Halla Visteon Climate Control Corp.

Advanced Climate Systems for EV Extended Range

(ACSforEVER)

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Presenter: Heidi Crandall

Halla Visteon Climate Control

June 10, 2015

Project ID # VSS135

Overview

HVCC

Timeline

Project Start: Oct. 2013

Project End: Jan 2017

Percent Complete – 40%

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 FY14: $901k

Funding for FY15: $1.7M

Project Partners

- Hyundai America Technical Center
  - Vehicle Integration and Testing
- National Renewable Energy Laboratory
  - CAE Modeling and Test Support
- Halla Visteon Climate Control
  - Project Lead

Relevance - DOE Support

Vehicle Technologies Program Goals:

- Develop more energy-efficient and environmentally friendly technologies…and enable America to **use less petroleum and reduce GHG** (greenhouse gases).
- Further **development and validation of models** and simulation tools to predict the performance of advanced conventional and electric-drive vehicle systems.
- Support **EV Everywhere Grand Challenge** 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 either pull-down (hot conditions) or raise (cold conditions) the temperature in the cabin
  - **Energy Load Reduction and Energy Management** to reduce thermal loads that the systems must address

Relevance – Project Objectives

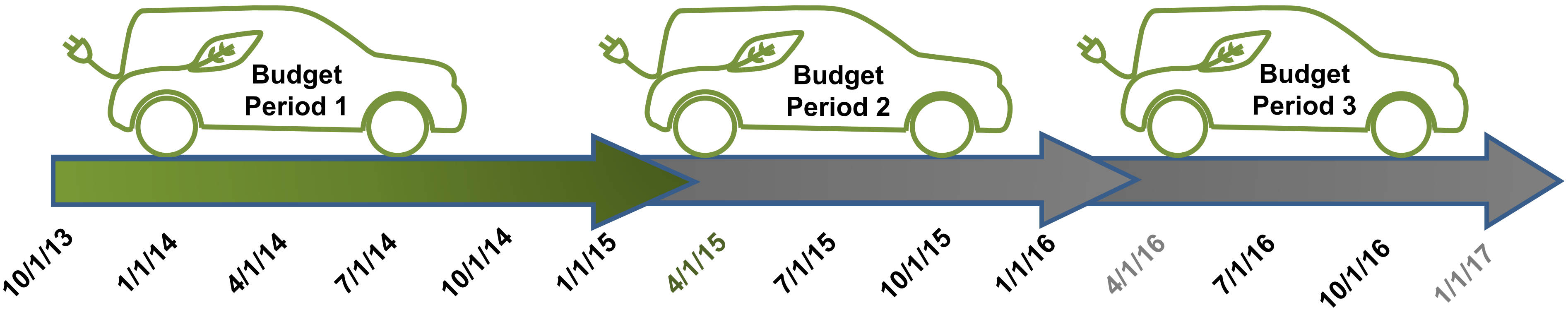
ACSforEVER project support of DOE VTP goals through:

- 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
      - » Perceived comfort control strategy & zonal
  - Maintain occupant comfort

- FY14 objectives:
  - Set performance targets
  - Complete baseline vehicle and bench testing
  - Develop, correlate, & utilize modeling tools
  - Define system architecture

ESS = energy storage system

Technical Approach



FY13/FY14 Tasks

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

FY15 Tasks

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

FY16 Tasks

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

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

Month/Year	Milestone	Type	Description
Mar-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
Jun-2016	Vehicle Integration	Technical	All subsystems integrated into vehicle and ready for testing
Dec-2016	Vehicle Demonstration	Technical	Demonstration vehicle testing complete

Accomplishments - FY13

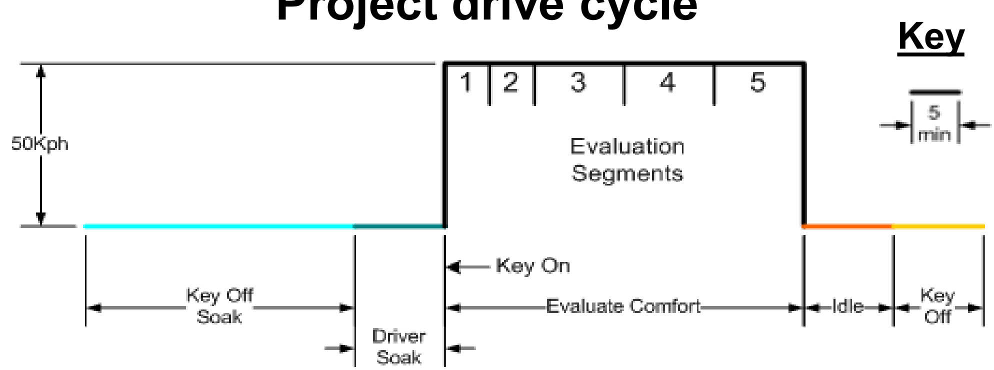
Selected Vehicle:
2015MY Kia Soul EV with heat pump and positive temperature coefficient (PTC) heater

Photo courtesy of Tony Vespa, HATCI

Project test conditions

Test	Temp	Solar Load (W/m^2)	Humidity
Cold 3	-18˚C (0˚F)	N/A	N/A
Cold 2	-5˚C (23˚F)	N/A	N/A
Cold 1	5˚C (41˚F)	N/A	N/A
Hot 1	28˚C (82˚F)	750	70%
Hot 2	32˚C (90˚F)	850	70%
Hot 3	43˚C (109˚F)	1000	40%

Project drive cycle



Technical accomplishments recap from FY13

Accomplishments - Performance Targets

HVCC

Refrigerant System Efficiency

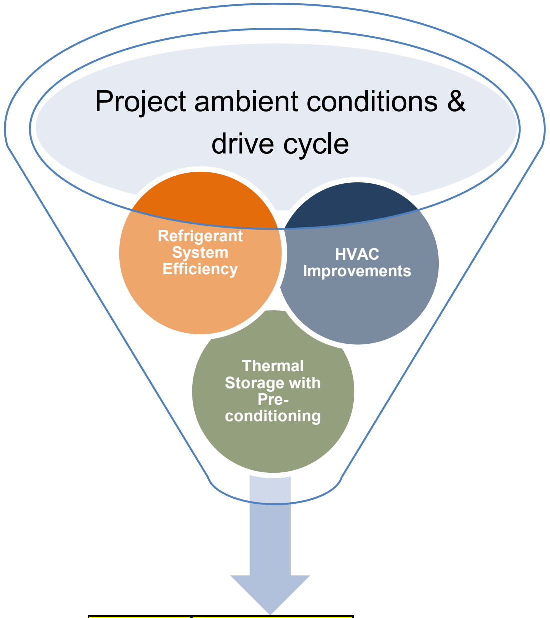
- Higher efficiency components
- Optimized control strategies
- Heat transfer componentry

HVAC Improvements

- Air handler blower technology
- Air handler scroll design
- Integrated heated surfaces
- Comfort perception and control

Thermal Storage with Pre-conditioning

- Battery storage
- Driveline storage
- Cabin structure storage
- Pre-conditioning



Test Condition	Target Range Improvement (%)
Cold 3 (-18°C)	10
Cold 2 (-5°C)	14
Cold 1 (5°C)	13
Hot 1 (28°C)	9
Hot 2 (32°C)	15
Hot 3 (43°C)	27

Transfer range extension percentage to energy

$$\text{Veh. } kJ * \left(1 - \frac{1}{1+\%}\right) =$$

Target Energy Improvement (kJ)
2503
2706
2099
1286
2130
4376

Values based on 40 minute project drive cycle

Targets: Improve range & maintain comfort at six ambient test conditions

Accomplishments - Vehicle Level Evaluations

Jan2014
Cold Weather Testing

- Took place in International Falls, MN
- HATCI “sign-off” trip
- Both PTC and HP vehicles tested
- **Benefit: Cold weather vehicle exposure, gain familiarity with road evaluation test methods and team building**

May2014
Wind Tunnel Testing

- Took place in Farmington Hills, MI
- Baseline HP Kia Soul vehicle tested
- 5 of 6 test conditions tested: -18°C, -5°C, +5°C, 28°C and 43°C
- **Benefit: Data utilized for model correlations**

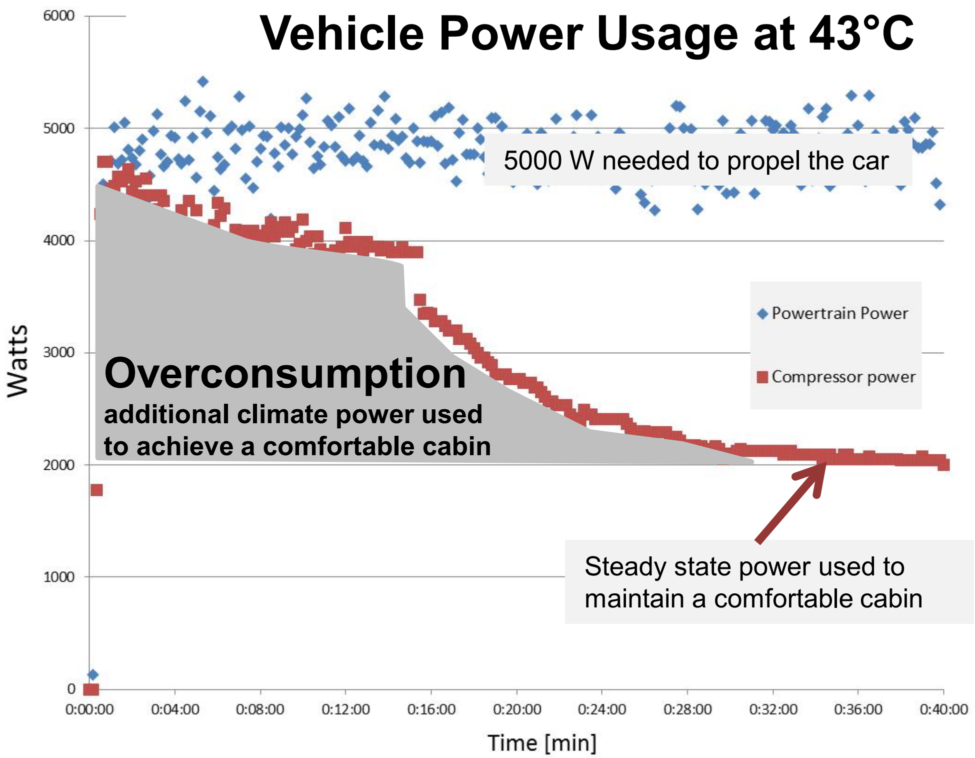
Jun2014
Hot Weather Testing

- Took place in Death Valley, CA
- HATCI “sign-off” trip
- Both PTC and HP vehicles tested
- **Benefit: Hot weather vehicle exposure and gain familiarity with road evaluation test methods**

Feb2015
Cold Weather Testing

- Took place in Ann Arbor, MI
- Kia HP baseline vehicle and second modification vehicle tested
- **Benefit: Early evaluations of various improvement concepts**

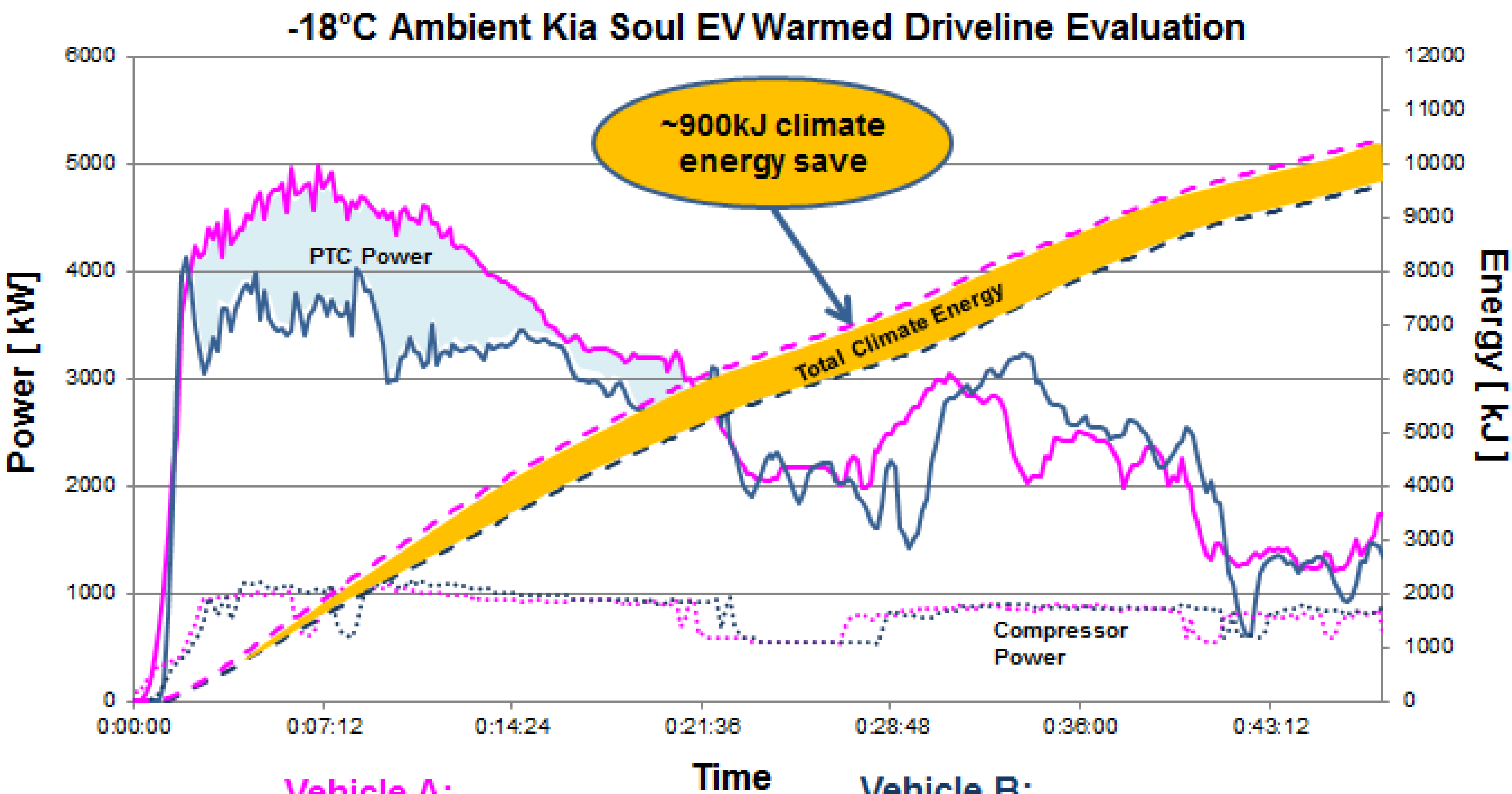
Accomplishments –Vehicle Wind Tunnel Evaluations



Ambient (°C)	Overconsumption (kJ)	Peak (kW)	Steady-State (kW)
-18	3240*	6.0*	2.6*
-5	3960	5.1	1.4
5	2520	3.8	0.5
28	720	2.7	0.9
32	1440**	3.2**	1.2**
43	3240	4.6	2.0

* Values from Feb2015 vehicle evaluation data
** Values are estimated, as no tests were run at 32°C

Overconsumption is a large energy savings opportunity



Vehicle A:
- Baseline vehicle
- No preconditioning

Vehicle B:
- Preconditioned driveline to 25°C
- Outside condenser bypassed

Directional improvement seen for driveline thermal storage

Accomplishments – System Bench Testing

A/C Testing

- Kia system built and fully instrumented in system test room
- 17 AC conditions evaluated
- 25°C to 60°C ambient temperatures
- 2,000 rpm to 7,000 rpm compressor speeds

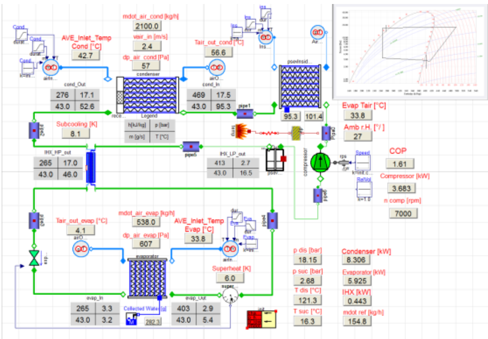
HP Testing

- Completed system room modifications to run heat pump conditions
- 33+ HP conditions evaluated
- 15°C to -10°C ambient temperatures
- 1,500 rpm to 5,000 rpm compressor speeds

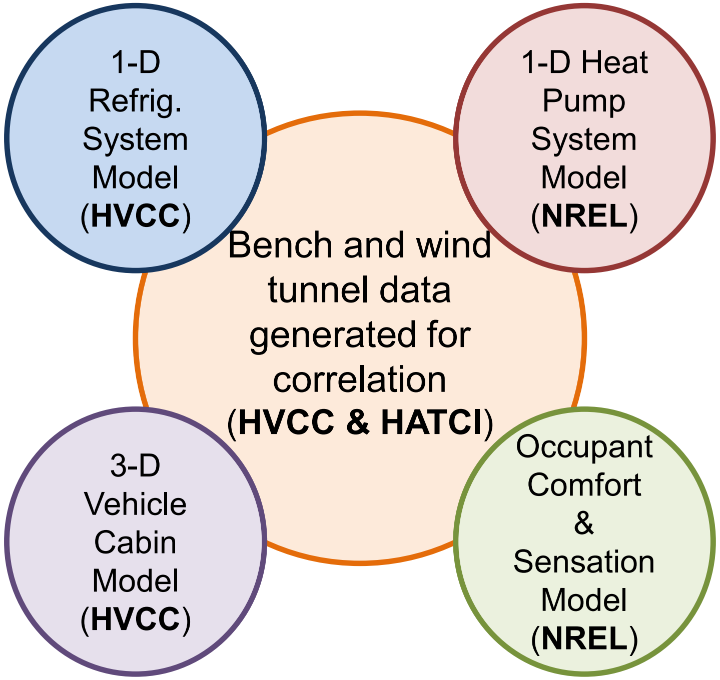
Data Collected

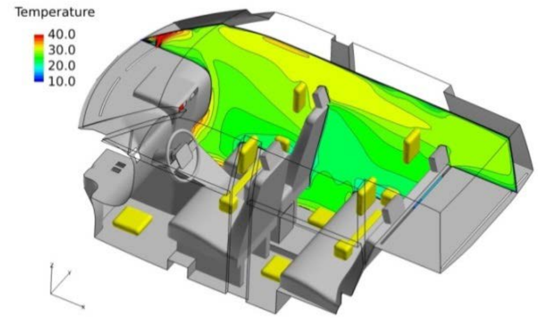
- **Utilized for model correlations**
- Characterize compressor
- System understanding
- Examine effect of warming glycol

Accomplishments - Modeling and Correlation



HVCC 1-D system model





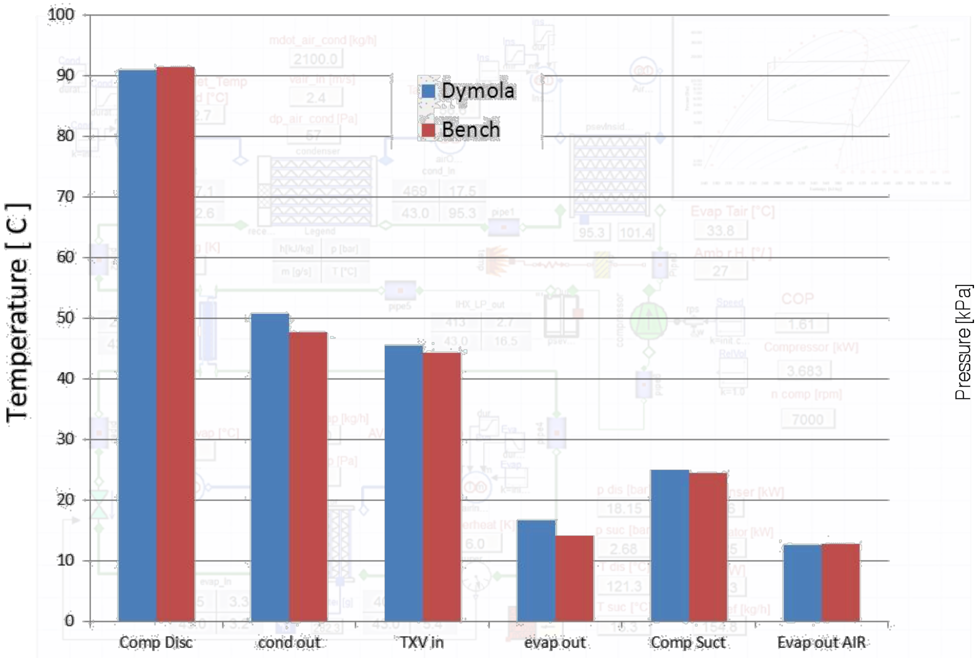
HVCC 3-D cabin model

- Modeling and correlation was a cooperative effort by HVCC, NREL and HATCI.
- Budget period one consisted 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 Model Development and Correlation

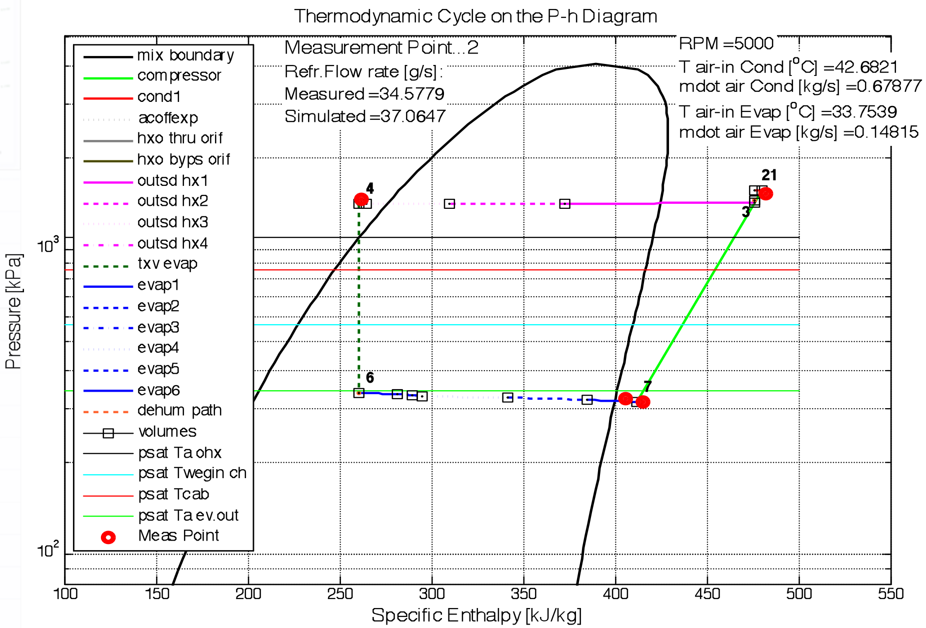
- 1-D thermal system models
  - Both HVCC and NREL have developed 1-D system models
  - HVCC is focusing on AC operation, NREL on heat pump

HVCC



1-D A/C thermal model correlation

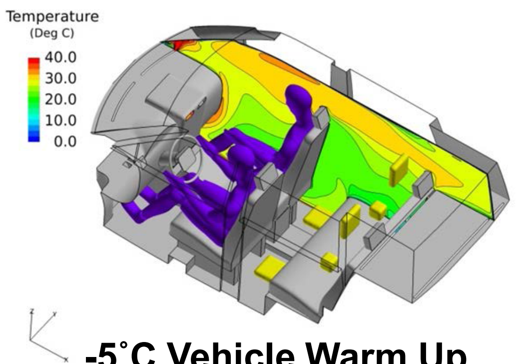
NREL



Modeling vs. data. Ph diagram for an operating condition

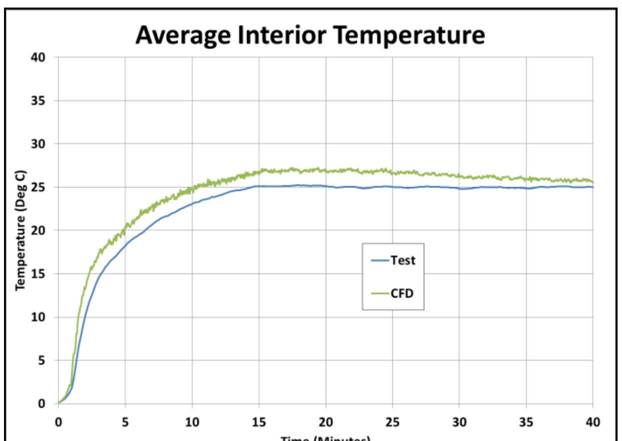
HVCC

Model Development and Correlation

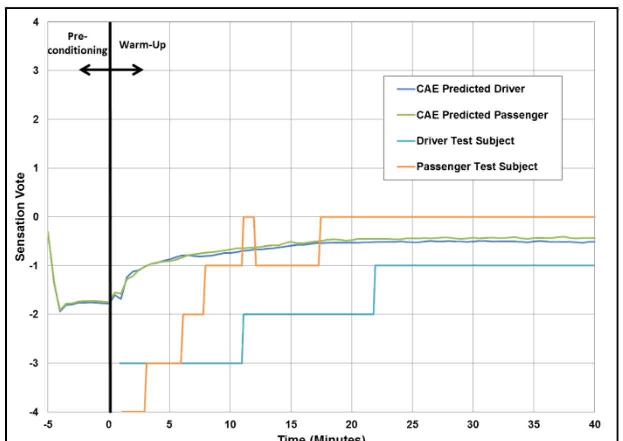


-5˚C Vehicle Warm Up

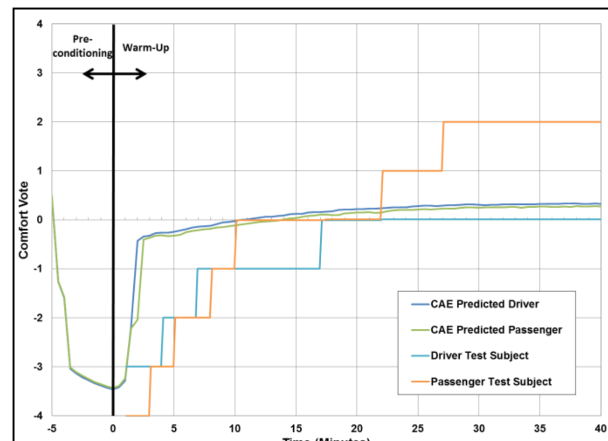
- A 3-D cabin model was built and successfully correlated to wind tunnel test data (5 cases).
- Mannequins were added to the cabin model in order to predict human thermal comfort.
- Results were used to aid the selection of some of the range extension ideas in FY14.
- Models will be used in FY15 for the design and optimization of the ideas.



-5˚C Average Interior Temperature



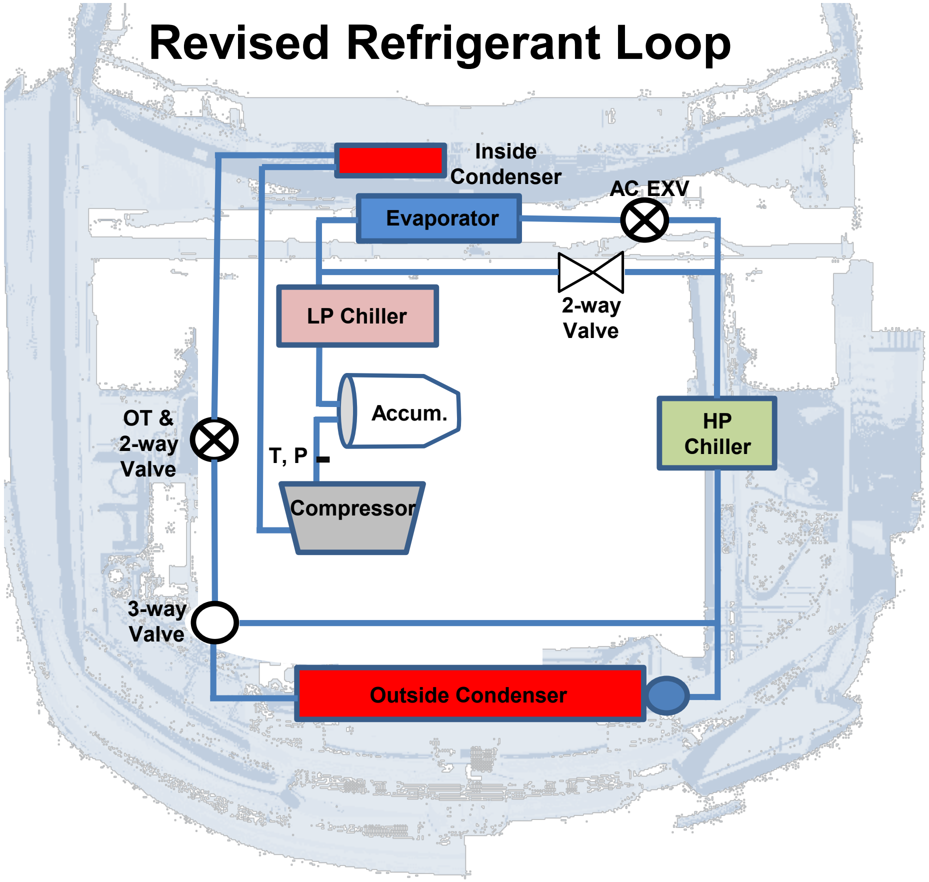
-5˚C Occupant Thermal Sensation



-5˚C Occupant Thermal Comfort

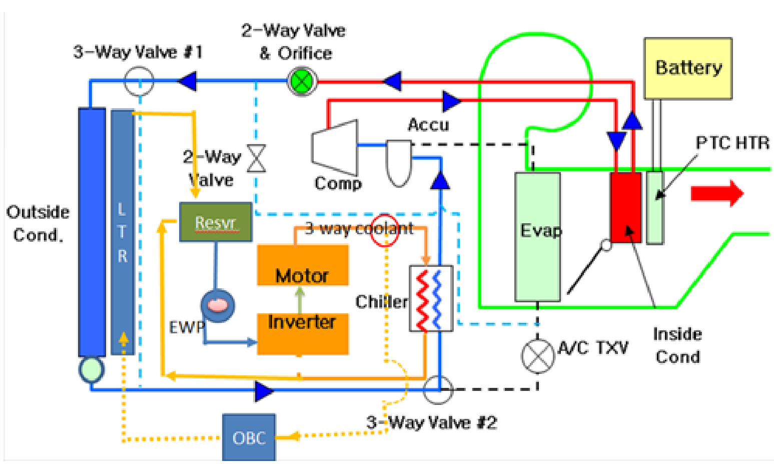
Accomplishments - Improved Refrigerant Loop Architecture

Revised Refrigerant Loop



- Replace TXV with EXV
- Add high-pressure chiller
- Remove "dehumidification" line and 2-way valve
- For dehumidification, flow goes through both 2-way and AC EXV
- Replace 3-way valve before chiller/evaporator with 2-way valve as shown
- Improve heat exchanger efficiency (condenser, evaporator, internal heat exchanger)

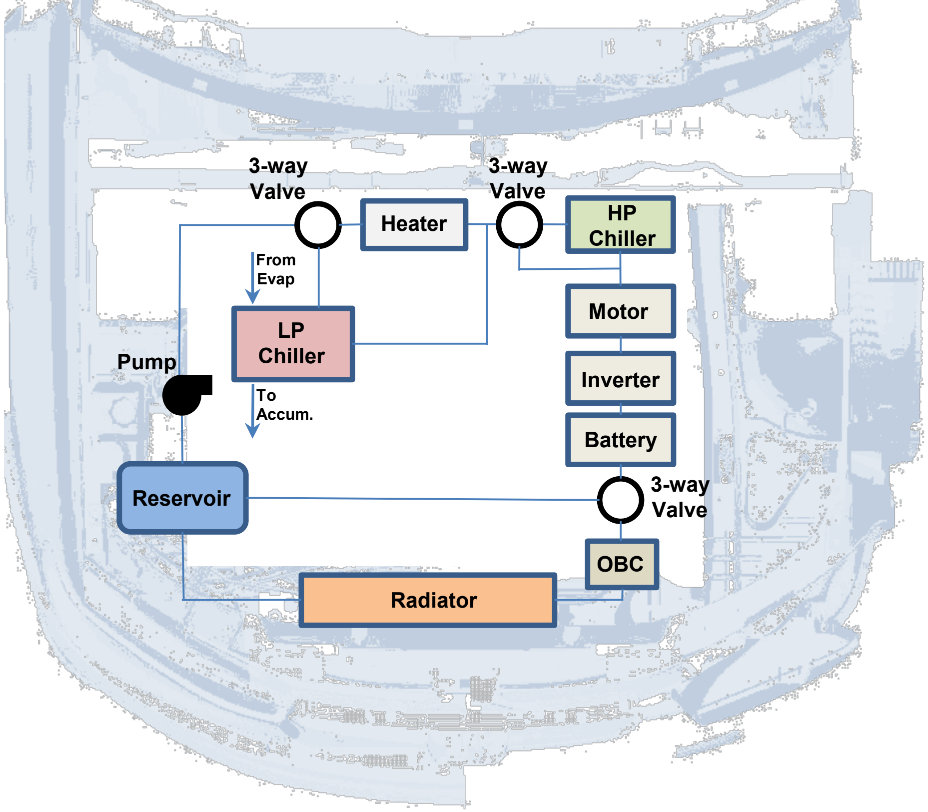
Baseline Refrigerant Loop



Accomplishments - Improved Coolant Loop Architecture

HVCC

Revised Glycol Loop

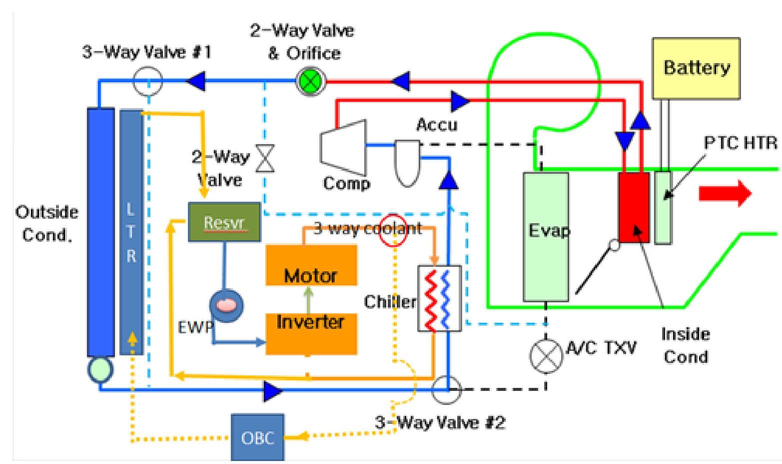


- Add high-pressure chiller
- Add two 3-way valves
- Add glycol heater
- Include battery (via cold plate) in glycol loop for thermal storage
- Utilize insulated motor & inverter for thermal storage

Additional architecture features:

- Enhance pre-conditioning method

Baseline Coolant Loop

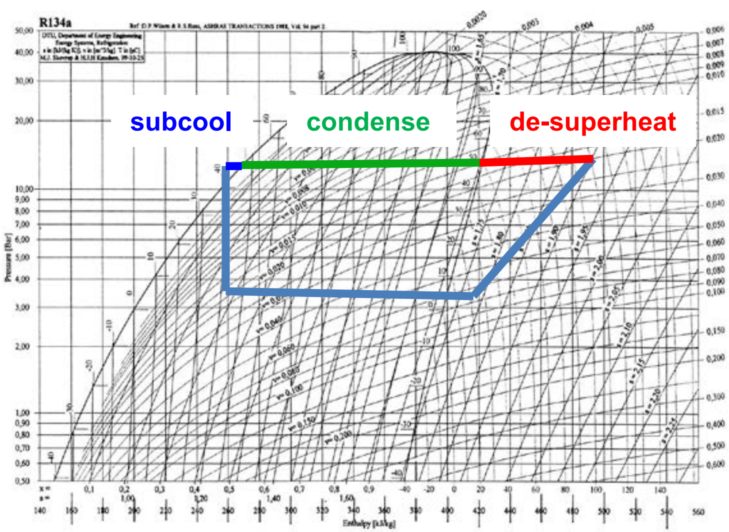


Progress Towards Targets

- Current architecture assessment shows range extension percentages shown while maintaining occupant comfort

- Opportunity areas include:
  - 5°C: Very low/no baseline PTC power consumption
    - » FY15 plan to evaluate potential improvements to provide heat while keeping compressor off for more significant contribution
  - 28-43°C: Using thermal storage to sub-cool refrigerant limits amount of heat transfer and therefore benefit
    - » Less than 1/3 of thermal storage used
    - » FY15 plan to evaluate potential opportunities to increase amount of heat transfer for additional benefits

Test Condition	Target Range Improvement (%)	March 2015 Assessment (%)
Cold 3 (-18°C)	10	15
Cold 2 (-5°C)	14	11
Cold 1 (5°C)	13	3
Hot 1 (28°C)	9	6
Hot 2 (32°C)	15	8
Hot 3 (43°C)	27	10



HATCI Collaboration and Coordination

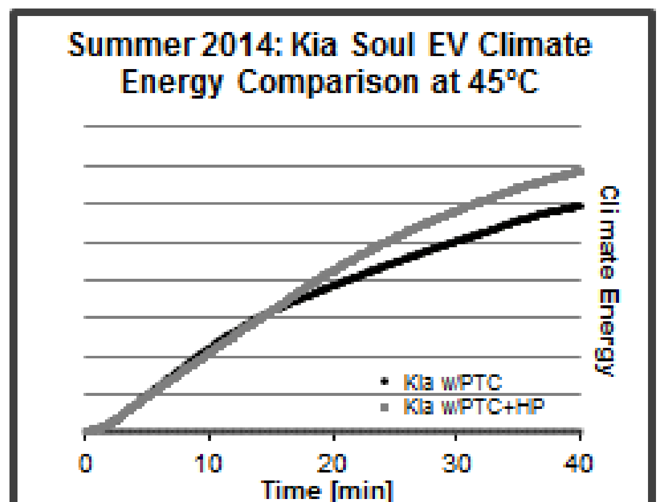
HVCC

Automotive OEM Partner Key Support:

- Vehicle Selection
  - Led vehicle selection task of Kia Soul BEV
  - Driving improvements beyond current state-of-the-art vehicle architecture
- Vehicle Testing
  - Coordinates cold and hot weather testing, as well as all wind tunnel testing
  - Provides instrumented vehicles to HVCC for evaluation
  - Leads data analysis following test trips
- Architecture Selection
  - Participation in brainstorming events and down-selection
  - Maintaining focus on value, not just performance
- Vehicle Technology Implementation
  - Integration support of vehicle technologies and instrumentation

HATCI
HYUNDAI AMERICA TECHNICAL CENTER INC.

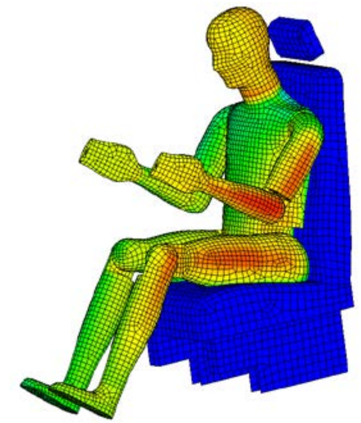

Photo courtesy of Tony Vespa, HATCI



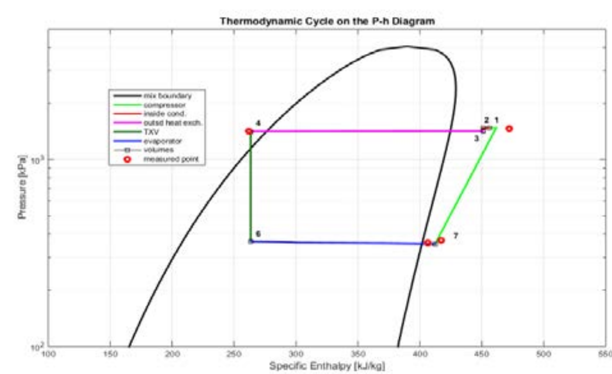
NREL Collaboration and Coordination

National Laboratory Partner Key Support:

- Comfort Modeling
  - Comfort model creation and correlation to wind tunnel data
  - Coordinated simulations for model accuracy
  - Comfort model assessment of heated surface impacts to occupant comfort
    - Results show positive impact of both radiant and contact heating surfaces
    - Results provide guidance in hardware selection
- Thermal Modeling
  - Creation of CoolSim thermal model in MATLAB/Simulink
  - Favorable correlation of baseline A/C and heat pump model when compared to experimental results
  - Heat pump model utilized in advanced system concept evaluations including stored heat harvesting
- Technology Validation
  - Support and consultation during improvement verification testing



Comfort model manikin with heated door panel

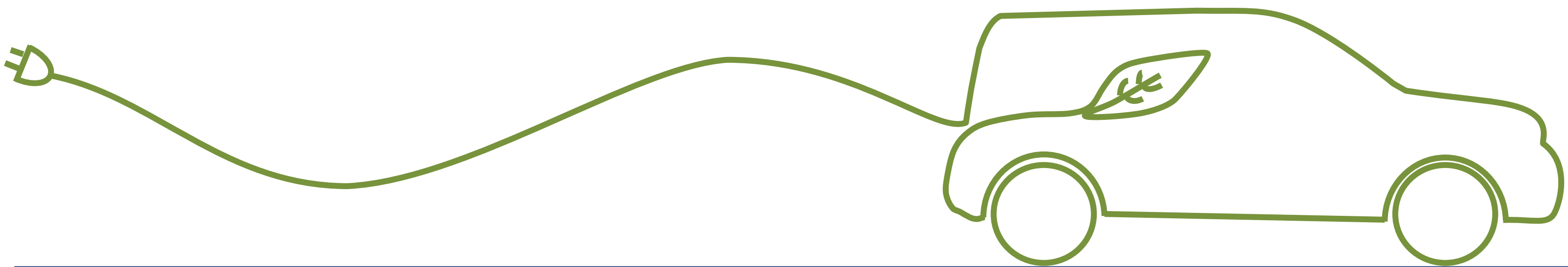


Enthalpy diagram for a thermal system operating condition

Barriers/Key Challenges

Barriers/Challenges	Roadmap
To meet thermal storage requirements, the battery pack will be included in the glycol loop	• Options being evaluated in the next phase are retrofitting the current battery and utilization of a surrogate.
Developing technologies that take advantage of thermal storage without hindering performance when no thermal storage is available	• Design considerations include evaluation of systems with and without thermal storage usage.
Because the vehicle uses very little HVAC power at +5ºC, meeting the range extension goal at this condition is challenging.	• FY15 work plan includes evaluation of identified improvement ideas to provide heat while keeping the compressor off. This will yield more significant range extension at +5ºC.
At hot ambient conditions, using thermal storage to sub-cool refrigerant limits amount of heat transfer	• FY15 work plan includes assessment of improvement ideas to increase heat transfer to mitigate this challenge
The area of human thermal sensation and comfort modeling is complex and still developing. The comfort rating aspect of the tool is relatively immature at extreme ambient conditions.	• Project team leading dialogue with comfort software supplier to help guide future improvements to human thermal comfort model • FY15 will include more in depth evaluator training

Future Work



FY2015 Roadmap

2Q15

- Complete vetting of engineering challenge opportunities and evolution of the system
- Specify and design heat exchangers and valves
- Design thermal storage components
- Create and execute keystone comfort control test cases

3Q15

- Continue design of components
- Begin prototype build of hardware
- Specify design and control of EXV
- Bench test thermal storage components

4Q15

- Build and bench test system
- Build and program test sequencer system
- Correlate models to bench testing as needed
- Refine system control

1Q16

- Continue bench testing
- Complete soak room vehicle evaluations
- Define final architecture
- Refine range estimates and system cost
- Correlate results to models

Response to Reviewer Comments

Criteria	Comment	Response
Approach	Reviewer focused on what expected benefit is in terms of percentage improvement in driving range.	• Vehicle range extension targets have been developed and presented in this presentation • Also included was an update on how we are progressing towards the targets and how remaining challenges are being addressed
Approach	The reviewer commented that the project did not provide specific targets that address EV viability in very cold and hot temperature operating environments that are characteristic of large portions of the U.S. market.	• The range targets established do account for the extreme and mild ambient temperatures experienced throughout the U.S. • Additionally, the coldest condition (-18C) shows the most benefit
Collaboration	Reviewer stated that NREL should be leveraged for CFD modeling due to their experience and knowledge base in developing and validating thermal models.	• NREL has been a key contributor in comfort and thermal modeling efforts. Their experience and knowledge in these areas has and will continue to be utilized for this project

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 comfort acceptability
- **Accomplishments:** Phase I architecture does extend the range of the 15MY Kia Soul EV while maintaining comfort with further improvement opportunities identified for FY15 evaluation
- **Collaboration:** Experienced OEM and National Laboratory partners continue to contribute key knowledge and expertise towards project success
- **Future Work:** FY15 roadmap paves the way through engineering challenges and tasks required to meet the project objectives

Thank You

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