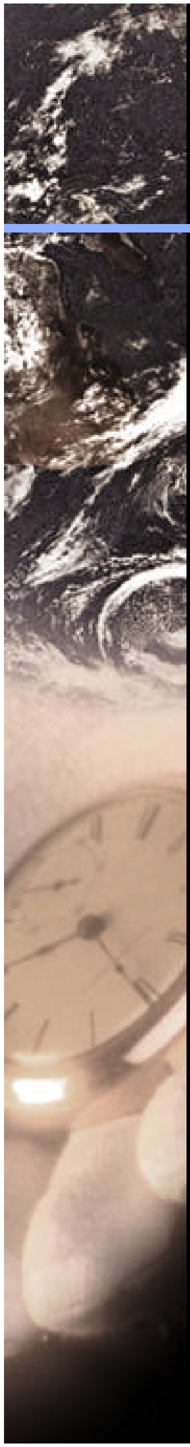


VTMS 4

May 26, 1999
London, UK

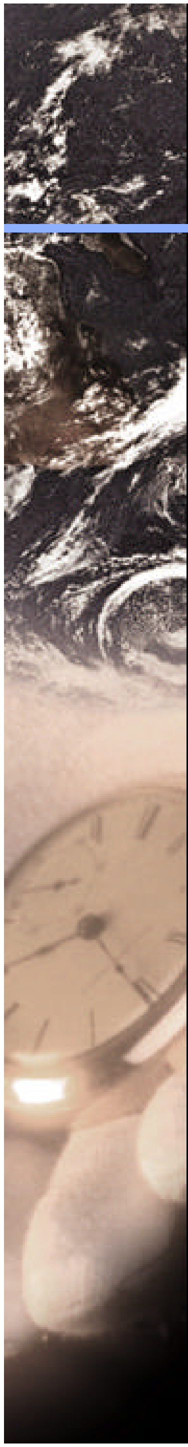
Challenges and Potential Solutions for Reducing Climate Control Loads in Conventional and Hybrid Electric Vehicles

Time for World Class Solutions

NREL

National Renewable Energy Laboratory
Robert B. Farrington Ph.D., P.E

CENTER FOR TRANSPORTATION TECHNOLOGIES AND SYSTEMS



NREL Mission

Lead the nation toward a sustainable energy future by developing renewable energy technologies, improving energy efficiency, advancing related science and engineering, and facilitating commercialization

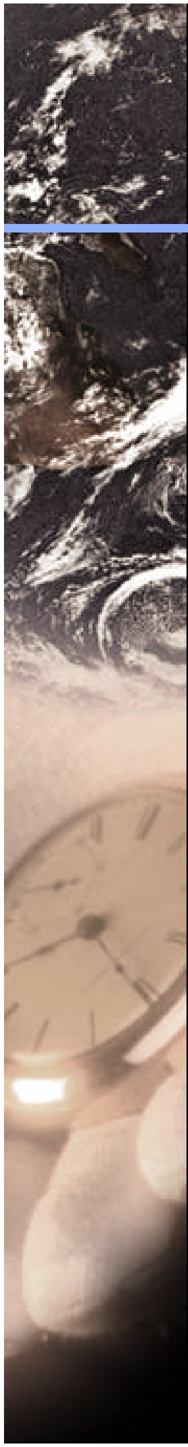
NREL Background

- Established in 1977 as Solar Energy Research Institute
- Current staff of approximately 900
- Operating budget of $170M for FY99

NREL Facilities

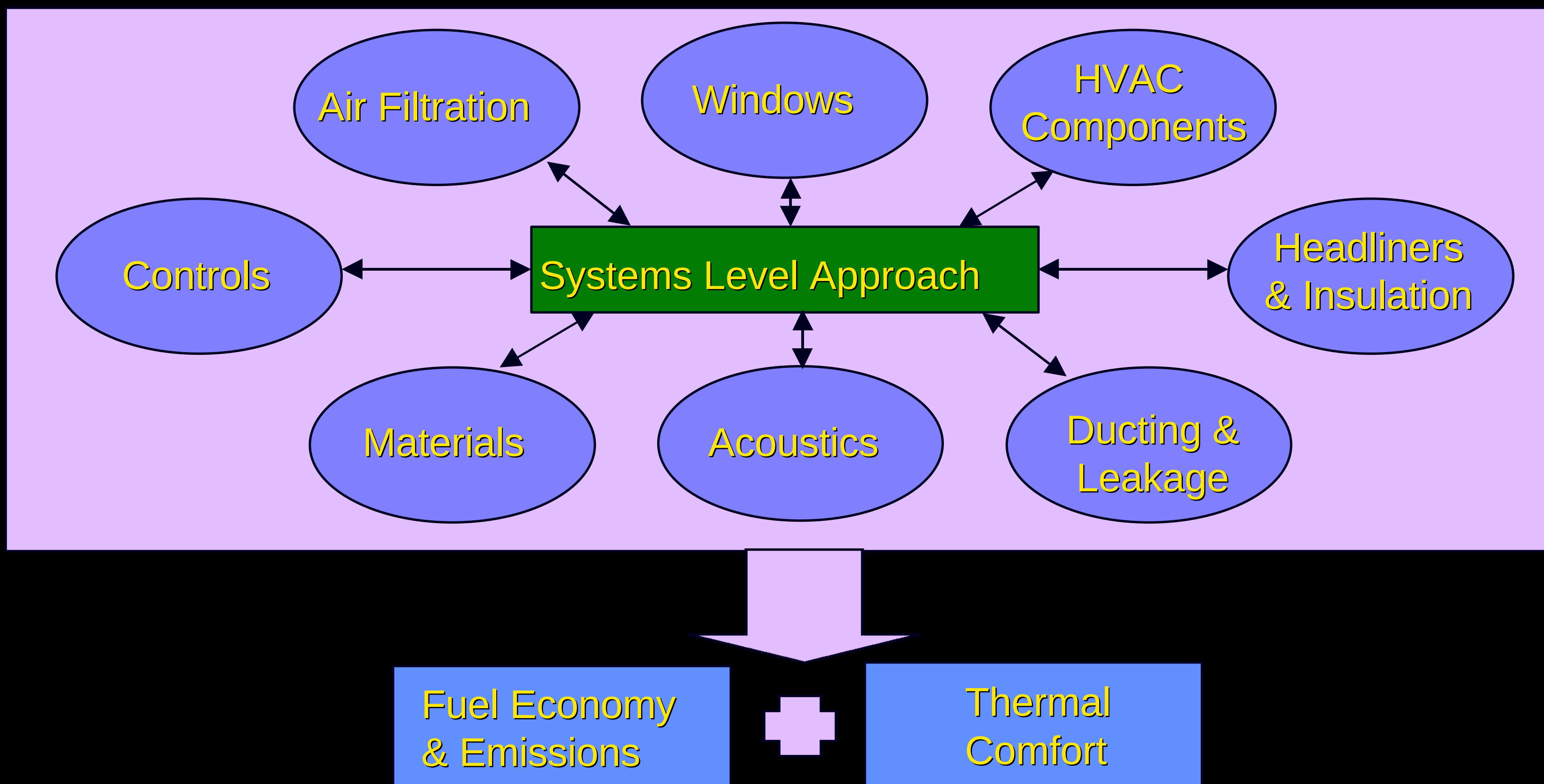
Cool Car Goal

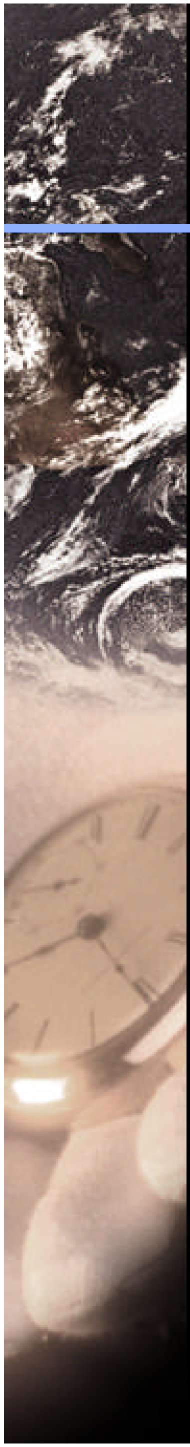
To reduce energy use for vehicle climate control by 50% while maintaining passenger thermal comfort and safety.



Our Approach

A systems approach to integrate components and systems to provide thermal comfort while reducing fuel consumption and emissions.



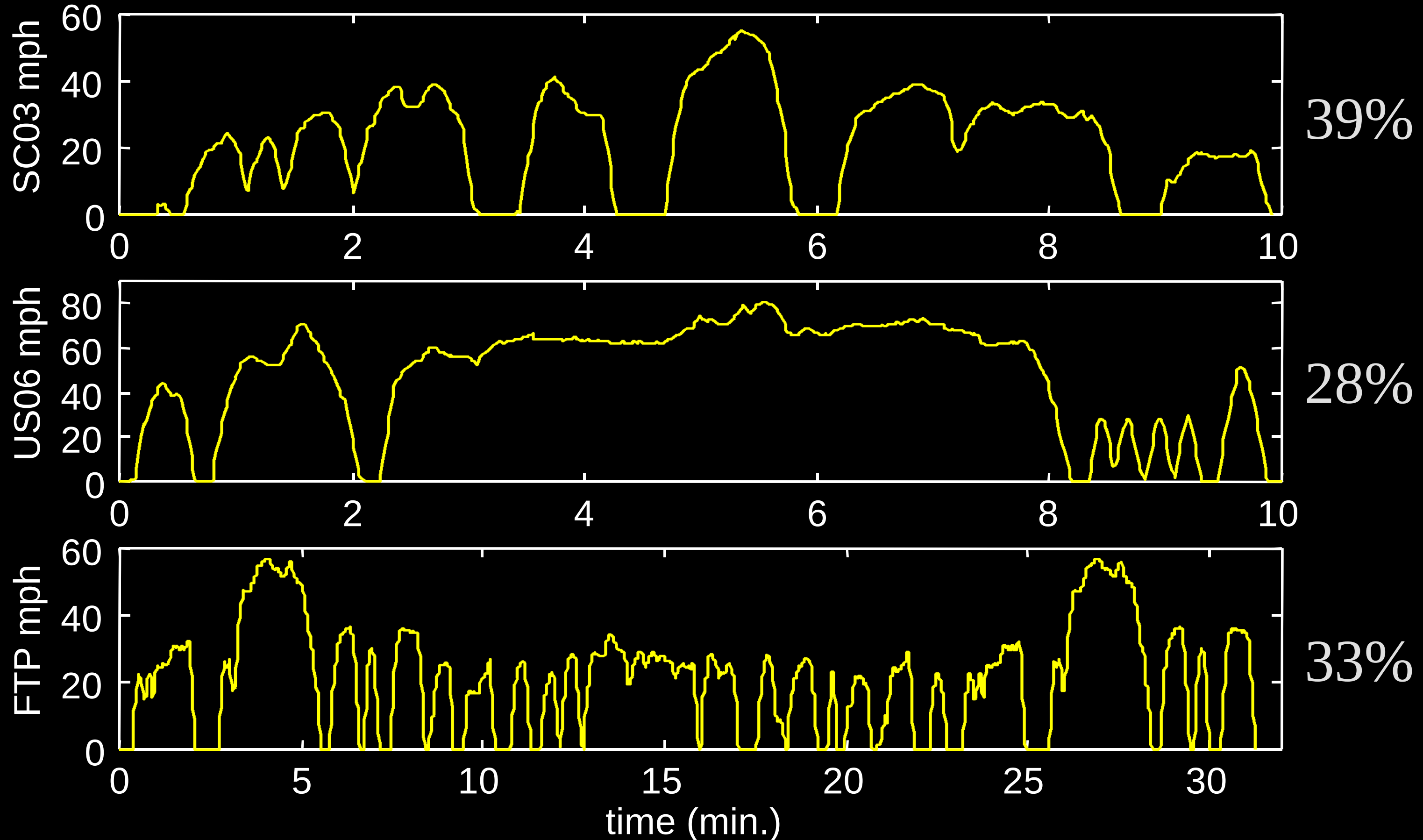


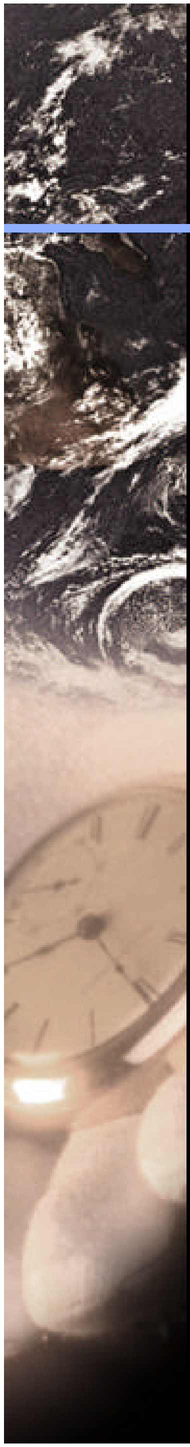
SFTP Timeline

- MY 2001: 25% of manufacturer’s fleet
- MY 2002: 50%
- MY 2003: 85%
- MY 2004: 100%

For cars & trucks under 5750 lb GVW

Supplemental Federal Test Procedure: Velocity Profiles

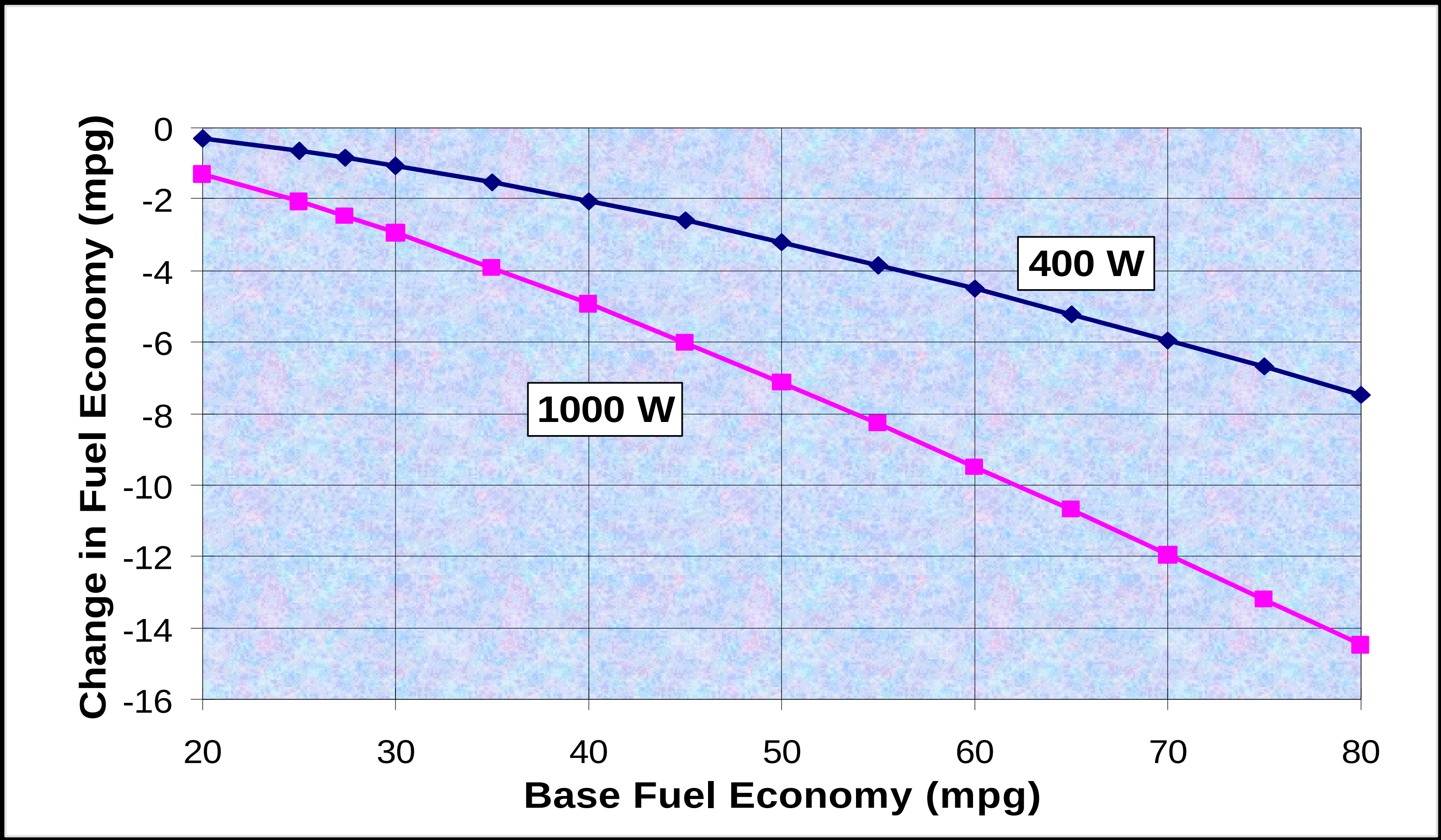




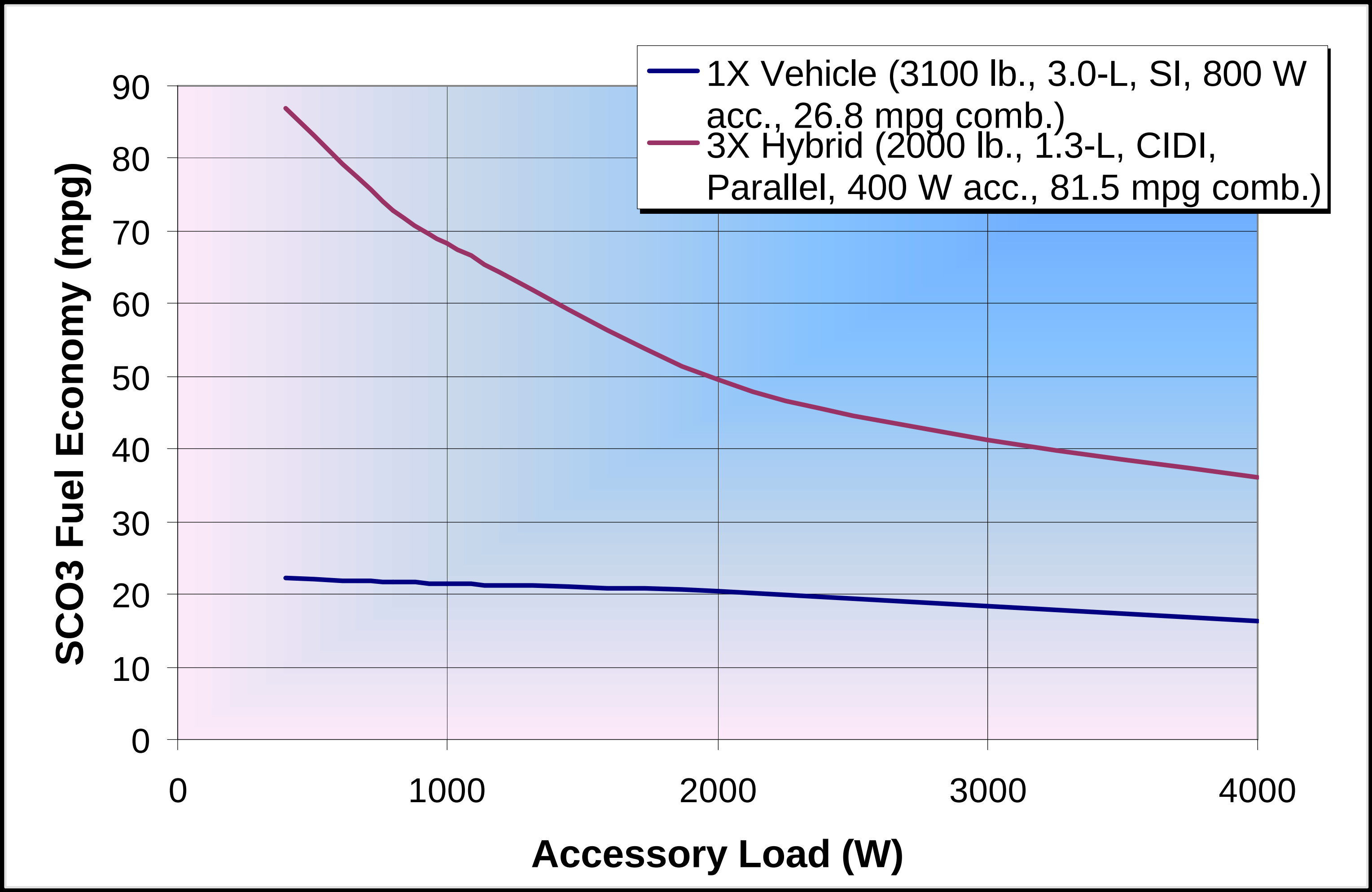
SFTP Specifications

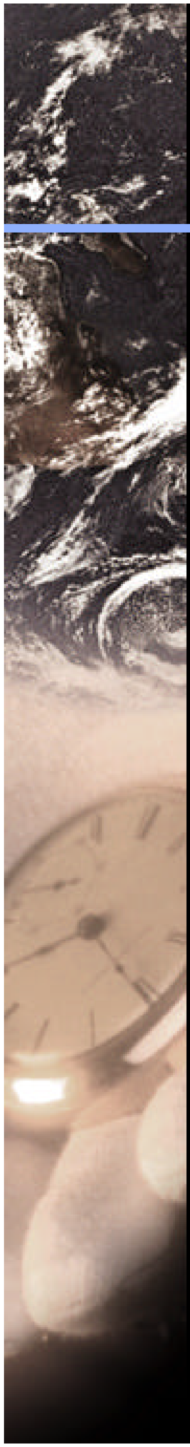
	FTP	SCO3	US06
Time (s)	1877	594	600
Max. speed (mph)	56.7	54.8	80.3
Max. acceleration (mph/s)	3.6	5.1	8
Distance (miles)	11.1	3.6	8
Contribution to total emissions value	33%	39%	28%

Fuel Economy Penalties From Auxiliary Loads



Fuel Economy Impact





Emissions Impact from A/C Load

Engine	Net COP = 2.25			Net COP = 1.25		
	HC	CO	NO_x	HC	CO	NO_x
1.5-L Geo	31%	22%	52%	50%	50%	113%
1.9-L Saturn	4%	51%	39%	13%	125%	58%
3.0-L Dodge	24%	26%	29%	46%	68%	56%
3.0-L Toyota	18%	11%	31%	29%	20%	54%

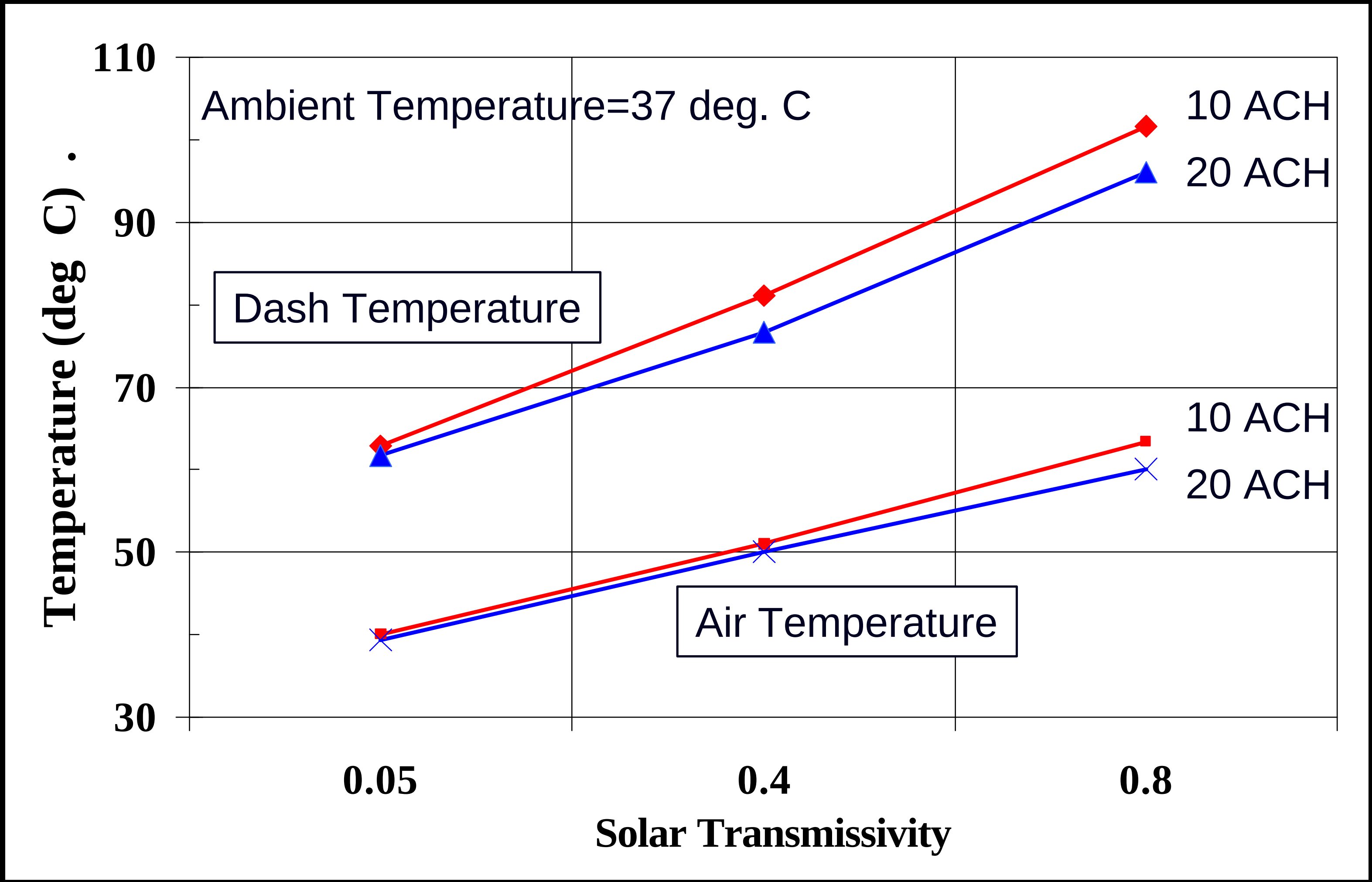
HEV F.E. Results for A/C Load

	500 W	1500 W		2500 W		3500 W	
	F. E. [mpg]	F. E. [mpg]	% decr.	F. E. [mpg]	% decr.	F. E. [mpg]	% decr.
FUDS	43.2	36.1	16%	30.6	29%	26.0	40%
HWFET	48.3	45.4	6%	42.9	11%	40.3	16%
US06	35.4	33.9	4%	32.2	8%	30.6	12%
SC03	39.5	34.1	10%	29.5	19%	25.1	28%

EV Range Results for A/C Load

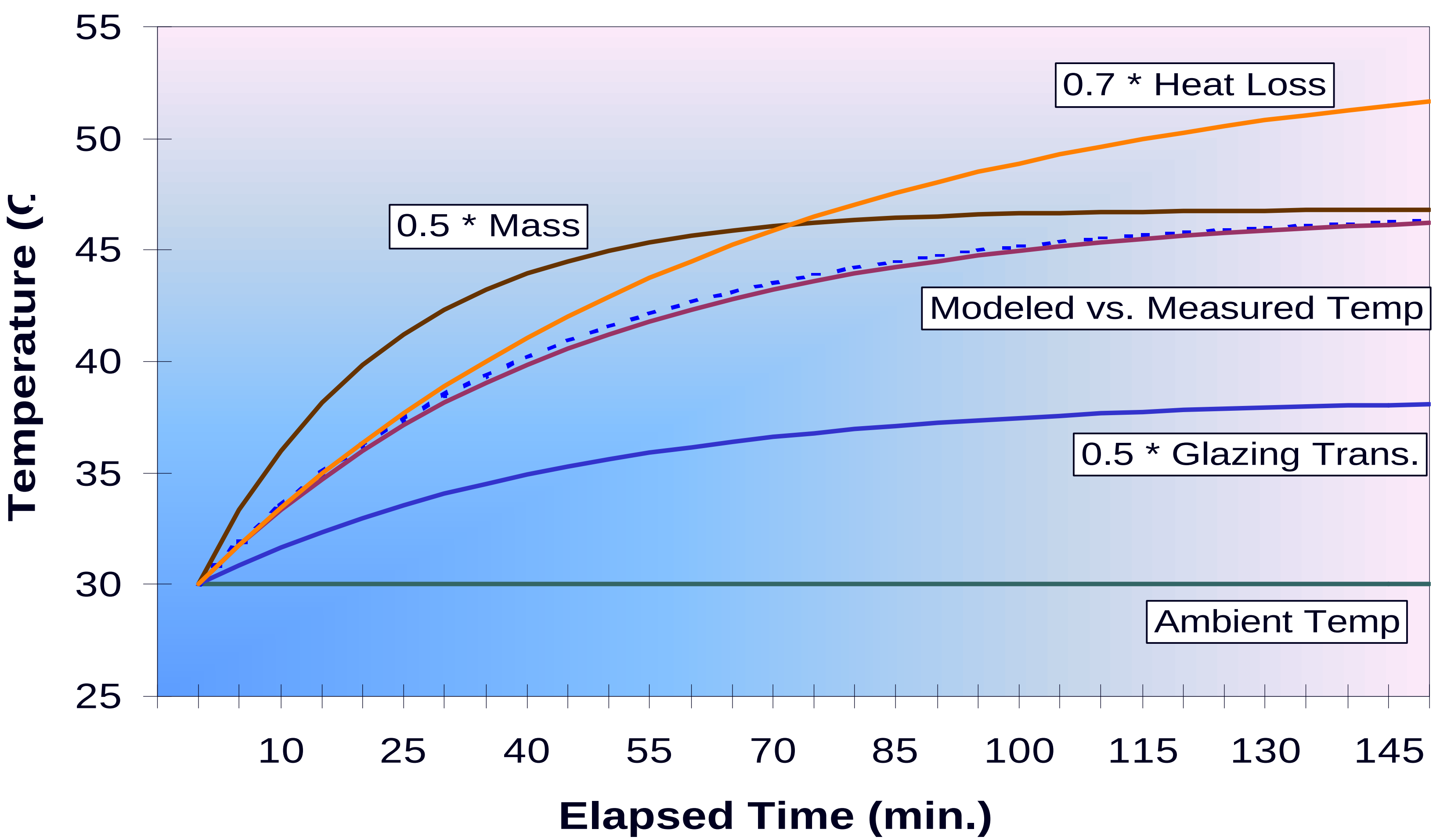
	500 W	1500 W		2500 W		3500 W	
	Range (mi)	Range (mi)	% decr.	Range (mi)	% decr.	Range (mi)	% decr.
FUDS	109.3	91.8	16%	78.0	29%	67.7	38%
HWFET	114.1	104.1	9%	95.7	16%	88.3	23%
US06	72.1	66.9	7%	63.7	12%	59.2	18%
SC03	108.3	91.3	16%	78.8	27%	69.1	36%

Predicted Peak Dash/Air Temps.

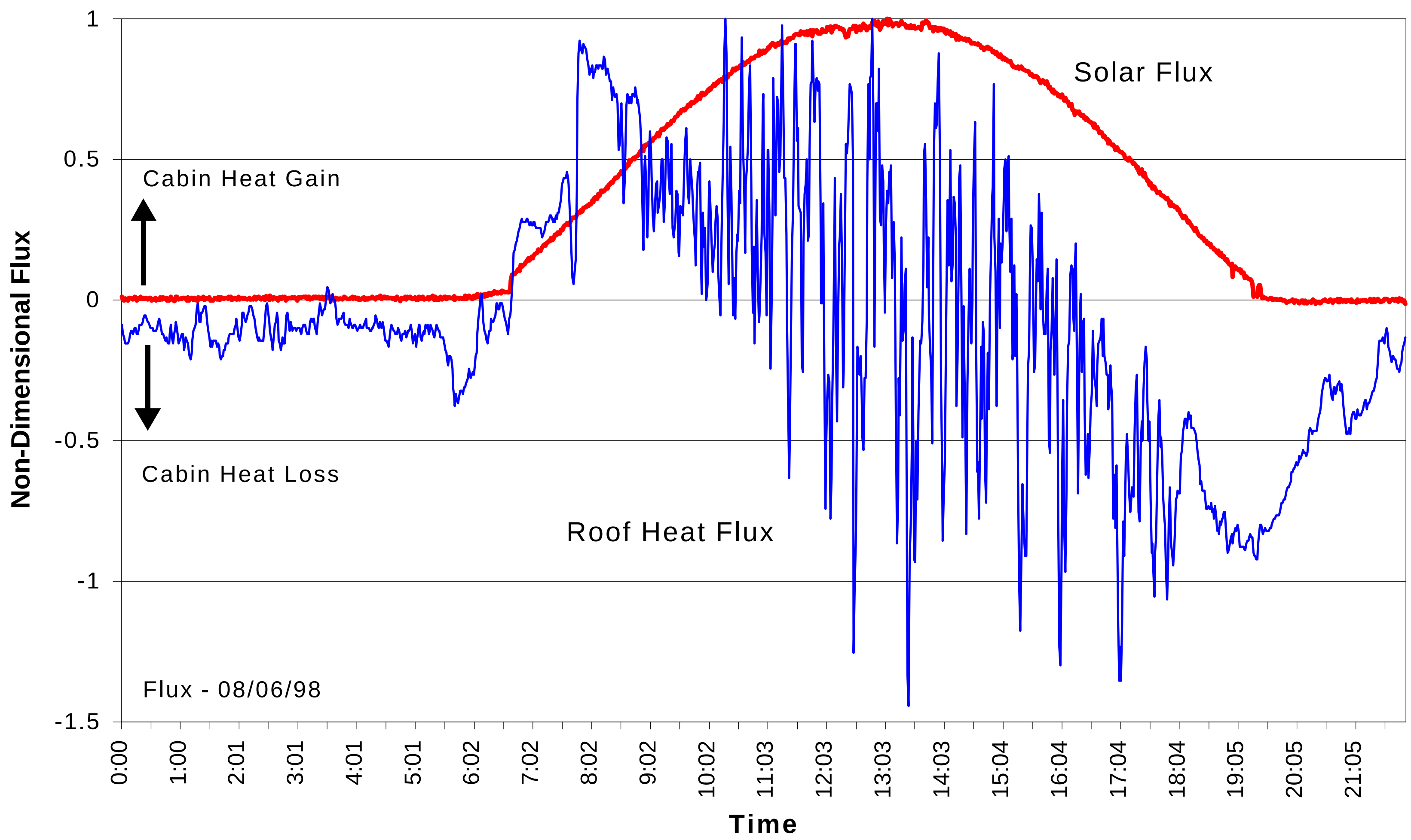


NREL’s Breeze Test Vehicle

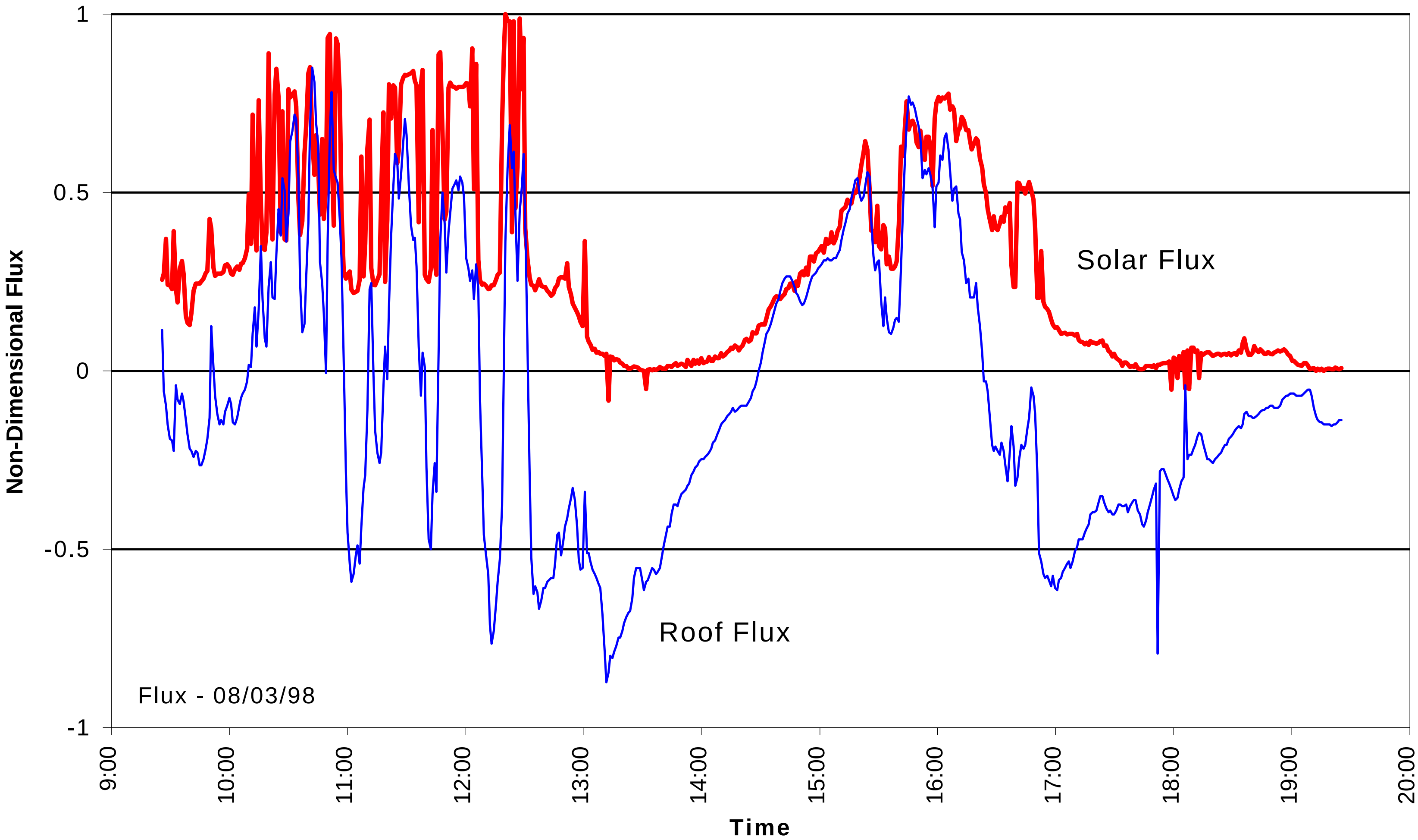
Soak Temperature Sensitivity



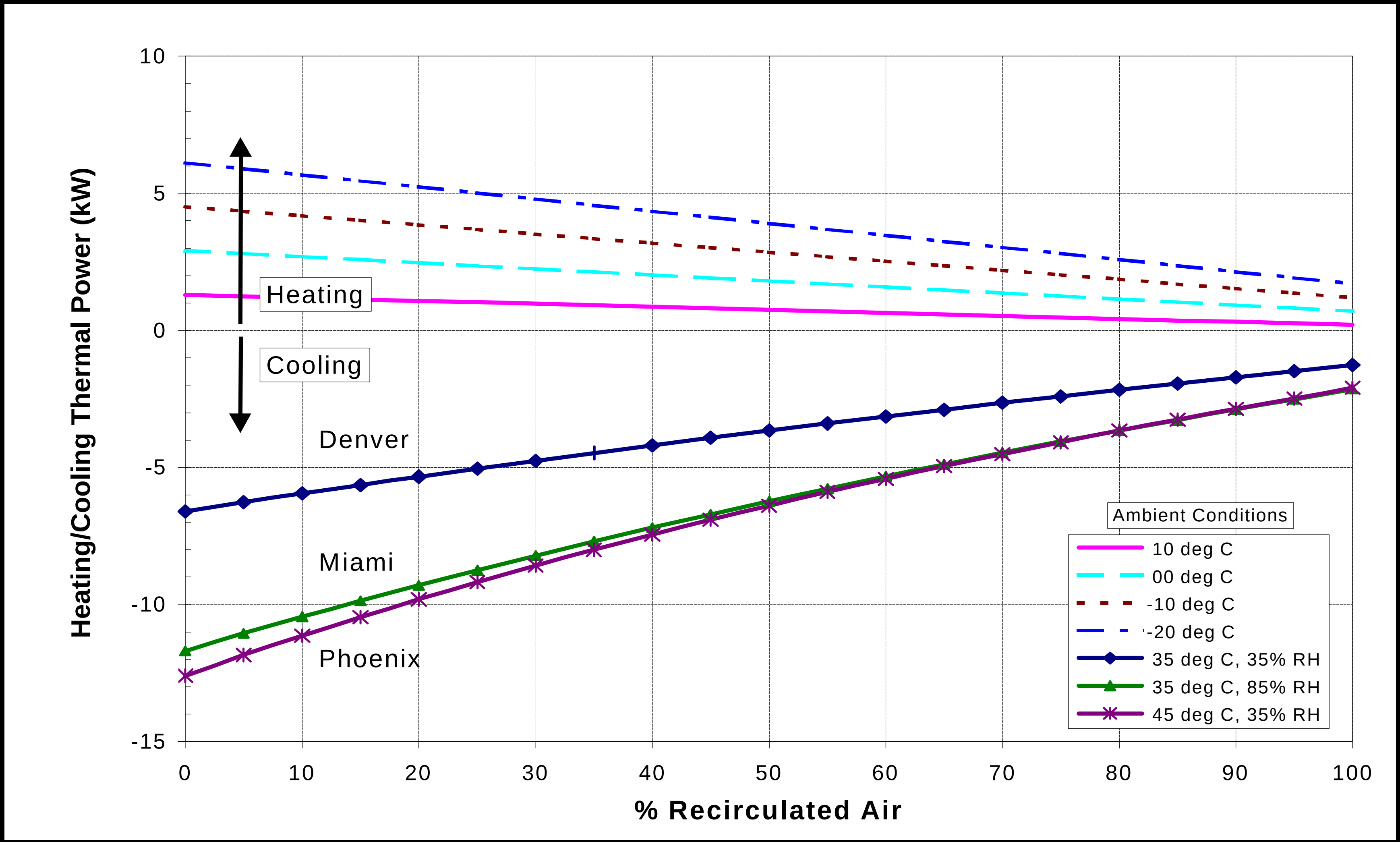
Cabin Heat Flux - Clear Day



Cabin Heat Flux - Cloudy Day



Thermal Power Requirements



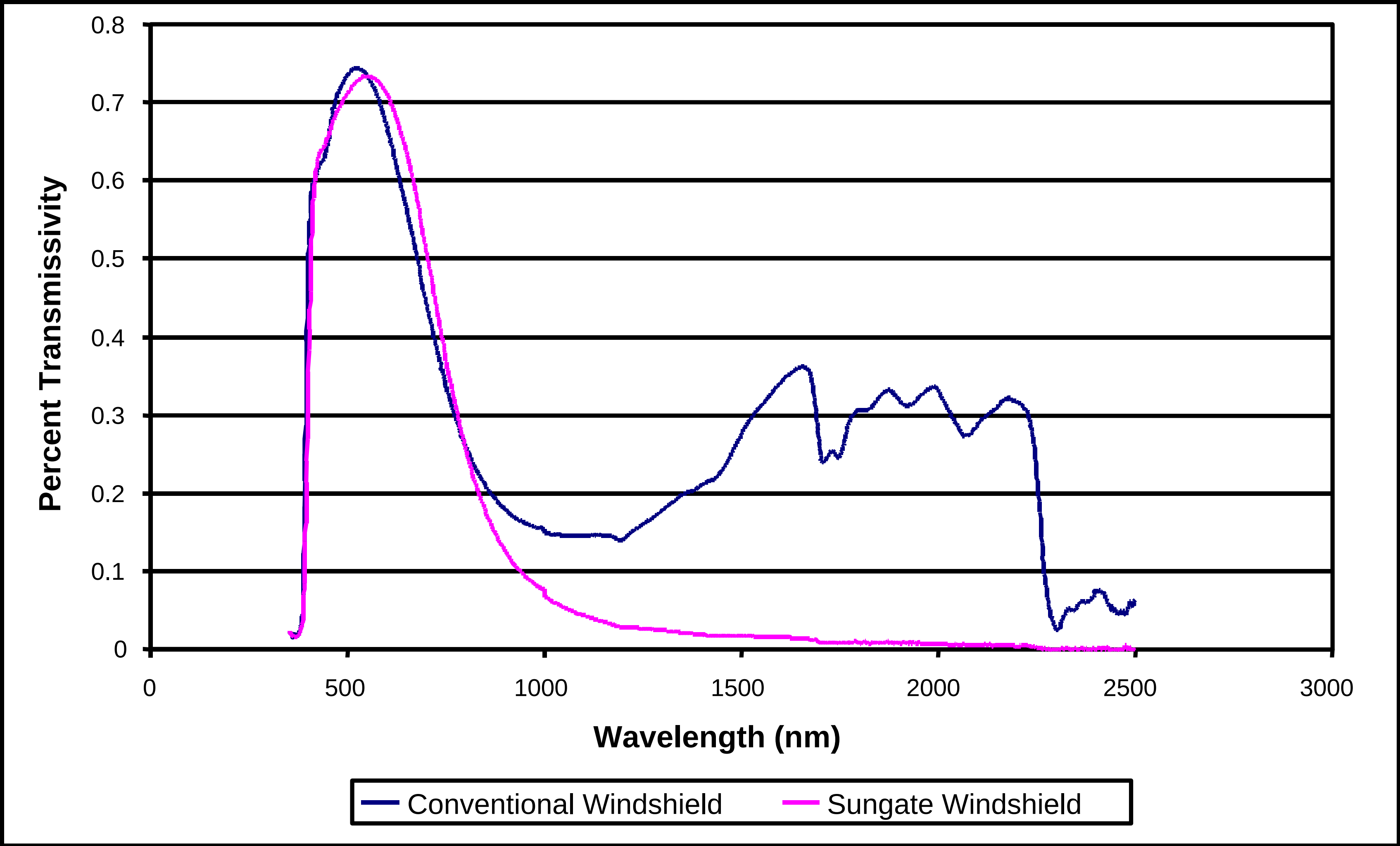
Solar Gain Reducing Windshields

NREL tested 3 different windshields:

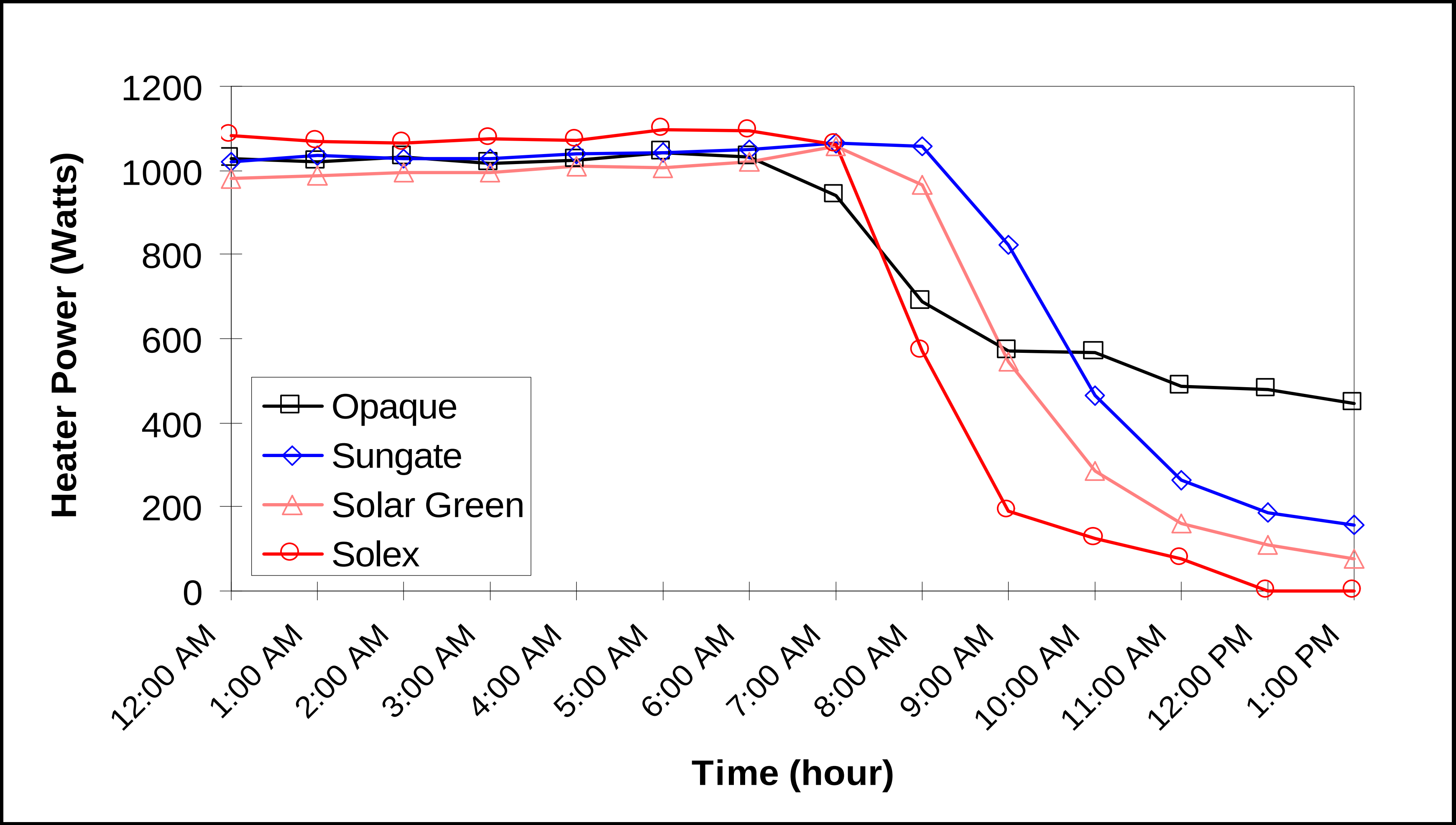
- Sungate
- Solex
- Solar green

Sungate Windshield Description

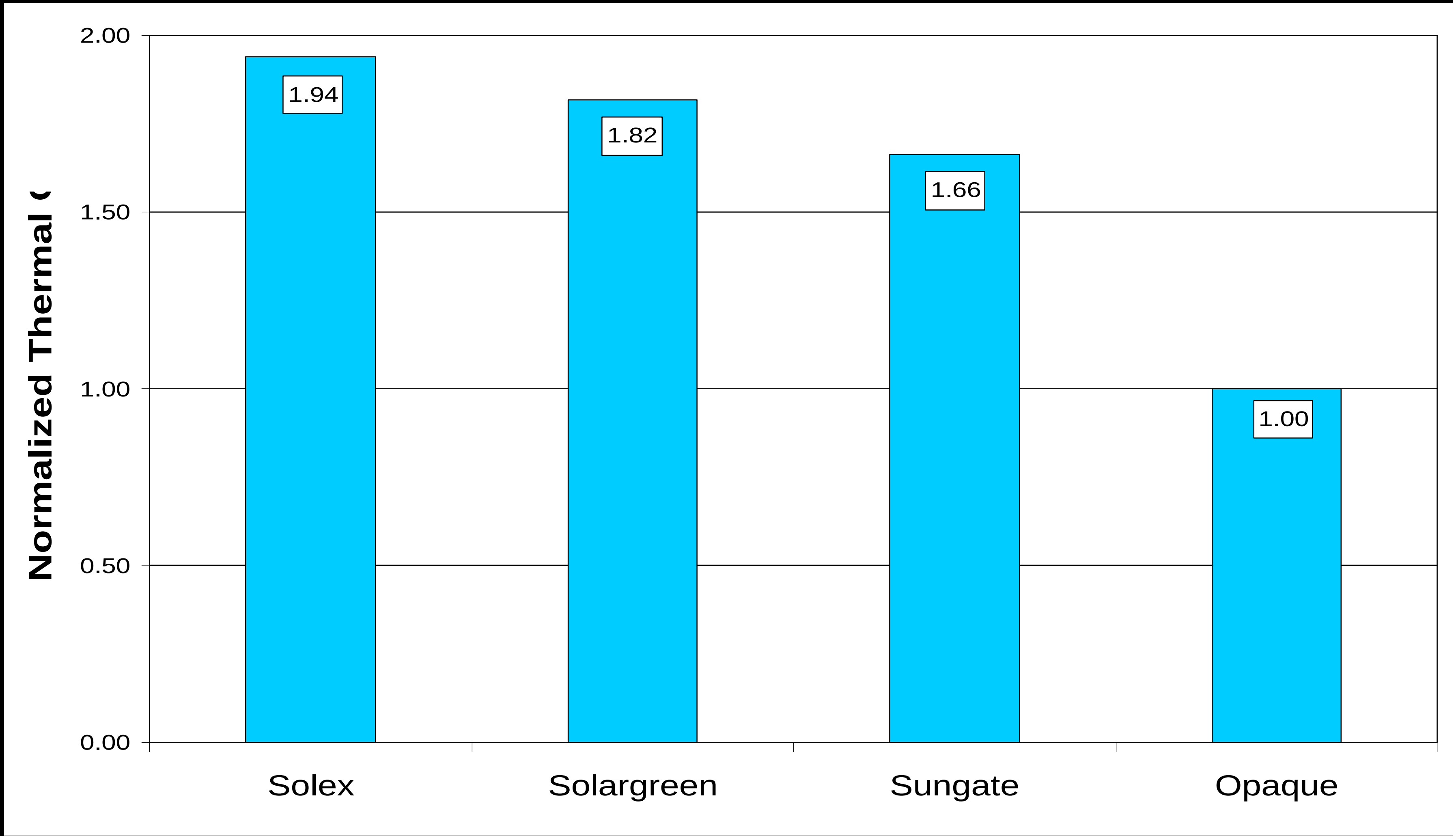
Solar Reflective Windshield



Windshield Co-Heating Tests



Windshield Results



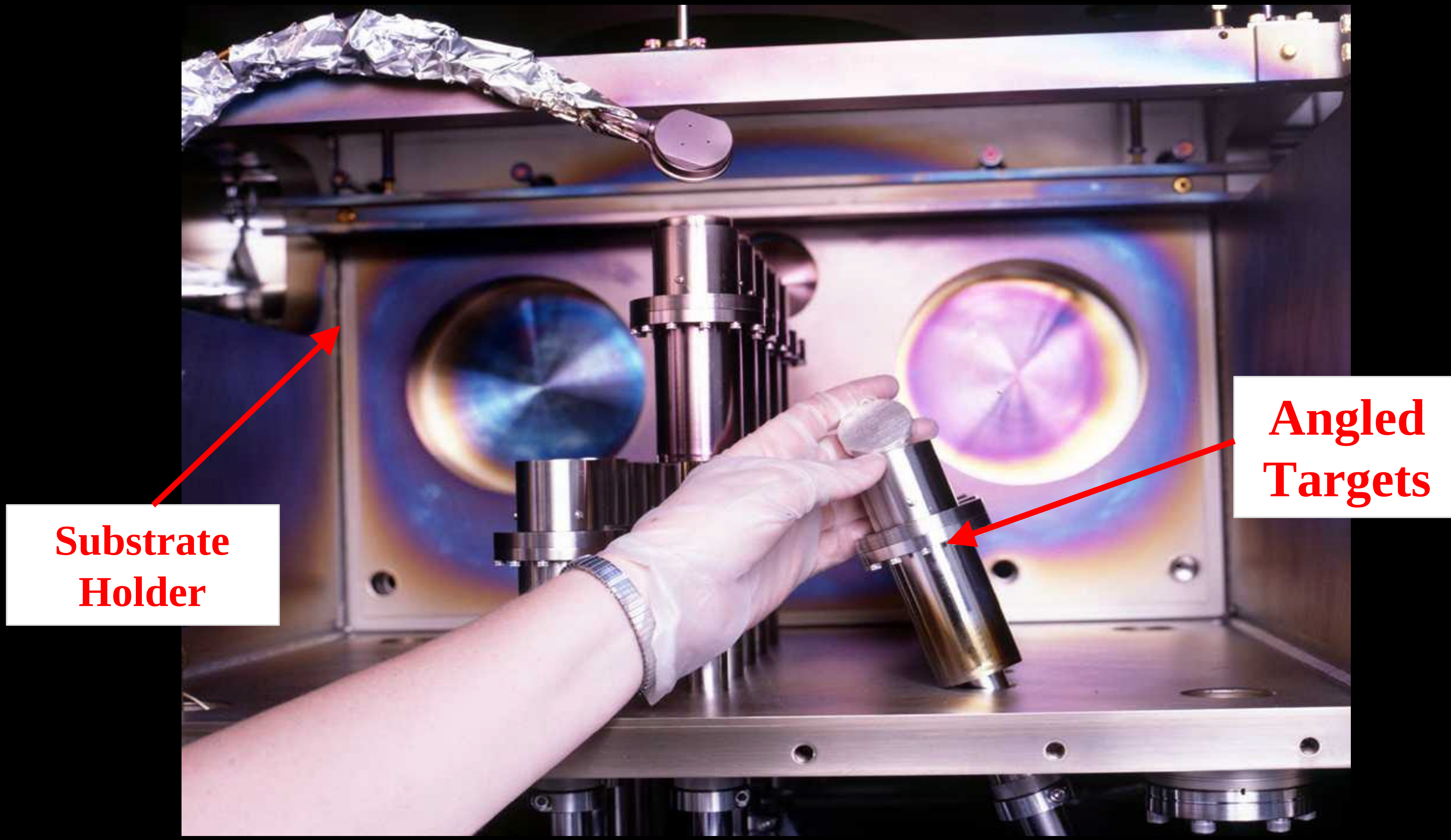
Fuel Economy Results

(assuming a compressor efficiency of 75%)

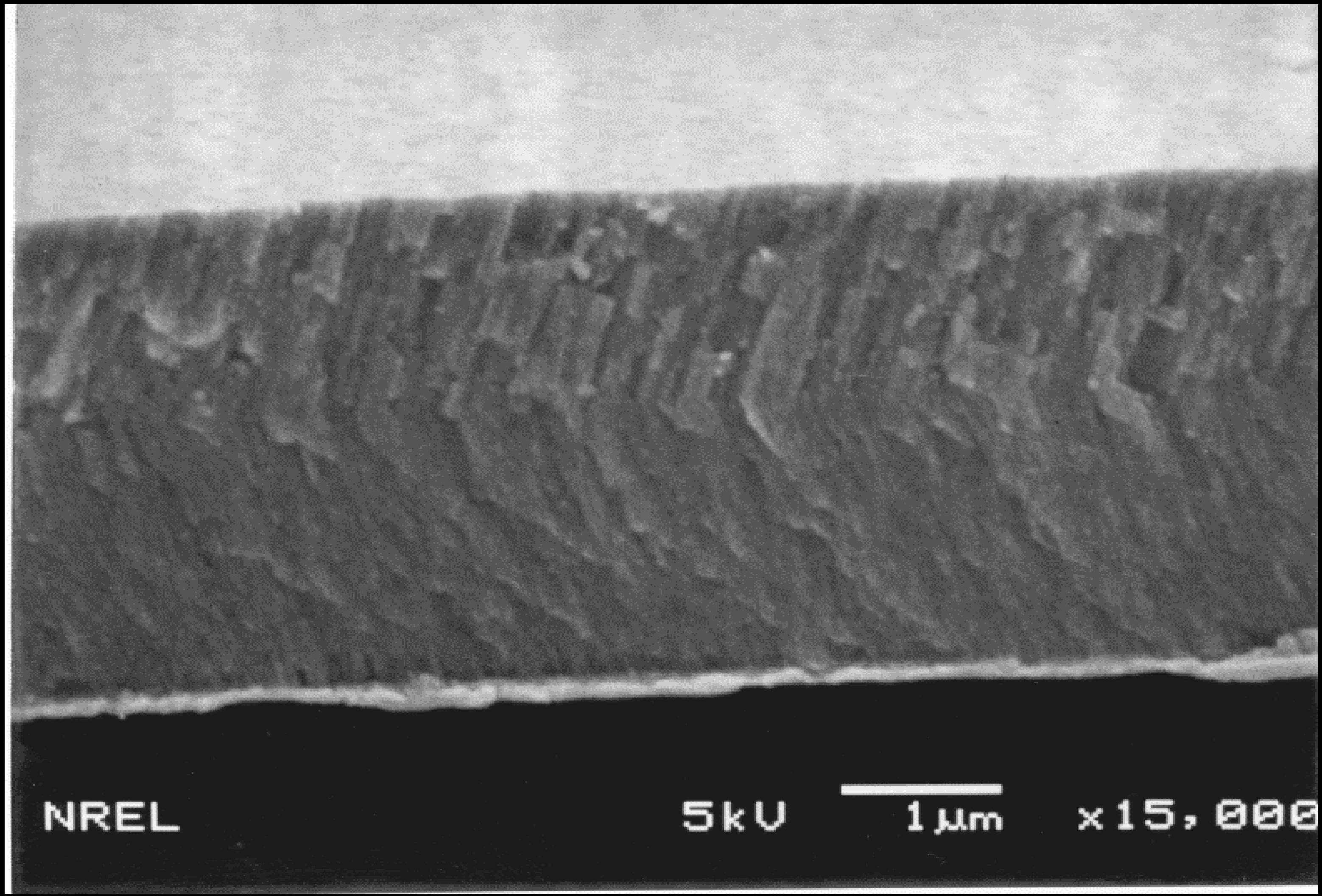
Windshield	Mechanical Accessory Load (kW/hp)	SFTP		SCO3 Only	
		Fuel Econ. (mpg)	% Change from Solex Baseline	Fuel Econ. (mpg)	% Change from Solex Baseline
Solex®	3.9/5.2	26.2	--	20.4	--
Sungate®	3.5/4.7	26.7	1.7%	21.1	3.4%

Angularly Reflective Glazing

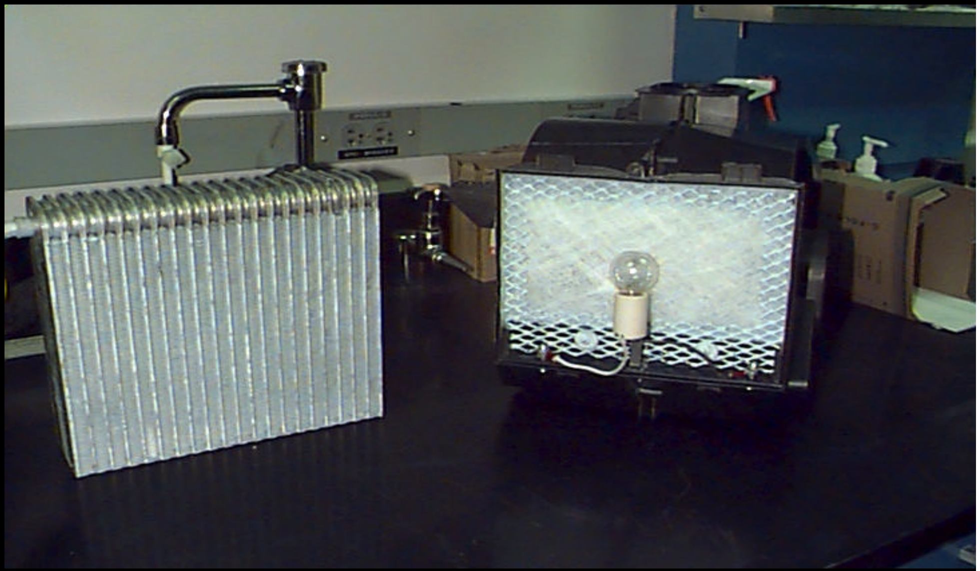
Magnetron Sputtering Chamber Showing Angled Target Array



SEM Showing Angular Morphology of Sputter Deposited Al_2O_3

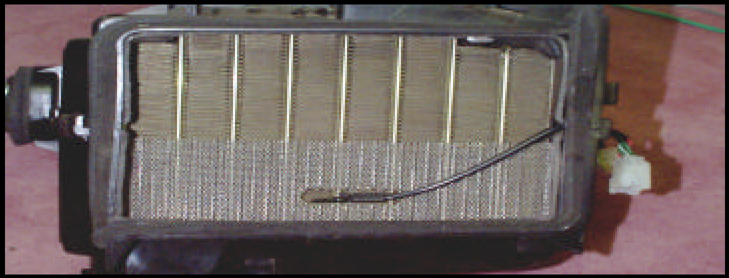
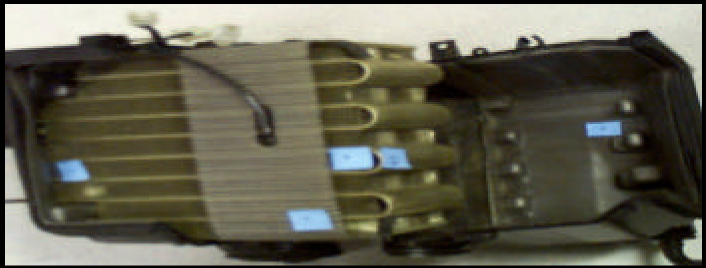


Cabin Air Cleaning

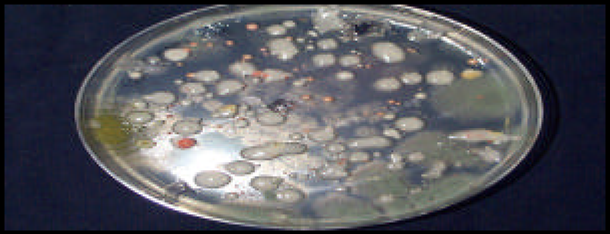
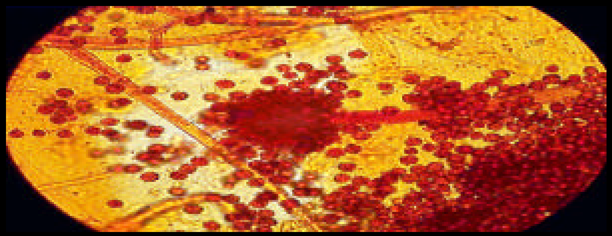
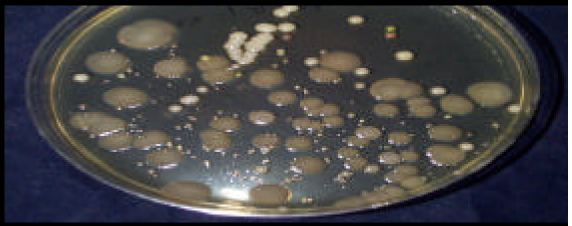


- Active
  - Integrated
  - Stand-alone
- Passive
  - Windshield System
  - Anti-fogging (VOCs)
  - UV-protection
- Baseline (VOC, Aerosol)
- Competitive Technologies (Activated Carbon)

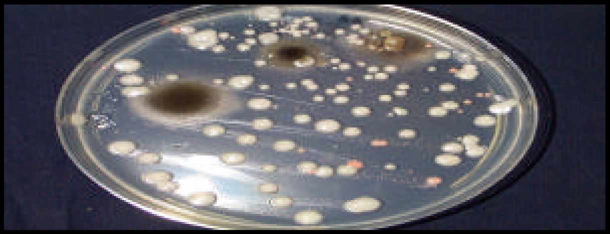
Microbial Examination of A/C System (Chrysler 1990)

Evaporator

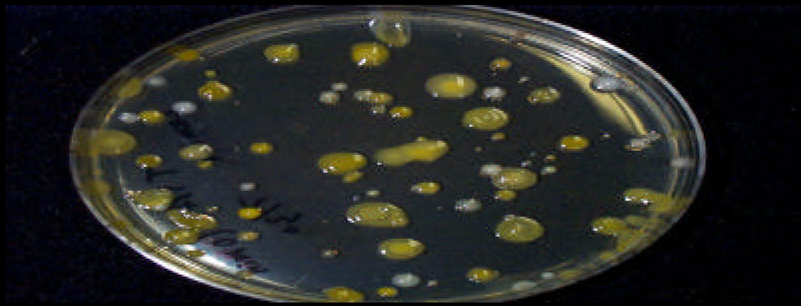




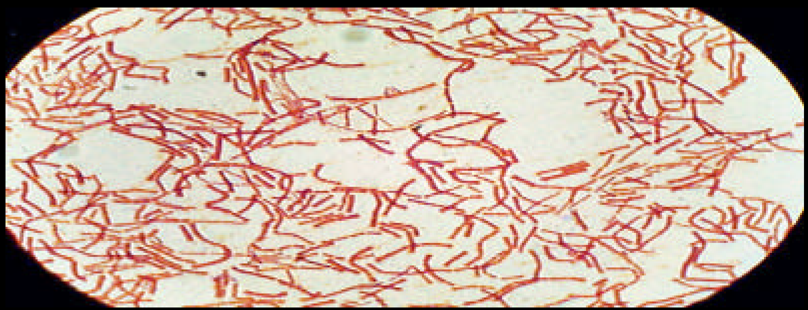
Fungal growth from evaporator A - swab sample



From evaporator B

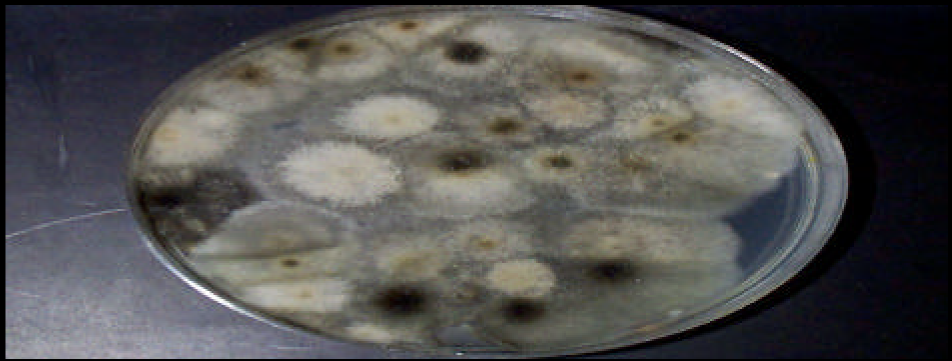
Microbial Examination of A/C System (‘96 Lumina)





Bacterial growth from A/C vent swab sample

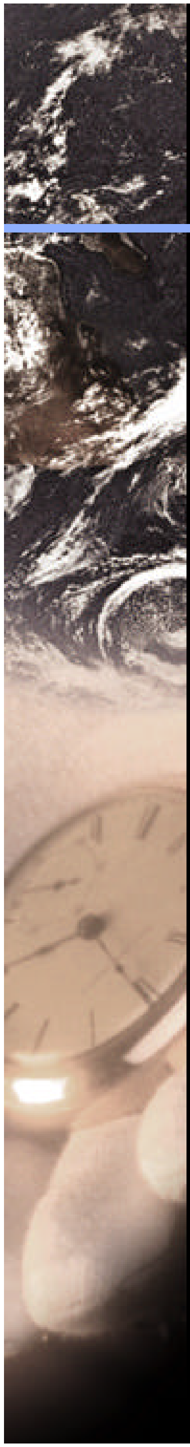
Outflow from A/C vent (10 min exposure)



Fungal growth from A/C vent (10 min exposure)

Cabin Air Cleaning Options

- Ventilation
- Activated carbon unit (requires regeneration or periodic replacement)
- Photocatalytic device (alone or in combination with activated carbon)
- Other chemical or photochemical treatment methods (ozone, catalytic oxidation, etc.)



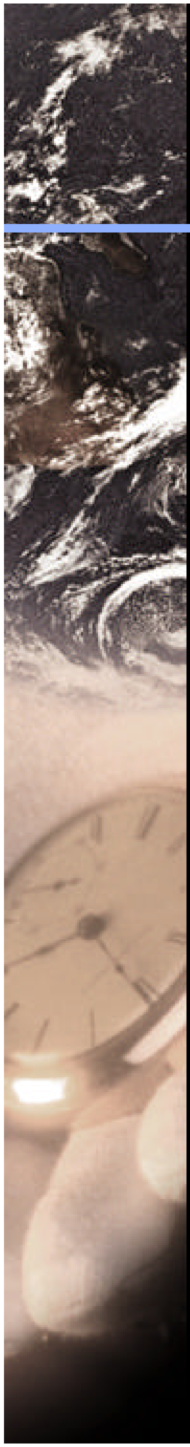
Objectives for Integrating Photocatalytic Oxidation (PCO) Unit into a Vehicle

- Simple unit that can be integrated into the HVAC assembly
- Power consumption less than 10 watts
- Unit cost less than $10
- Capable of removing VOC’s from fuels, vehicle emissions, odors, and interior materials
- Can increase use of recirculated air

Advantages of PCO System

- Acts as a self cleaning filter for VOCs and bioaerosols
- Low maintenance - light bulb and catalyst/filter media (project long life unless it becomes contaminated with inorganic matter)
- Operates at ambient conditions - insensitive to temperature, 0 - 82 C

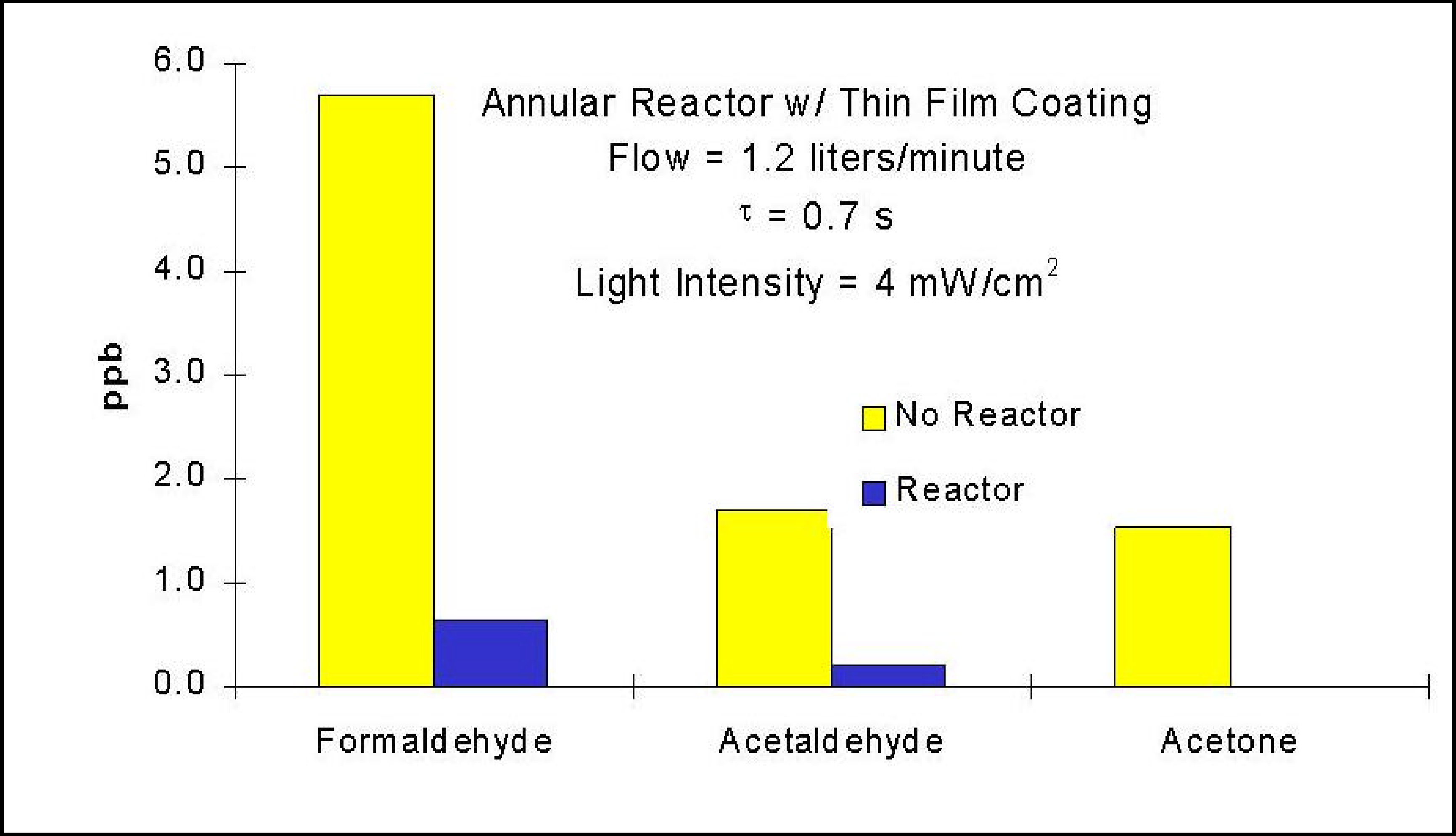
NREL's PCO Device



Measured VOC Concentrations (ppbv)

	Formaldehyde	Acetaldehyde	Acetone
’87 Camry (a.m.)	81	71	20
’87 Camry (p.m.)	171	204	39
’98 Subaru (p.m.)	86	47	28
’91 4Runner (a.m.)	17	13	5

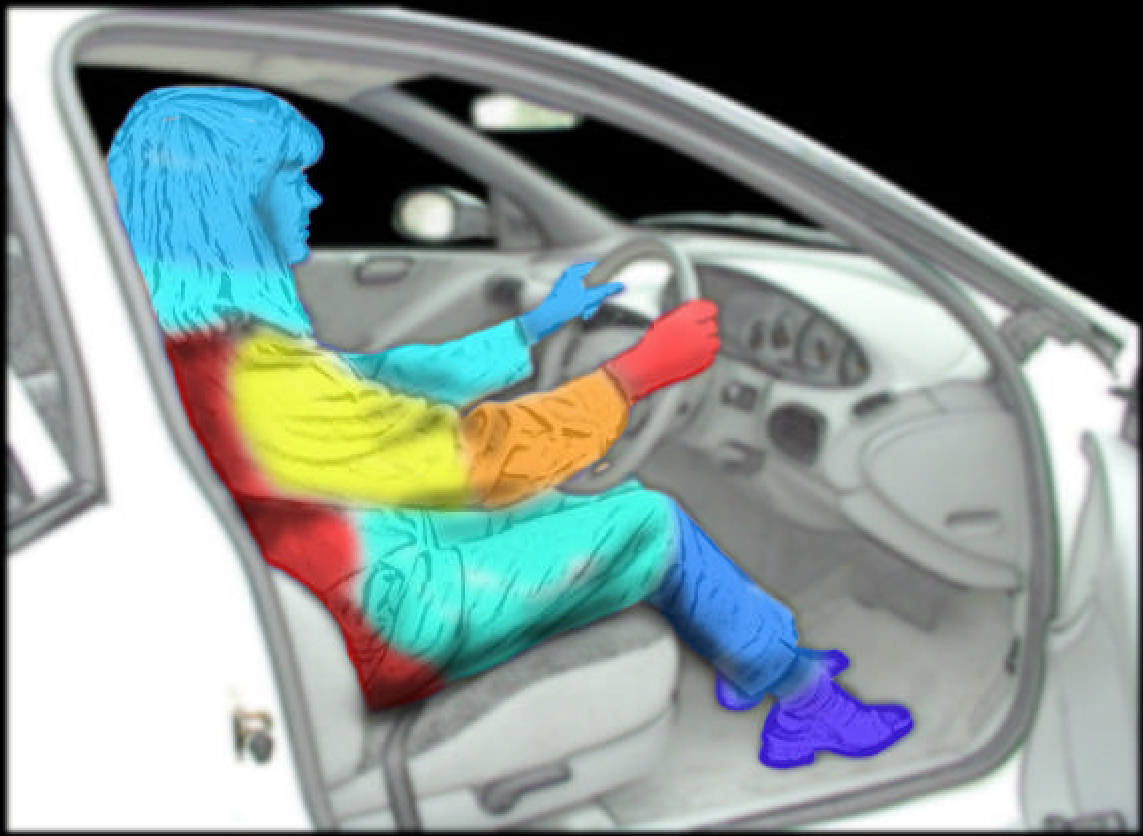
PCO Performance



Average Energy Thermal Comfort Model

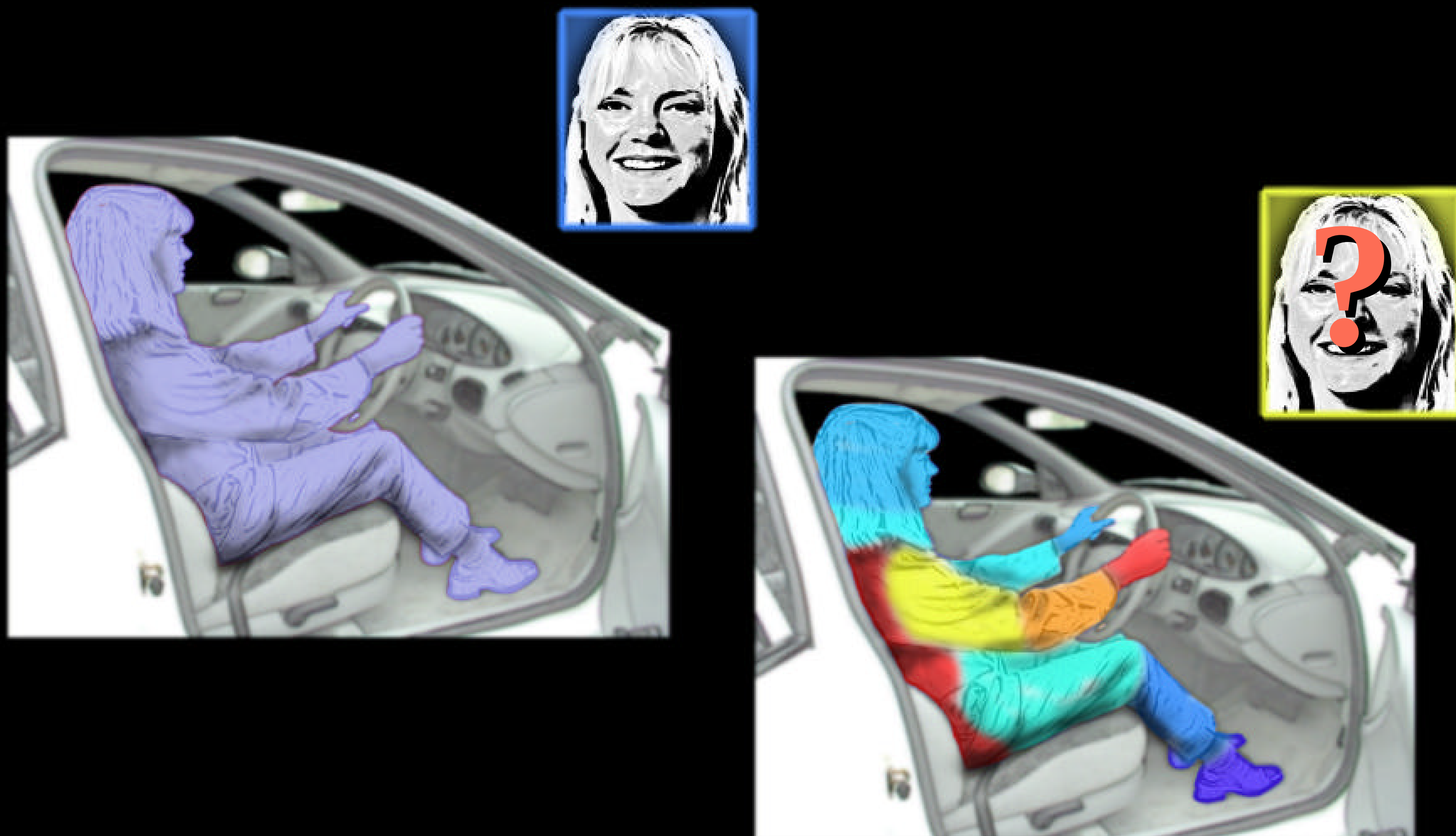
Well-suited for a uniform environment, such as in a building.

16-Segment Thermal Comfort Model

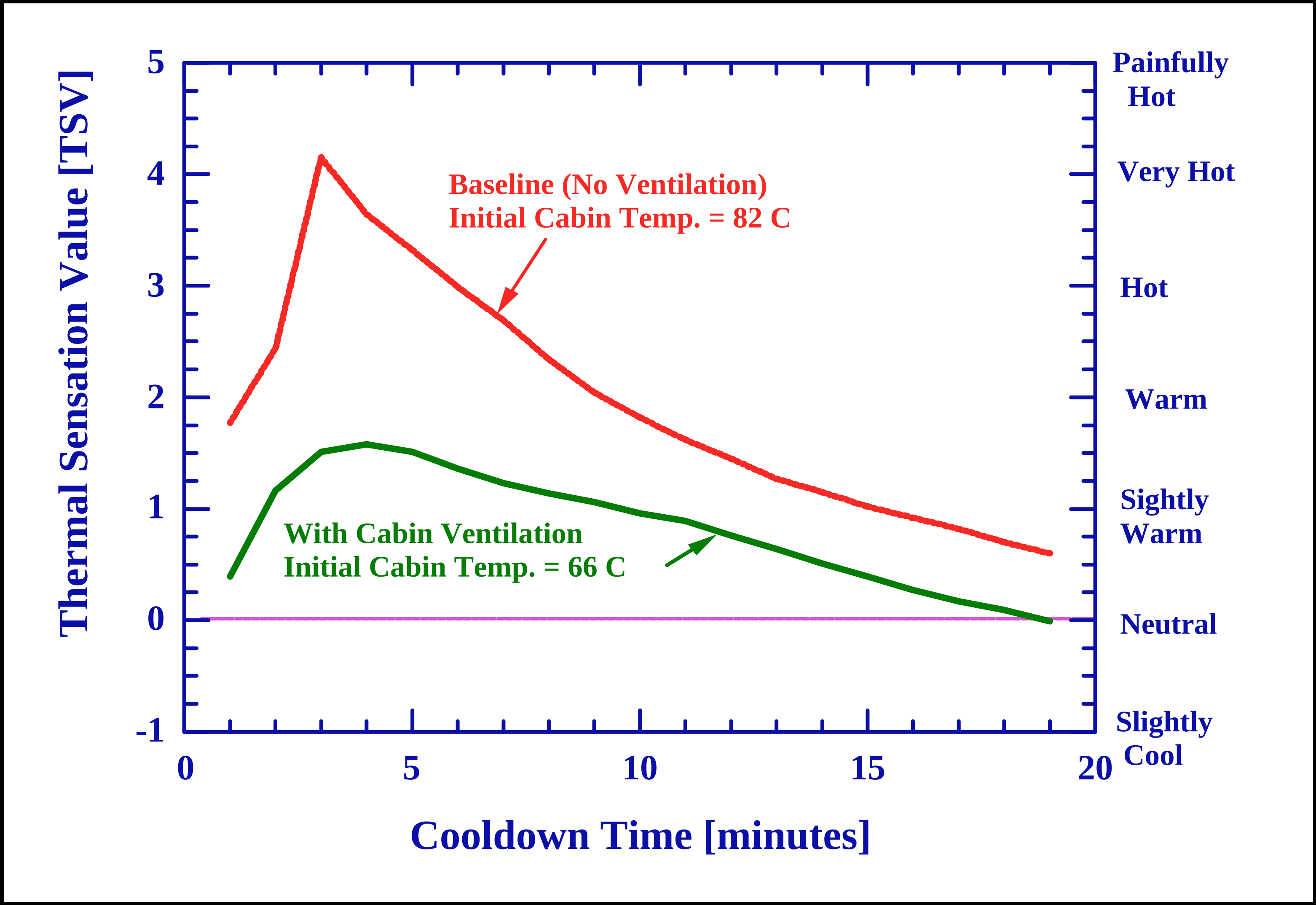


Well-suited for a nonuniform environment, such as in a vehicle.

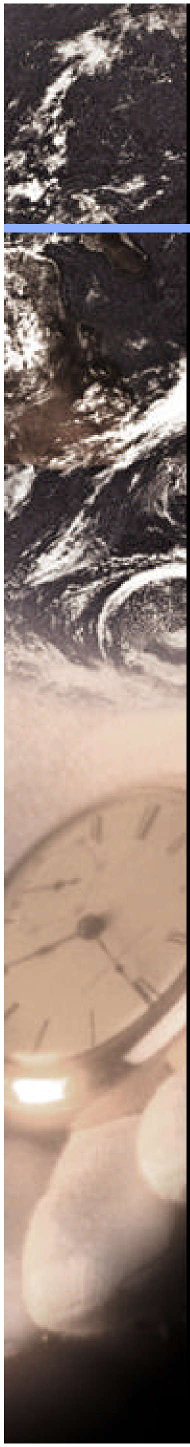
Thermal Comfort Prediction

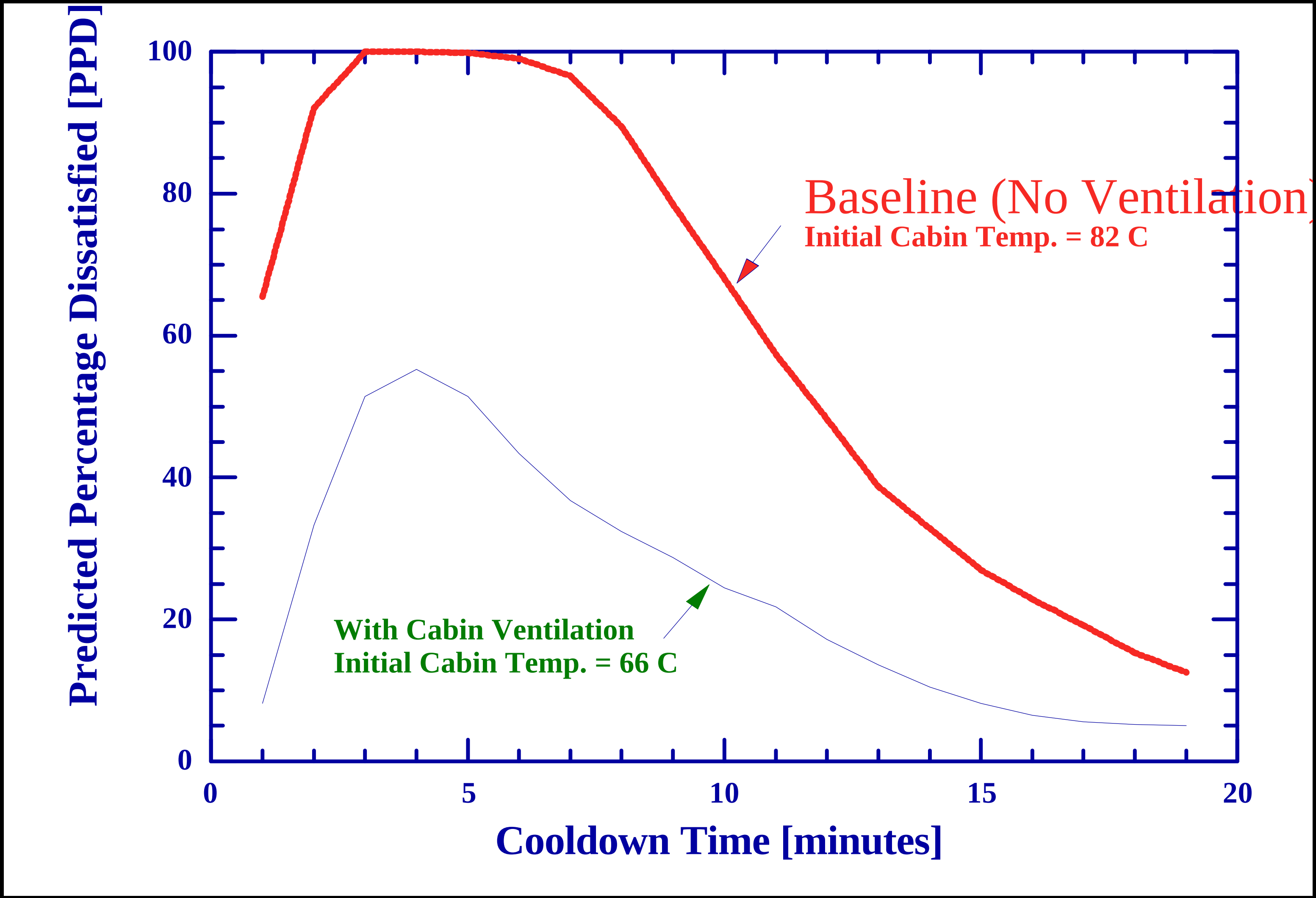


Thermal Comfort - TSV

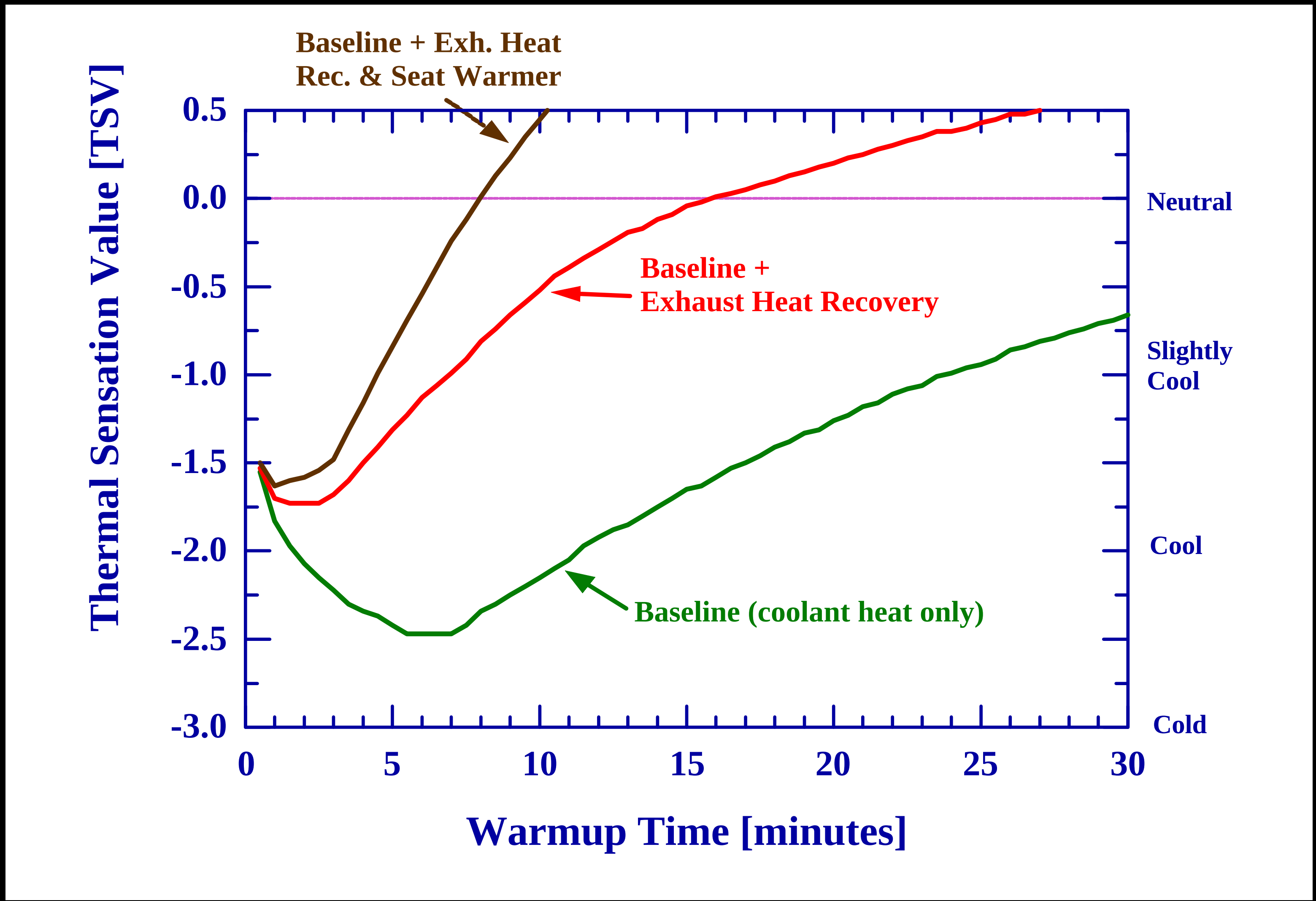


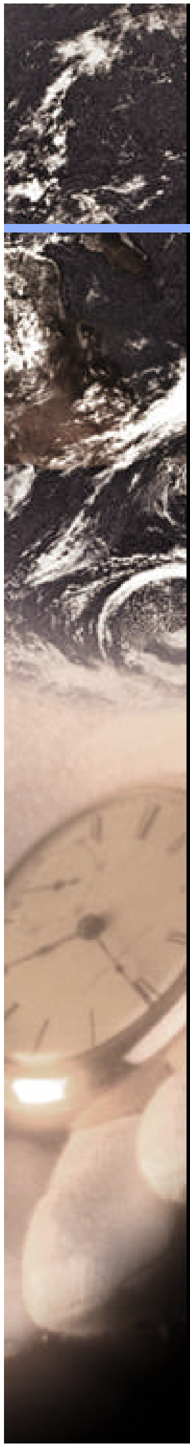
Thermal Comfort - PPD





Cabin Warm-up: TSV





Acknowledgments

- Robert Kost, U.S. Department of Energy
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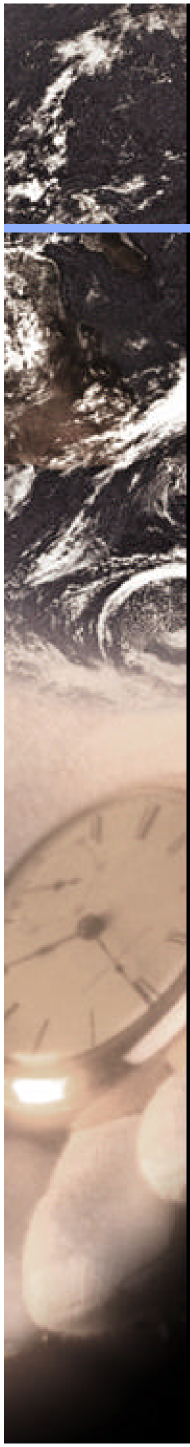
- Bill Jacoby, Photocatalysis
- Terry Penney, Technology Manager
- Ahmad Pesaran, Desiccant Technology
- Cassie Quaintance, Cabin Thermal Modeling
- Loreno Roybal, Photovoltaics
- Tom Thoensen, Vehicle and Subsystem Testing

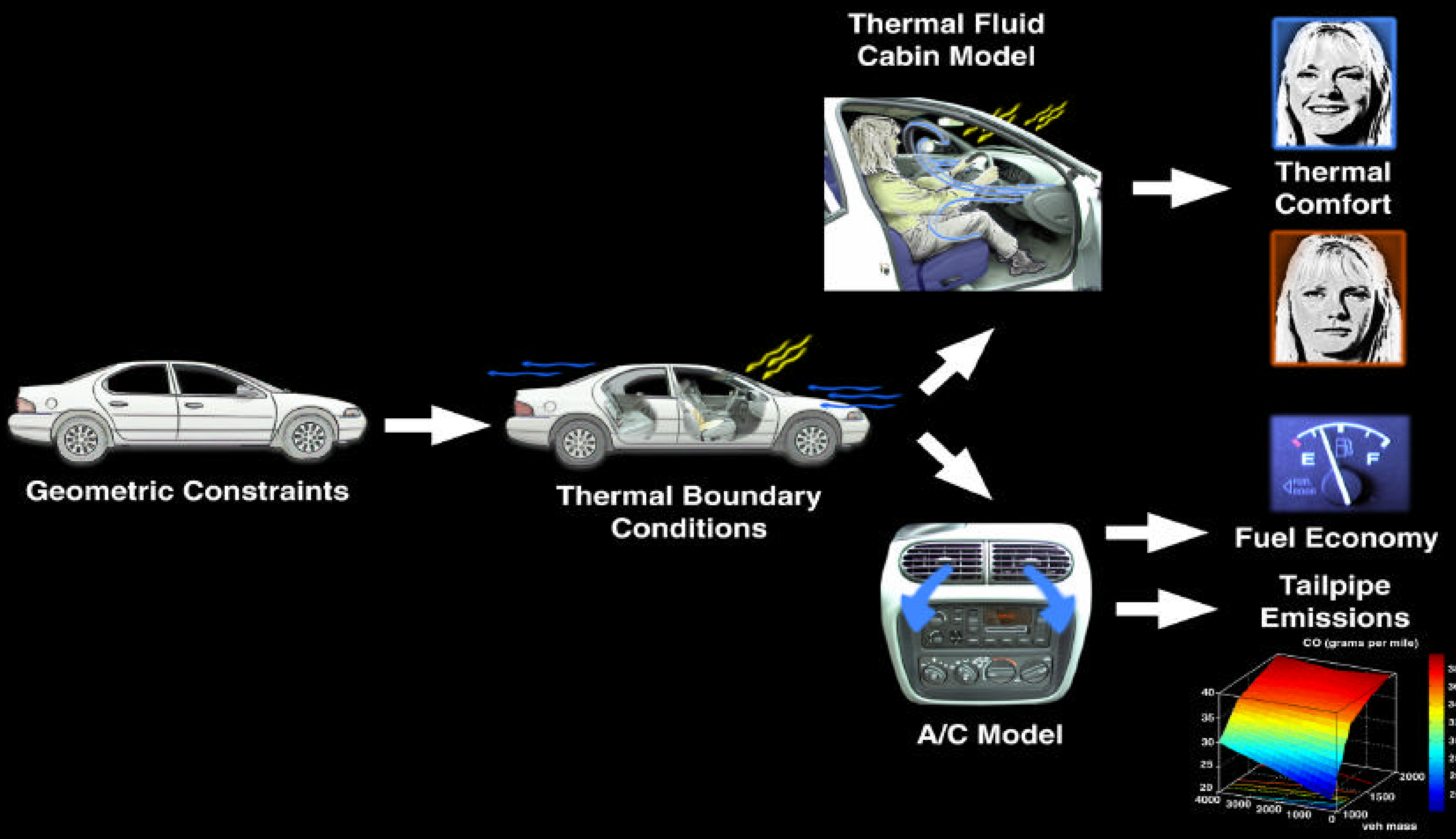
Integrated Vehicle Climate Control Modeling



Objective:

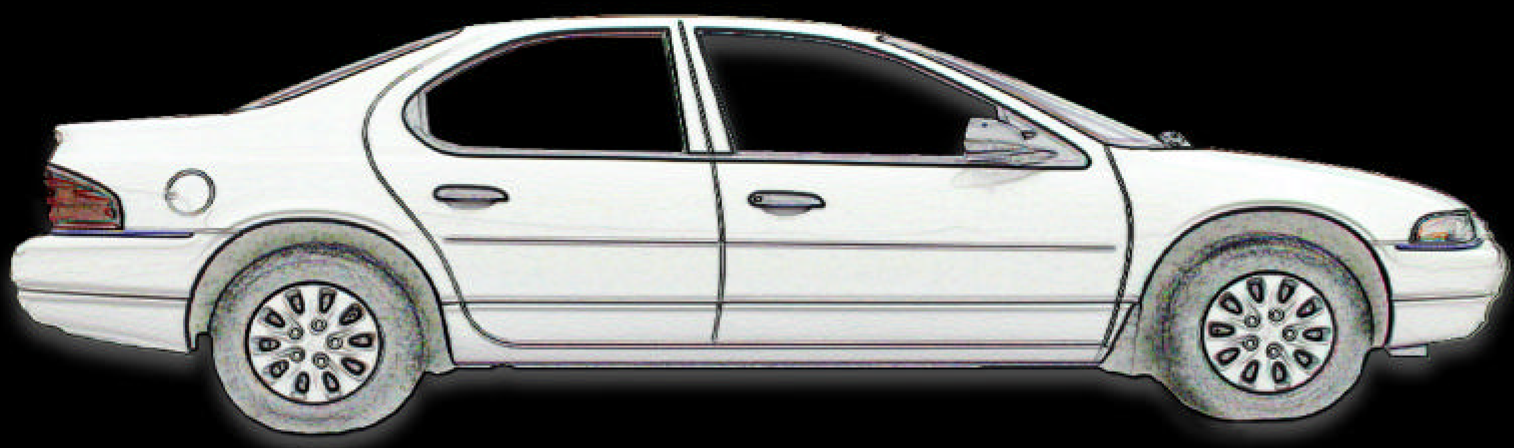
To meet thermal comfort, fuel economy, and emissions targets by using an integrated modeling approach composed of CAE, CFD, thermal comfort, and vehicle simulation tools.

The Modeling Process



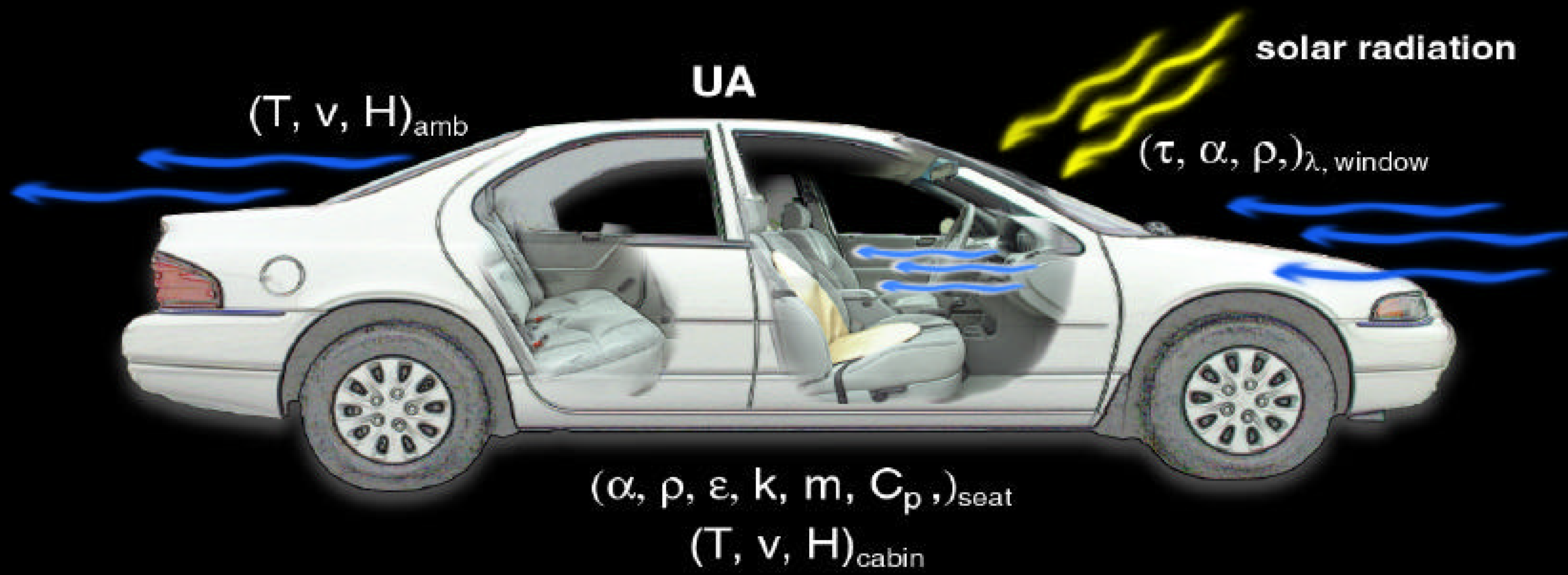
Vehicle Geometry

- **Objective:** To specify the cabin geometry.



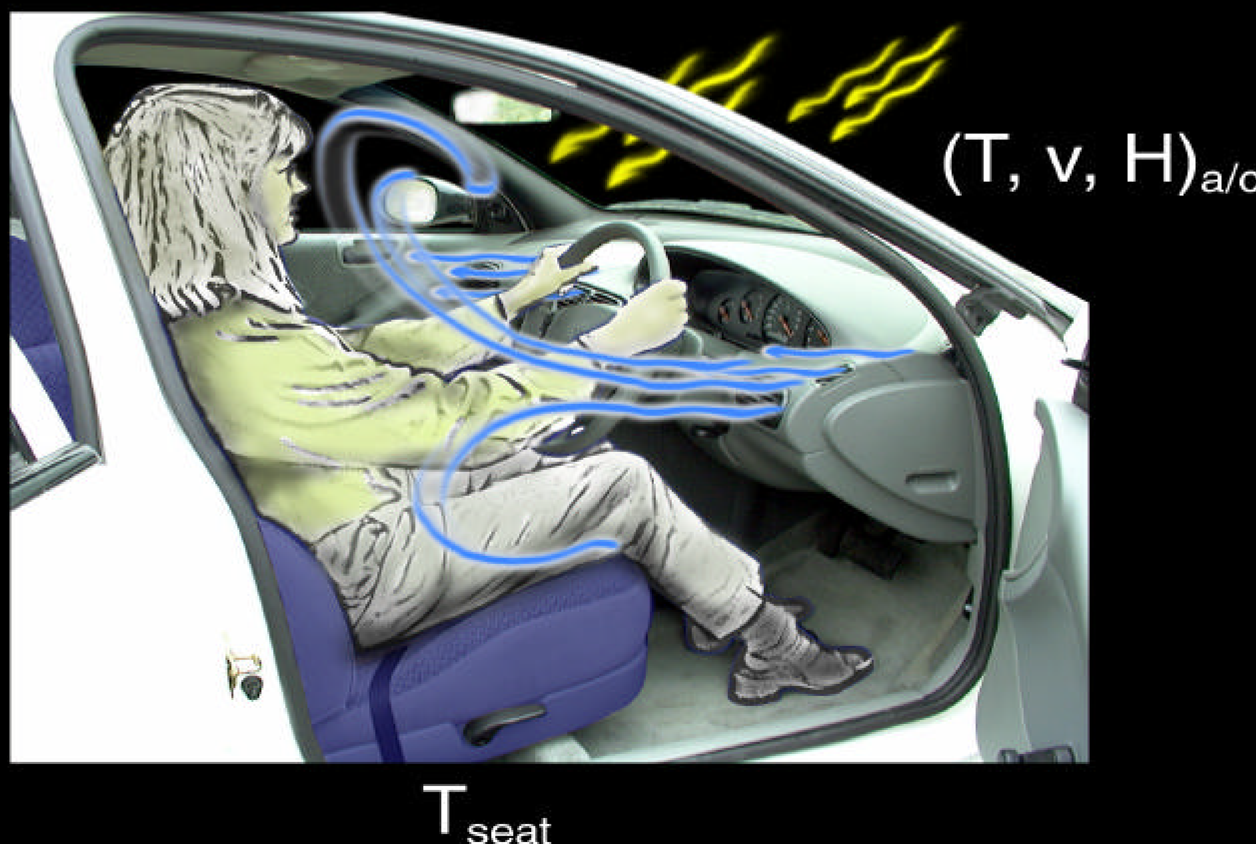
Thermal Boundary Conditions

- **Objective:** To specify the cabin thermal properties and boundary conditions.



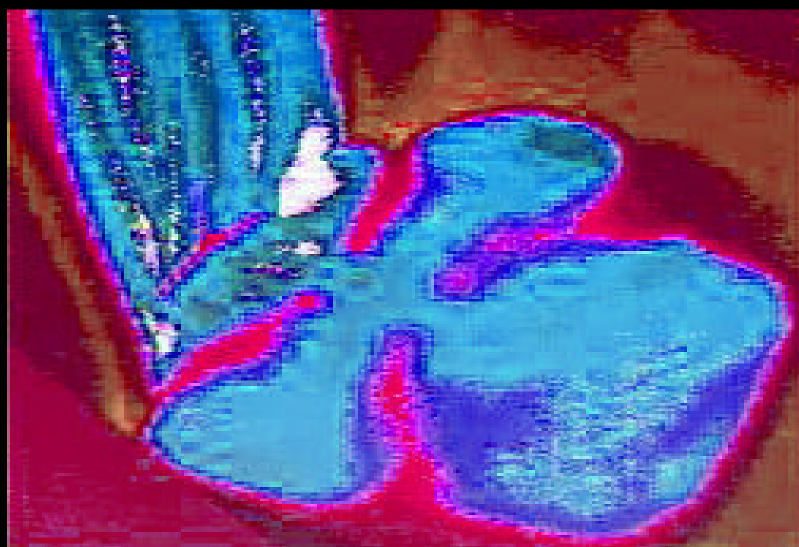
Thermal/Fluid Cabin Model

- **Objective:** To predict thermal environmental conditions.



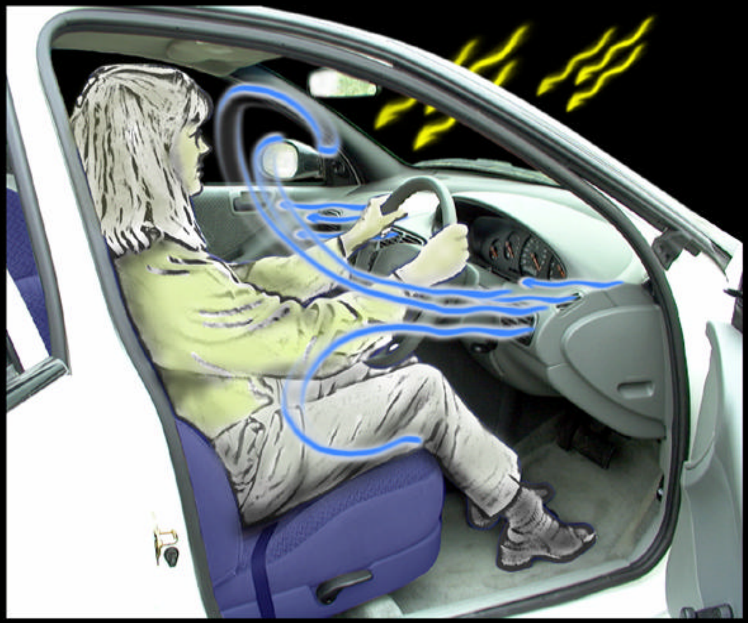
Air-Conditioning Model

- **Objective:** To design the A/C system based on environmental conditions and thermal comfort feedback.



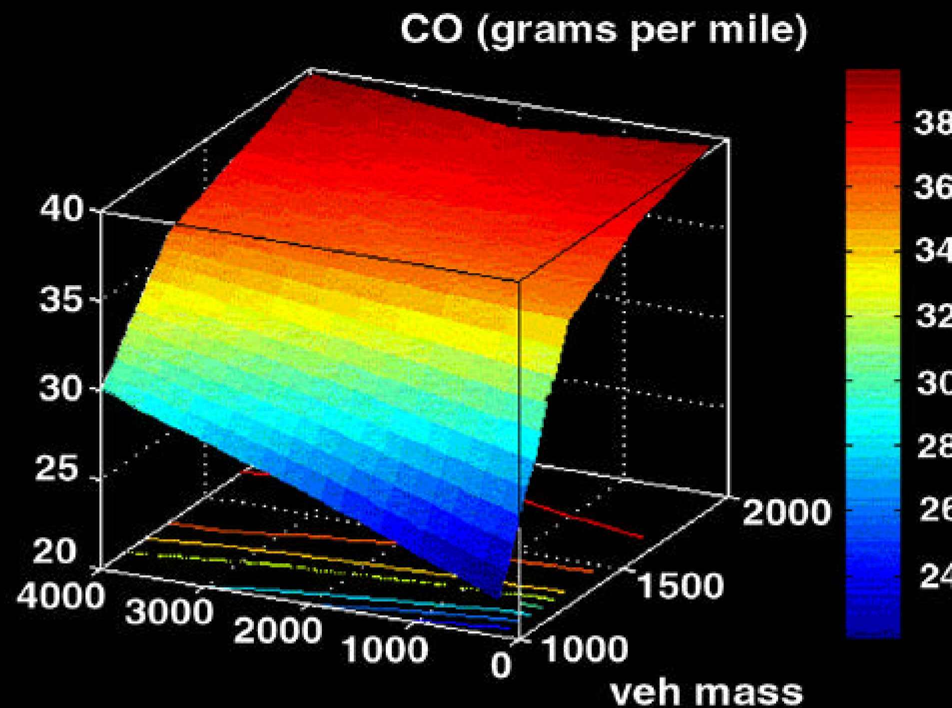
Thermal Comfort Model

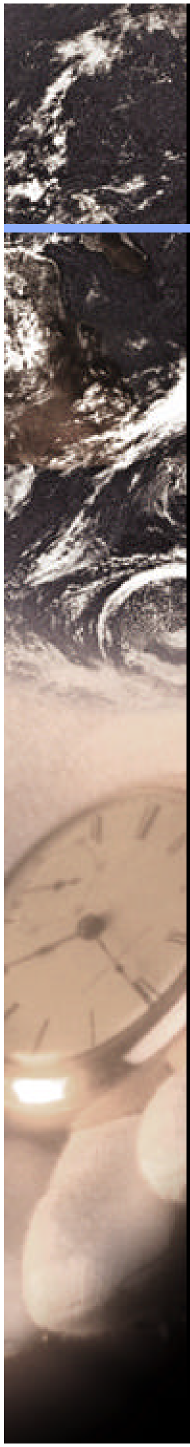
- **Objective:** To predict occupant thermal comfort based on environmental conditions and A/C design.


Vehicle Model

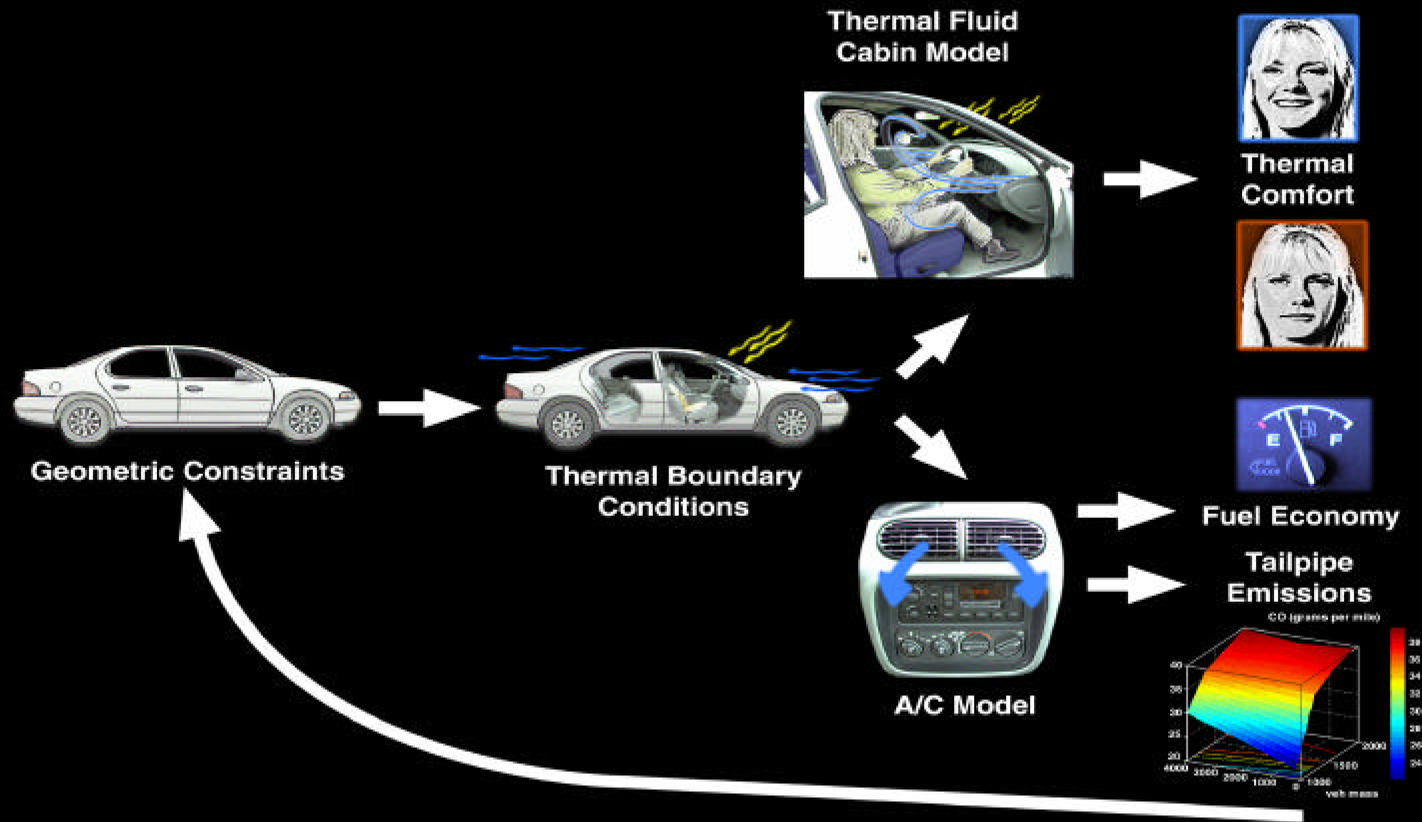
- **Objective:** To predict vehicle fuel economy and tailpipe emissions with A/C use.





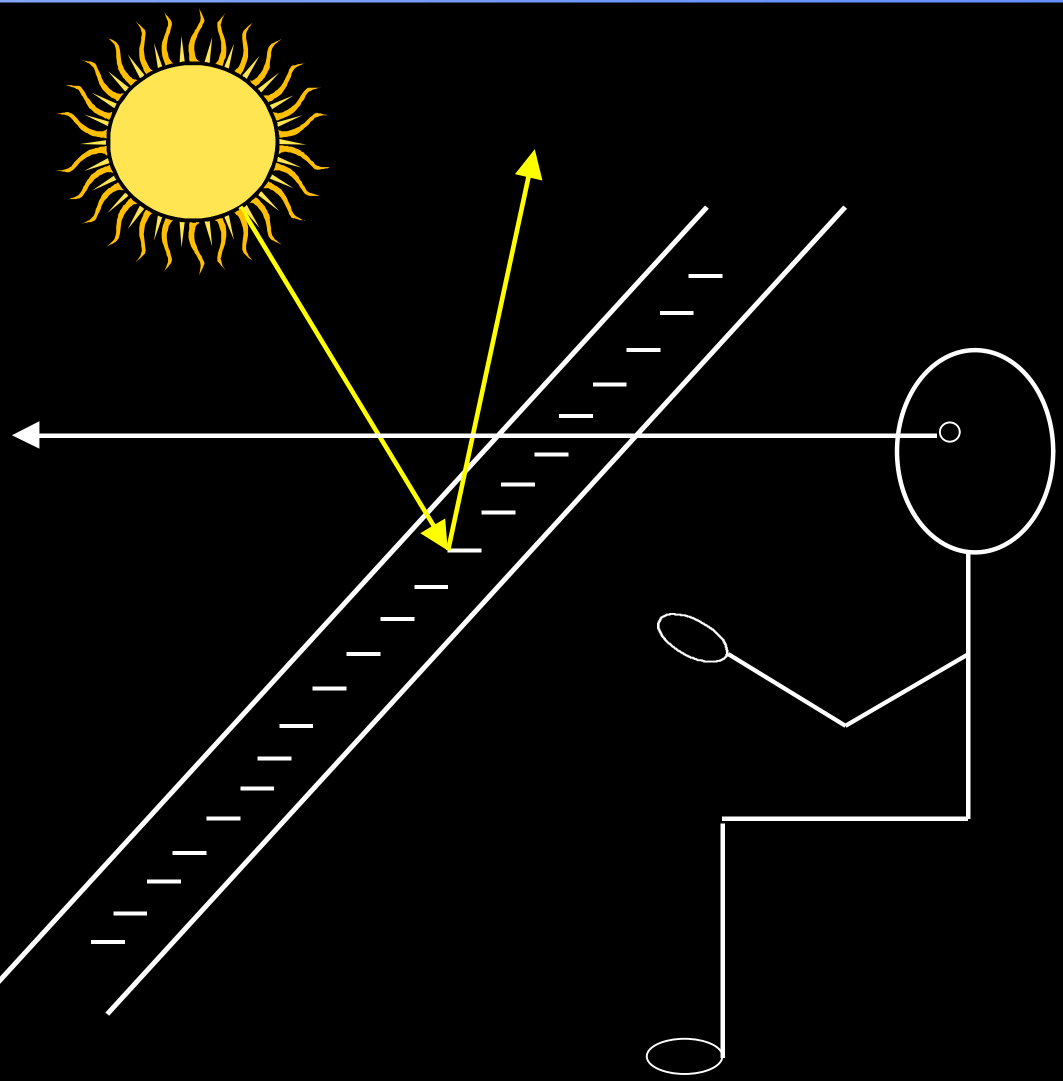
Feedback Loop

- **Objective:** To meet thermal comfort, fuel economy, and emissions goals by iterating the modeling processes.

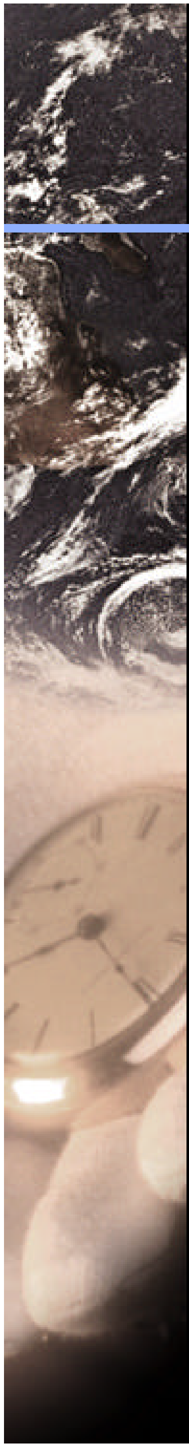


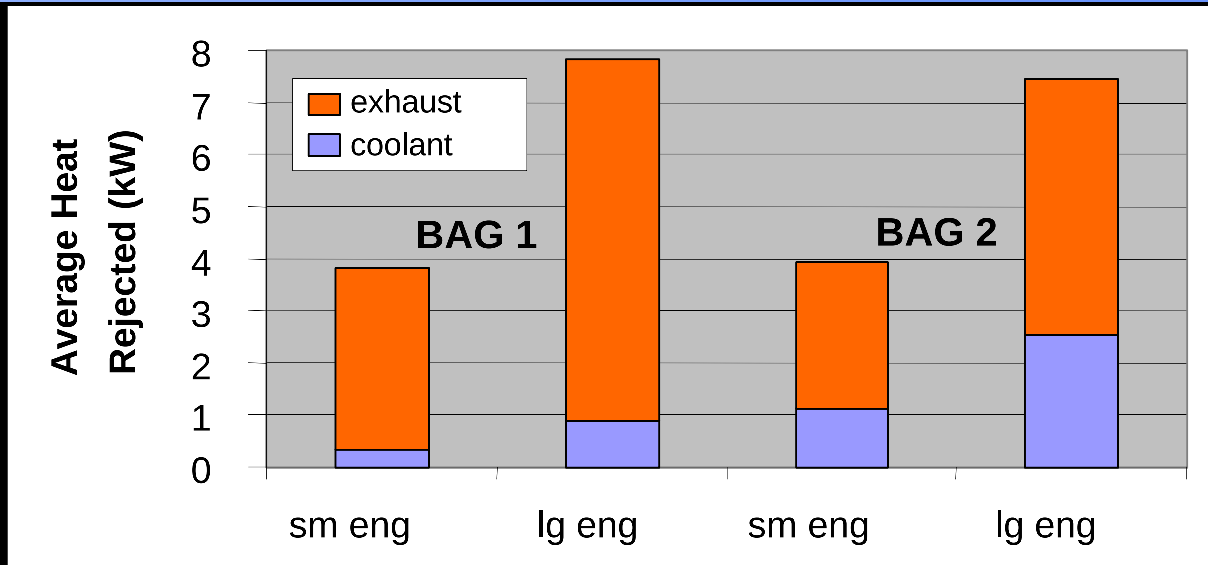
Angularly Reflective Glazing

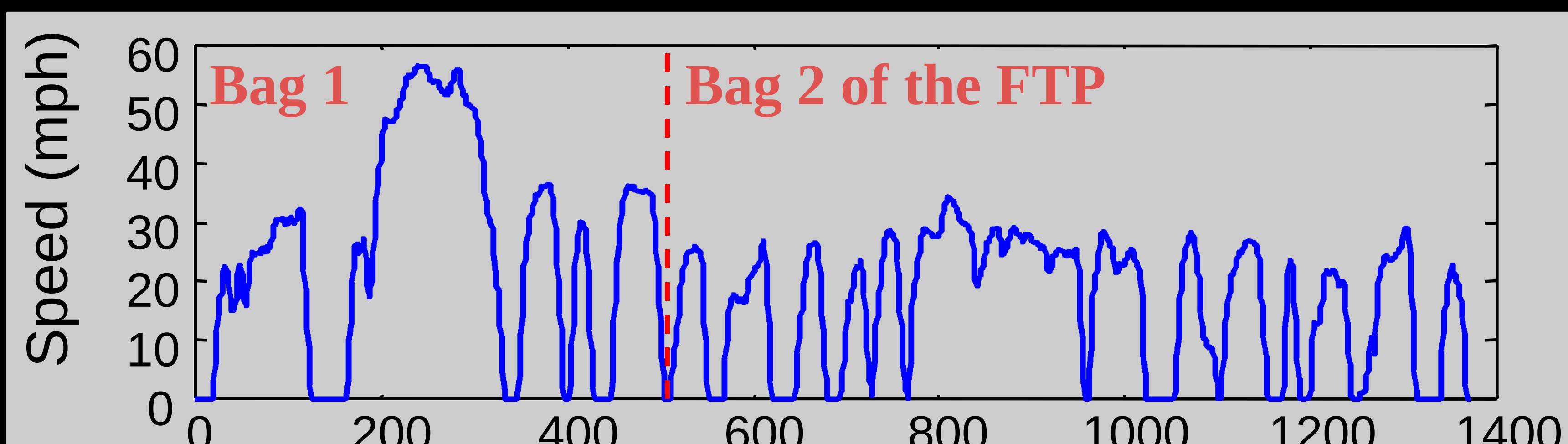
Angularly Reflective Glazing



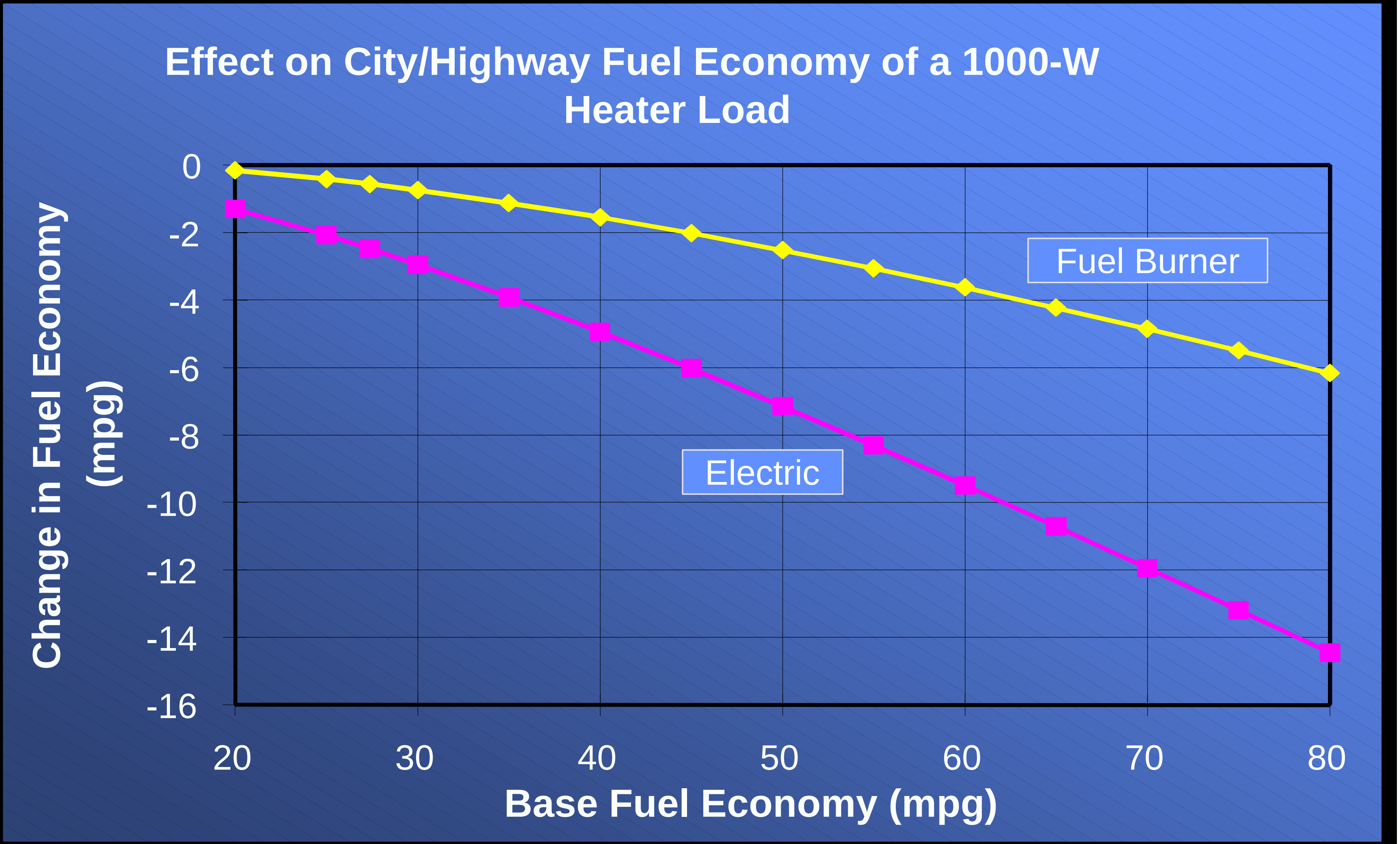
EHR - Opportunity/Challenge



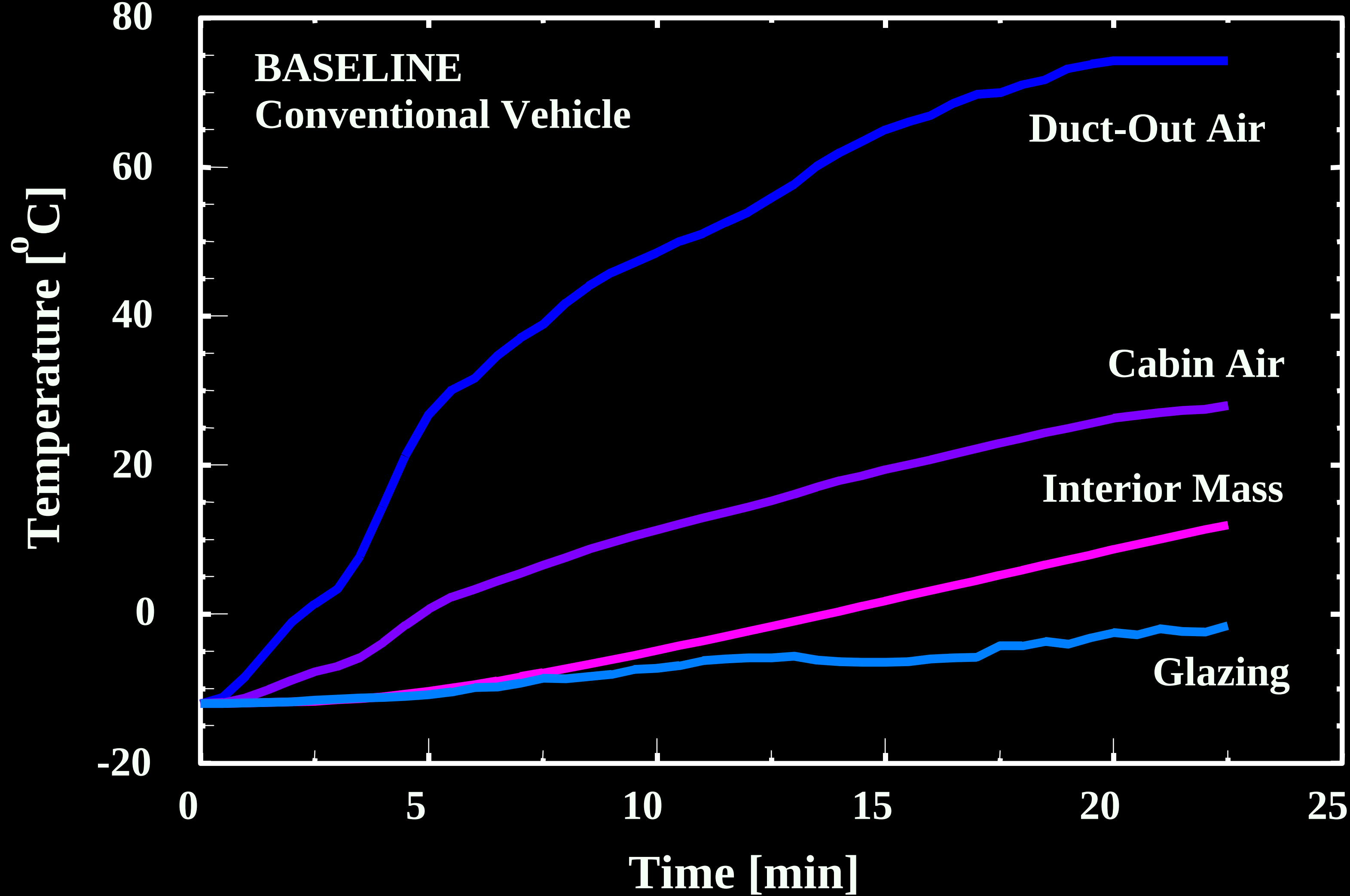




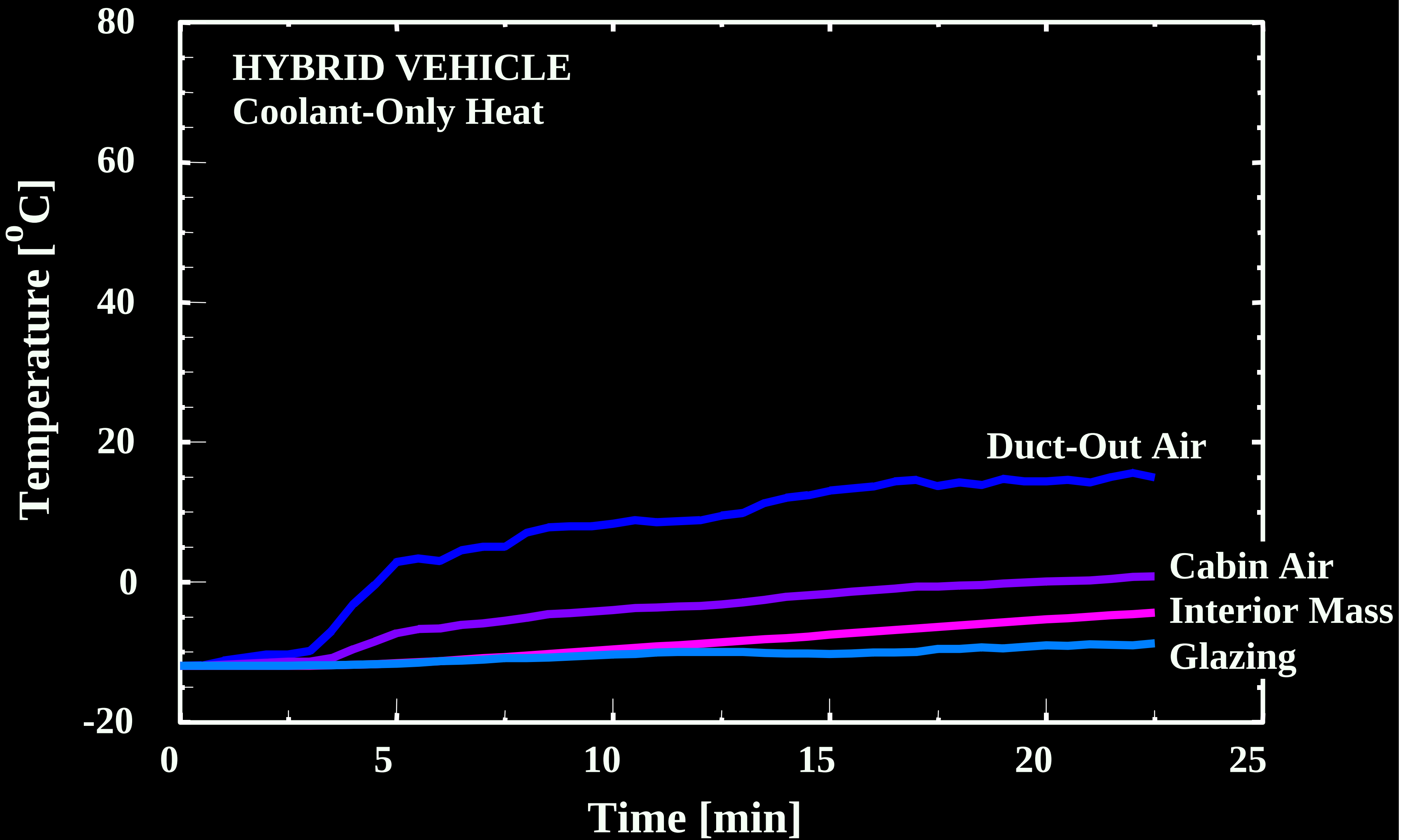
EHR Potential



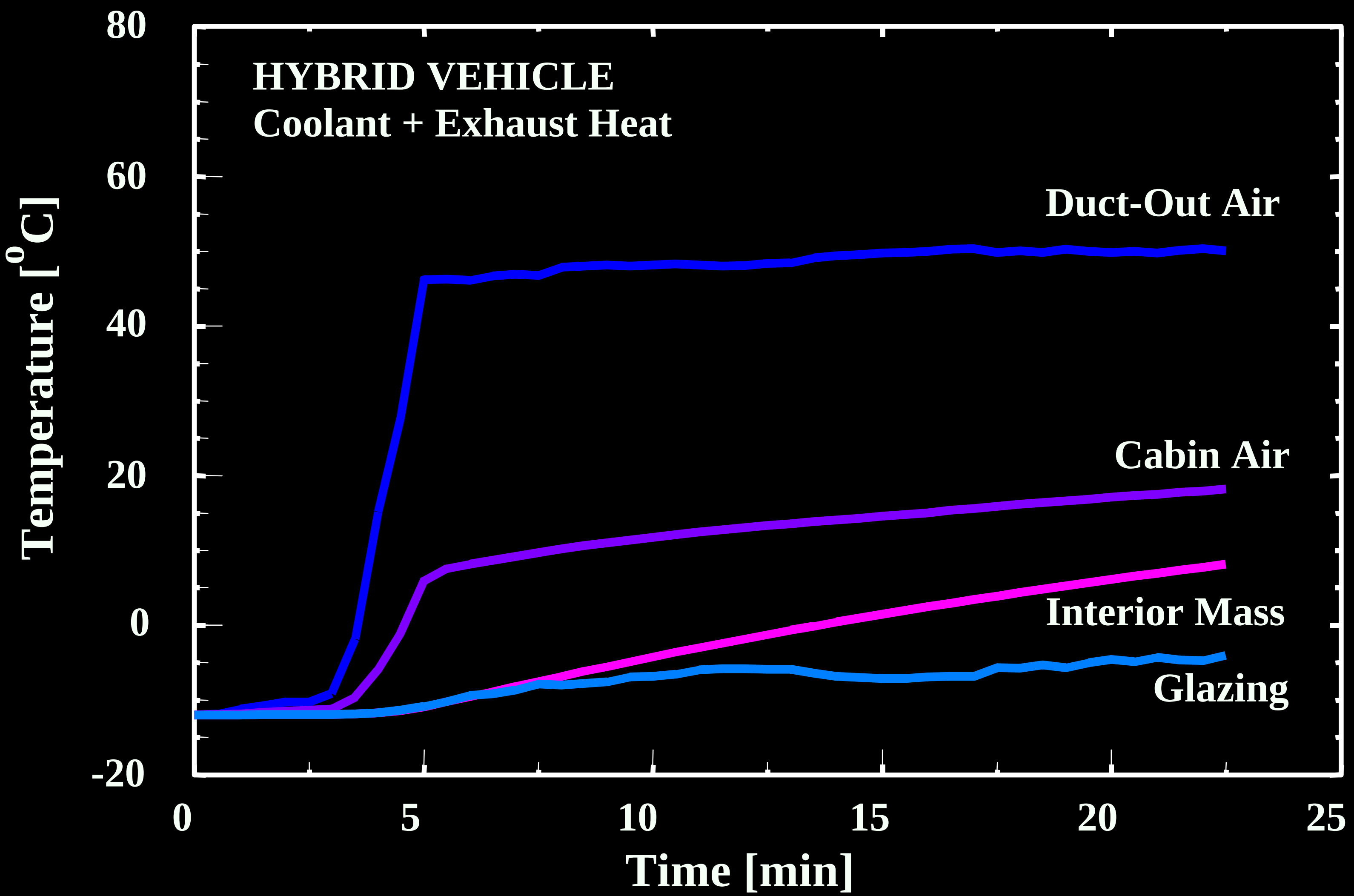
Conventional Vehicle: $T_{interior}(t)$



HEV w/Coolant: $T_{interior}(t)$



HEV w/Coolant + EHR: $T_{interior}(t)$



Effect of EHR on Thermal Comfort