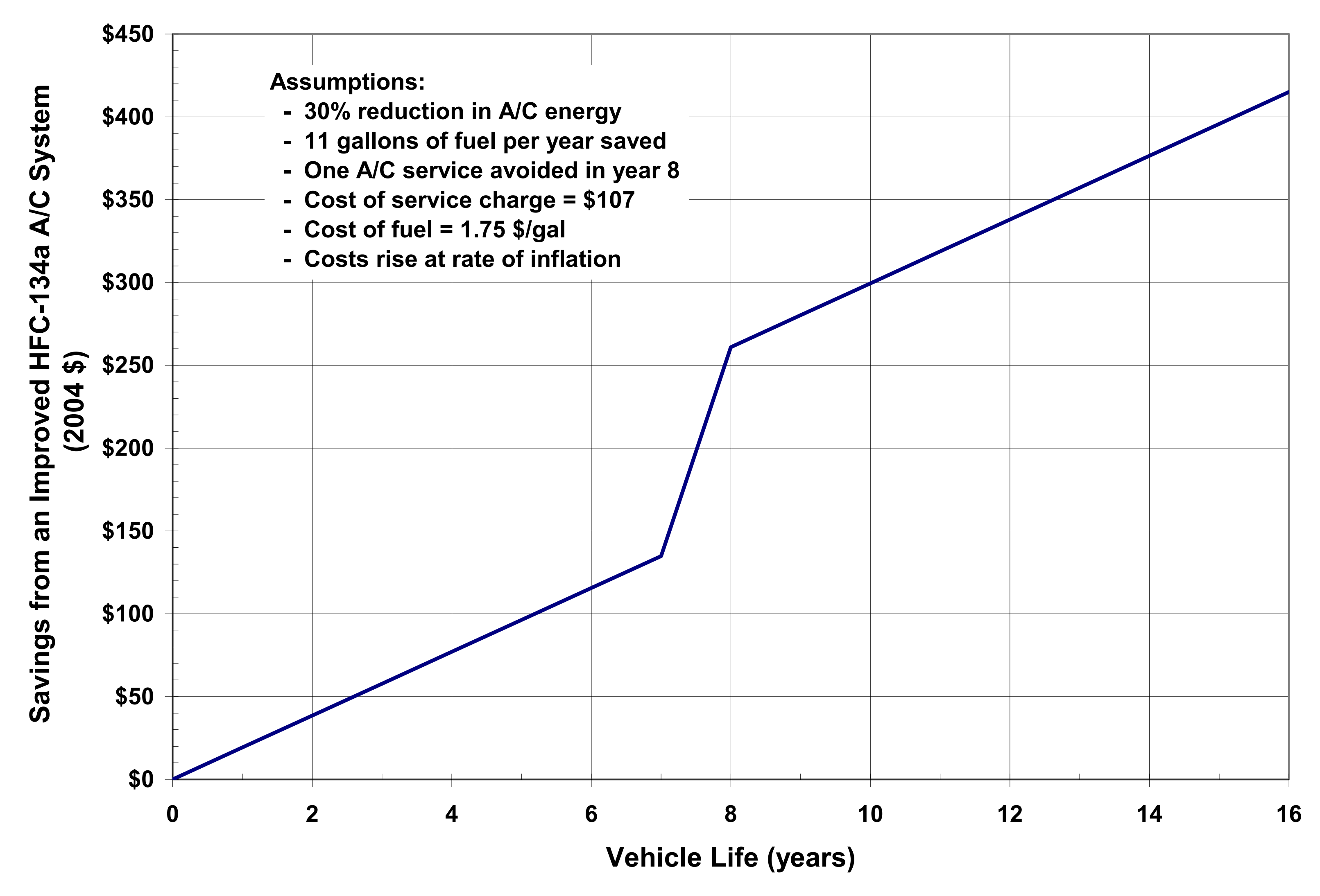


U.S. Fuel Savings Taking into Account New Technology Penetration

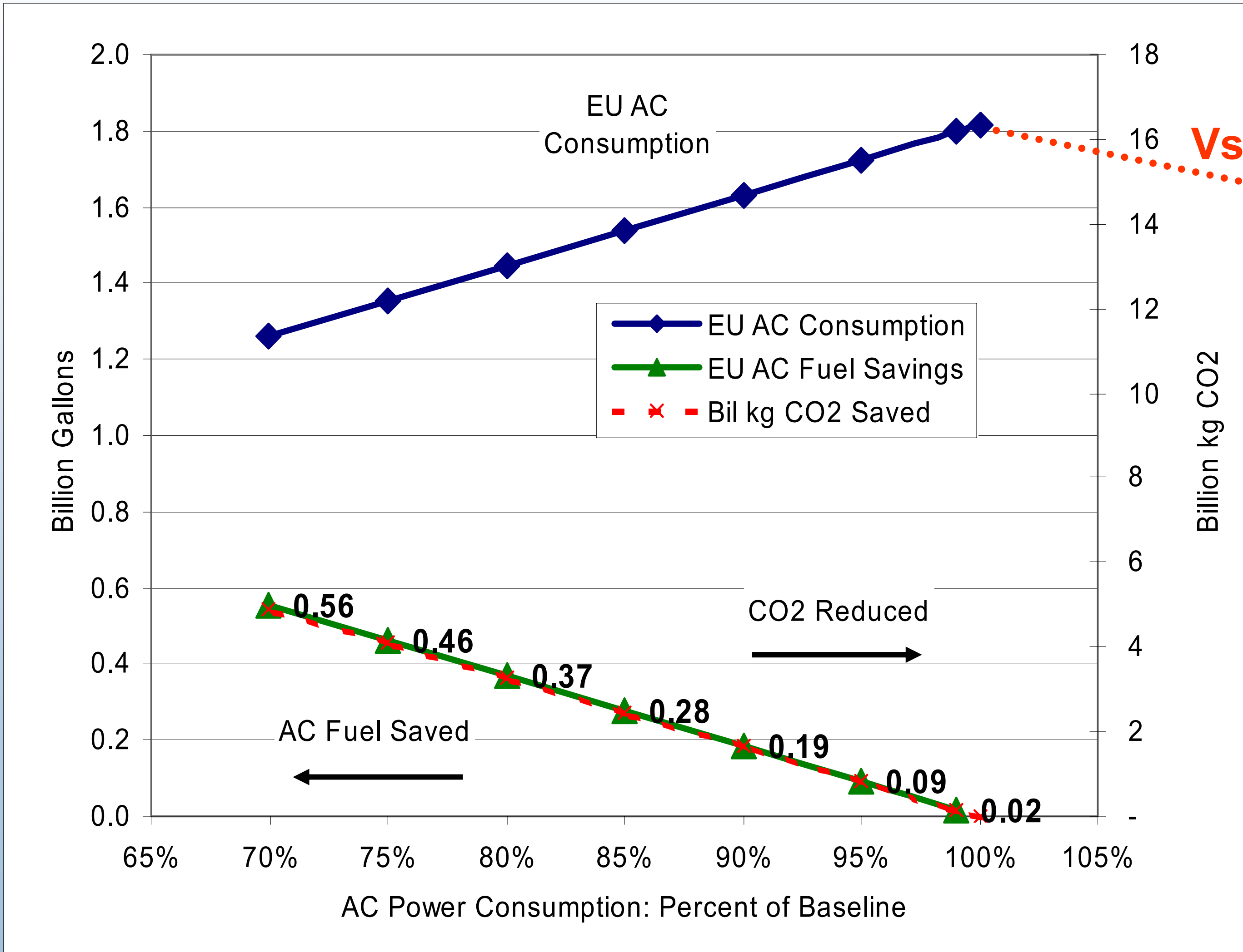
- Assumptions
  - 15% and 30% reductions in AC power
  - Power reductions begin in 2010
  - Fleet grows through time (DOE's Vision model)
    - 234 million in 2010
    - 293 million in 2050
  - Fleet turnover in 16 years
  - VMT increases over time
    - 13,500 miles in 2010
    - 19,950 miles in 2050



Per Vehicle Savings from an Improved MAC



EU Fuel Saved by Reducing AC Power Consumption

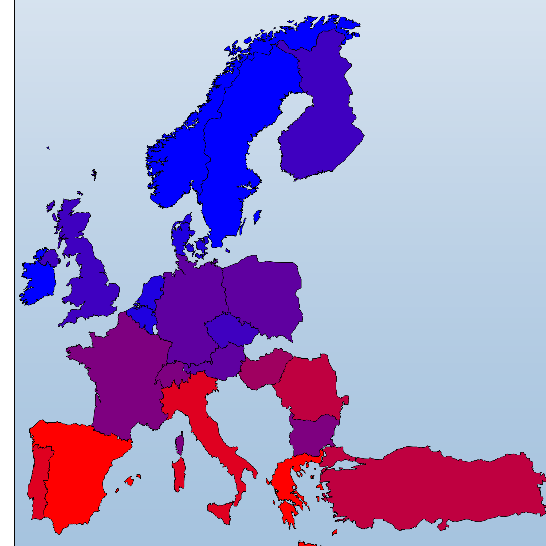


Vs. Total Consump.

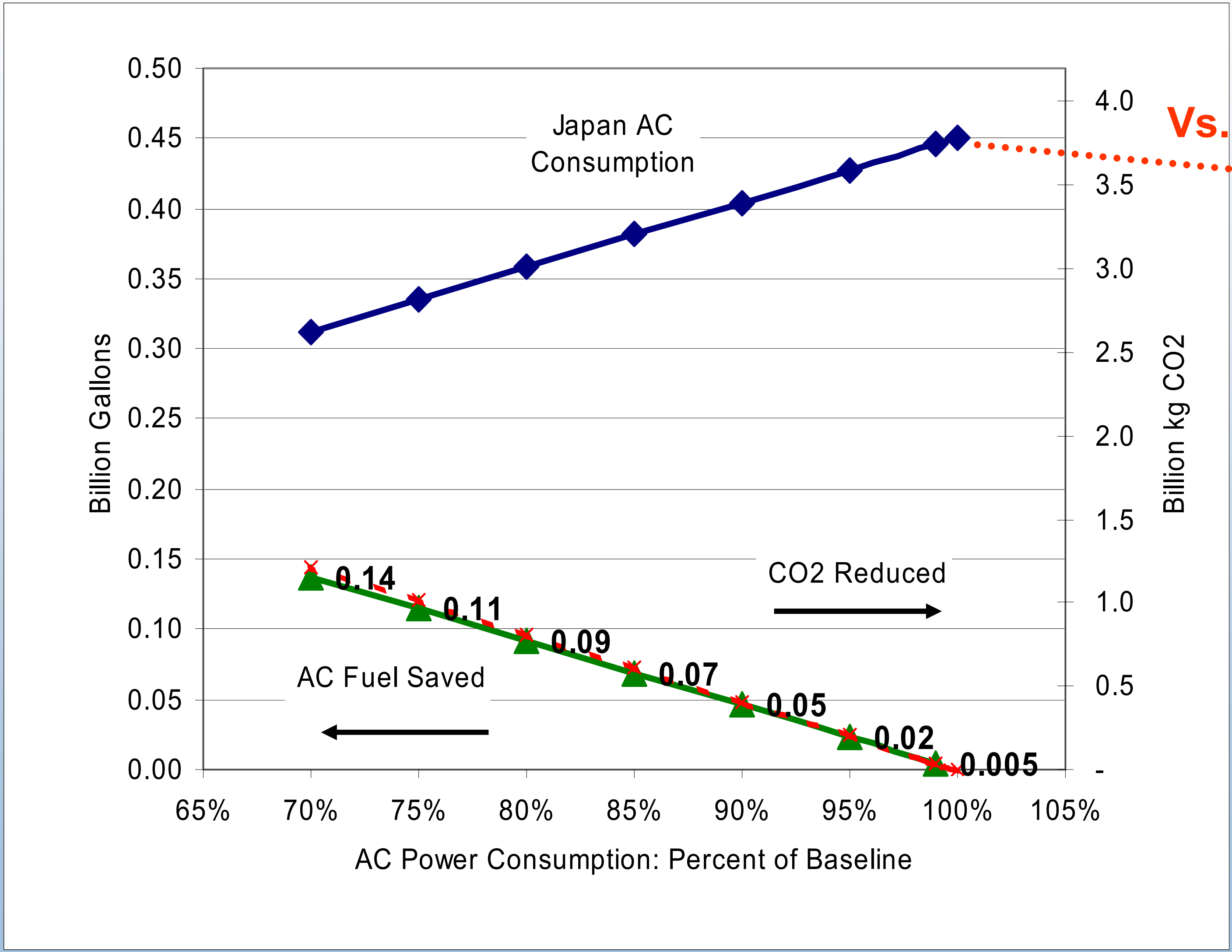
3.2%

↓

2.2%



Japan Fuel Saved by Reducing AC Power Consumption



Vs. Total Consump.

3.4%

2.4%

Conclusions

- MAC fuel use & CO2 emissions are strong functions of:
  - Vehicle design
  - Vehicle use
  - Environment
- Solutions to reduce fuel consumed by MACs
  - Reduce the thermal load – improve vehicle design
  - Improve delivery – design for occupant thermal comfort
  - Improve equipment
  - Educate consumers on impacts of driver behavior on MAC fuel use

Conclusions (cont.)

- Thermal comfort-based AC fuel use prediction

	US	EU	Japan
AC Fuel Use, Billion Gallons	7.0	1.82	0.45
AC Fuel Use, Percent of Total Consumption	5.5%	3.2%	3.4%

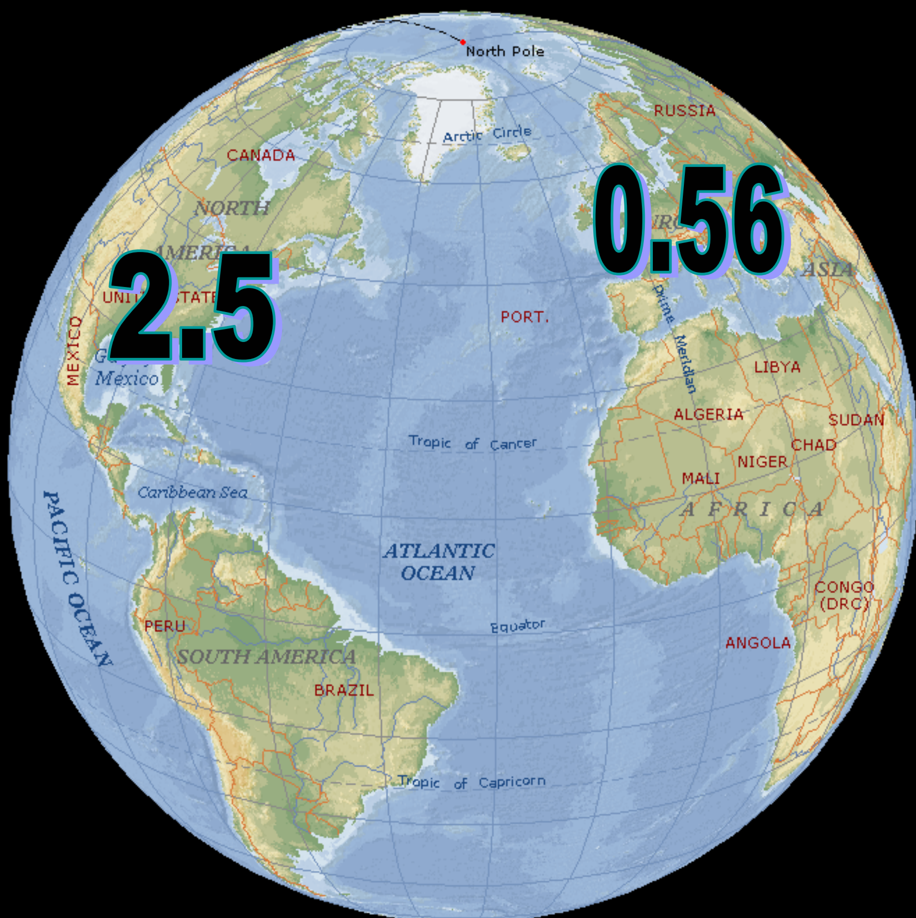
- Reducing AC fuel use has the potential to greatly benefit the nation
  - Reduce imported oil
  - Reduce CO_2
- Per vehicle savings allow calculation of payback time

30% Reduction in Power	Units	US	California	EU	Japan
Savings per Vehicle	*gal/year*	**11.0**	**11.0**	**2.5**	**2.2**
Reference Total Consumption	*gal/year*	30.8	30.5	8.0	7.2
Savings of Total Consumption	*%*	2.0%	-	1.0%	1.0%
Fuel Saved	*Bil Gallons*	2.5	0.26	0.56	0.14
Fuel Saved	*Bil Liters*	9.5	1.0	2.1	0.5
Emissions Reduced	*Bil kG CO2*	22.1	2.3	4.9	1.2

- Impact of incremental reduction in AC power: states, nations, world

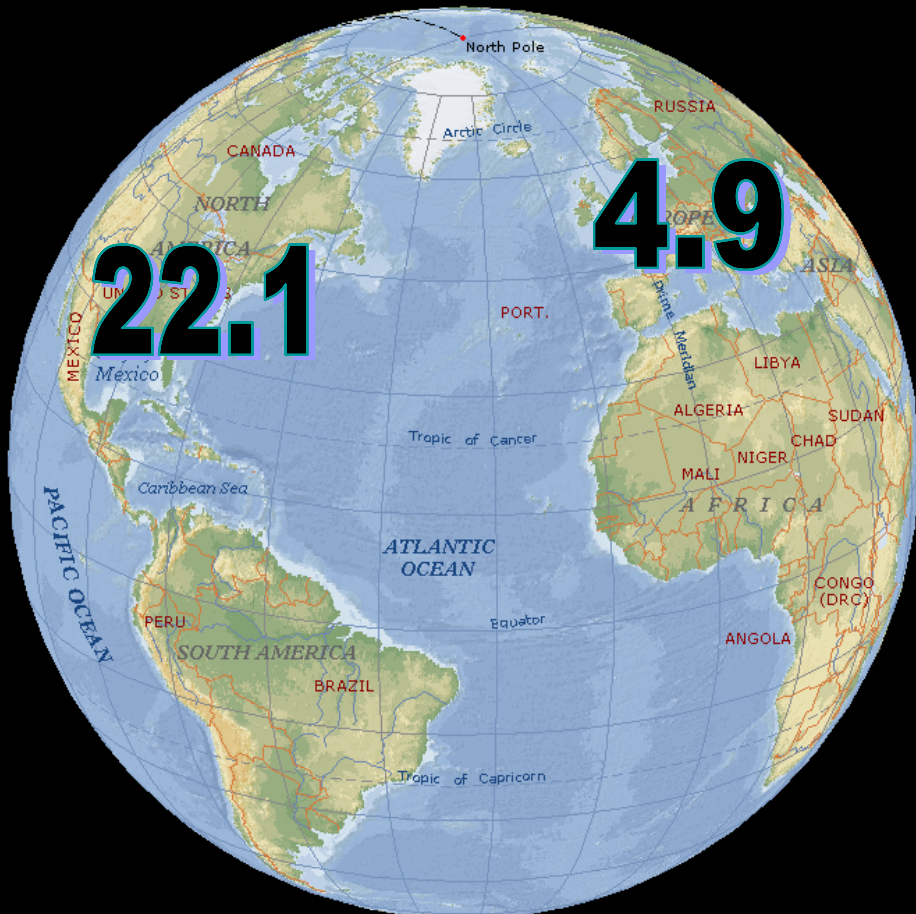
Fuel Savings across the World

Billion Gallons: Savings with 30% Drop in AC Power



CO_2 Reduction across the World

Billion kg CO_2: Reduction with 30% Drop in AC Power



Thank you!

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Back Up

Why So Much Fuel for A/C?

Metabolic Heat Generation

150 Watts

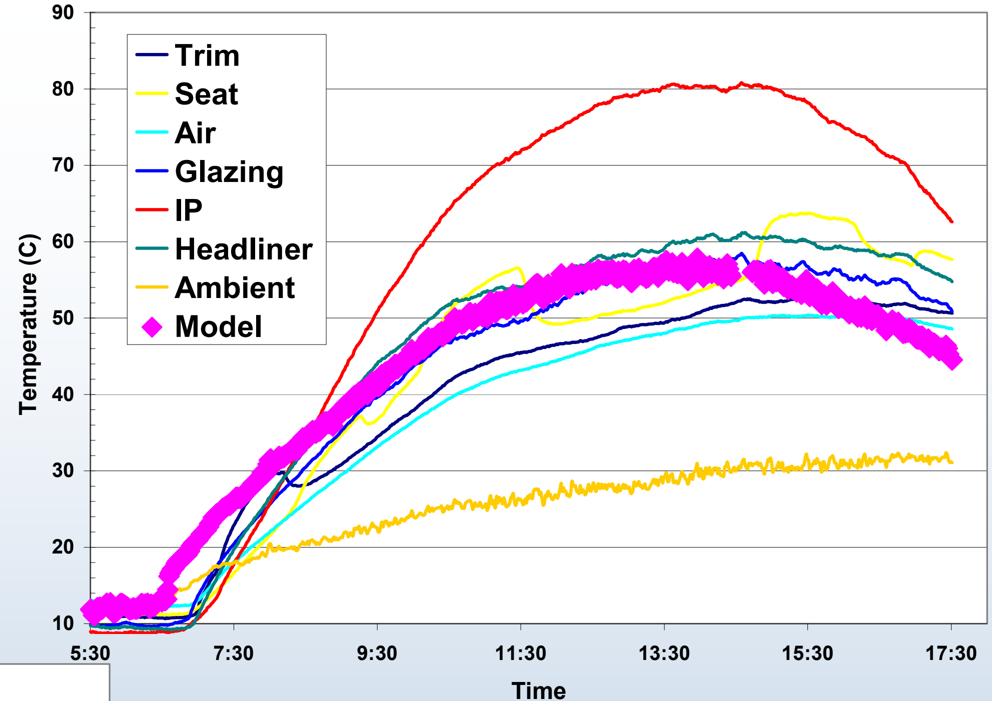
A/C Cooling
3-6 kW_{th}!

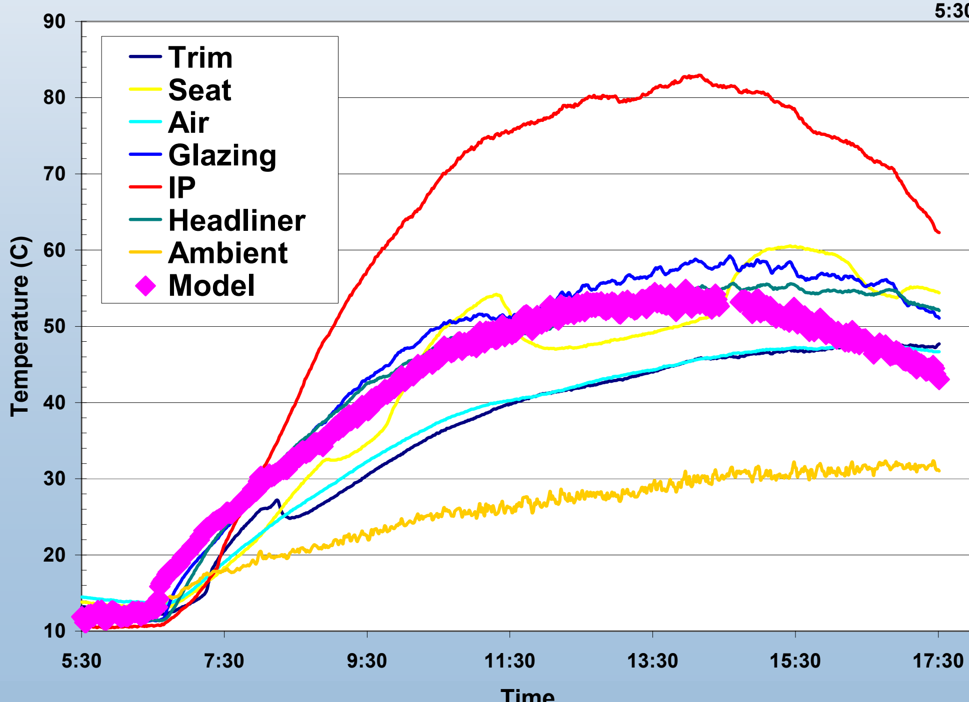
Cities Used from TMY Data Base

National Renewable Energy Laboratory

Car & Truck MRT

- Plymouth Breeze
- July 12
- Golden, CO

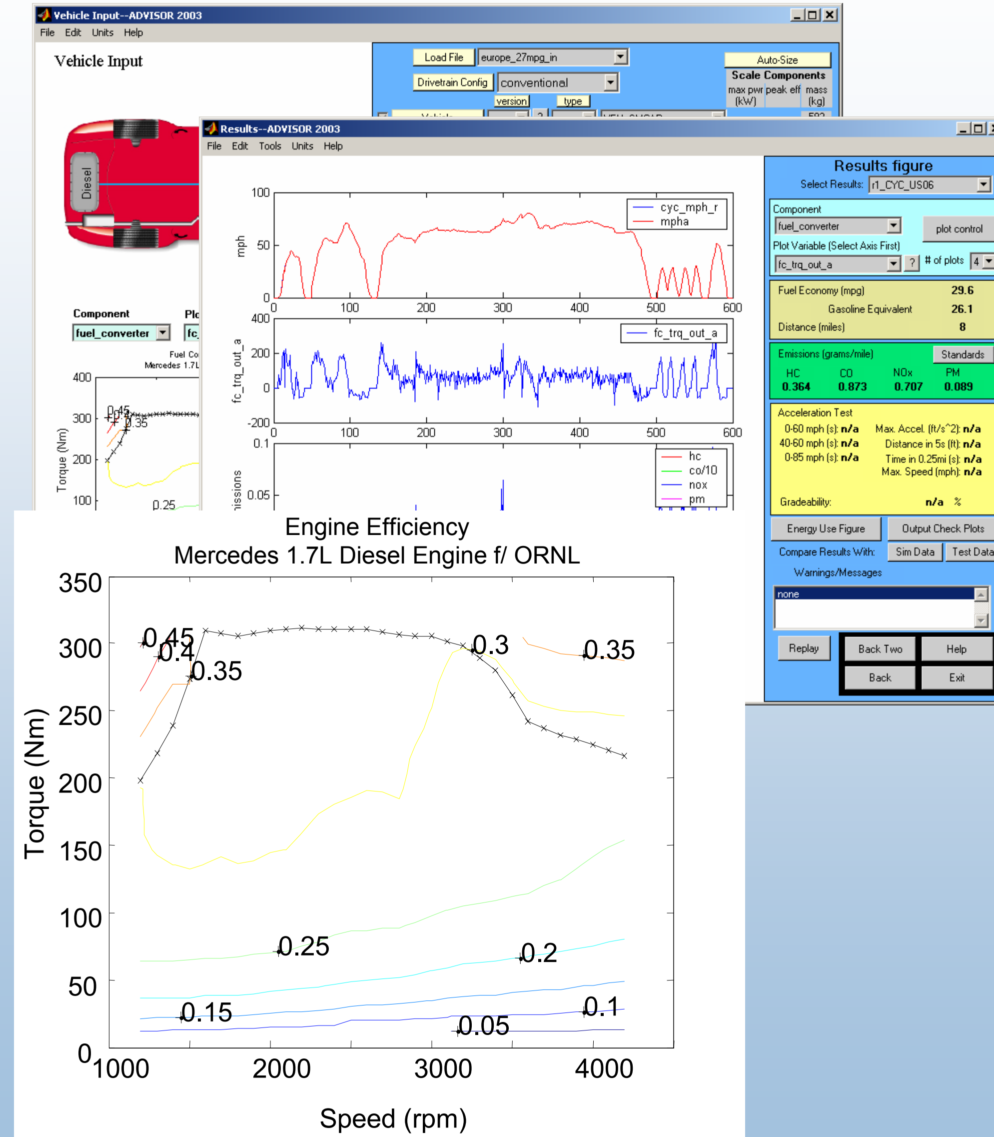




- Jeep Grand Cherokee
- July 12
- Golden, CO

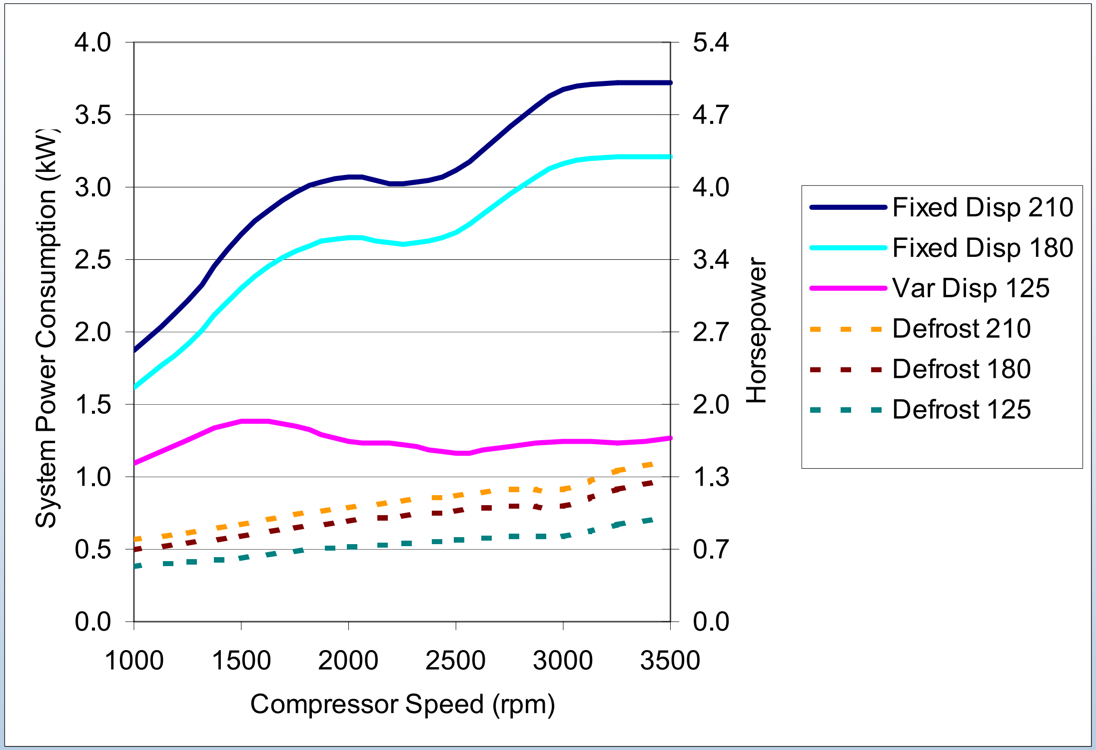
Vehicle Modeling in ADVISOR

- U.S. Car
  - 115 kW SI engine, 1300 kg
- U.S. Truck
  - 144 kW SI, 1924 kg
- EU Vehicle
  - 91 kW compression ignition diesel, 1220 kg
- Fuel economy expressed in gasoline equivalent fuel consumption
- CO_2 emissions determined from fuel consumption
  - 2.33 kg CO_2/liter fuel



AC Modeling

- HFC-134a
  - U.S. trucks: 210 cc fixed
  - U.S. cars: 180 cc fixed
  - EU vehicle: 125 cc variable displacement
  - Compressor power consumption based on Delphi compressor curves
  - Total power = $P_{compressor}$ + P_{blower}
    - P_{blower} = 120 W
- Engine speed/compressor speed ratio = 0.64



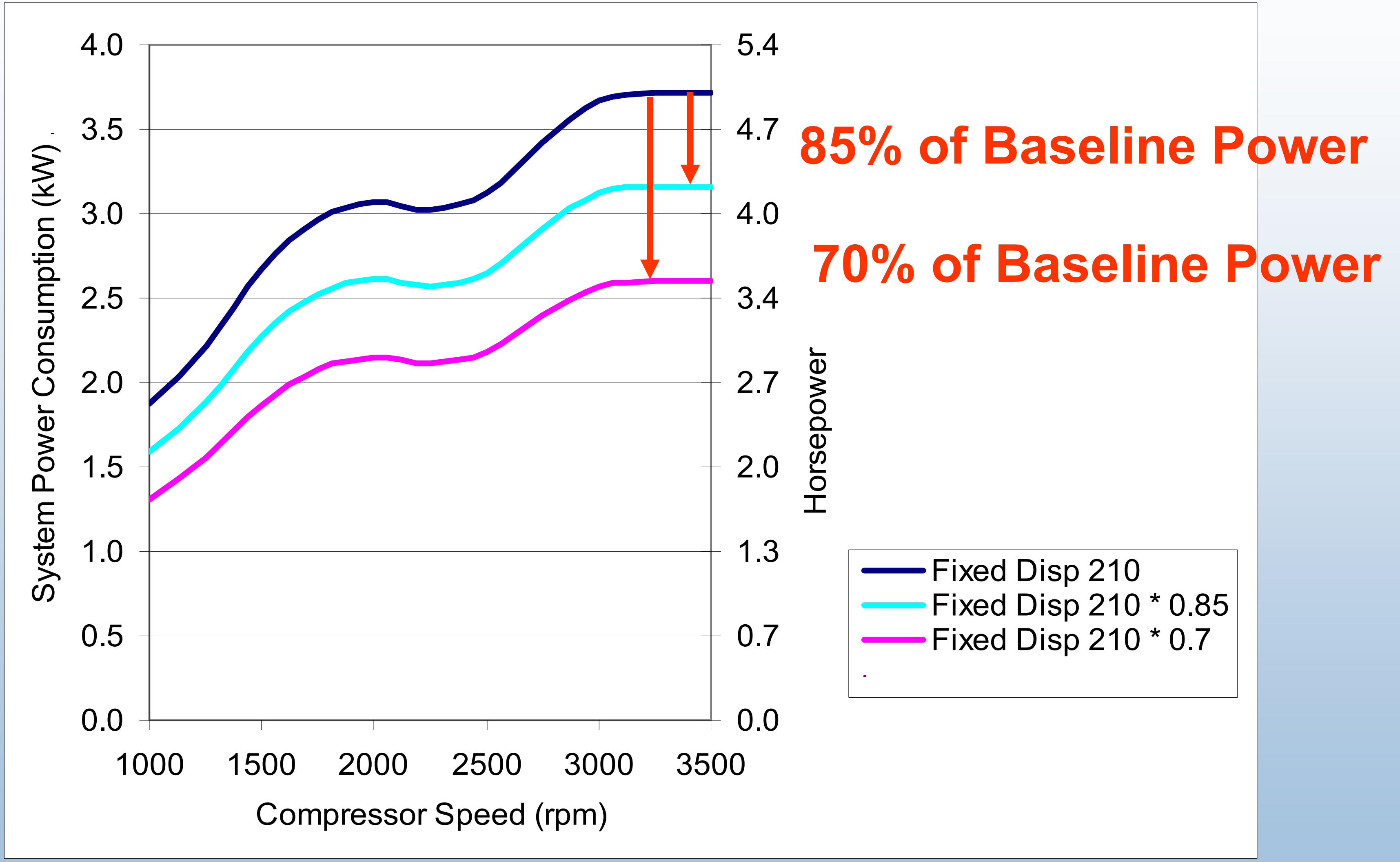
Curves based on work by Forrest at Delphi

- Cooling mode: 27°C, 60% RH
- Demist mode: 16°C, 80% RH

Conservative Estimate of Fuel Used for AC

- Fanger's thermal comfort model excludes:
  - Sun hitting a driver
  - Thermal asymmetry
  - Sitting on a hot seat
  - High humidity impacts
- Model excludes AC use due to
  - Automatic Temperature Control
- EU compressor power

Incremental Reduction in AC Power



EU/Japan Per Vehicle Fuel Saved by Reducing AC Consumption