Halla Visteon Climate Control Corp.

Advanced Climate Systems for EV Extended Range

(ACS forEVER)

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Presenter: John Schneider

Halla Visteon Climate Control

June 19, 2014

Project ID # VSS135

Overview

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Timeline

- Start: Oct. 2013
- End: Jan 2017
- Percent complete – 15%

Barriers

- Public acceptance of electric drive as central vehicle choice.

Budget

- Total project funding: $4.68M
  - DOE share: $2.34M
  - Contractor share: $2.34M
- Funding received in FY14: $59k

Partners

- Interactions / collaborations
- Hyundai America Technical Center: Vehicle Integration and Testing
- National Renewable Energy Laboratory: Comfort Modeling and Test Support
- Project lead - HVCC

Project Objectives – Relevance

- The objective of the project is to identify a technical and business approach that will reduce the load on grid connected electric drive vehicles (GCEDV) while maintaining occupant comfort and thus increase the range of the vehicle. The program will demonstrate the technical feasibility and commercial value of an innovative thermal system for light-duty vehicles by evaluating the impact of:
  - Cabin pre-conditioning
  - Thermal storage
  - Innovative thermal comfort delivery methods
  - Efficient generation of heat/cool
- FY2014 Objectives
  - Vehicle selection
  - Establish test conditions, metrics, and performance criteria
  - Baseline test vehicle and validate computer models
  - Create CAE models for a heat pump subsystem, thermal storage subsystem, and airflow distribution subsystem
  - Begin trade-off analysis of potential heat pump, thermal storage, and airflow distribution subsystem configurations leading to determination of a final system architecture

Milestones

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Budget Period 1: Subsystem Design and Specification Development

Month/Year	Milestone	Type	Description
Sep-14	Baseline Vehicle Testing	Technical	Completion of baseline vehicle testing in a wind tunnel.
Sep-14	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
Sep-15	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-16	Vehicle Integration	Technical	All subsystems integrated into vehicle and ready for testing
Mar-16	Vehicle Demonstration	Technical	Demonstration vehicle testing complete

Technical Approach

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- Choose a "state of the art" vehicle for the baseline
- Define test conditions and performance criteria that reflect real-world usage
- Create and validate computer models that describe the subsystems involved
- Leverage the models to develop optimum subsystem parameters and component specifications
- Design and fabricate components that meet the new specifications
- Bench test the new components and subsystems to validate performance
- Use CAE models to quantify improvement offered by new hardware
- Integrate new subsystems into a vehicle
- Test vehicle to verify predicted improvements in performance

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Vehicle Selection

- The follow vehicles were considered
  - Nissan Leaf – PTC only
  - Nissan Leaf – PTC and heat pump
  - Kia Soul BEV – PTC only
  - Kia Soul BEV – PTC and heat pump
  - 2016 MY Hyundai PHEV (PTC only)
- The vehicles were graded based on eight criteria – availability, technical data access, currently has a heat pump, electric propulsion, has a PTC only option, cost of vehicle, model lifetime, and image
- Selected project vehicle based on highest criteria rating is Kia Soul BEV with PTC and Heat Pump

Photo courtesy of Hyundai America Technical Center Inc.

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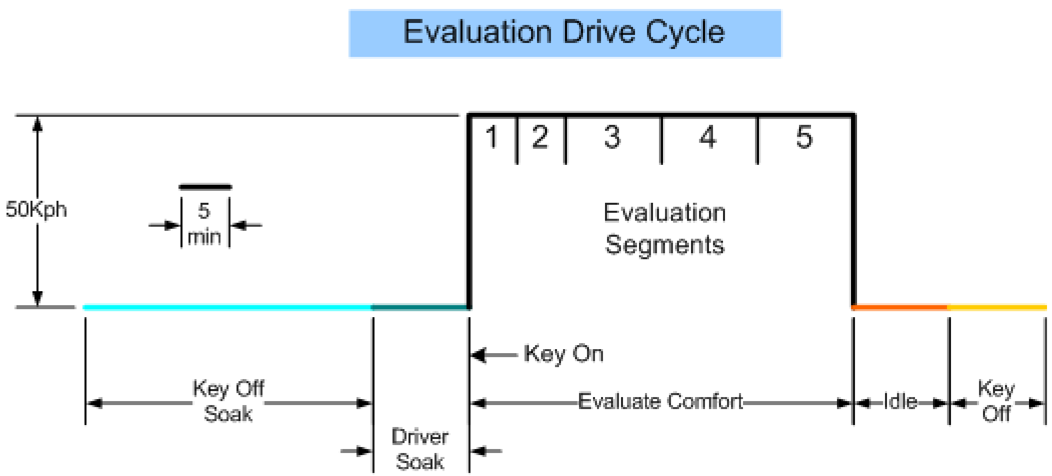
Test Conditions & Metrics Definition

- Test conditions and metrics based on real-world usage data
- Final test conditions represent a balance between minimizing amount of testing without sacrificing accuracy
- Chosen test conditions based on four primary factors
  - Regional populations, weather patterns, driving patterns, distribution of GCEDVs
- Analysis resulted in six unique environmental conditions

Test	Temp	Solar Load (W/m^2)	Humidity	Number of Occupants	Final Weight %
Cold 3	-18˚C (0˚F)	N/A	N/A	2	0.0
Cold 2	-5˚C (23˚F)	N/A	N/A	4	11.1
Cold 1	5˚C (41˚F)	N/A	N/A	1	42.6
Hot 1	28˚C (82˚F)	750	70%	1	43.6
Hot 2	32˚C (90˚F)	850	70%	2	2.6
Hot 3	43˚C (109˚F)	1000	40%	1	0.0

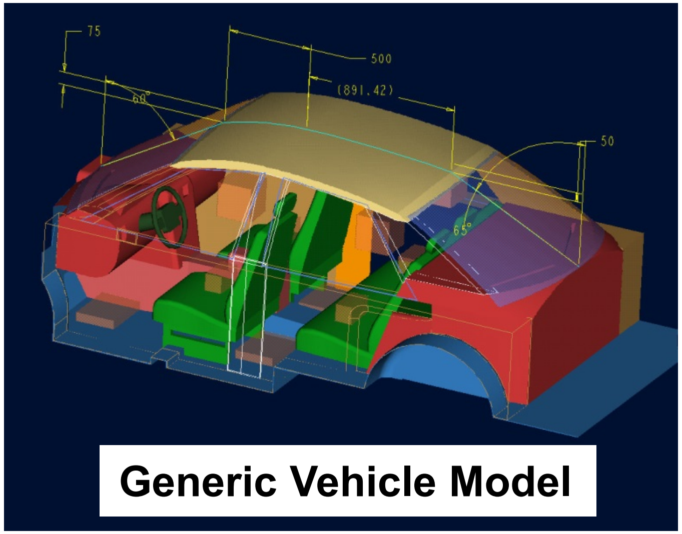
Test Conditions & Metrics Definition Continued

- A test procedure has been defined for each of the six tests
- A drive cycle was developed to reflect real world conditions
- During each test, comfort will be evaluated at the end of five segments
- The 30 (six tests x five segments) evaluations will be used to quantify the performance of the vehicle

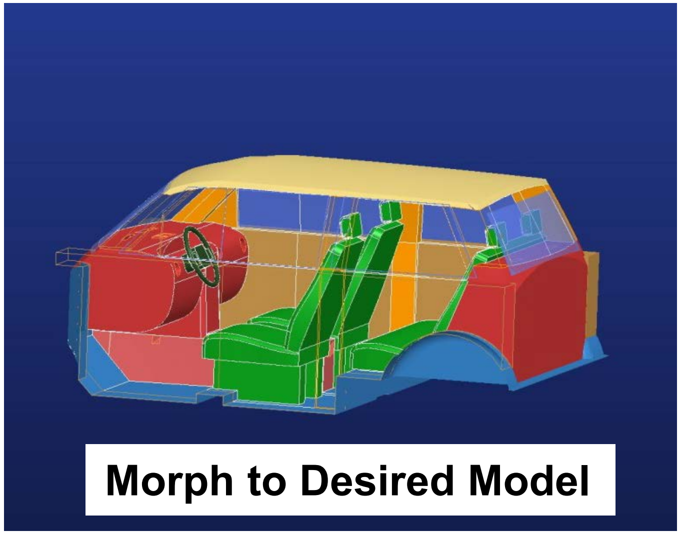


Stage	Duration	Speed	
Key off Soak	0-30 minutes	0 kph	
Driver Soak	10 Minutes	0 kph	
Segment 1	5 minutes	50 kph	Comfort Evaluation
Segment 2	5 minutes	50 kph	
Segment 3	10 minutes	50 kph	
Segment 4	10 minutes	50 kph	
Segment 5	10 minutes	50 kph	
Idle	10 minutes	0 kph	
Engine off	10 minutes	0 kph	

Evaluation of Transient Interior Environment Using CFD – Computational Fluid Dynamics



Generic Vehicle Model


Morph to Desired Model

- **Started building baseline vehicle CFD model using parametric geometry.**
- **Parametric geometry is utilized to decrease modeling time while maintaining acceptable accuracy.**
- **Began correlation of model simulations with A/C pull down and heater warm up test data.**

Collaboration and Coordination with Other Institutions

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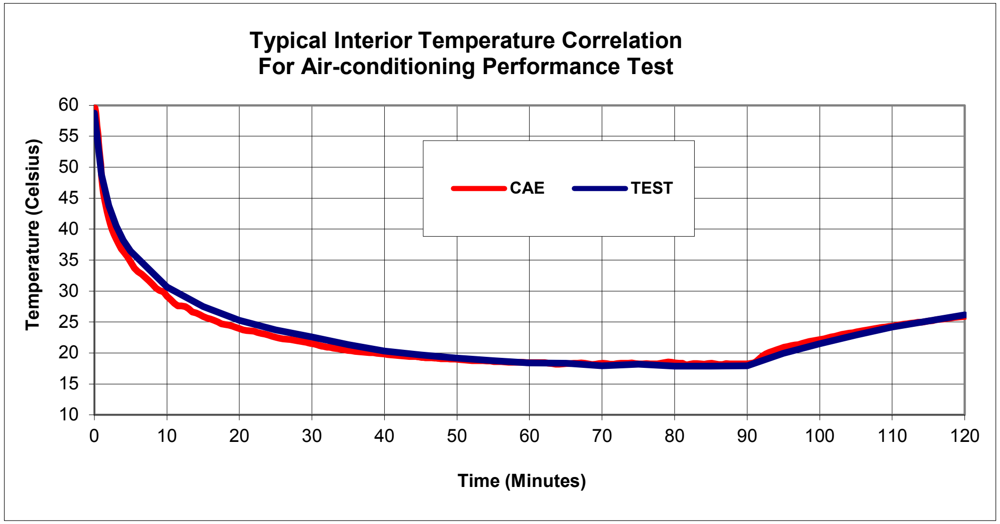
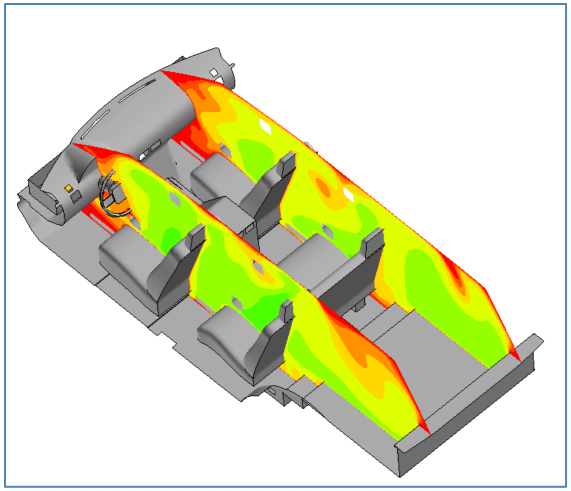
Collaborators	Relationship	Type	Role
Halla Visteon Climate Control USA LLC	Prime	Automotive Climate Control Supplier	- CAE & CFD Modeling - Component/System Design - Bench & Vehicle Testing - Comfort Evaluation - Commercialization Planning
Hyundai America Technical Center Inc.	Subcontractor	Automotive OEM	- Vehicle Selection & Modeling - Performance Criteria - Vehicle Integration - Vehicle Testing - Comfort Evaluation - Commercialization Planning
National Renewable Energy Laboratory	Subcontractor	National Laboratory (DOE EERE)	- CAE Comfort Modeling - Bench Testing Participation - Vehicle Testing Participation

Key Challenges

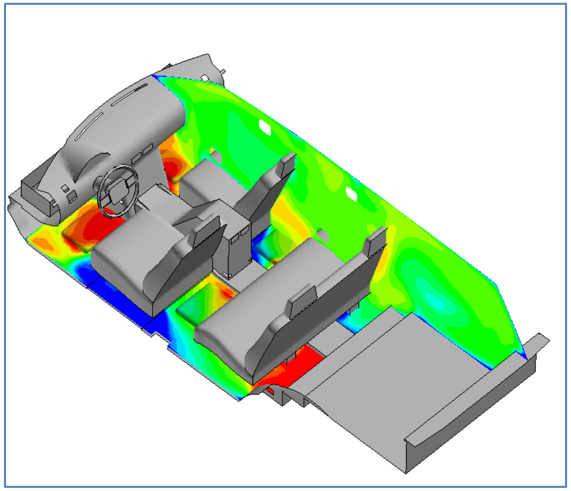
- Efficiency vs. cost challenges in the automotive world abound. In plug in electric vehicles efficiency is valued far more than in other vehicles because of the range effect.
- Modern vehicle infrastructure is very complex. The introduction of new technology is more challenging every year as we move forward. There is no ‘empty space’ to put things.
- Electric vehicle design is a compromise between range and customer expectations. Consumers want all the perks of a gasoline engine and the maximum range possible, all at minimal additional cost.
- The statement “The technology shall be ready for production within one year of project conclusion” in the FOA may constrain the level of technology that can be introduced into a vehicle.

2014FY Future Work – CFD Baseline Modeling





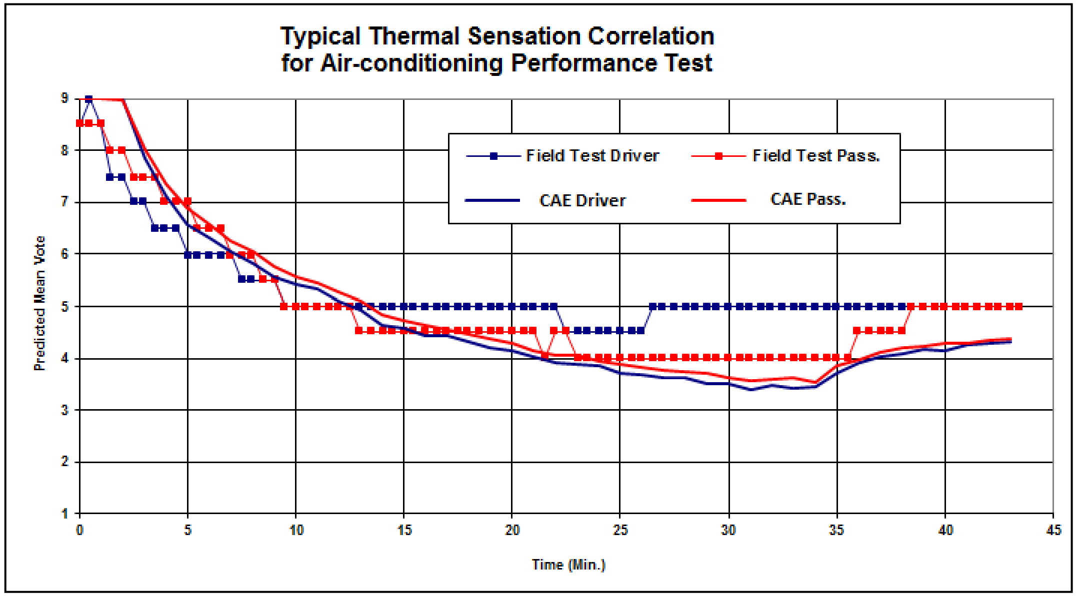
Sample Warm Ambient Simulation



Sample Cool Ambient Simulation

- **Continue correlation of model simulations for all hot and cold test cases.**
- **Incorporate zonal strategies within cabin model to evaluate their performance relative to the baseline vehicle.**

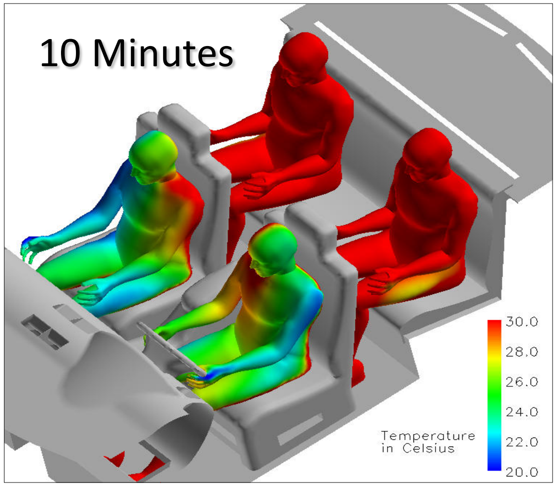
2014FY Future Work – Occupant Comfort Modeling

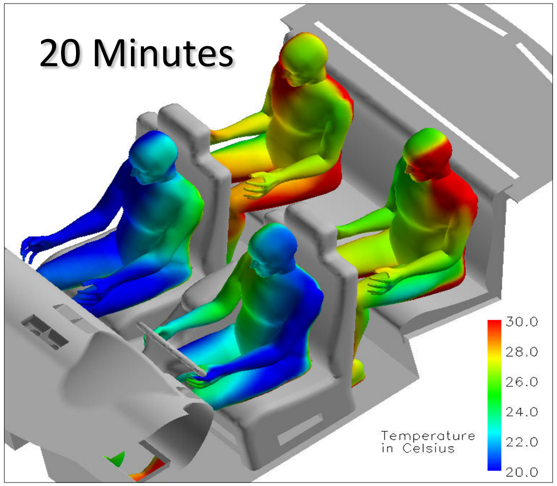


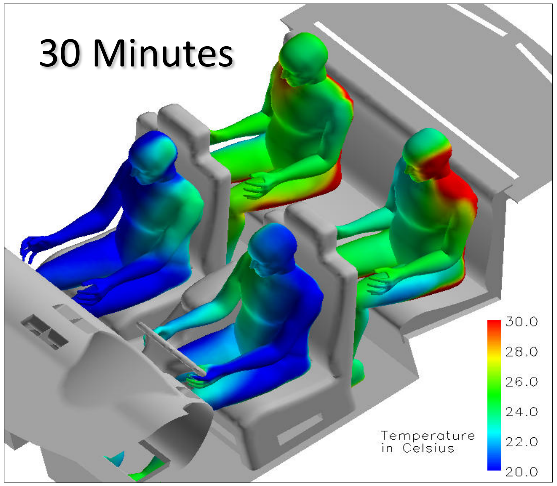
CFD solution data converted into transient occupant thermal comfort / sensation predictions.

Occupant thermal comfort / sensation predictions are a function of:

- Temperature
- Velocity
- Solar Load
- Surface Radiation
- Humidity







*Note: Data shown is example only

2014FY Future Work – Heat Pump Modeling

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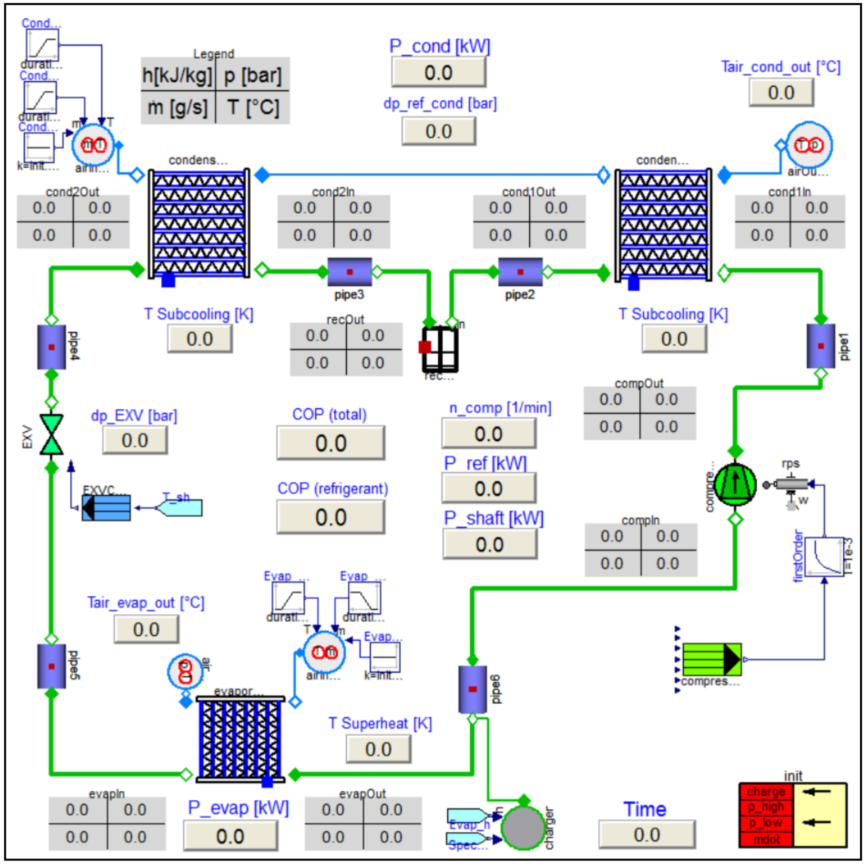


Sample Heat Pump Subsystem Model

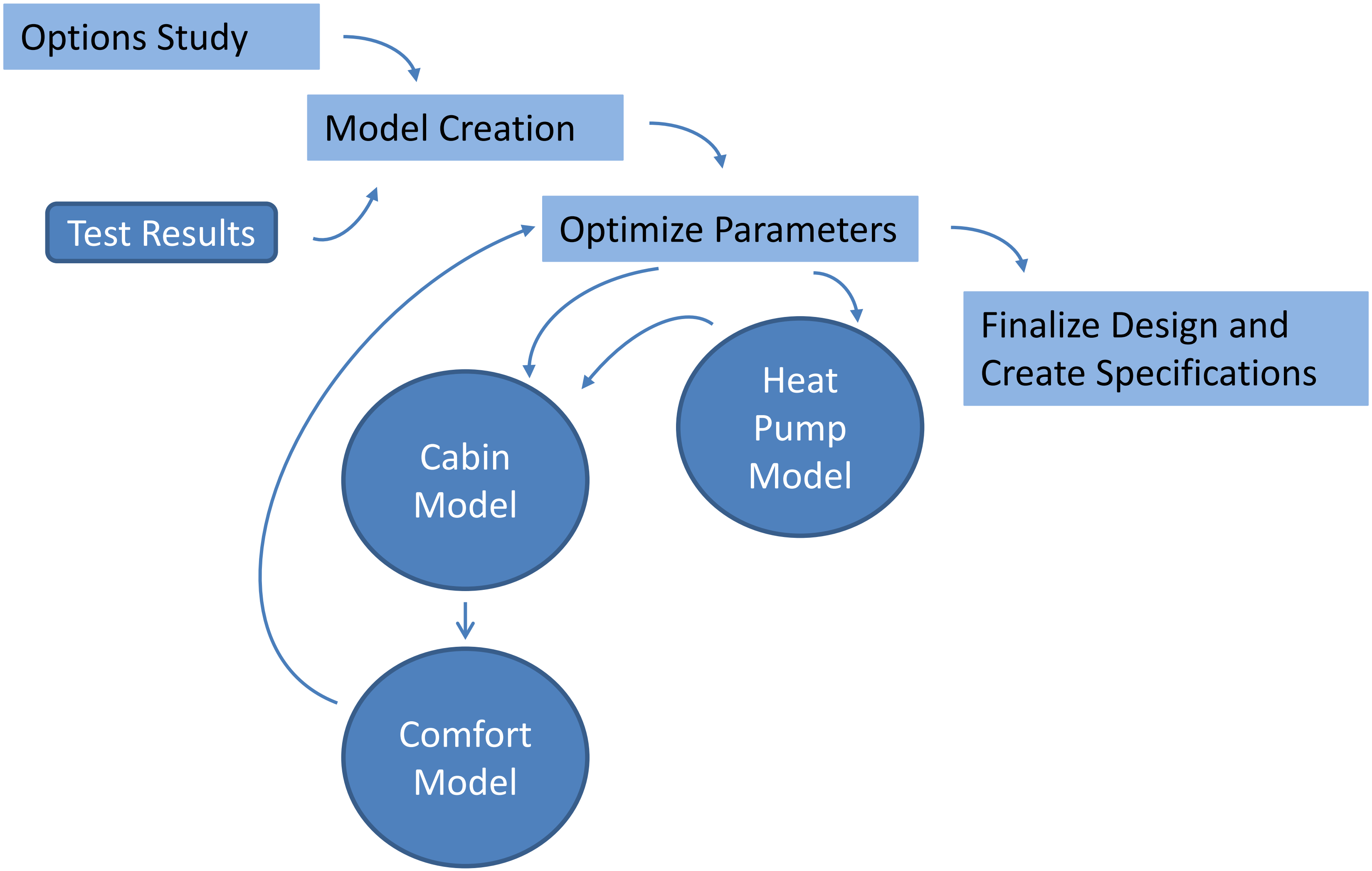
- Continue correlation of heat pump subsystem simulations for all hot and cold test cases.
- Utilize subsystem models to conduct trade-off studies of various subsystem configurations.
- Utilize subsystem models to calculate total power required and how this affects vehicle range.

2014FY Future Work – Subsystem Development

For each of the three subsystems, heat pump, zonal distribution and thermal storage:

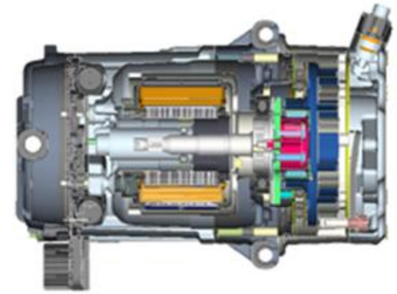
- Computer modeling of the subsystem
  - Baseline built from current and gathered data
  - Subsystem design iterations based on recommendations from design team trade off analysis
  - Provide data to NREL for comfort modeling to support subsystem definition
  - Integrate with other HVCC subsystems to define final system design
  - **Outcome**: Subsystem final computer design model
- Develop cost estimates for the subsystem
  - Create component bill of materials and initial cost assumptions
  - **Outcome**: Subsystem initial cost estimate
- Determine the architecture and physical locations of the subsystem
  - **Outcome**: Subsystem initial CAD modeling and packaging
- Develop basic controls for the subsystem
  - **Outcome:** Document detailing the basic controls required for the subsystem
- Determine the impact of the subsystem on the vehicle
  - Determine the impact of the subsystem on the vehicle infrastructure
  - **Outcome**: Understand and document the integration needed, and the costs incurred
- Create detailed specifications for the subsystem and components within
  - **Outcome**: Subsystem and subcomponent specifications

2014FY Future Work – Subsystem Development



2015FY Future Work – Design, Fabricate, Validate

Model Components as Required



Design Components

Fabricate Components

Validate Components

Build Subsystem

Validate Subsystem

Compare performance to models

Summary

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- This project is appropriate for the times; range extension of EV's is a key to their mass market adoption.
- The technical approach is sound and can be contained within the constraints of the project. Improvements to the latest vehicle technologies, although challenging, will provide the most value to the consumer.
- The technical accomplishments thus far are progressing considering how recently development was started.
- The future work planned is methodical and uses the latest development strategy and tools. We look forward to 'pushing the envelop' in the areas we have selected.
- We have chosen the right mix of collaborators. Each organization has the expertise to contribute significantly to the overall development.