Advanced Climate Systems for EV Extended Range

(ACSforEVER)

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Presenter: John Meyer

Hanon Systems

June 6, 2017

Project ID # GI135

Overview

Timeline

Project Start: Oct. 2013

Project End: Sept. 2017

Percent Complete – 90%

Barriers/Challenges

- EV market adoption
- Minimize climate system impact on vehicle energy storage system
- Extended range across broad selection of ambient environments

Budget

Total project funding: $4.68M

- DOE share $2.34M
- Contractor share $2.34M

Funding received in FY16: $ 0.3M

Funding for FY17: $ 0.3M

Project Partners

- Hyundai America Technical Center
  - Vehicle Integration and Testing
- National Renewable Energy Laboratory
  - CAE Modeling and Test Support
- Hanon Systems
  - Project Lead

Relevance – DOE Support

Vehicle Technologies Program Goals:

- Develop more energy-efficient and environmentally friendly technologies
- Further development and validation of models and simulation tools to predict the performance of advanced conventional and electric-drive vehicle systems.
- Support vehicle electrification through DE-FOA-000793 Area Of Interest 11 - Climate Auxiliary Load Reduction focus areas:
    - **Advanced HVAC Technologies** to achieve passenger comfort with reduced auxiliary loads
    - **Cabin Pre-conditioning** while connected to the grid to reduce the amount of energy needed from the battery upon initial vehicle operation to condition the cabin environment, increasing range
    - **Energy Load Reduction and Energy Management** to reduce thermal loads that the systems must address

Relevance – Project Objectives

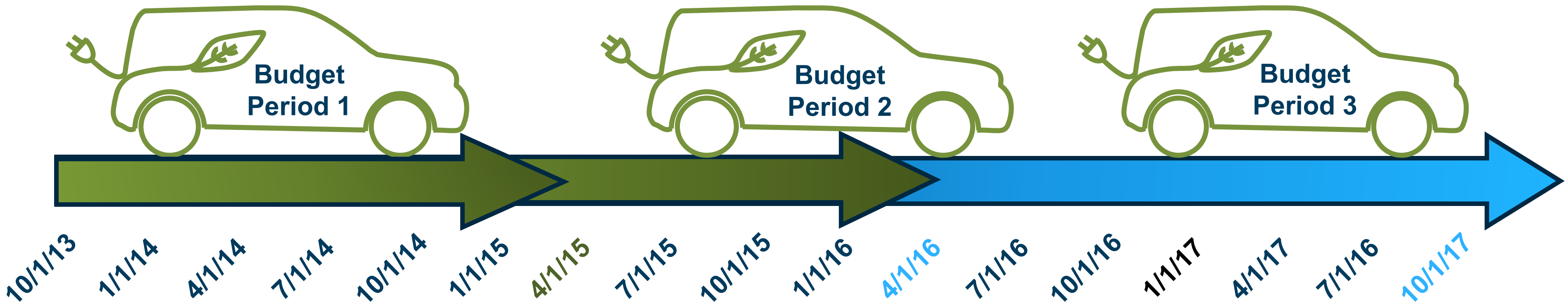
ACSforEVER project support of DOE VTO goals through:

- Overall objectives:
  - Extend electric vehicle range
    - Reduce climate energy usage from vehicle ESS
    - Development and validation of modeling tools
    - Technical areas of focus:
      - » Cabin pre-conditioning
      - » Thermal energy storage
      - » Refrigerant system efficiencies
  - Maintain occupant comfort

- FY16/17 objectives:
  - Validate selected system architecture
  - Design, fabricate and install PTC only version of selected system hardware

ESS = energy storage system

Technical Approach



- Select vehicle
- Define test conditions
- Define performance targets
- Complete baseline testing
- Develop & correlate models
- Define climate system architecture

FY13/FY14 Tasks

- Design componentry
- Fabricate hardware
- Bench test components & subsystems
- Analyze results to model predictions

FY15 Tasks

- Test baseline vehicle
- Integrate new climate system into vehicle
- Validate climate system performance impacts
- Analyze results

- Expand to PTC only
- Design, fabricate, install and validate

FY16/FY17 Tasks

Milestones

Budget Period 1: Subsystem Design and Specification Development Complete

Month/Year	Milestone	Type	Description
Sep-2014	Baseline Vehicle Testing	Technical	Completion of baseline vehicle testing in a wind tunnel.
Mar-2015	System Architecture Complete	Go/No Go	Completion of system architecture design for each subsystem to verify established system requirements are met

Budget Period 2: Design, Fabricate, and Validate Complete

Month/Year	Milestone	Type	Description
Apr-2016	Bench Testing	Go/No Go	Subsystems testing to verify established system requirements are met

Budget Period 3: Integration and Vehicle Validation

Month-Year	Milestone	Type	Description
Mar-2017	Vehicle Integration	Technical	All subsystems integrated into vehicle and ready for testing
Jul-2017	Vehicle Demonstration	Technical	Demonstration vehicle testing complete

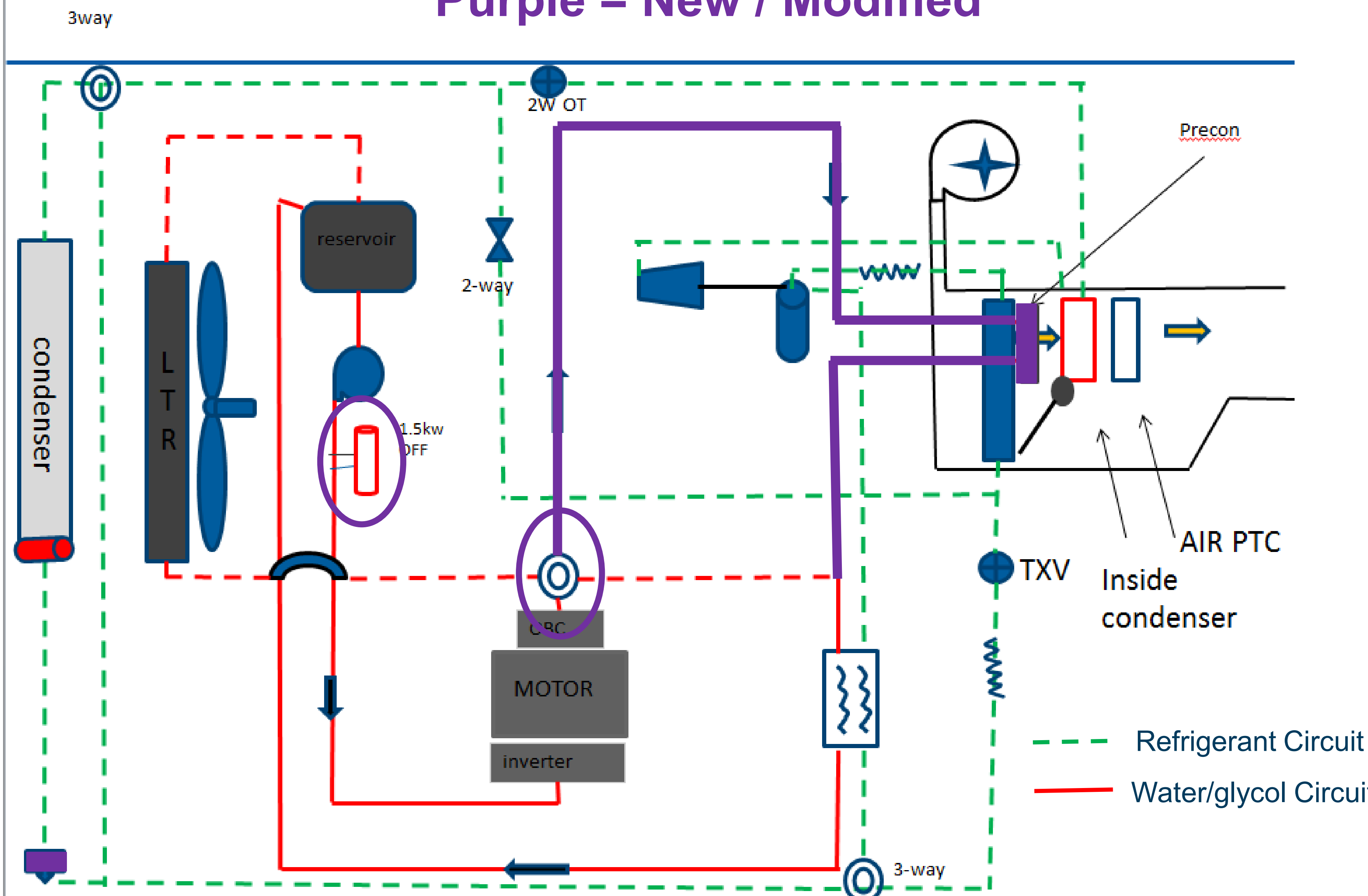
April 2016 Go/No-Go

- Project originally investigated range improvement technologies for heating and cooling
- Using the on-board AC system to build “cold” storage is inefficient and expels a tremendous amount of heat
- No-Go – Enhanced AC
  - Current technology mature
  - Thermal storage offers benefits, but at poor value
- Go – Enhanced Heating
  - Current solutions to heating an EV immature
  - Thermal storage offers substantial benefits at low cost

Schematic

Hanon SYSTEMS

Purple = New / Modified



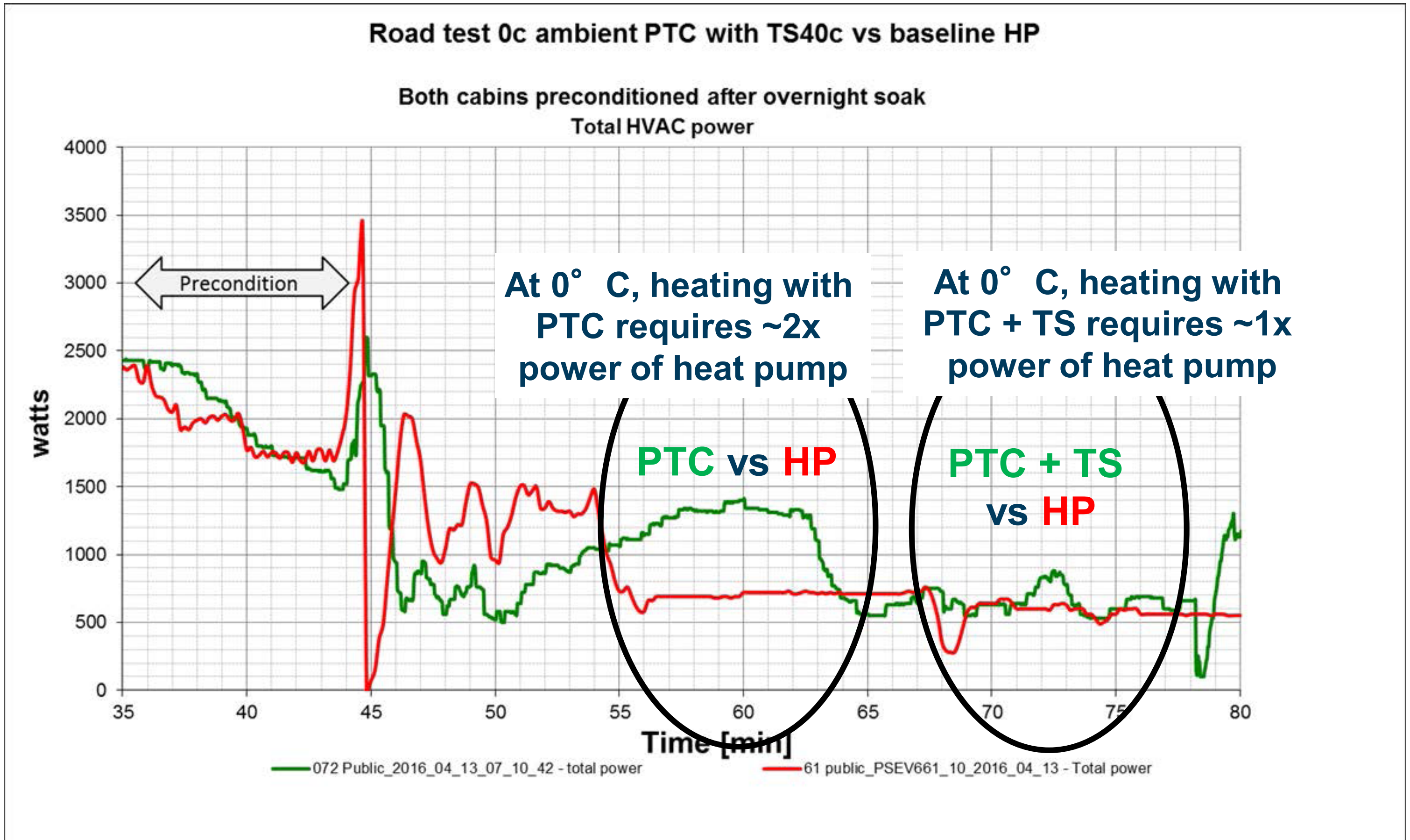
New/Modified Hardware

- Glycol heater
- Heater core
- Hoses
- 4-way glycol valve (was 3-way)
- Water/glycol mixture
- Controls
- Refrigerant check valve

- Total incremental cost ~XX$US
- Opportunity to reduce further with elimination of a heater

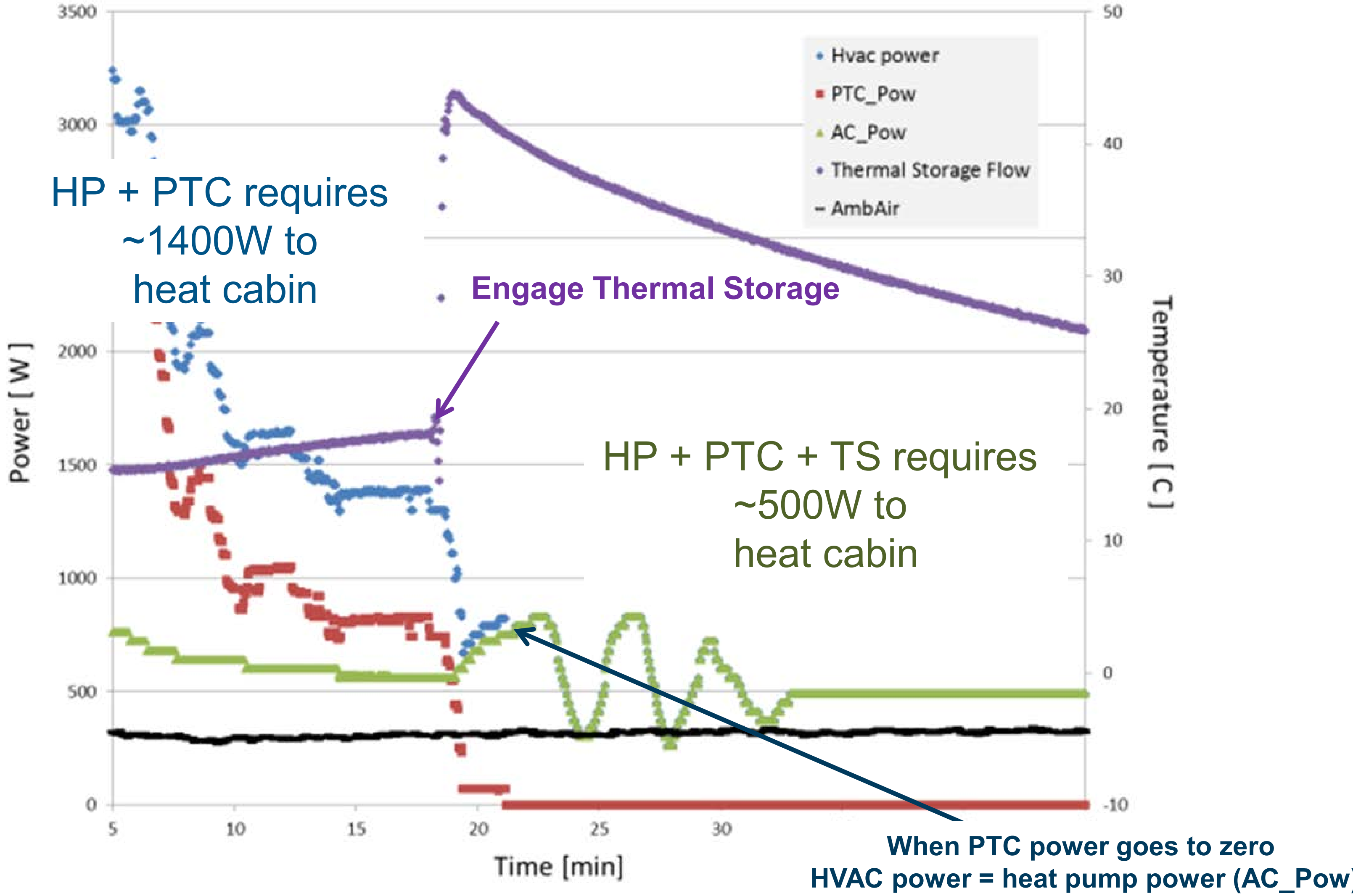
Additional Scope Included in Project

- Included PTC-only vehicle to scope
- Investigate benefits of adding Thermal Storage (TS) to PTC-only vehicle

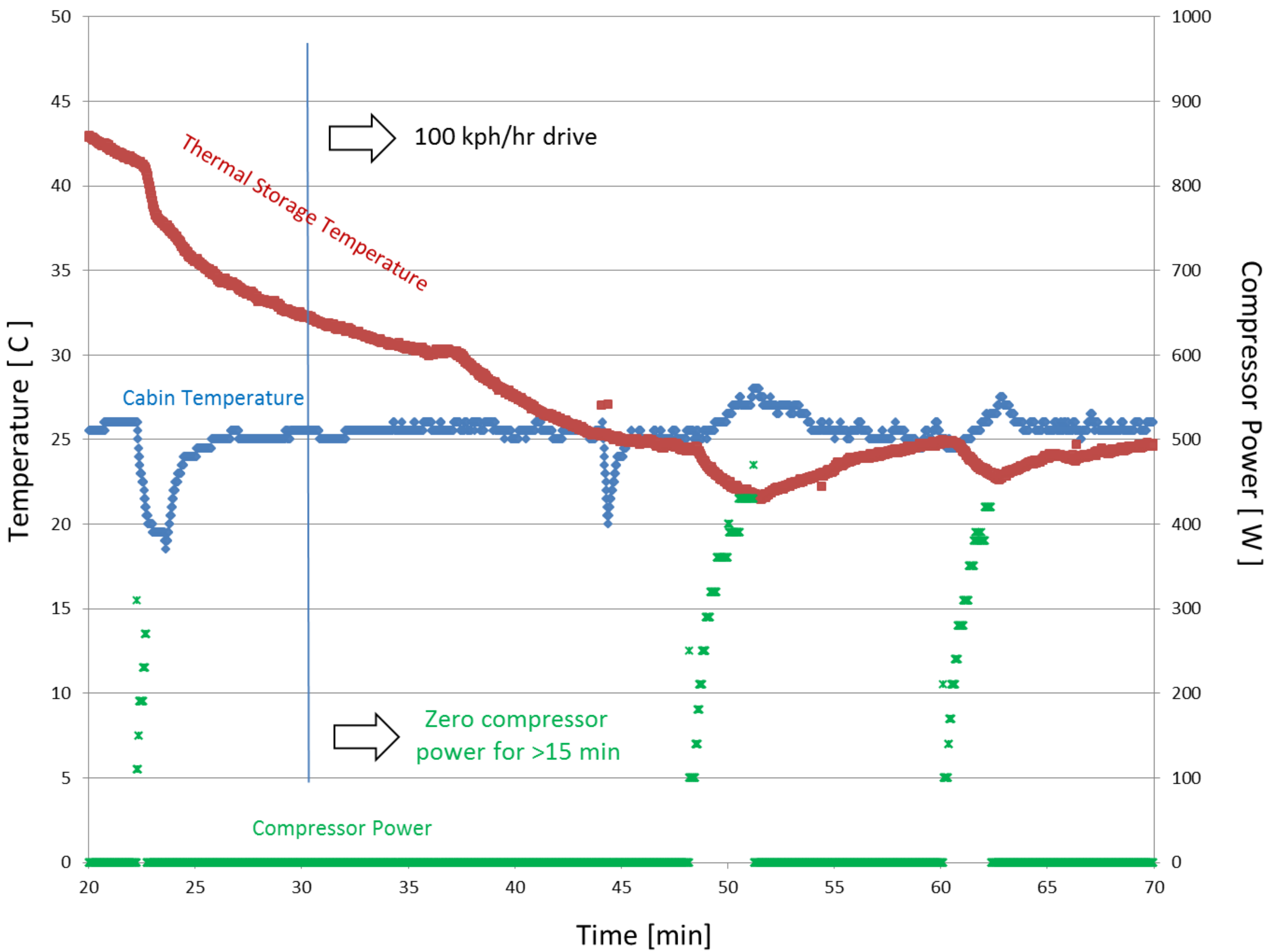


HVAC Power Consumption (road, -4°C)

Before and after engaging Thermal Storage



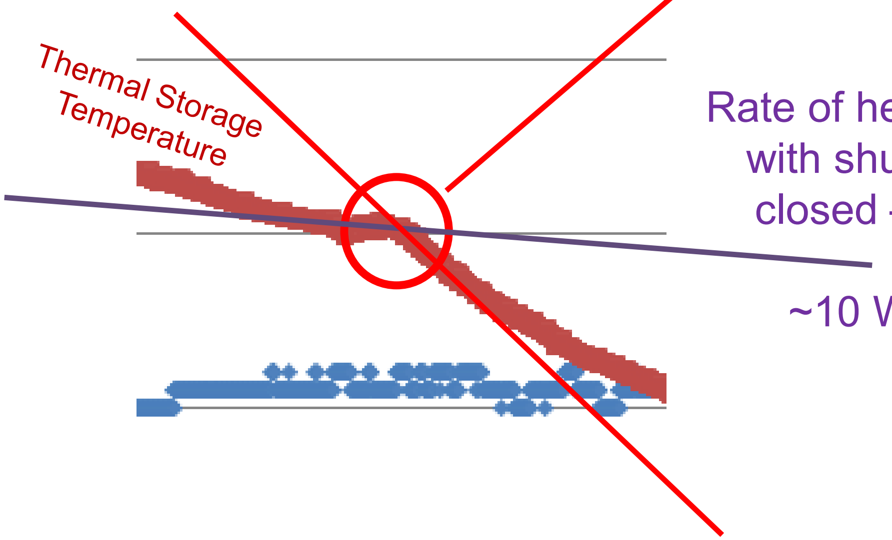
Initial Road Test of Final Configuration (5°C)



Effect of Grill Shutters

On Thermal Storage Heat Loss

Slope of line indicates
rate of heat loss



Rate of heat loss
with shutters
closed – low

~10 W/C

Rate of heat loss
with shutters
Open – much higher
~22 W/C

Controls

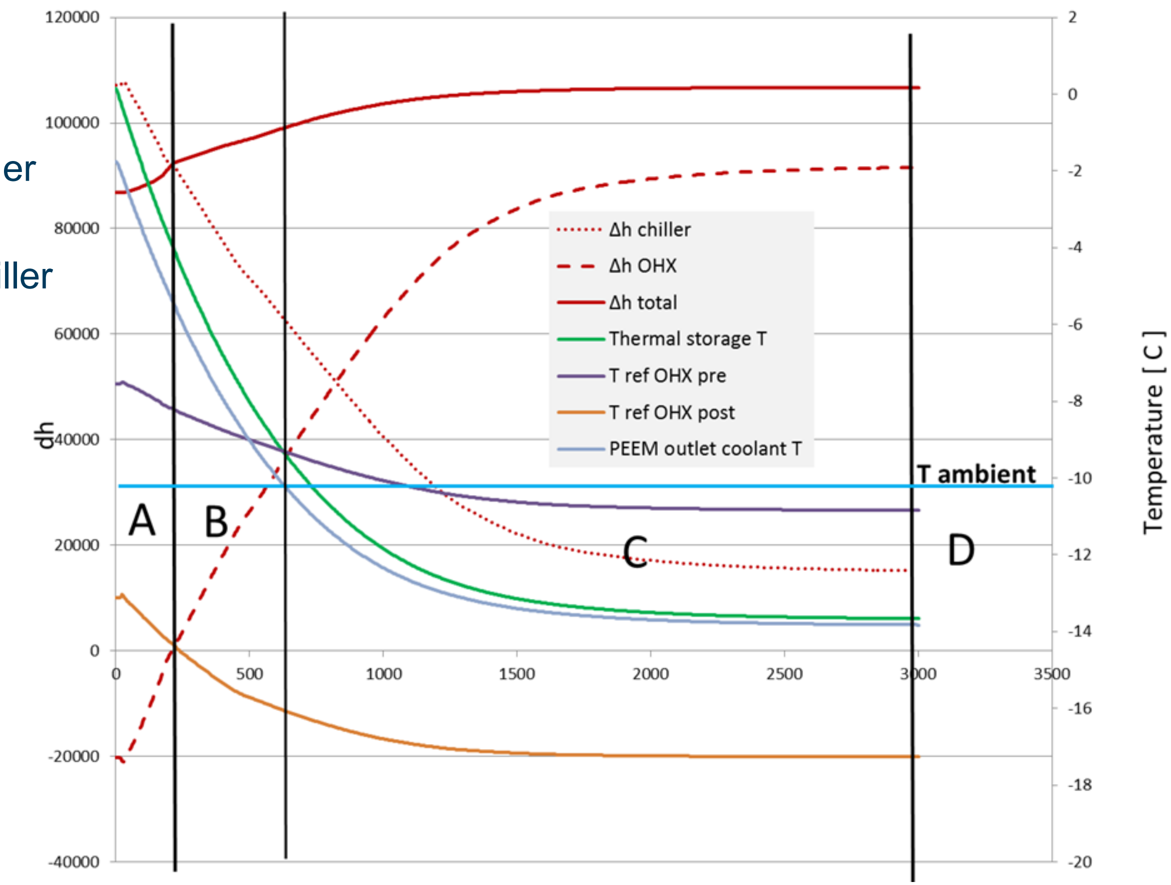
- Two Refrigerant Flow Options
  - Through outside heat exchanger
  - Bypass outside heat exchanger
- Three Glycol Flow Options
  - Flow through HVAC case and chiller
  - Flow through chiller only
  - No flow through HVAC case or chiller
- NREL modeled performance

A bypass OHX and flow glycol through precon and chiller

B flow through OHX and flow glycol through precon and chiller

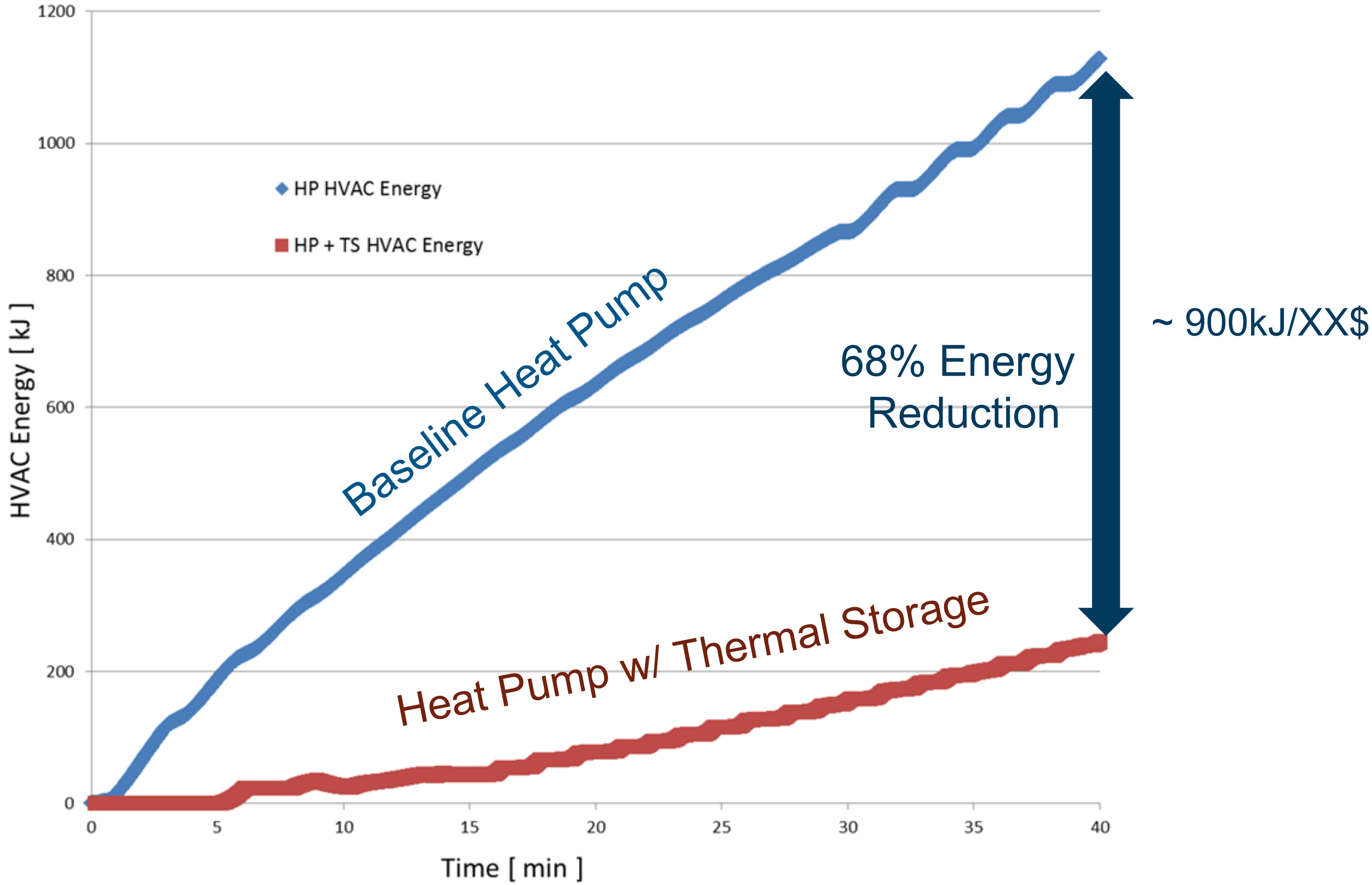
C flow through OHX and flow glycol through chiller only

D flow through OHX and turn pump off



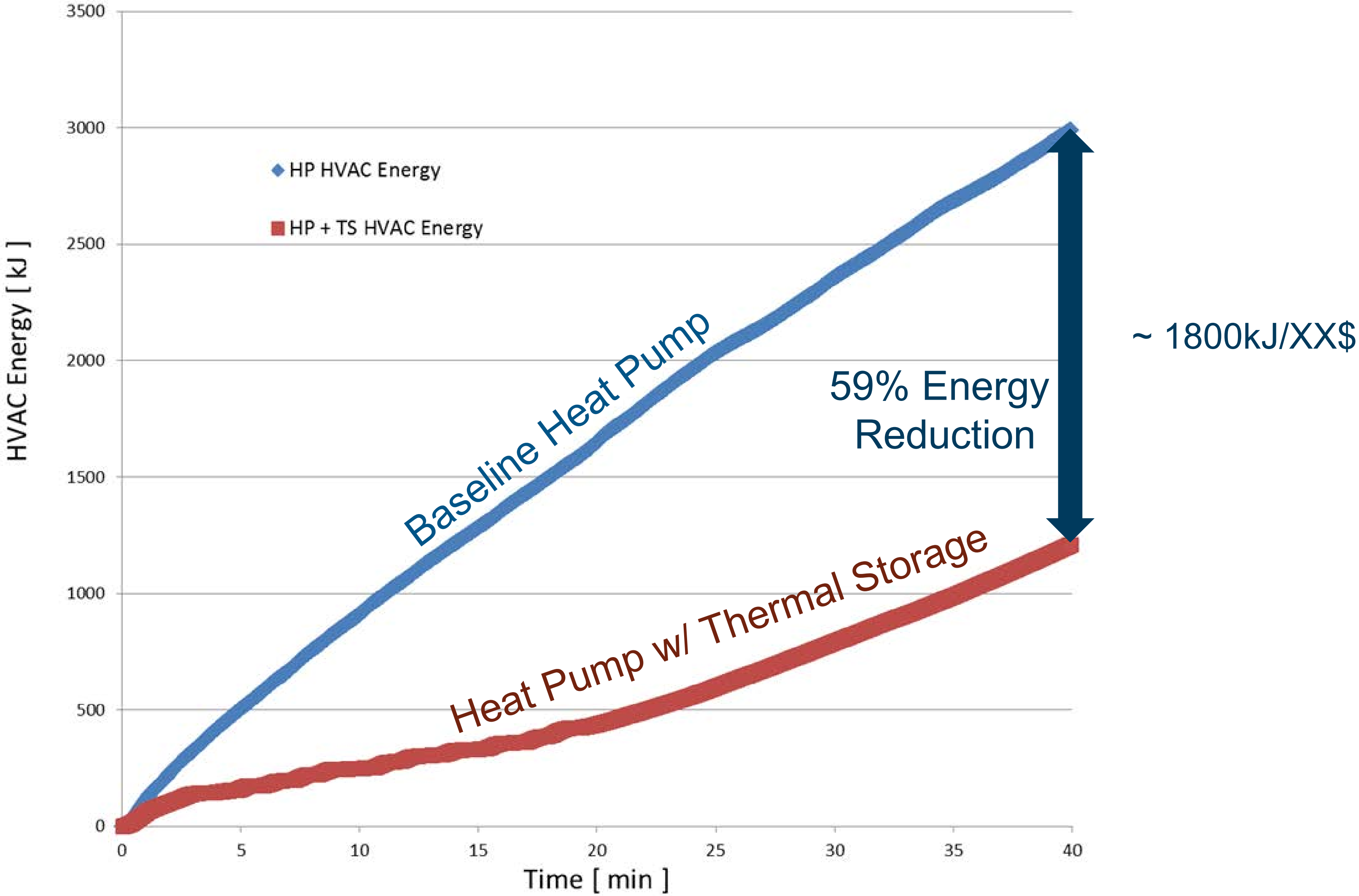
Final Testing @ +5°C

- 40-Minute, 50 kph Drive Cycle
- 68% Reduction in energy consumption
- Near-zero energy consumption for the first five minutes



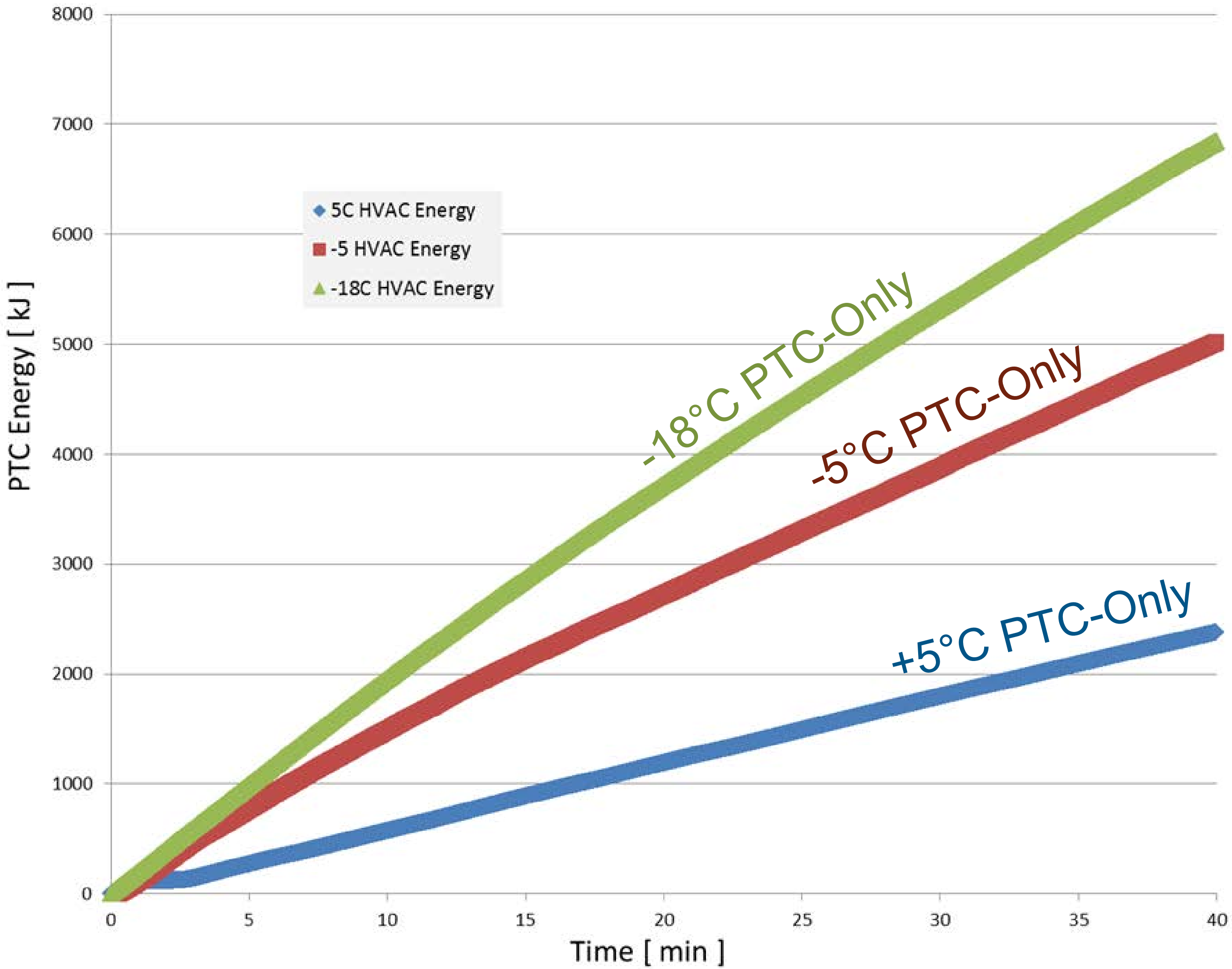
Final Testing @ -5°C

- 59% Reduction in energy consumption



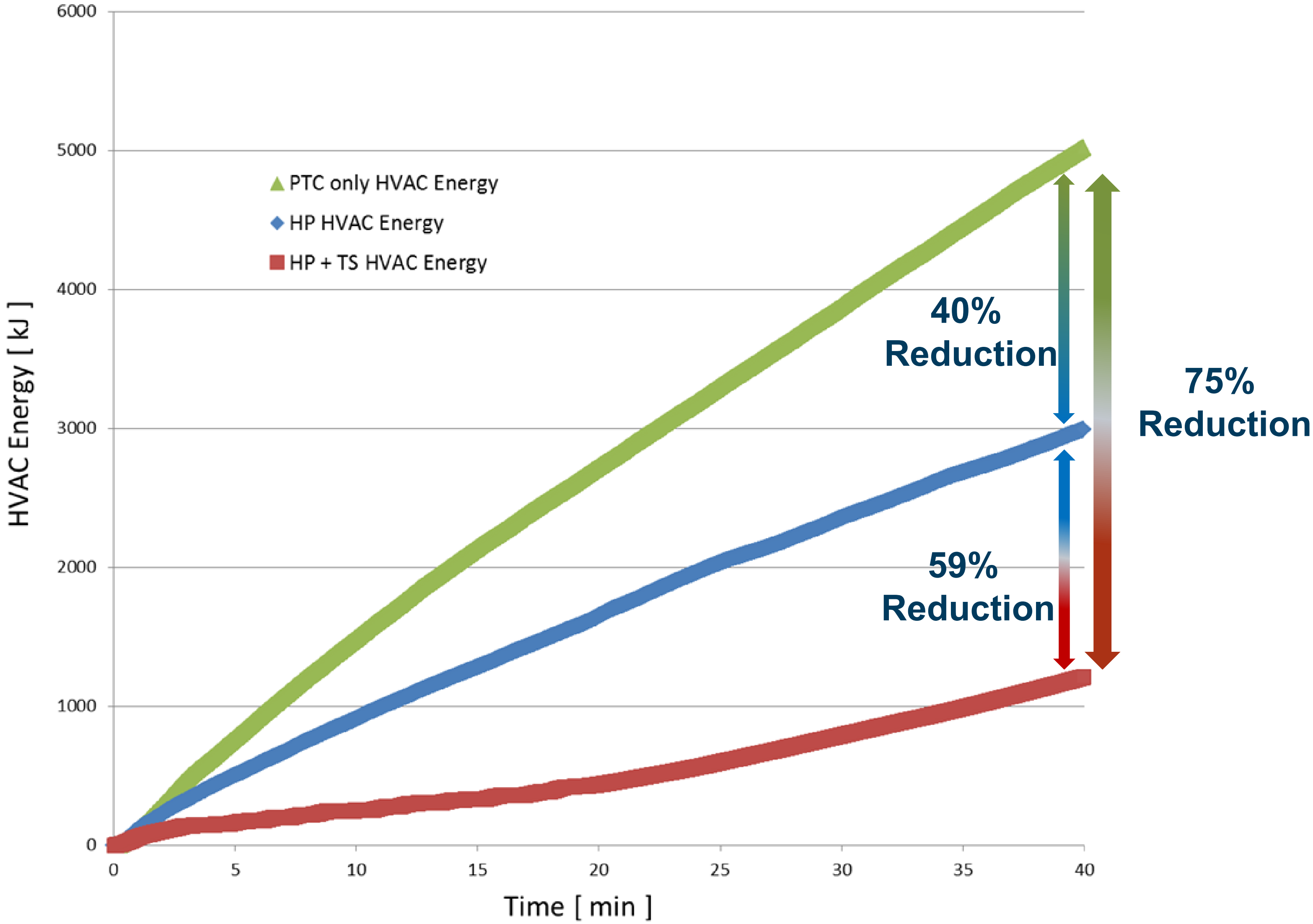
Baseline PTC-Only testing

- -18°C test defaulted to recirculation
- Tests to be Repeated with Thermal Storage



All Three Systems at -5°C

HVAC Energy Consumption of PTC-Only vs Heat Pump vs Heat Pump with Thermal Storage



Accomplishments
Progress Toward Targets

PTC Controls Issue
Prevented Good Test

Test Condition	Target Range (%)	Feb/March 2016 Testing (%)	March 2017 Testing (%)
Cold 3 (-18C)	9.9	14%	-%
Cold 2 (-5C)	13.9	9%	10%
Cold 1 (5C)	13.3	4.5%	4.8%
Hot 1 (28C)	9.5	6%	NA
Hot 2 (32C)	15.0	9%	NA
Hot 3 (43C)	27.2	- %	NA

Values in table assume all trips are 40 minutes. Thermal storage before each trip

- -18°C Assessment Delayed

HATCI Collaboration and Coordination

Automotive OEM Partner Key Support:

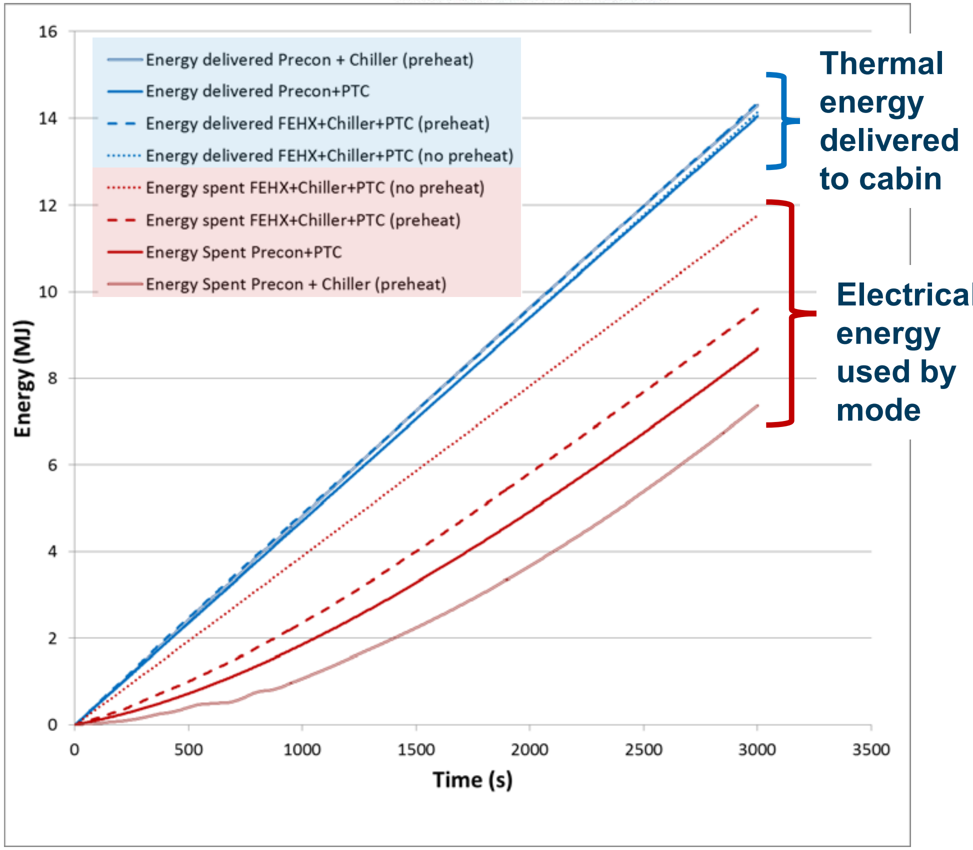
- Vehicle Testing
  - HP Baseline Test 2016
    - Prepared Baseline Vehicle with instrumentation
    - Tested in Michigan
  - HP Final Testing support
    - Tested in wind Tunnel April 2017
    - Modified front fascia with active shutters
  - PTC Only Vehicle Baseline Testing Feb, 2017
    - Prepared vehicle instrumentation
- Architecture Selection
  - Worked with Hanon on PTC system development
- Vehicle Technology Implementation
  - Integration support of vehicle technologies and instrumentation
- Joint Patent Application
  - Patent for PTC with Precon system

Underhood Sealing

Active Shutters

NREL Thermal Modeling

- Modeling results used to down select system design for testing
- Created model that includes all heating modes of operation
- Model used to inform design of experiments for FY17 wind tunnel tests
- Used model to evaluate control strategies and identify energy savings. Determined:
  - efficient methods to heat the cabin at various ambient temperatures.
  - the benefit of preheating the motor and the battery.
  - when to switch the heat pump thermal source from ambient to thermal storage and ambient



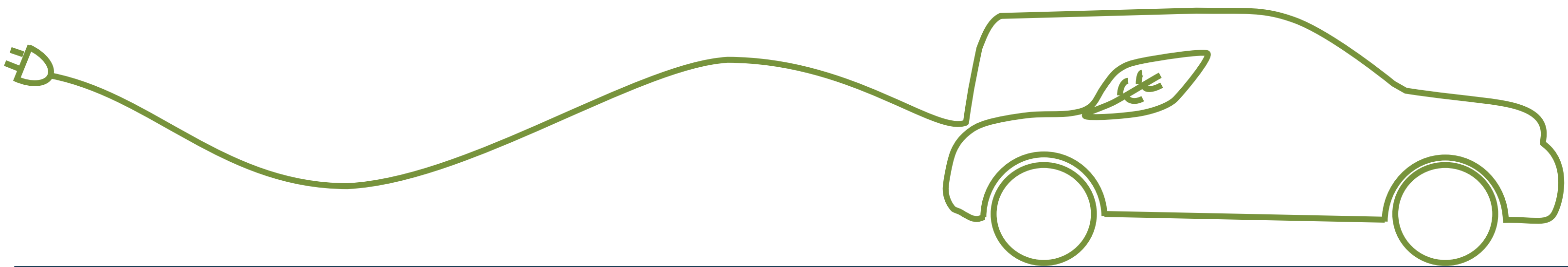
Energy delivered to the cabin and battery energy spent for various system modes at -18^{0}C ambient temperature

- FEHX – evaporator accepting energy from ambient
- Chiller – evaporator accepting energy from thermal storage
- Precon – WEG to air heat exchanger heating the cabin
- PTC – Positive temperature coefficient heater
- Preheat – preheating thermal storage

Barriers/Key Challenges

Barriers/Challenges	Roadmap
The cooling system in production today is quite efficient, leaving small allowance for improvement	• Discontinue improvements to the cooling system, focusing resources on the more fruitful heating enhancements
Control logic of production vehicle not prepared for warmth from thermal storage	• Occasional manual control of system
Production control system makes unanticipated moves during testing	• Over-riding production control strategy required at some conditions
Conservation of PTC-only waste heat	• Do not cool off motor until a preset temperature is reached, building thermal storage in case it is needed

Future Work



FY2017 Roadmap

1Q17

- Complete wind tunnel testing of heat pump vehicle at -18°C
- Complete wind tunnel testing of PTC vehicle at all conditions
- Analyze data and prepare final report

2Q17

- Demonstration vehicle road testing
- Final analysis and project summary

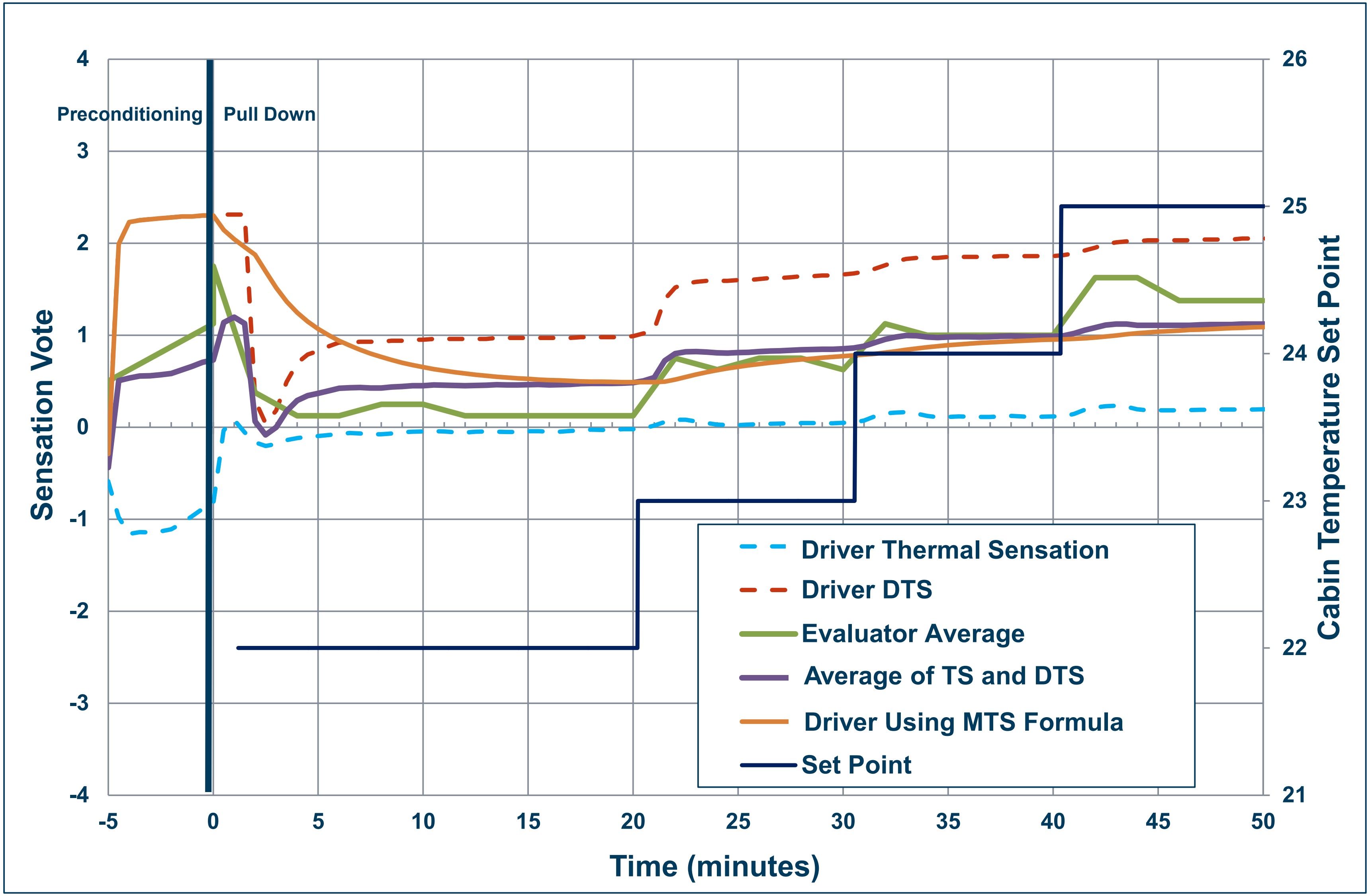
Any proposed future work is subject to change based on funding levels

Response to Reviewer Comments

Criteria	Comment	Response
Approach	• The project team stated that "neither the Berkeley nor the Fiala models adequately predicted the effects of cabin temperature changes on thermal sensation. The reviewer asked on what basis the team concluded that they are not adequate	• We make no general claim about the validity of the various thermal comfort models. We simply noted that, for our specific need, the models did not predict thermal comfort well enough to benefit our effort (see next slide)
Technical Accomplishments	• There seemed to be no consideration apparent on $/mi of range extension	• Although not stated externally, financial calculations were made and contributed to Go / No-Go decisions.
Future Research	• There was insufficient time allowed for vehicle testing and proposed that the project team may want to do a no-cost time extension	• We agree. A no-cost extension of nine months was requested and granted with the added scope of the PTC-only vehicle

28°C Vehicle Pull Down w/ Multiple 1°C Changes in Set Point, Soak Room Data

Revisited…



Summary

- **Relevance:** Project scope addresses VTO objectives of extending electric vehicle driving range through climate load reduction, thus aiding in market adoption
- **Approach:** Team is utilizing complimentary blend of modeling and testing efforts to identify and verify load reduction and resulting range extension
- **Accomplishments:** Systems have been successfully designed, fabricated, tested, analyzed, installed in vehicle, and verified
- **Collaboration:** Experienced OEM and National Laboratory partners continue to contribute key knowledge and expertise towards project success
- **Future Work:** In FY17 (1Q & 2Q) we will complete final analysis of system performance, including PTC-only vehicle, demonstrate vehicles, and give final report/presentation

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

Thank You

Accelerating Innovation