NATIONAL RENEWABLE ENERGY LABORATORY

Design and Implementation of a Thermal Load Reduction System in a Hyundai PHEV

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Task Leader: John Rugh

National Renewable Energy Laboratory

June 6, 2017

Project ID GI165

Overview

Timeline

- Project start date: FY15
- Project end date: FY17
- Percent complete: 80%

Budget

Fully funded FOA project

- Total project funding: $3,054,817
  - DOE share: $2,443,790
  - Contractor share*: $ 611,027
- Funding in FY 2016: $ 0
- Funding in FY 2017: $ 0

* Contractor share represents 20% cost share for the project

Barriers

- Risk Aversion: Manufacturers are sometimes reluctant to invest in and introduce new technologies.
- Cost: Effective, timely evaluation of advanced vehicular components and configurations is needed.
- Range: Large climate control loads can significantly impact electric-drive vehicle (EDV) range, leading consumers to make less energy-efficient choices.

Partners

Interactions/collaborations:

- **Hyundai America Technical Center, Inc. (HATCI)**
- **Hanon Systems**
- **Sekisui Chemical Company, Ltd.**
- **Pittsburgh Glass Works, LLC (PGW)**
- **PPG Industries, Inc.**
- **Gentherm, Inc.**
- **3M Company**

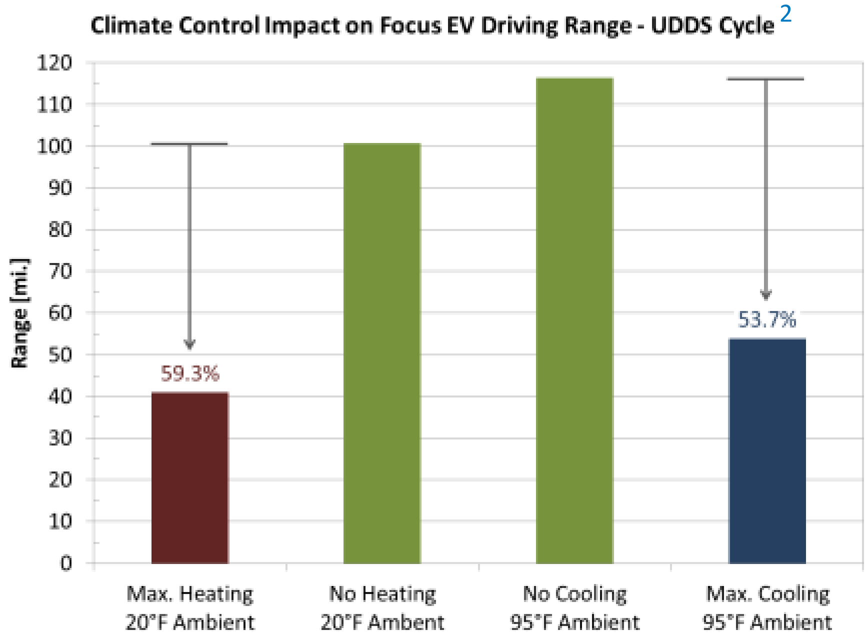
Project lead

- **National Renewable Energy Laboratory**

Relevance

THE CHALLENGE

- Annual light-duty vehicle fuel use estimated at equivalent of 3 billion barrels of oil equivalent[1]
- Increased adoption of EDVs requires overcoming:
  - Original equipment manufacturer (OEM) aversion to risk of adopting technologies
  - Limited vehicle range and associated customer range anxiety
  - Elevated cost of EDVs in comparison to existing conventional vehicles.
- Climate control loads significantly degrade EDV range



1. *Data Source: EIA Annual Outlook 2015. http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf*, pg. A-17, accessed March 2016
2. *Data Source:* Argonne National Laboratory's Advanced Powertrain Research Facility

UDDS - Urban Dynamometer Driving Schedule

Relevance

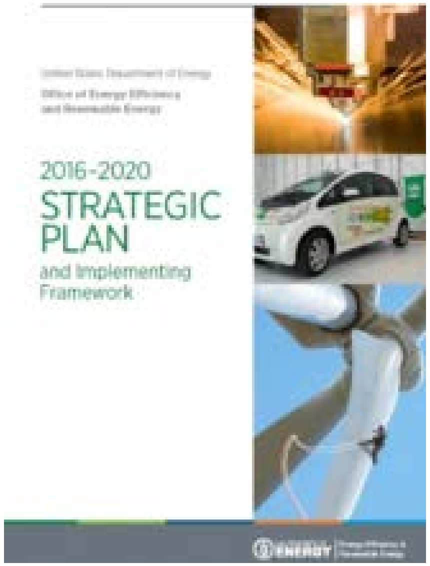
THE OPPORTUNITY

- Reducing climate control loads enables:
  - Smaller, cheaper batteries
  - Smaller climate control components
  - Advanced climate control strategies.
- Load reduction system performance data decreases OEM risk for adoption
- HVAC load reduction and advanced climate control design can positively impact occupant comfort

HVAC: heating, ventilating, and air conditioning

Alignment with DOE VTO

- Supports EERE's 2016 – 2020 strategic plan
  - Develop technologies that enable the cost-effective production of electric vehicles (EVs) and reduce vehicle energy use[1]



- Decreasing thermal loads in vehicles:
  - Reduces national fuel use
  - Improves national energy security.

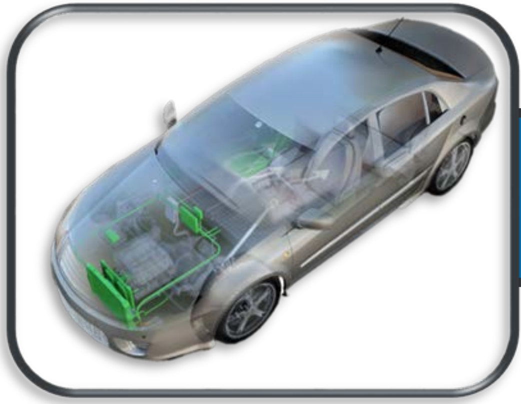
1. Office of Energy Efficiency and Renewable Energy, *2016-2020 Strategic Plan and Implementing Framework*. http://energy.gov/sites/prod/files/2015/12/f27/EERE_Strategic_Plan_12.16.15.pdf

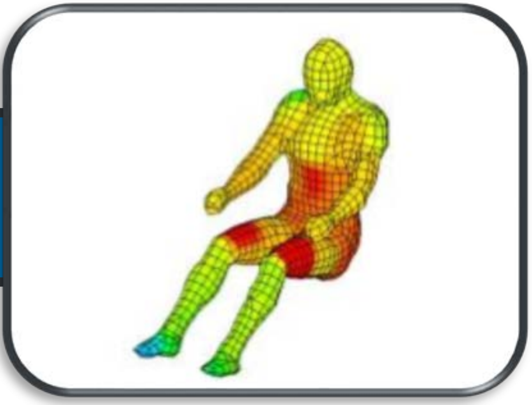
Relevance

THE GOAL

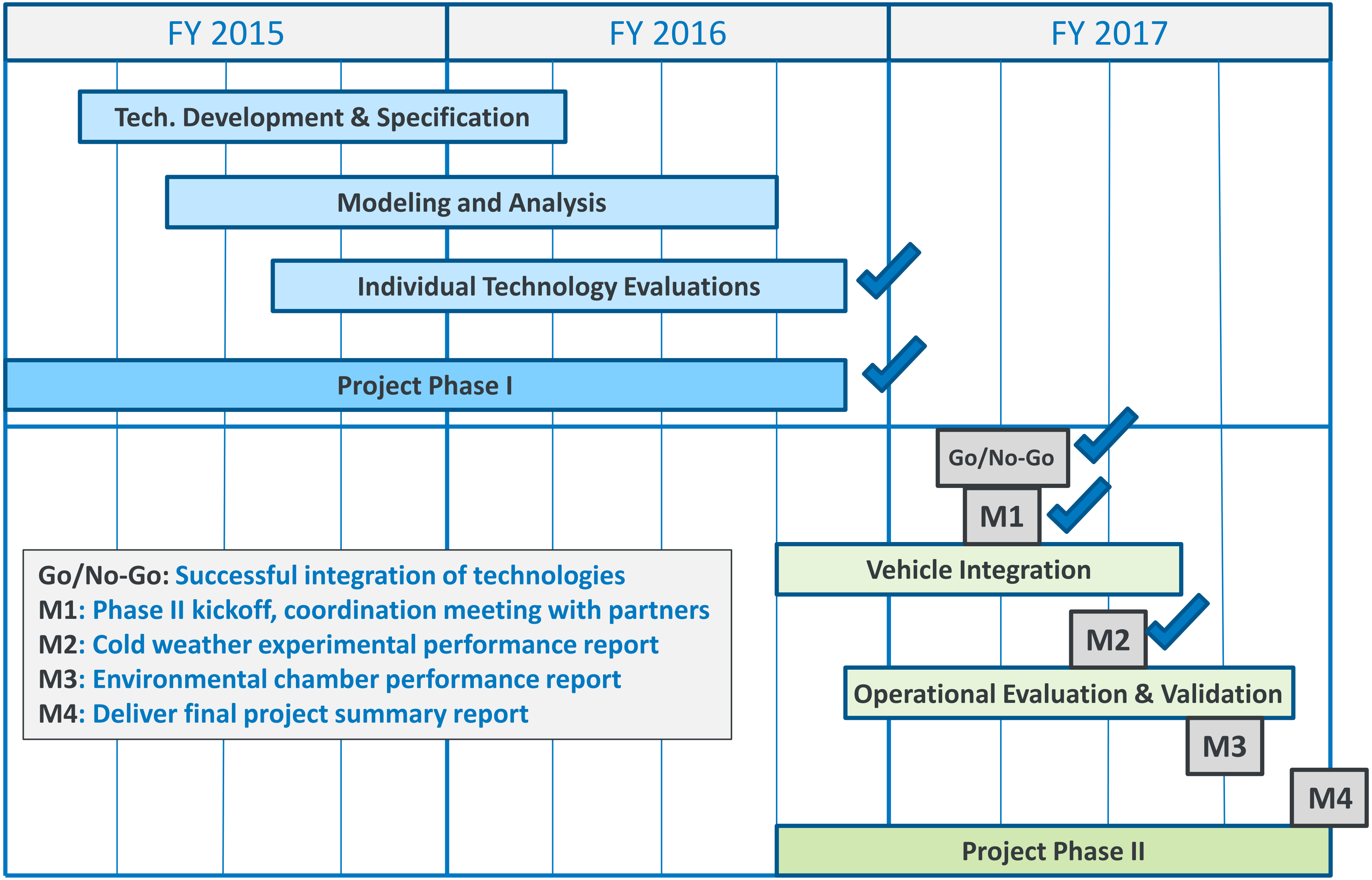
Increase grid-connected EDV range by 20% during operation of the climate control system over the standard vehicle configuration by reducing vehicle thermal loads

- Design and implement the thermal load reduction system on a production drivable vehicle
- Evaluate the range impact over the combined city/highway drive cycle at peak heating and cooling conditions
- Maintain occupant thermal comfort in the implemented system

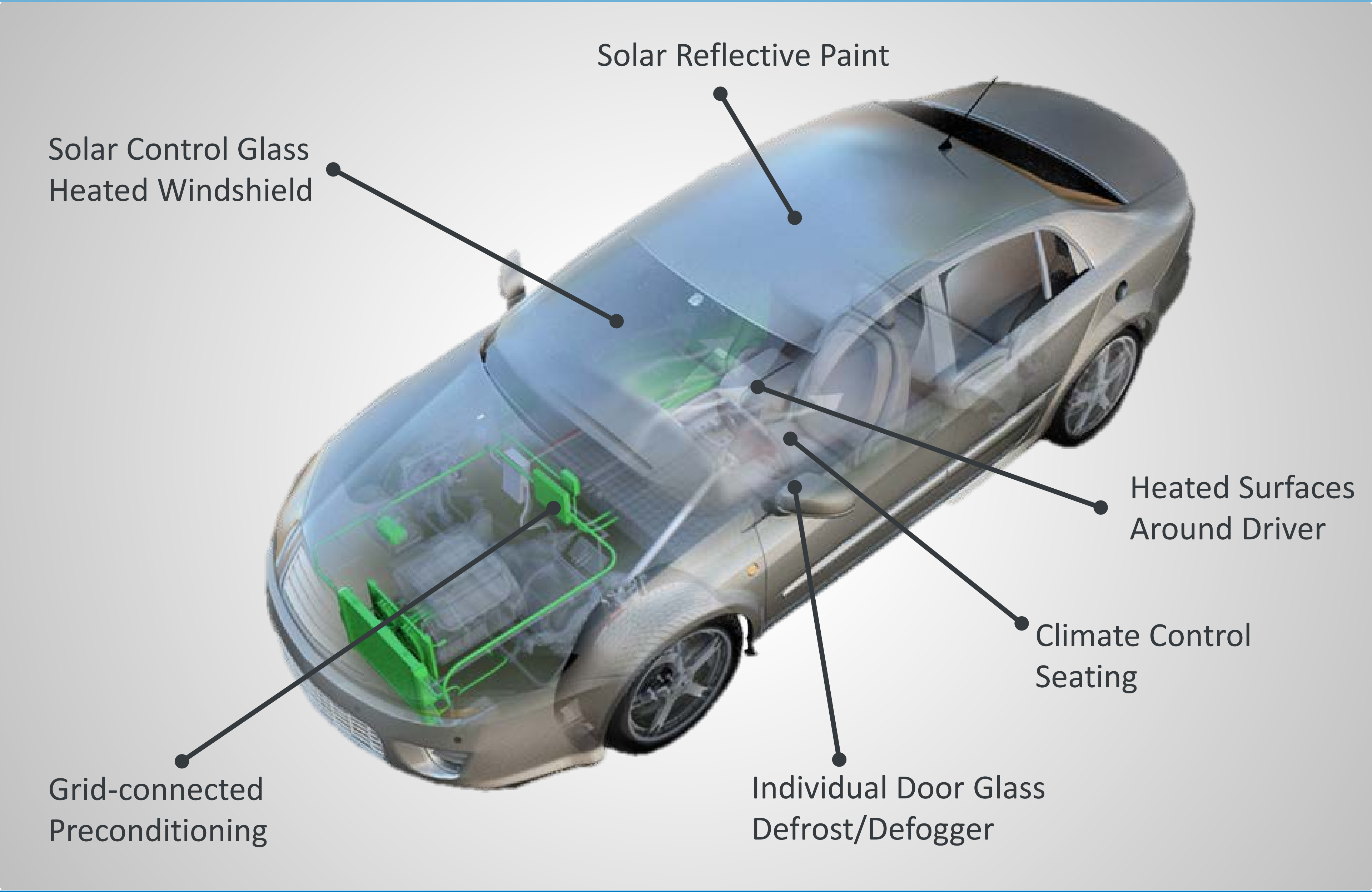




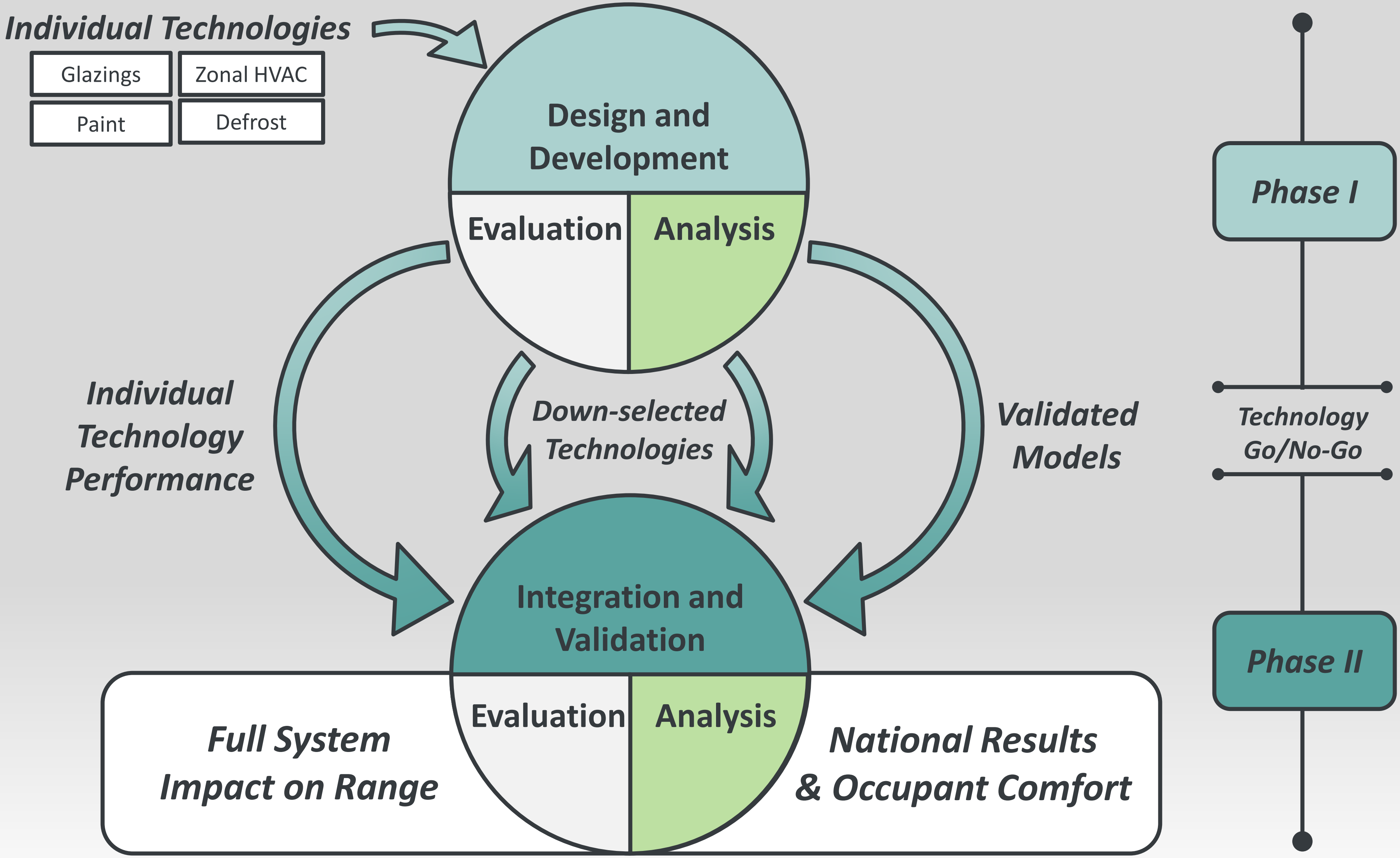
AOP Milestones 2017



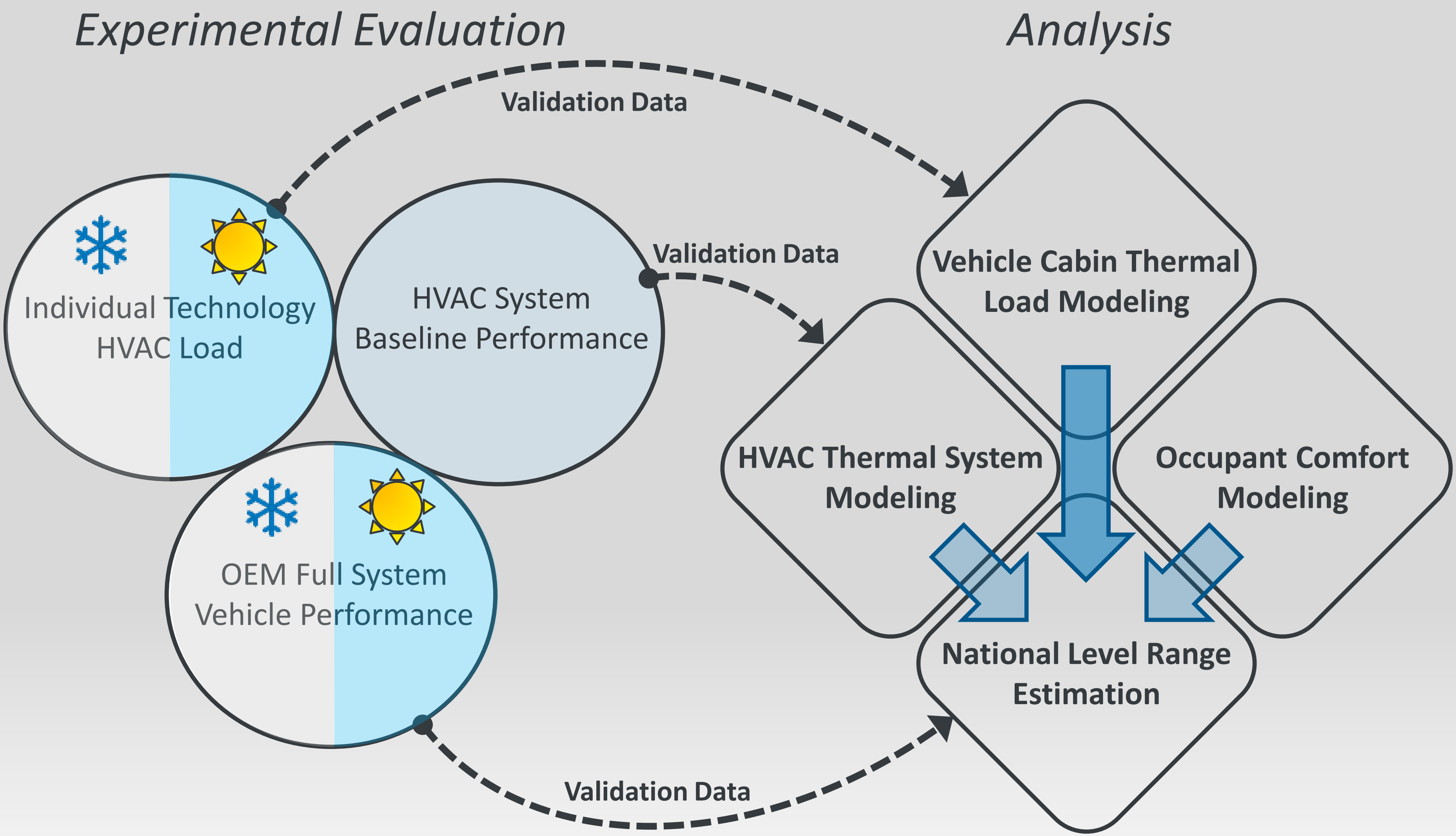
Approach – Technology Areas



Approach – Two-Phase Process



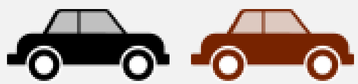
Approach – Testing and Analysis Strategy



Approach – Range Estimation Process

Vehicle Configurations

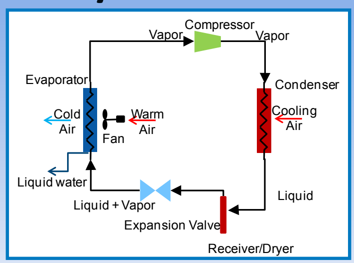
Baseline Vehicle
Thermal Load Reduction Vehicle



CoolCalc Cabin Model

Cabin Thermal Load

CoolSim A/C Model

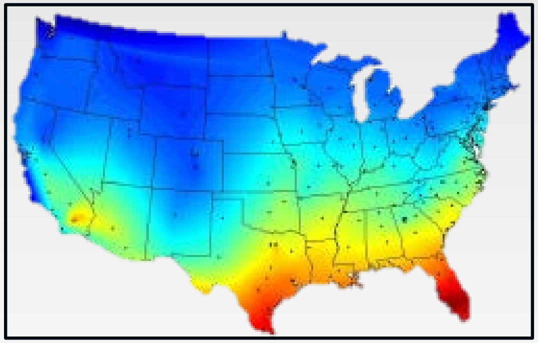


Accessory Load

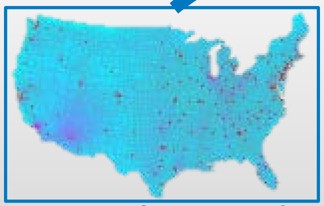
FASTSim Vehicle Model

Vehicle Range

Impact of Technologies on National EV Climate Control Range



Driver Behaviors



Weather and Vehicle Registrations

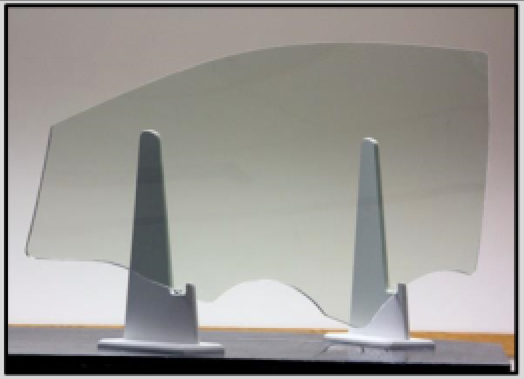
Accomplishments: Phase I Summer Technology Evaluation

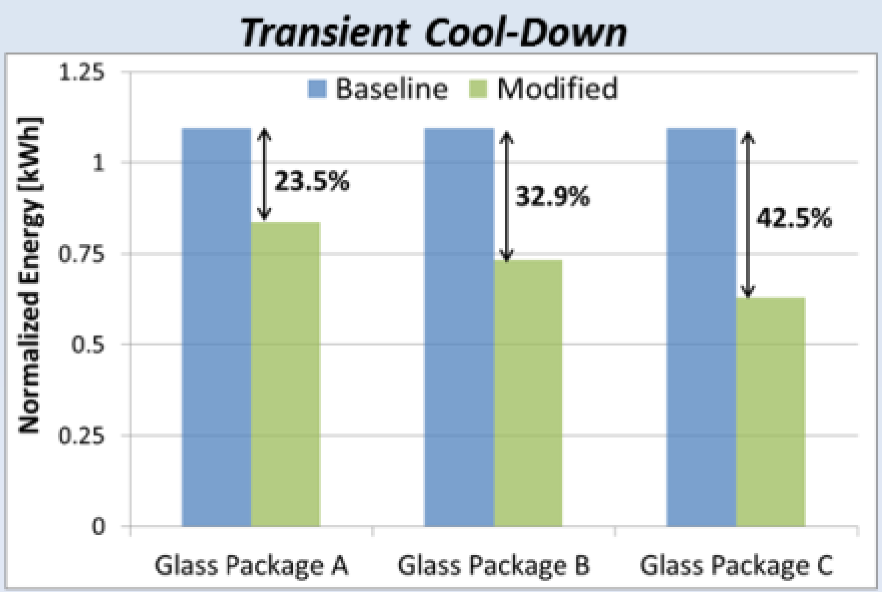
Best glass package: 42.5% transient and 12.8% steady-state cooling load reduction

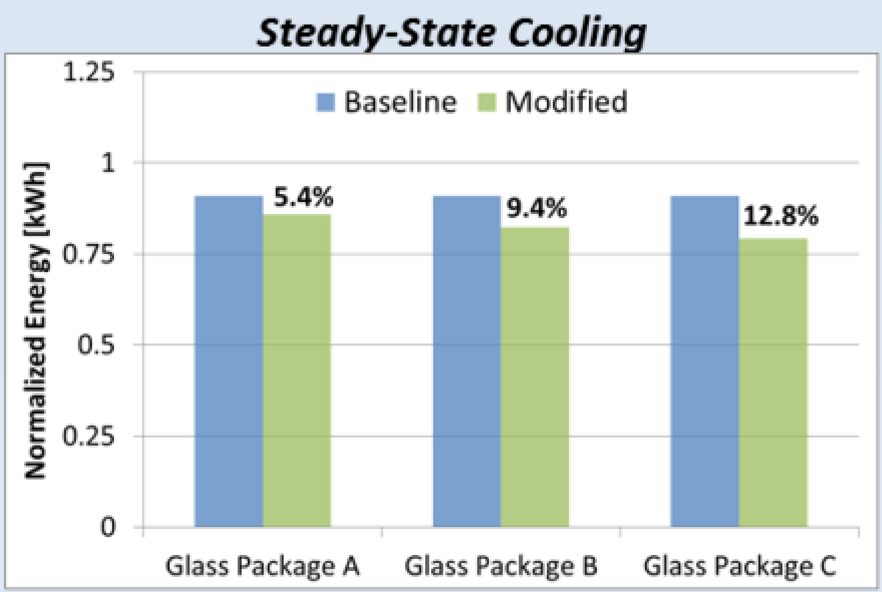
Solar Control Glazings: PGW & Sekisui

	Package A	Package B	Package C
Outer Glass	2.1 mm Clear	2.1 mm Clear with Double Silver IR Reflective Coating	2.0 mm Ultraclear with Triple Silver IR Reflective Coating
Interlayer	Sekisui IR Reflecting & Absorbing	Sekisui IR Absorbing	0.76 mm Polyvinyl Butyral
Inner Glass	2.1 mm Green	1.8 mm Solex	2.1 mm Clear

Laminated solar control automotive glass for windshield, front door, and rear door locations.







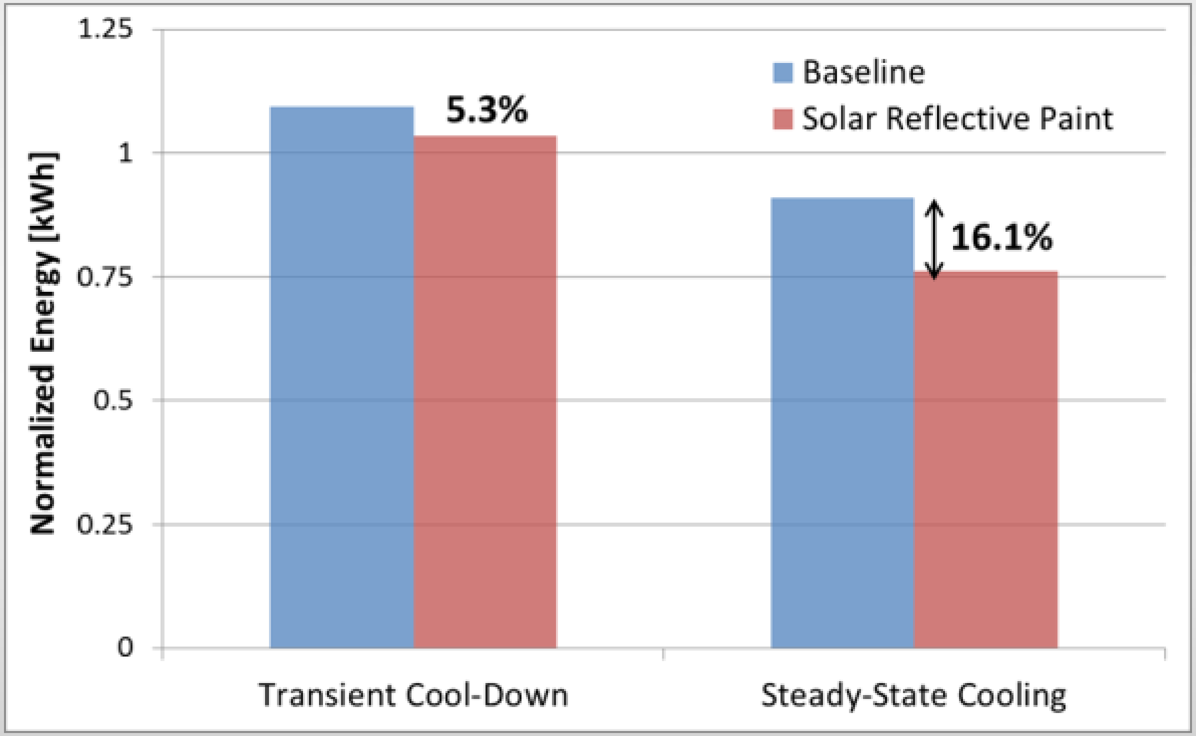
Accomplishments: Phase I Summer Technology Evaluation

Solar reflective paint: 5.3% transient and 16.1% steady-state cooling load reduction

Solar Reflective Paint: PPG Industries

	Total Solar Reflectivity [%]
Conventional Vehicle Paint	6.62%
NIR Reflective Vehicle Paint	38.11%
Difference	31.49%

Automotive paint with an elevated reflectivity in the near infrared spectrum.



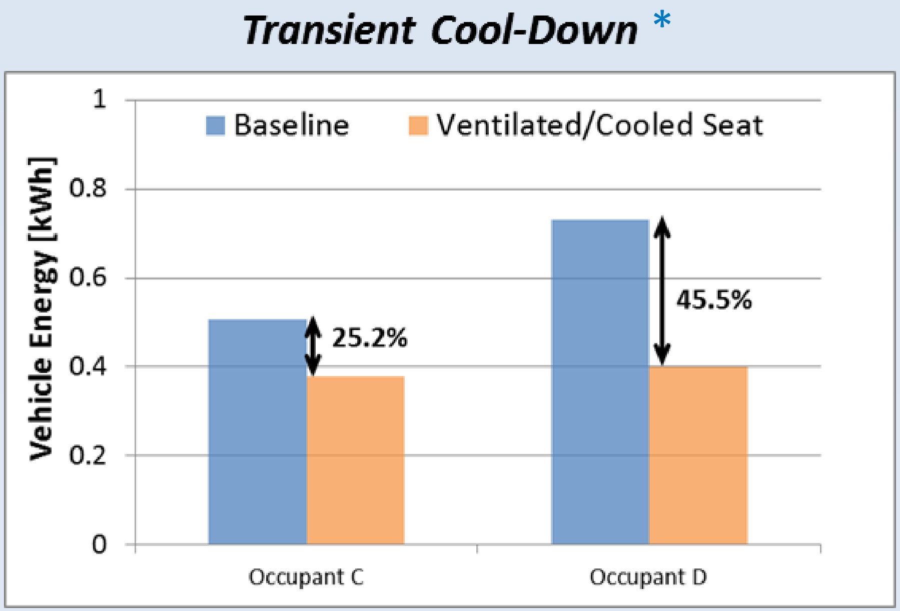
Accomplishments: Phase I Summer Technology Evaluation

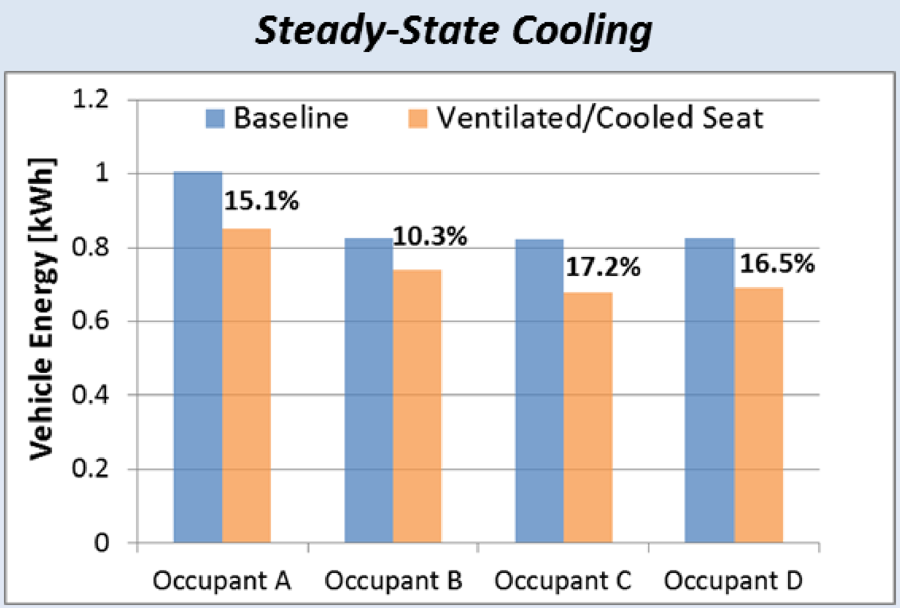
Ventilated/Cooled Seat: 25%-45% transient and 10%-17% steady-state cooling load reduction

Ventilated/Cooled Seats: Gentherm

Power Requirements	Standard 12VDC System
Seat Cooling Levels	High, Medium, Low, Off
Test Procedure Used	Transient and steady-state with occupant thermal sensation evaluation

Modified climate control seat ventilated cushion and back with thermoelectric device enabled cooling.





* Due to poor weather conditions, occupants A and B transient test data were omitted from the results.

Accomplishments: Phase I Winter Technology Evaluation

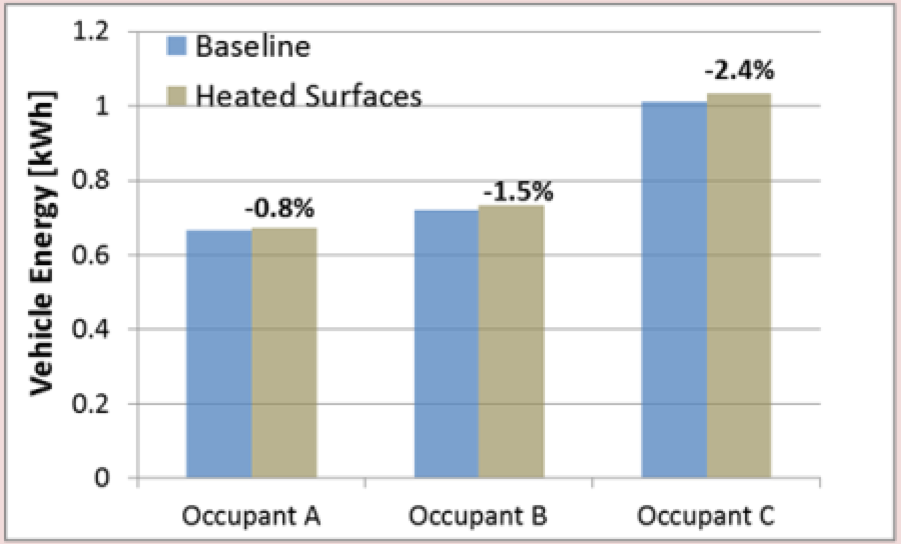
Heated Surfaces: -1% to -2% transient and 29%-59% steady-state cooling load reduction

Heated Surfaces: Gentherm

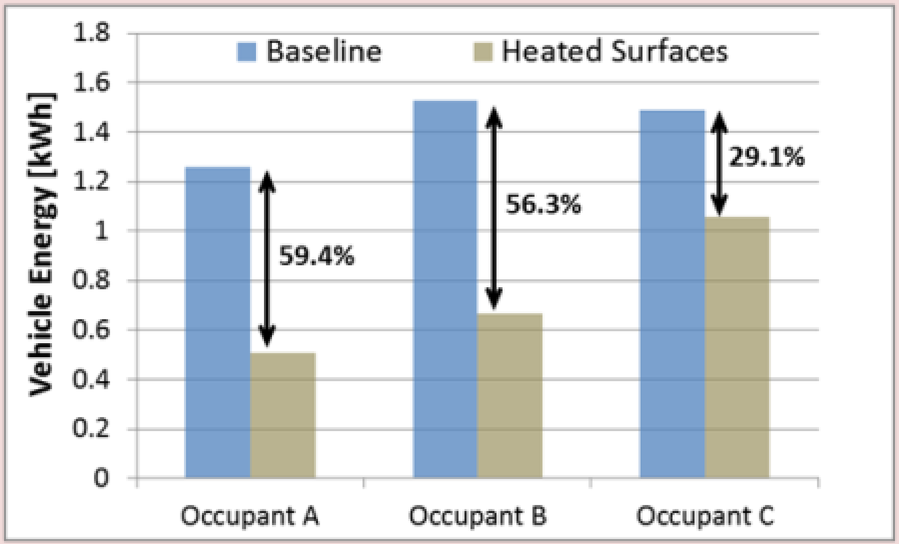
Driver Side Surfaces	Door arm rest and bolster, crash pad, console wall, console top, advanced heated seat
Passenger Side Surfaces	Console wall, glove box, door arm rest and bolster
Test Procedure Used	Transient and steady-state with occupant thermal sensation evaluation

Temperature regulated electrical resistance heaters embedded in select interior body panels.

Transient Warm-Up



Steady-State Heating



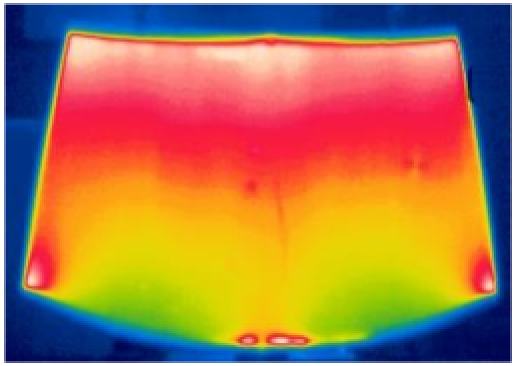
Accomplishments: Phase I Winter Technology Evaluation

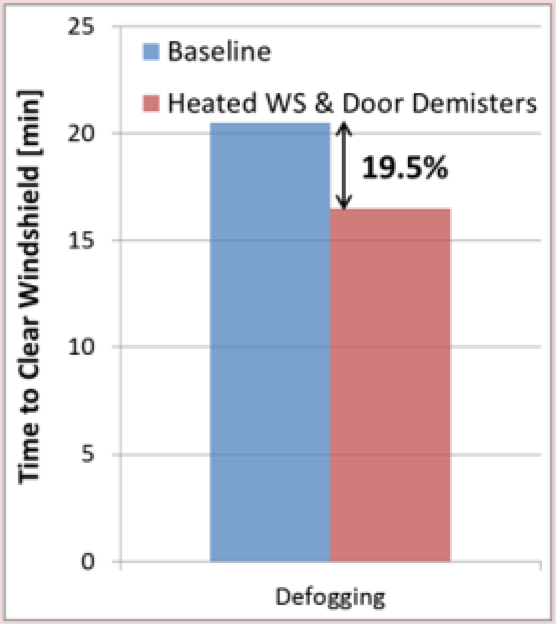
Heated WS & Demisters: 19.5% reduction in time to clear WS and reduced power demand

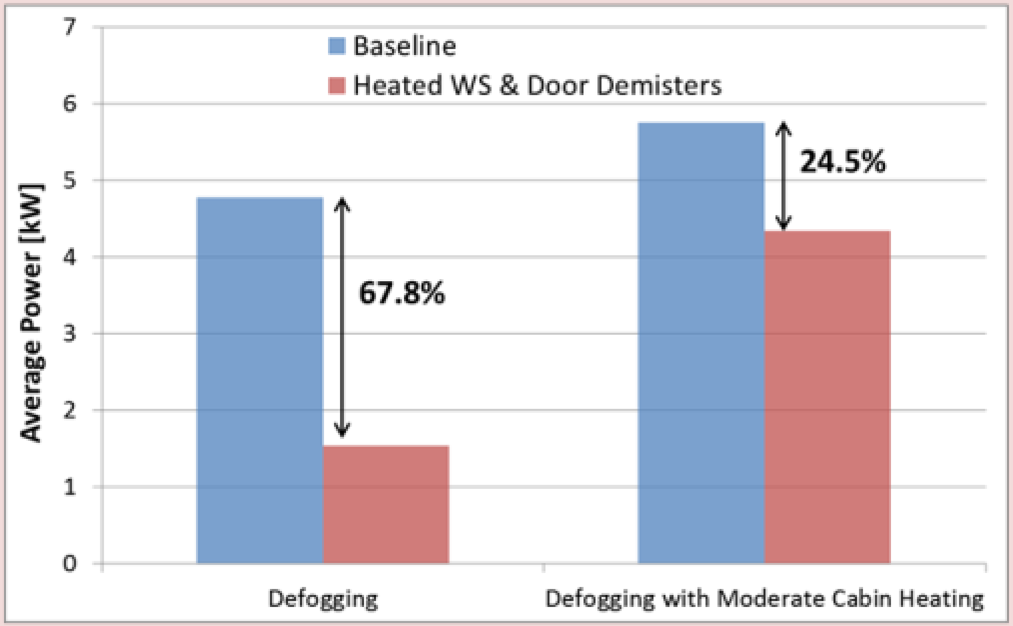
Heated Windshield & Door Demisters: PGW & Gentherm

Power Requirements, Windshield	42VDC
Power Requirements, Door Demister	Standard 12VDC System
Door Demister Heater Type	PTC Heater
Test Procedure Used	Cold Weather Defogging

Electrical resistance heated windshield (PGW) combined with PTC heater based demister and integrated blower assembly (Gentherm)







PTC = Positive Temperature Coefficient

Accomplishments – Phase II Technology Go/No-Go

Candidate technologies were selected for Phase II system integration

Candidate Technology	Transient Improvement	Steady-State Improvement	Go/No-Go for Phase II
Glass Package A	24 %	5 %	No-Go
Glass Package B	33 %	9 %	No-Go
Glass Package C	43 %	13 %	Go
Ventilated/Cooled Seats	25 to 46 % (occupant specific)	10 to 17 % (occupant specific)	Go
Solar Reflective Paint	5 %	16 %	Go
Heated Surfaces	-1 to -2% (occupant specific)	29 to 59 % (occupant specific)	Go
Heated Windshield & door demisters	20 % improvement in time-to-clear 25 - 68 % estimated energy savings dependent on cabin heating settings		Go

Response to Previous Year Reviewers' Comments

FY16 AMR Question 1: Approach to performing the work – the degree to which technical barriers are addressed, the project is well-designed, feasible, and integrated with other efforts.

Comment:	…The reviewer offered that one of the biggest barriers is OEMs' concern of the increased cost, and suggested that some analysis on the increased cost and payback period could be added to the project.
Response:	Determination of the increased cost and payback period for the technologies is a challenging task due to the sensitivity of this information and difficulty in assessing the technology performance from a national perspective. However, the project intends to use the developed analysis tools to quantify the national impact of the selected technologies as part of the final project deliverable. This critical information can then be used with technology cost estimates to determine the payback period of the technologies.

FY16 AMR Question 2: Technical accomplishments and progress toward overall project and DOE goals – the degree to which progress has been made, measured against performance indicators and demonstrated progress towards DOE goals.

Comment:	The reviewer suggested it would be beneficial if a better understanding was provided of the level of efficiency improvement over the typical driving cycle (as just opposed to at warm-up and steady state)…
Response:	For Phase I of the project, the focus was on individual technology evaluations, and performance was characterized for both transient and steady-state heating/cooling conditions to better understand the performance trade-offs. However, in Phase II evaluations, both real-world driving and chamber test cycles will be used to characterize system performance. In addition, the national-level A/C fuel use analysis process will be used with representative drive cycles to determine technology performance throughout the United States.

Collaboration and Coordination with Other Institutions

Hyundai America Technical Center

- Subtier Industry Partner
- Automotive OEM Supplier
- Lead on Phase II Technology Integration
- Lead on Phase II Full System Experimental Evaluation
- Technology Supplier (collaboration with Gentherm)

Hanon Systems

- Subtier Industry Partner
- Baseline HVAC System Experimental Evaluation
- HVAC System Modeling Support

Gentherm

- Subtier Industry Partner – in kind
- Door Defrost/Defog Technology Supplier
- Heated Surfaces Technology Supplier (collaboration)
- Advanced Seating Technology Supplier (collaboration)

Pittsburgh Glass Works

- Subtier Industry Partner
- Glass Package Manufacturer
- Advanced Glass Technology Supplier

PPG Industries

- Subtier Industry Partner
- Automotive Paint Supplier
- Advanced Paint Technology Supplier

Sekisui

- Subtier Industry Partner
- Advanced Solar Control Interlayer Supplier

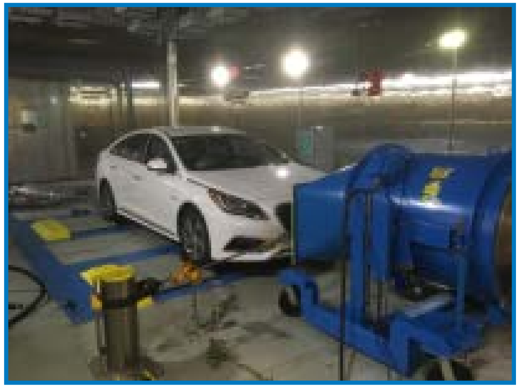
3M

- Subtier Industry Partner – in kind
- Advanced Solar Control Film Supplier
- Advanced Insulation Technology Supplier

Proposed Future Research

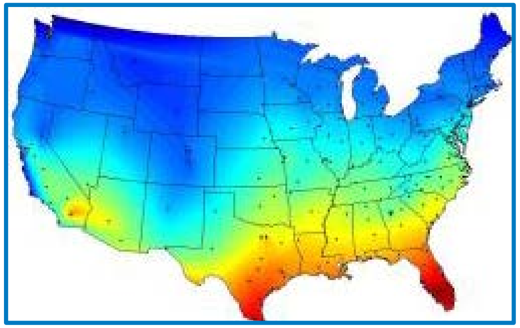
Completion of Phase II: Technology Integration and Validation

- Perform cold and warm weather environmental chamber evaluation on baseline and thermal load reduction system vehicles (HATCI Ann Arbor, MI facility)
- Perform hot weather field evaluation on baseline and thermal load reduction system vehicles (Death Valley, CA and Las Vegas, NV)
- Refine models with individual technology experimental results and perform national-level analysis for EV range impact determination



Project Completion

- Final vehicle project summary and/or presentation to DOE
- SAE presentations and journal article submissions highlighting key findings on the project



Any proposed future work is subject to change based on funding levels

Summary

- The project's focus is to implement a thermal load reduction system into a production electric drive vehicle and quantify the impact on thermal comfort, fuel use, and EV range
- Key industry partners enable production-ready and cost-effective technologies and vehicle-level integration
- Experimental evaluation and analysis are used together to quantify system performance and national-level impact

Accomplishments

- Completed Phase I evaluation of candidate technologies and selection for Phase II system integration and evaluation
  - Phase II System Package: Solar control glass, solar reflective paint, ventilated/cooled seats, heated surfaces, heated windshield and door demisters
- Integrated Phase II technologies into the vehicle and completed cold weather performance evaluation
- Scheduled Phase II environmental chamber and hot weather field evaluations
- Developed a national-level analysis process for EV range estimation in varying U.S. environments

Acknowledgments and Contacts

Special thanks to:

- **Lee Slezak and David Anderson**
  Vehicle Technologies Office

For more information:

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- Slide 4: Gentherm
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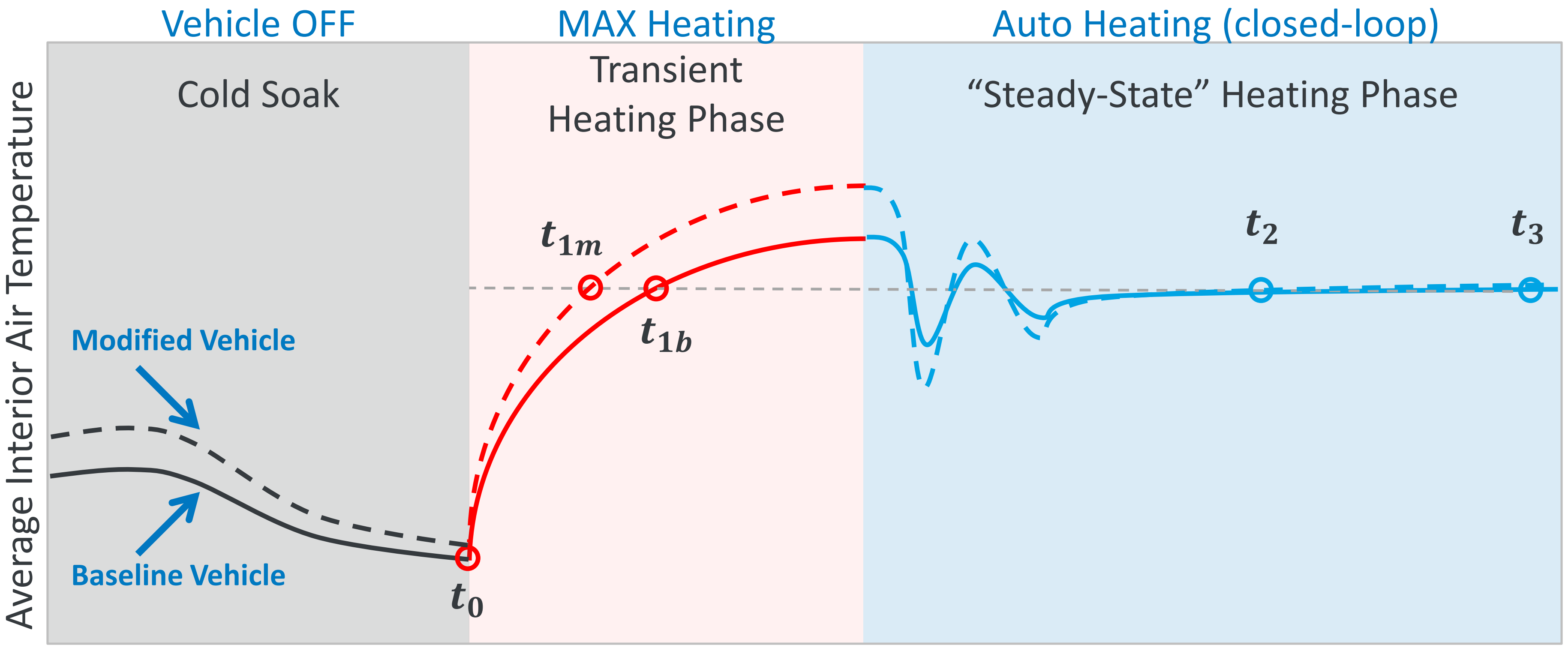
- Slide 19: Cory Kreutzer, NREL
- Slide 19: Matthew Scott, HATCI
- Slide 21: Cory Kreutzer, NREL

Technical Back-Up Slides

Winter Heating Test Procedure

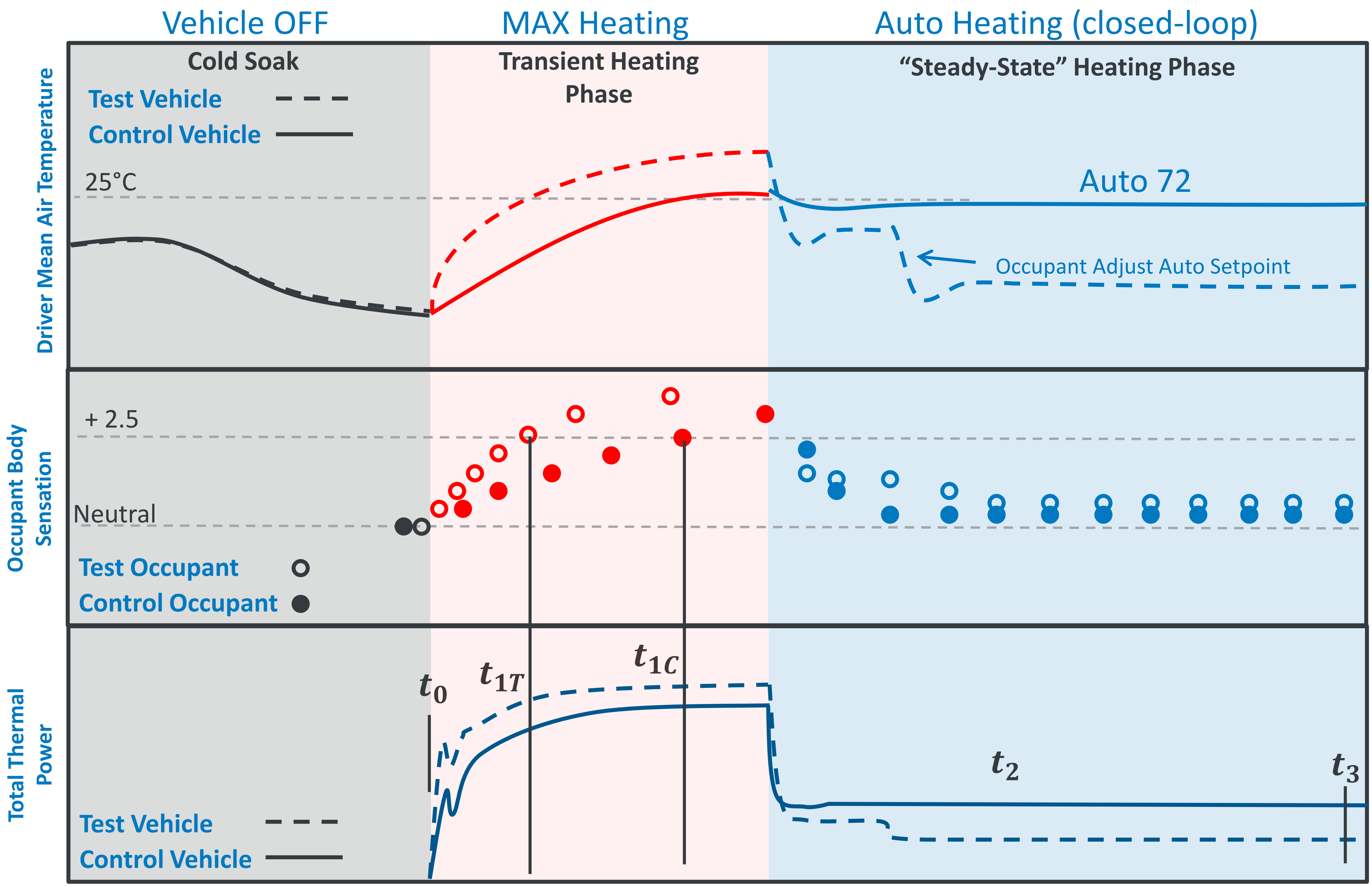
- Heating test method used for baseline and insulation performance testing



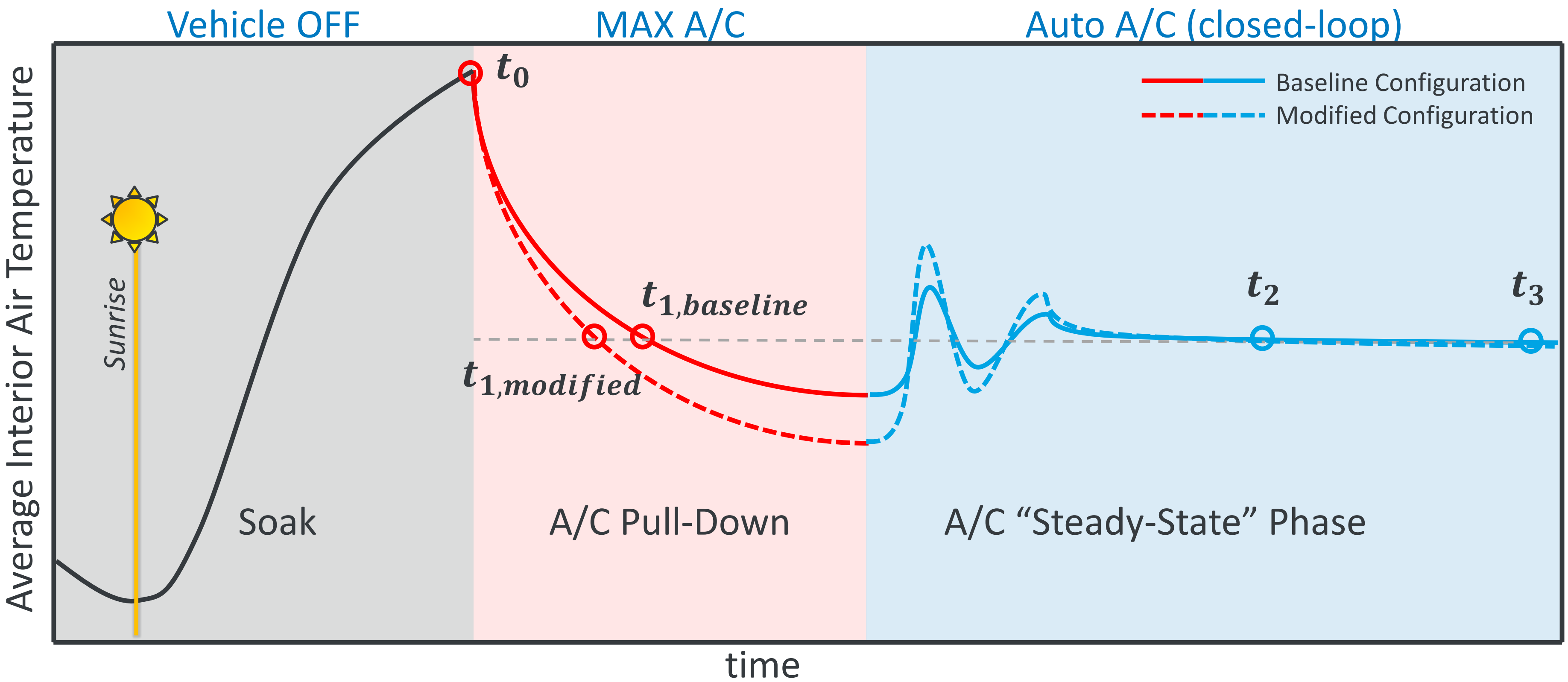
Baseline Vehicle:
Energy from $t_0 \rightarrow t_{1b}$
Modified Vehicle:
Energy from $t_0 \rightarrow t_{1m}$

Both Vehicles:
Energy from $t_2 \rightarrow t_3$

Heated Surfaces Test Procedure



Phase I Summer A/C Test Approach



- Two-part A/C test method
  - Pull-down and steady-state phases independently measured
- Energy use during each test period integrated over specified time interval
- Method is intended to increase repeatability and isolate technology impact