EXTENDING THE RANGE OF A BEV – EARLY PROGRESS

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SAE INTERNATIONAL

HANON SYSTEMS

Outline

- Project scope
- Base vehicle
- Methodology
- Initial testing
- Tools
- Summary

Project Objective

Objective: Maintain occupant thermal comfort and increase the range of Grid Connected Electric Drive Vehicles (GCEDV).

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Project Scope

Vehicle Technologies Office Program Goals:

- Develop more energy-efficient and environmentally-friendly technologies
- Further development and validation of models and simulation tools
- Support EV Everywhere Grand Challenge

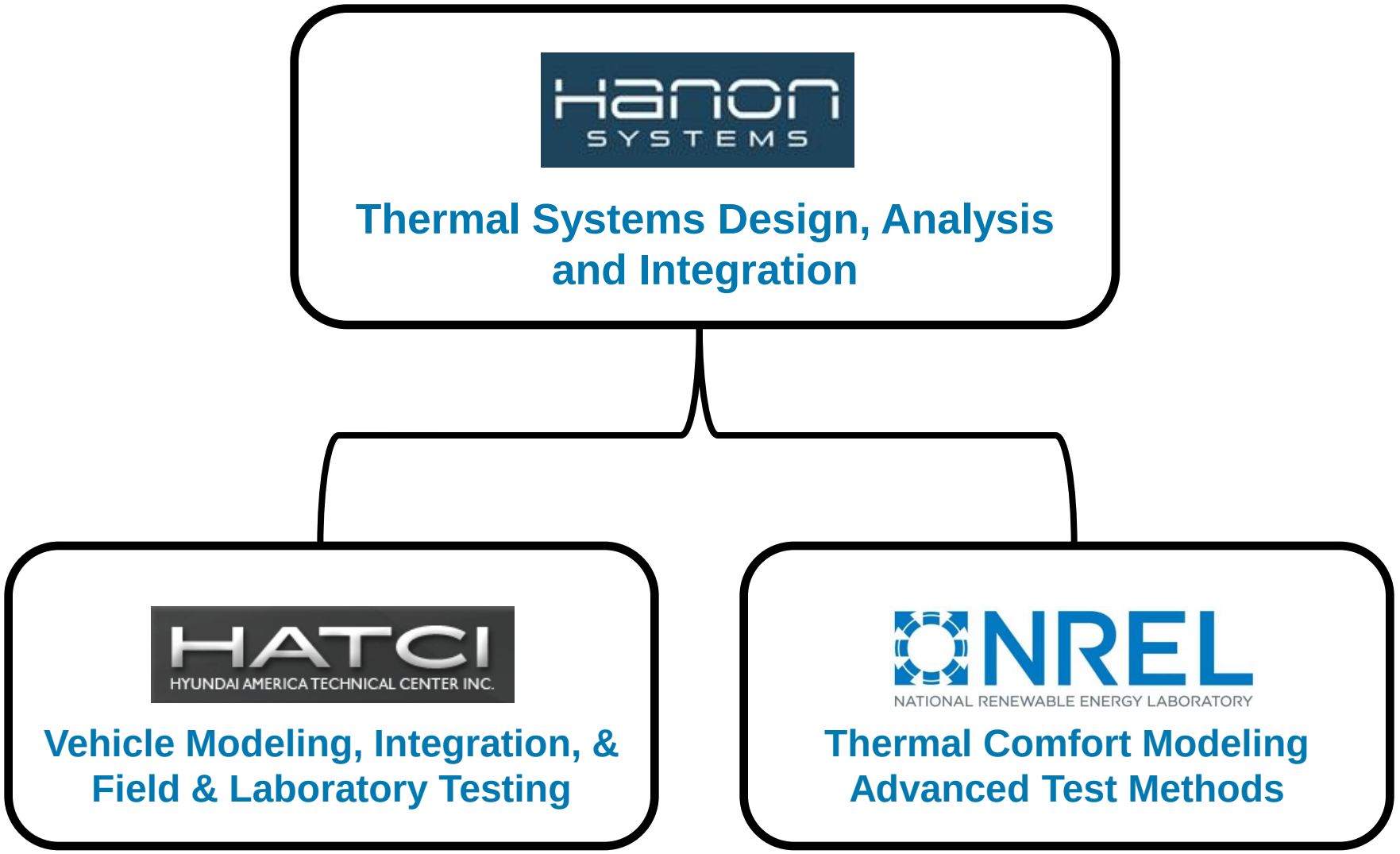
Timing:

- October 2013 - January 2017

Project Partners:

- Hanon Systems USA, LLC
- Hyundai America Technical Center Inc. (HATCI)
- National Renewable Energy Laboratory (NREL)

Participants



Selected 2015MY Kia Soul EV with Heat Pump

Heated and Ventilated Seats

Heated Steering Wheel

Eco-Mode

Air Cooled Battery

Driver-Only Mode

Heat Pump

Positive Temperature Coefficient (PTC) Heater

Pre-conditioning

Dual Zone HVAC

Partial Recirc Strategy

Photo courtesy of Hyundai America Technical Center, Inc.

Challenges and Opportunities

Baseline Vehicle has Many Range Extension Technologies

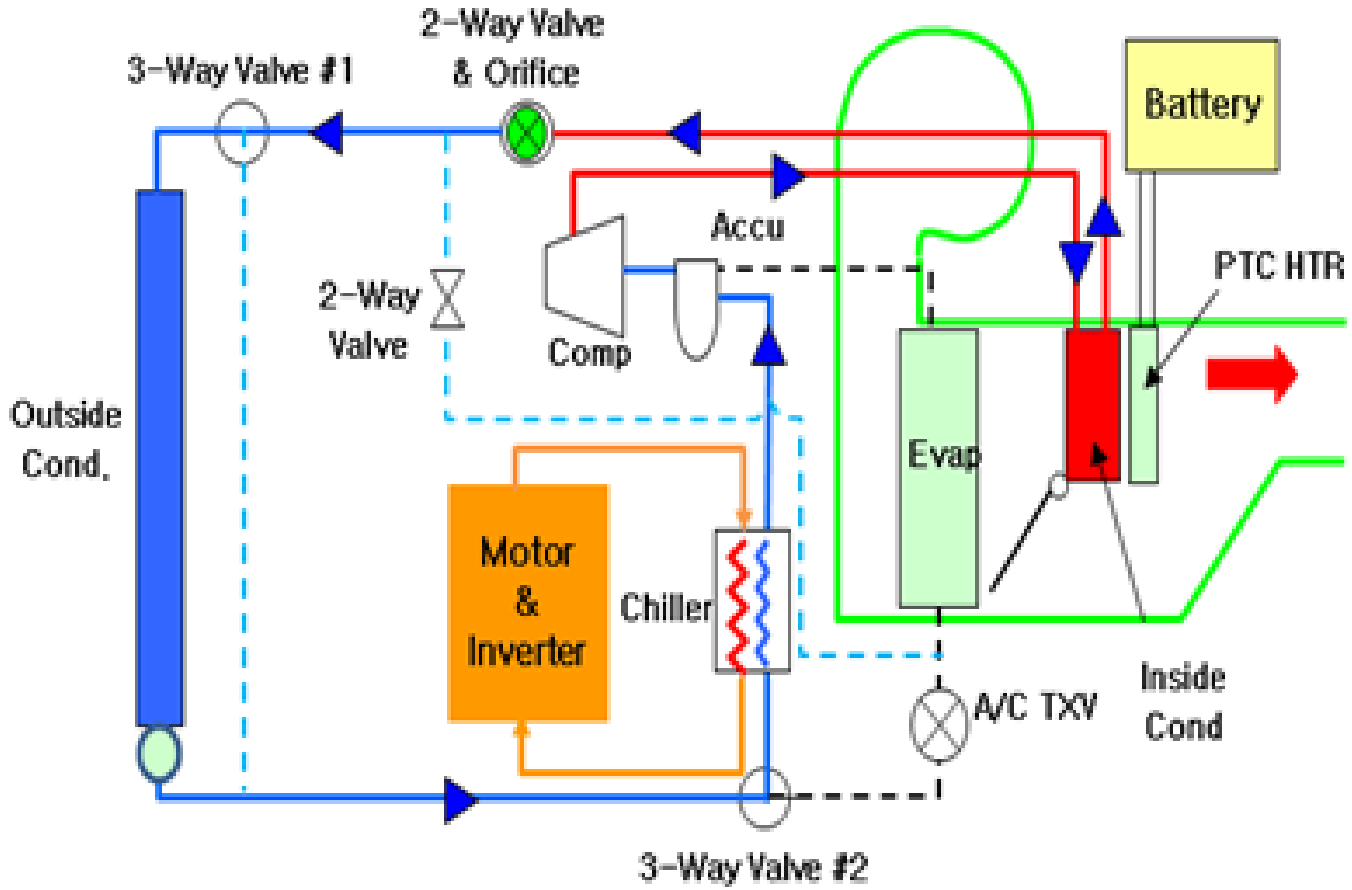
- Heat pump
- Preconditioning
- Zonal
- Heated and ventilated seats
- Heated steering wheel

Opportunities

- Enhance preconditioning
- Add thermal storage
- Improve component effectiveness
- Integrate heated surfaces with controls

System Schematic

System shown in heat pump mode



Development Methodology

Test Baseline System (Bench and in Vehicle)

- Cold weather – 2014 International Falls
- Hot weather – 2014 Death Valley
- Hot and cold – 2014 wind tunnel
- Hot and cold – 2014 bench

Build and Verify CAE Models

- 1-D system
- 3-D cabin
- Comfort

Design and Quantify system Enhancements

- Use models to predict performance

Verify Enhancements with Bench Testing

Install and Demonstrate Technologies in vehicle

Past

Present

Future

Assumptions

- Ambient Conditions
  - Temperatures and population across US was considered
  - -18ºC, -5ºC,+5ºC, +28ºC, +32ºC, and +43ºC were chosen for evaluation
- Drive Cycle
  - Average drive times were considered
  - Wanted to accurately use CAE models to predict outcomes
  - Decided on 50kph for 40 minutes, with 45 minute soak
- Weighting Factors
  - If weighted by population, -18ºC and 43ºC factors become zero
  - In support of “EV Everywhere” each condition considered separately
  - Within each drive, early comfort is heavily weighted

Baseline Testing – Vehicle

January 2014 – International Falls, MN

- HATCI sign-off trip
- Both PTC only and HP Kia Souls participated
- Quantified benefit of heat pump

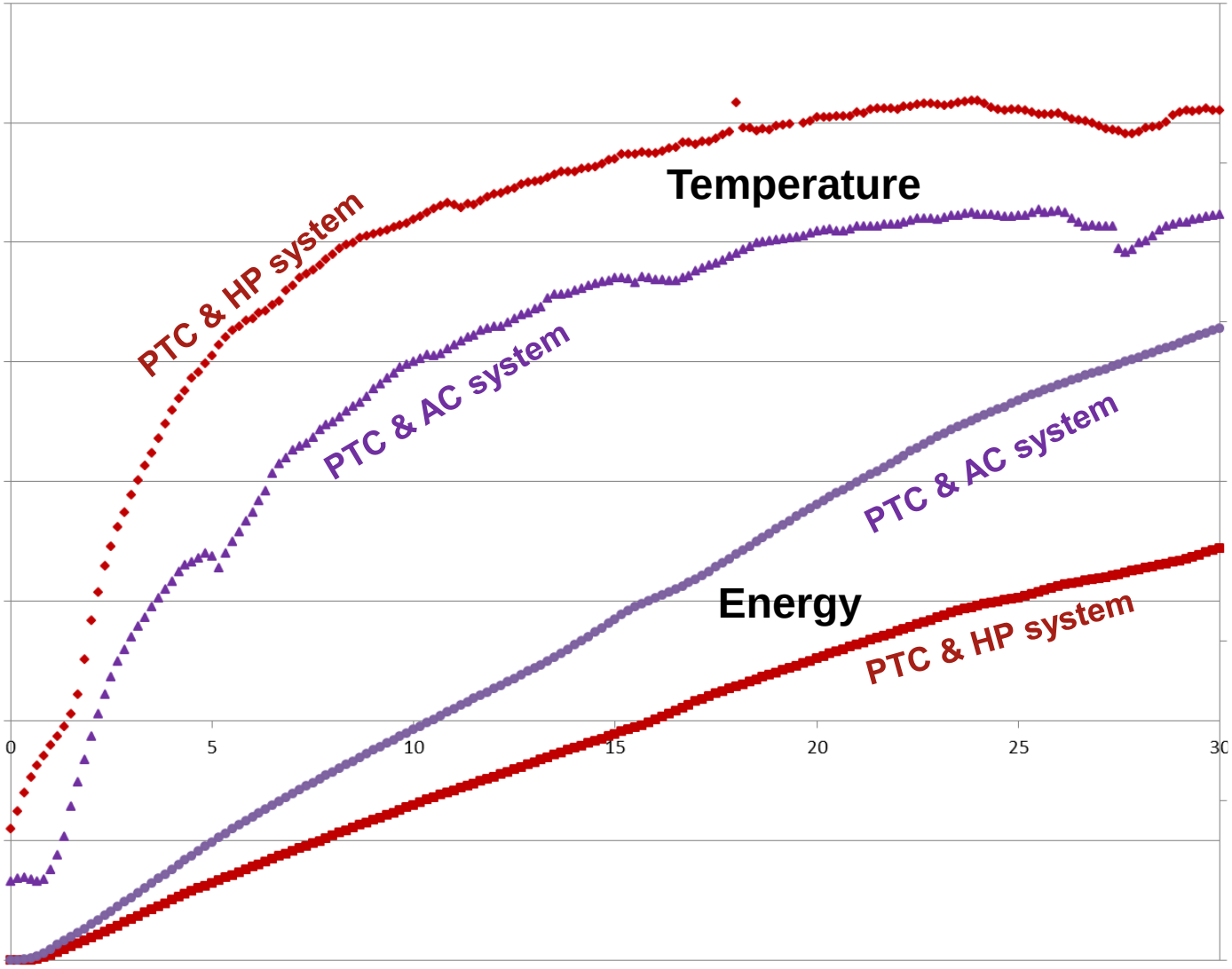
May 2014 – Wind Tunnel

- Both hot and cold conditions tested
- Measured HVAC power
- Data used for model correlation

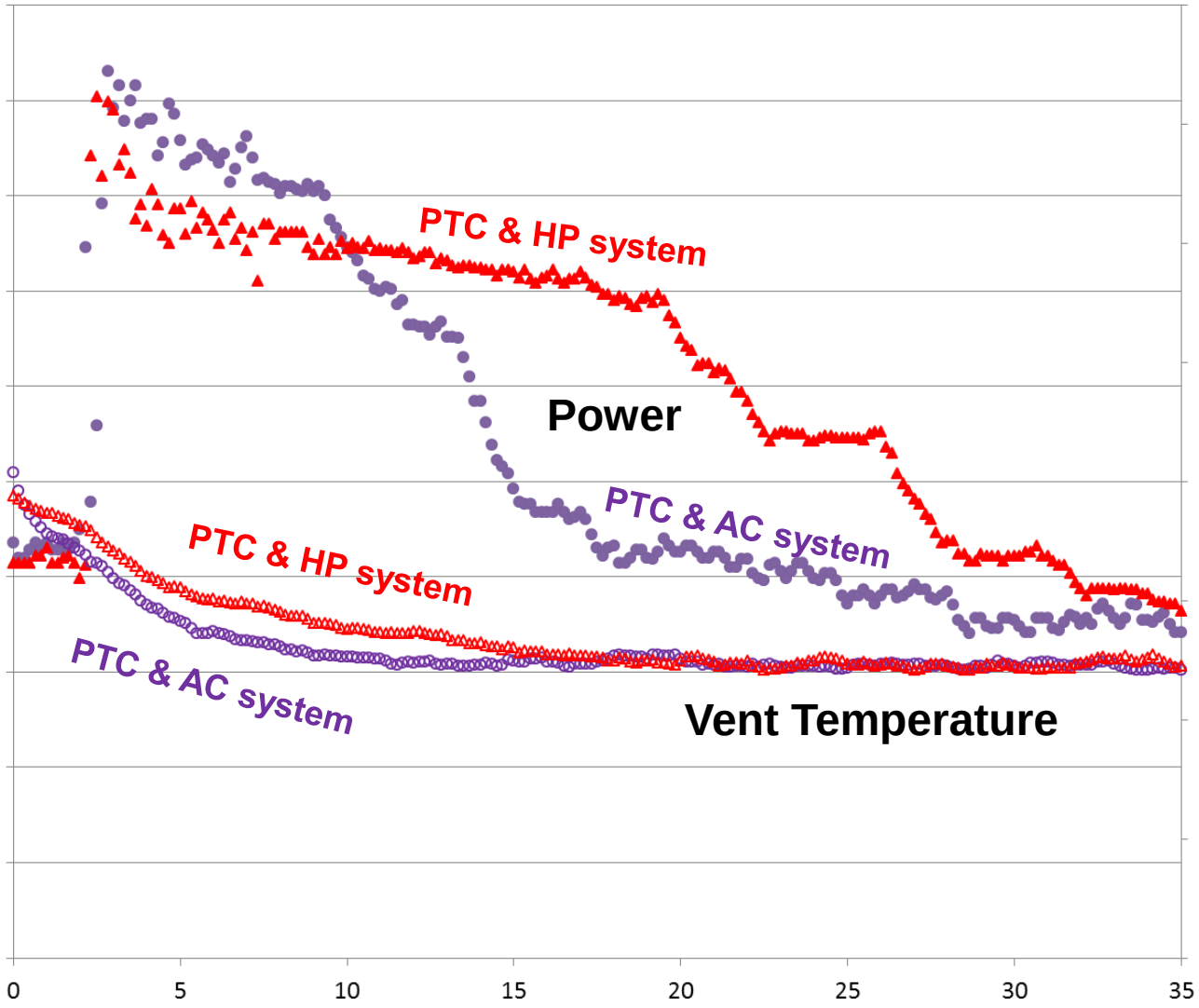
June 2014 – Death Valley, CA

- Both PTC only and HP Kia Souls participated
- Evaluated power consumption during pulldowns

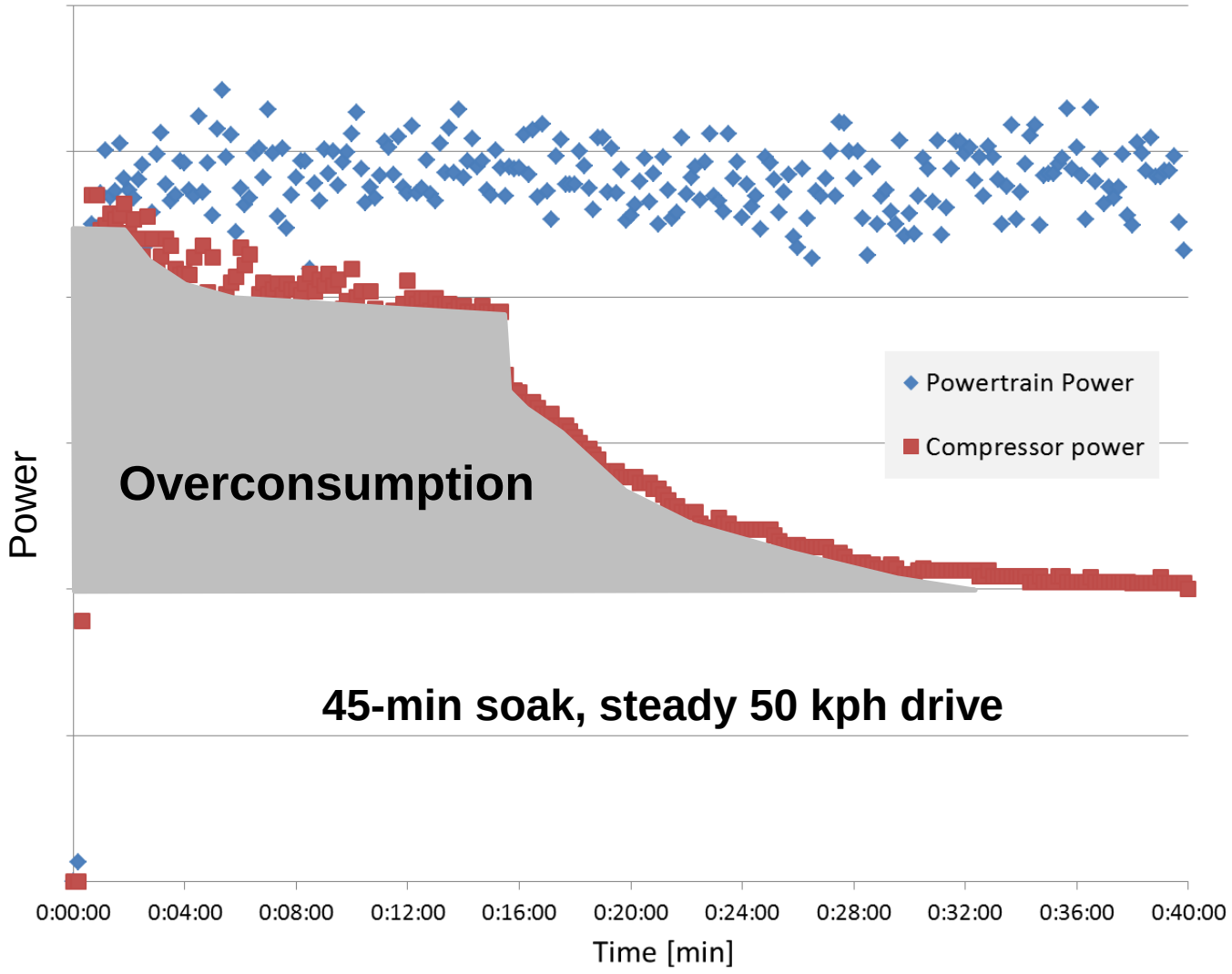
Baseline – Max Heating Comparison (-18C)



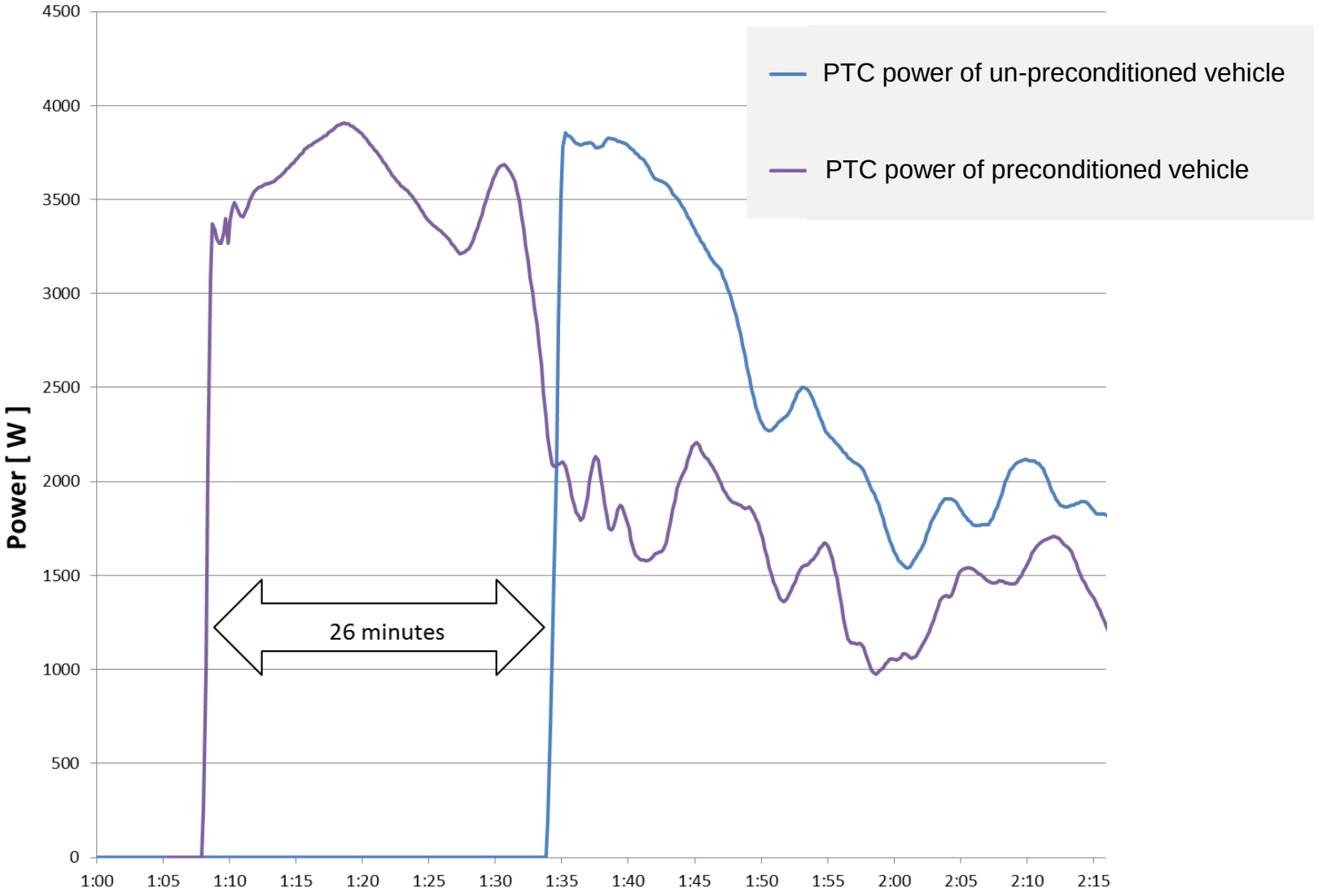
Baseline – Cooldown Comparison (45C)



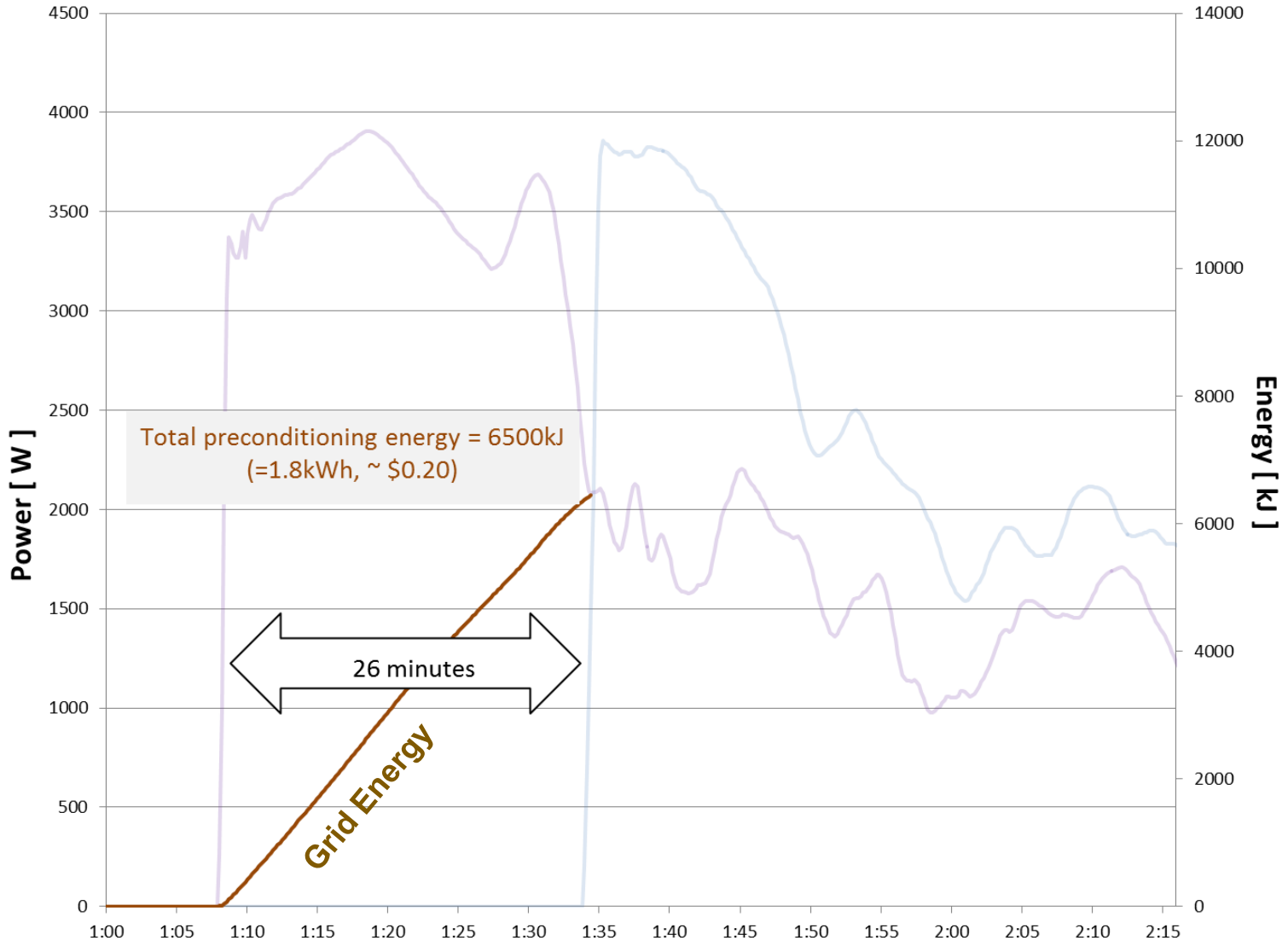
Importance of Preconditioning (43C)



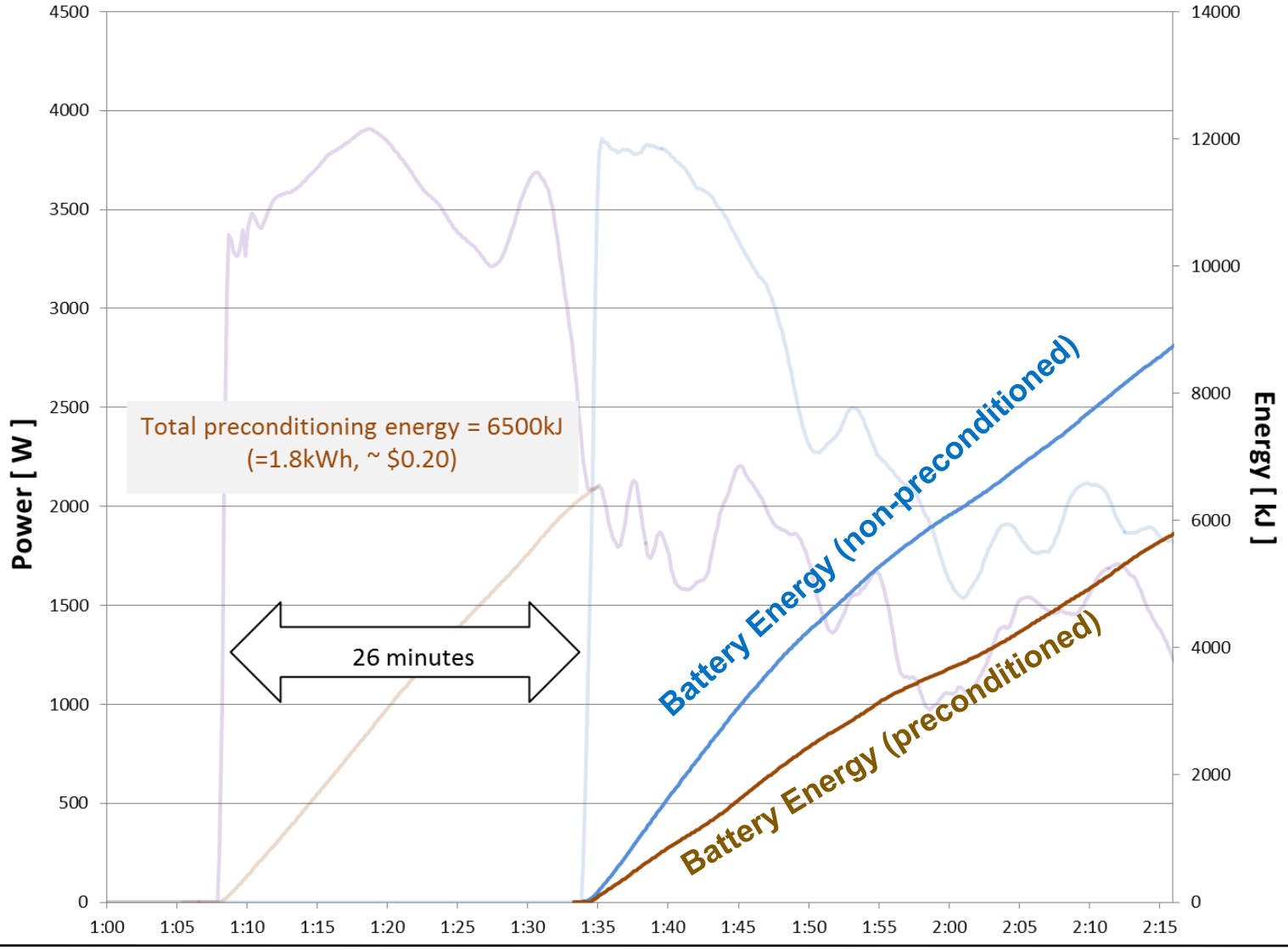
Effect of Preconditioning a Cold Interior (-15C)



Effect of Cabin Preconditioning a Cold Interior (-15C)

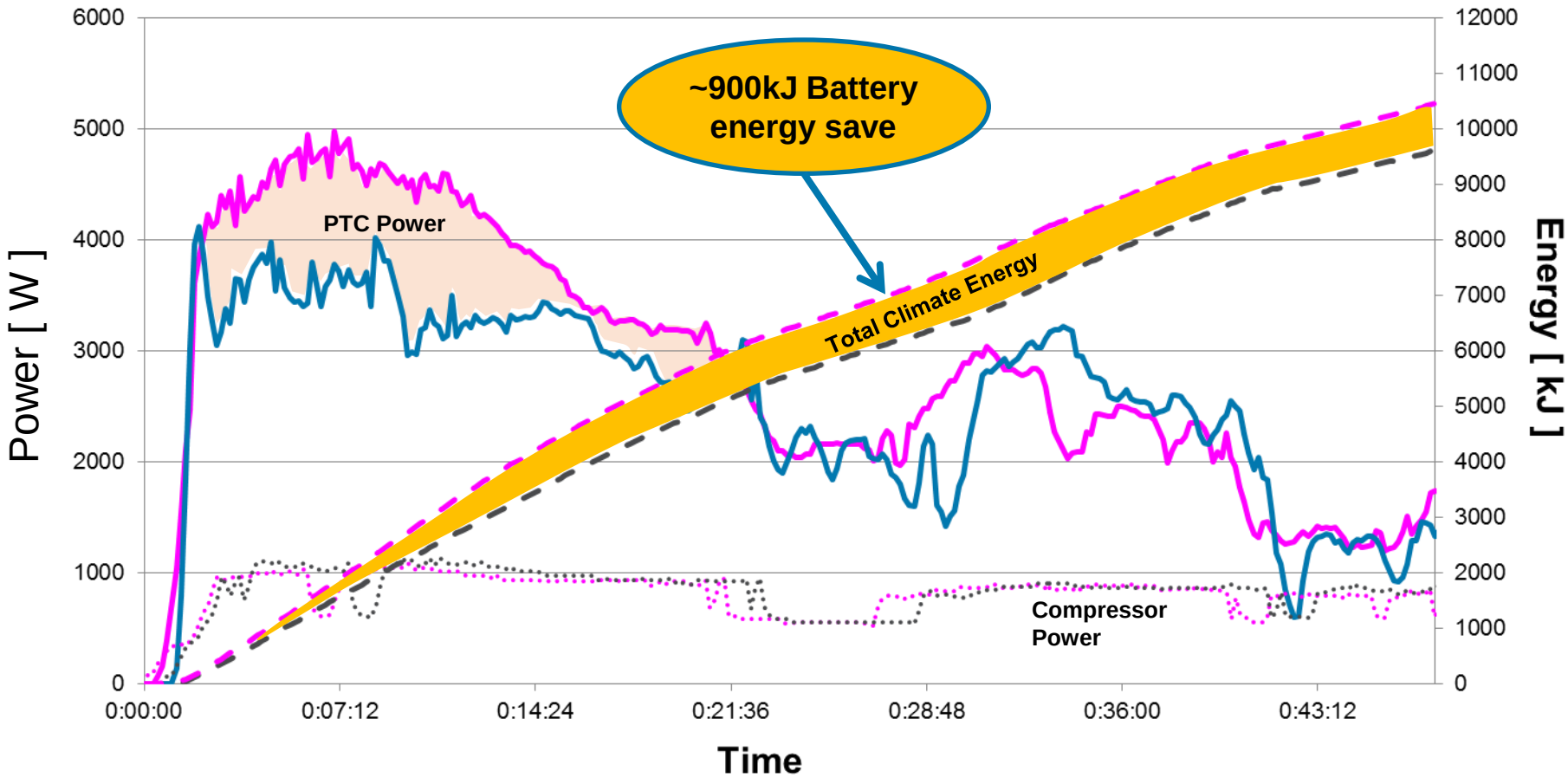


Effect of Preconditioning a Cold Interior (-15C)



Cold Weather Testing (-18C)

Initial Thermal Storage Evaluation



Baseline Testing – Bench

Production A/C system bench tested

- 17 Conditions
- 25ºC to 60ºC ambient temperatures
- 2,000 to 7,000 compressor RPM

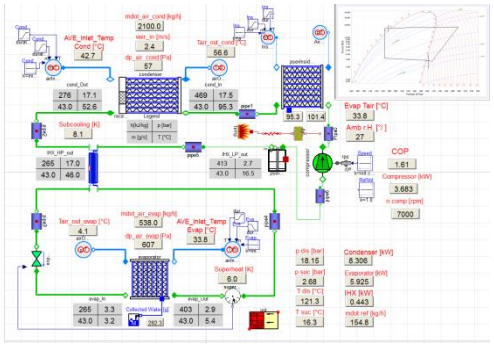
Bench modified for heat pump conditions

- 33 conditions
- 15ºC to -10ºC ambient temperatures
- 1,500 to 5,000 compressor RPM

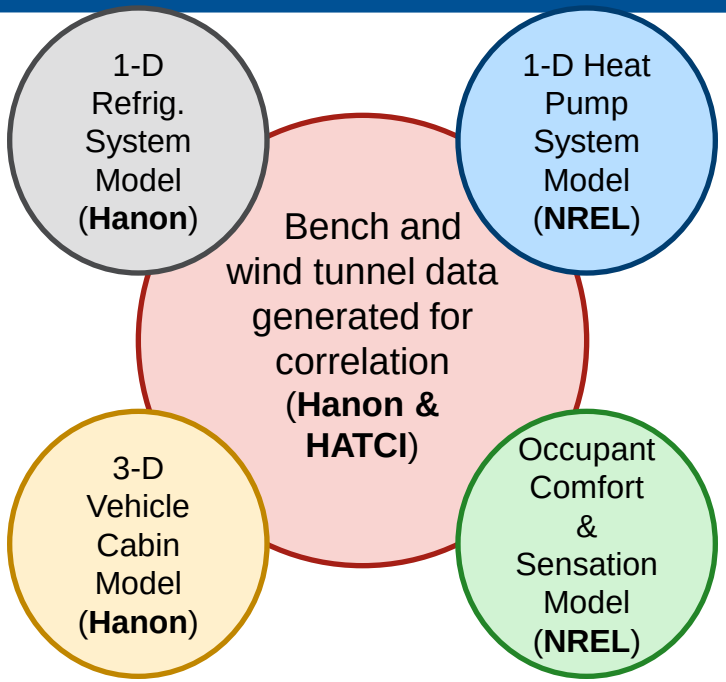
Results used for

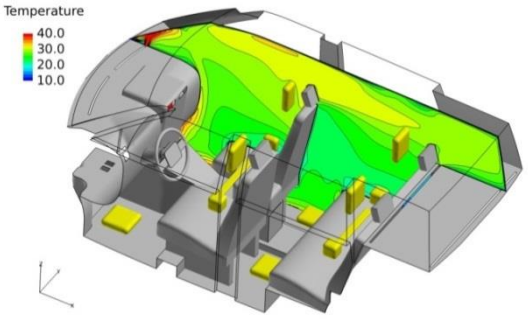
- Model correlation
- System understanding
- Initial evaluation of thermal storage

Modeling and Correlation



Hanon 1-D system model





Hanon 3-D cabin model

Modeling and correlation was a cooperative effort by HVCC, NREL and HATCI, consisting of two primary modeling efforts:

- Develop correlated CAE models from vehicle and system testing.
- Leverage models to aid the selection and definition of specific range extending ideas.

Specific modeling tools utilized:

- 1-D heat pump and air-conditioning system models
- 3-D transient Computational Fluid Dynamics (CFD) cabin models
- Transient human thermal comfort models

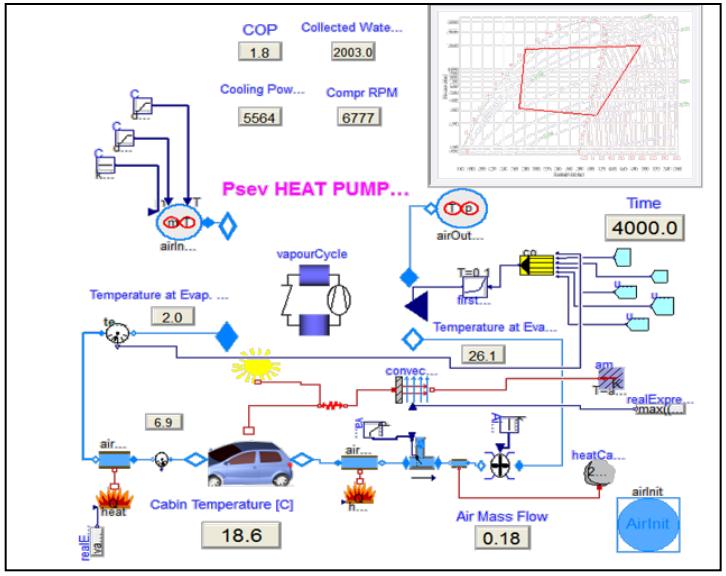
Thermal Modeling Collaboration

1-D models

Both Hanon and NREL have developed 1-D system models

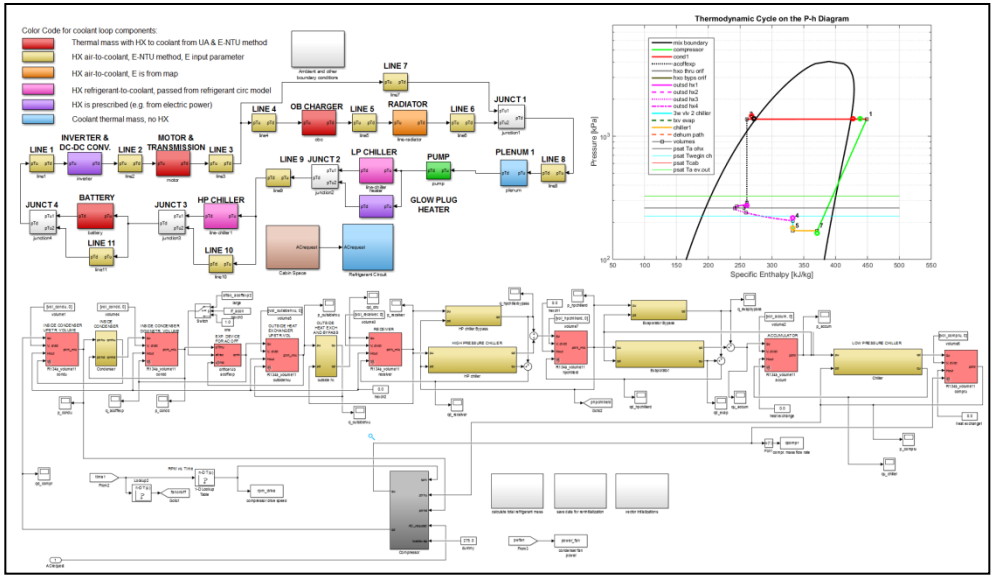
Hanon is focusing on A/C operation, NREL on heat pump operation

Hanon Systems



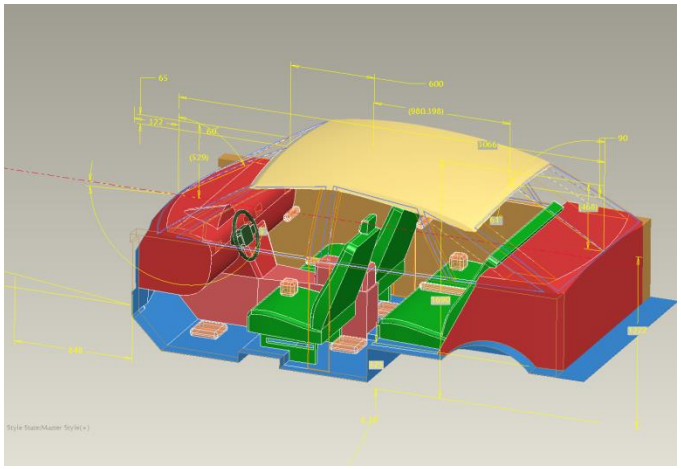
A/C system model front end

NREL



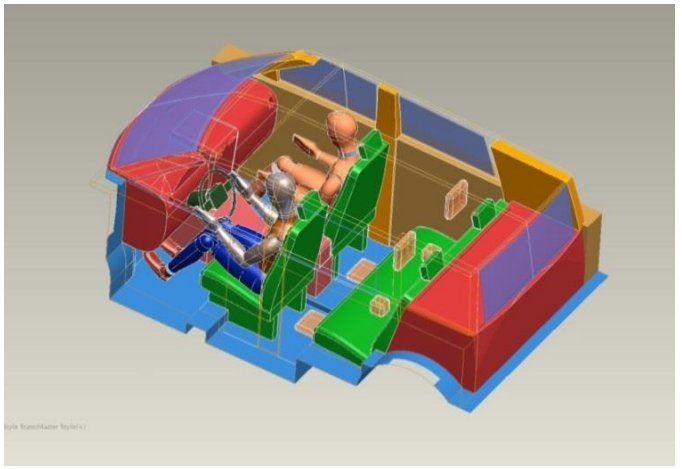
HP system model front end

Vehicle Cabin Modeling (3-D)

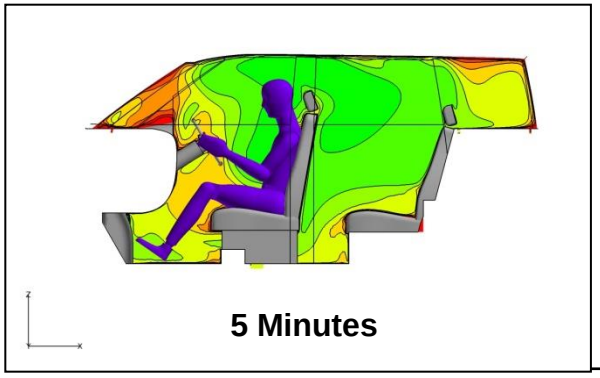


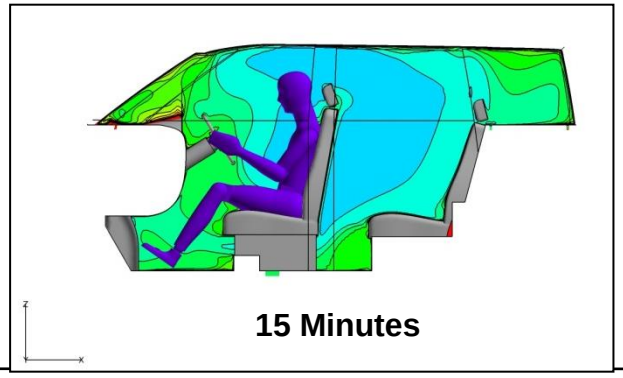
The parametric vehicle model was morphed into a close representation of the Kia Soul.

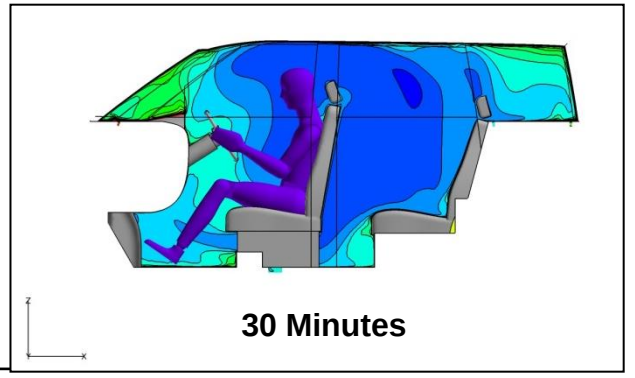
System modifications can be quickly incorporate and recalculated.



CFD was used to simulate the heating and cooling performance of the Kia Soul. The pictures below show interior temperature progression for a 43˚C cool down.



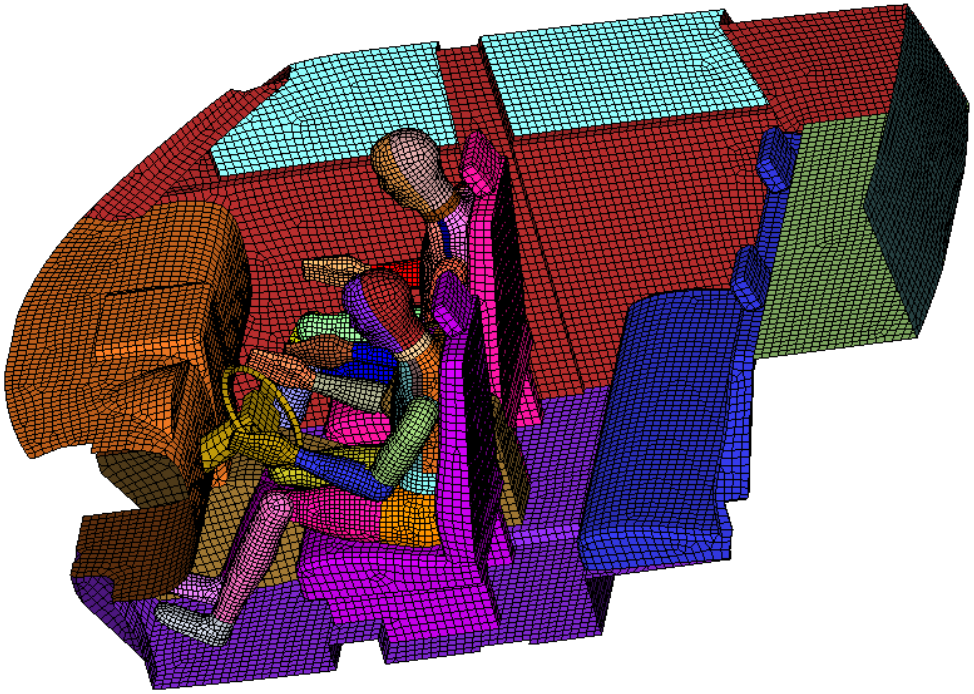


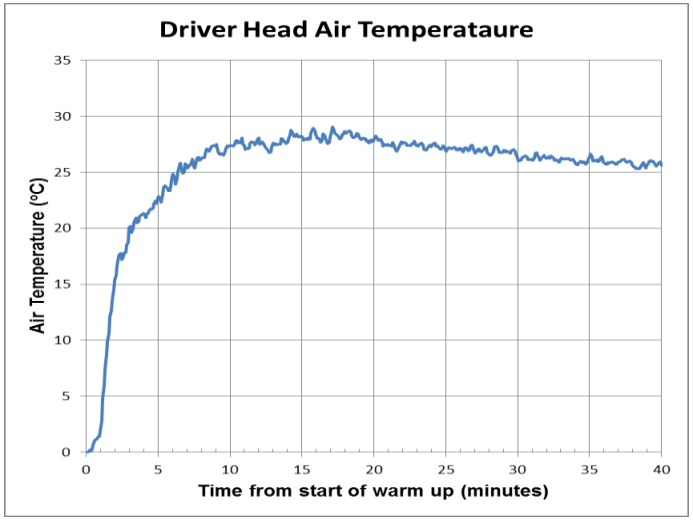


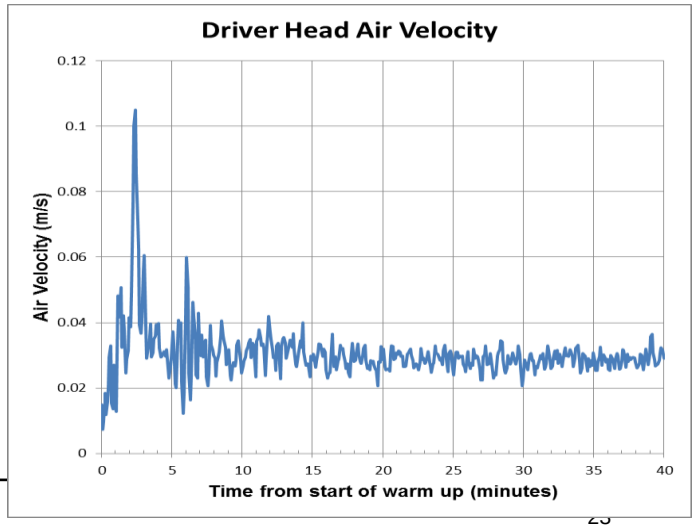
Thermal Comfort Modeling

The Human Thermal Comfort software module (ThermoAnalytics, Inc.) was utilized to evaluate occupant thermal sensation and comfort for all test cases.

- Near manikin air temperature and velocity from the CFD simulations were input for each of the 21 manikin segments.
- Transient vehicle surface temperatures from the CFD results were input into the software.
- Clothing ensemble applied to manikins.







Range Extension

- Using our assumptions, the vehicle range extension predictions

Test Condition	August 2015 Assessment (%)
Cold 3 (-18C)	26%
Cold 2 (-5C)	8%
Cold 1 (5C)	9%
Hot 1 (28C)	8%
Hot 2 (32C)	9%
Hot 3 (43C)	12%

Summary

Vehicle Selection

- 2015 Kia Soul BEV with heat pump
  - Many range extending technologies in production
  - Thermal storage offers the largest improvement

Initial Testing

- Behavior of baseline systems understood
- Data used to validate CAE models
- Areas for enhancements identified and targeted

Next Steps

- Design and fabricate components for enhanced system
- Bench test and analyze data
- Retrofit into vehicle and demonstrate