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THERMAL MANAGEMENT SYSTEMS

UTEMPRA – Unitary Thermal Energy Management for Propulsion Range Augmentation

Main Author - Dr. Sourav Chowdhury, Mahle Behr Troy Inc., Principal Investigator

Co-Authors - Lindsey Leitzel, Mark Santacesaria, Mark Zima, Timothy Craig, Paul Droman, Mahle Behr Troy Inc;
Jason Lustbader, Eugene Titov, John Rugh, National Renewable Energy Laboratory;
Aamir Khawaja, Murali Govindarajalu, FCA US LLC.

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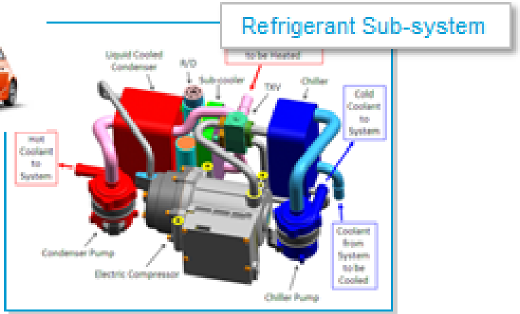
NREL/PR-5400-72680

Project Overview



Benefits

- Enables distributed or modular cooling
- Integrated for heat recovery and range improvement in cold weather
- COP 1.5 to 3.5 over heating ambient range (-15°C to 20°C)
- Lower system cost with Heat Pump function
- Idle NVH improvement - coolant thermal inertia enables compressor off at stop
- Less refrigerant; gives a pre-charged option
- Simple refrigerant controls
- Integrates with vehicle coolant system
- One front end heat exchanger improves compliance with passenger crash

Main Features

- Refrigerant sub-system is compact
- Five heat exchangers and MAHLE electric compressor
- Heat pump and heat scavenging features
- Coolant valving is compact: minimizes cost & mass
- Architecture easily adaptable for system configuration, additional components

Applicability

- Any EV and HEV's which experience range degradation at cold ambient temperatures due to direct electric heating

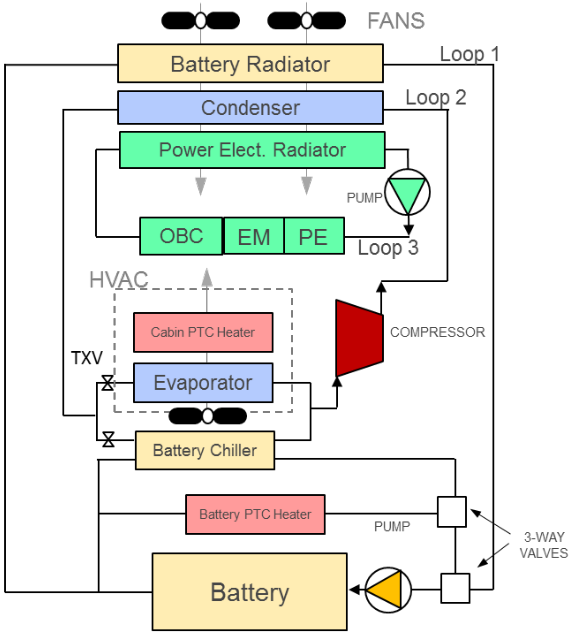
Critical Feature

- Low-cost and high performance valve system design

Baseline BEV – Fiat 500e (2015 MY)

2015MY Fiat 500e BEV

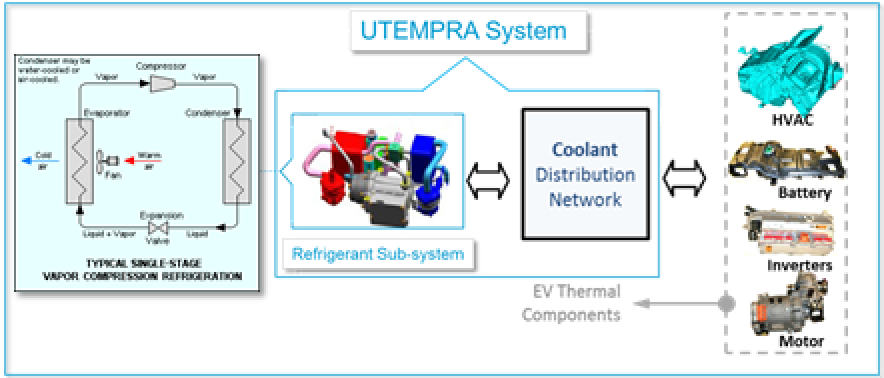
- Cooling: Traditional Direct A/C System
  Heating: PTC Heater (qty. 2)
- Thermal Conditioning of Battery, Power Electronics and Cabin are independent
- Two PTC (Resistive) Heaters for the Cabin and Battery - significant drain on the battery
- Relatively simple control but no heat recovery/thermal optimization applied

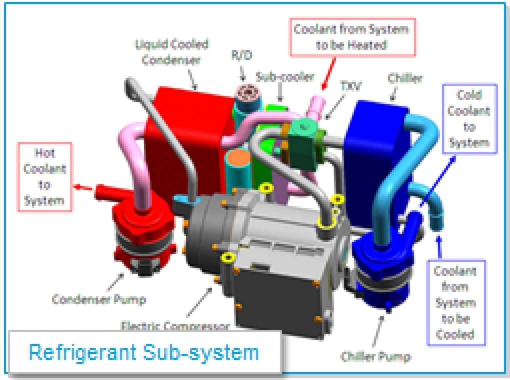


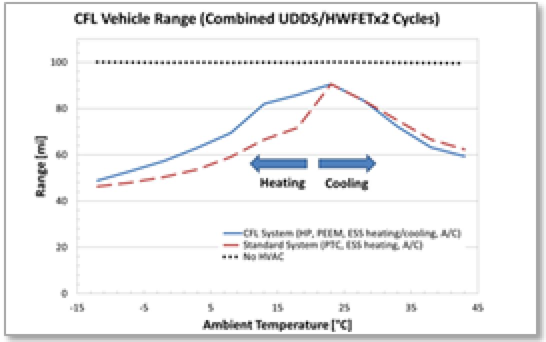
2015 Fiat 500e Thermal Management System

OBC – On-board Charger
EM – Electric Motor (Vehicle Propulsion)
PE – Power Electronics (Inverter)

Technical Approach – UTEMPRA





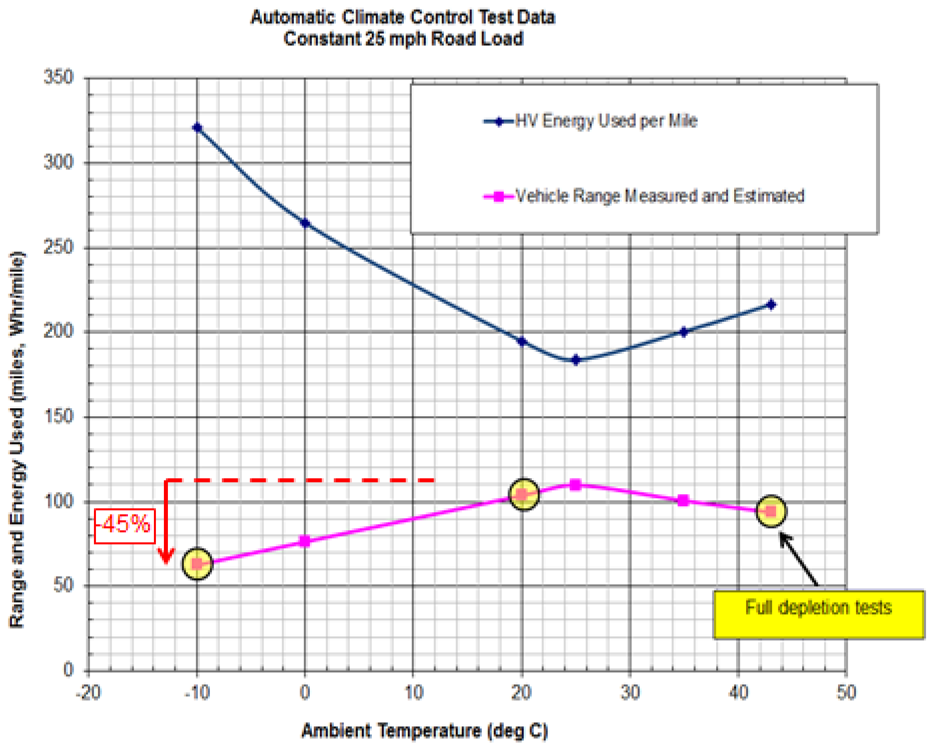


D. Leighton et al. SAE 2014

<u>NREL Bench Test + Simulation Study</u>

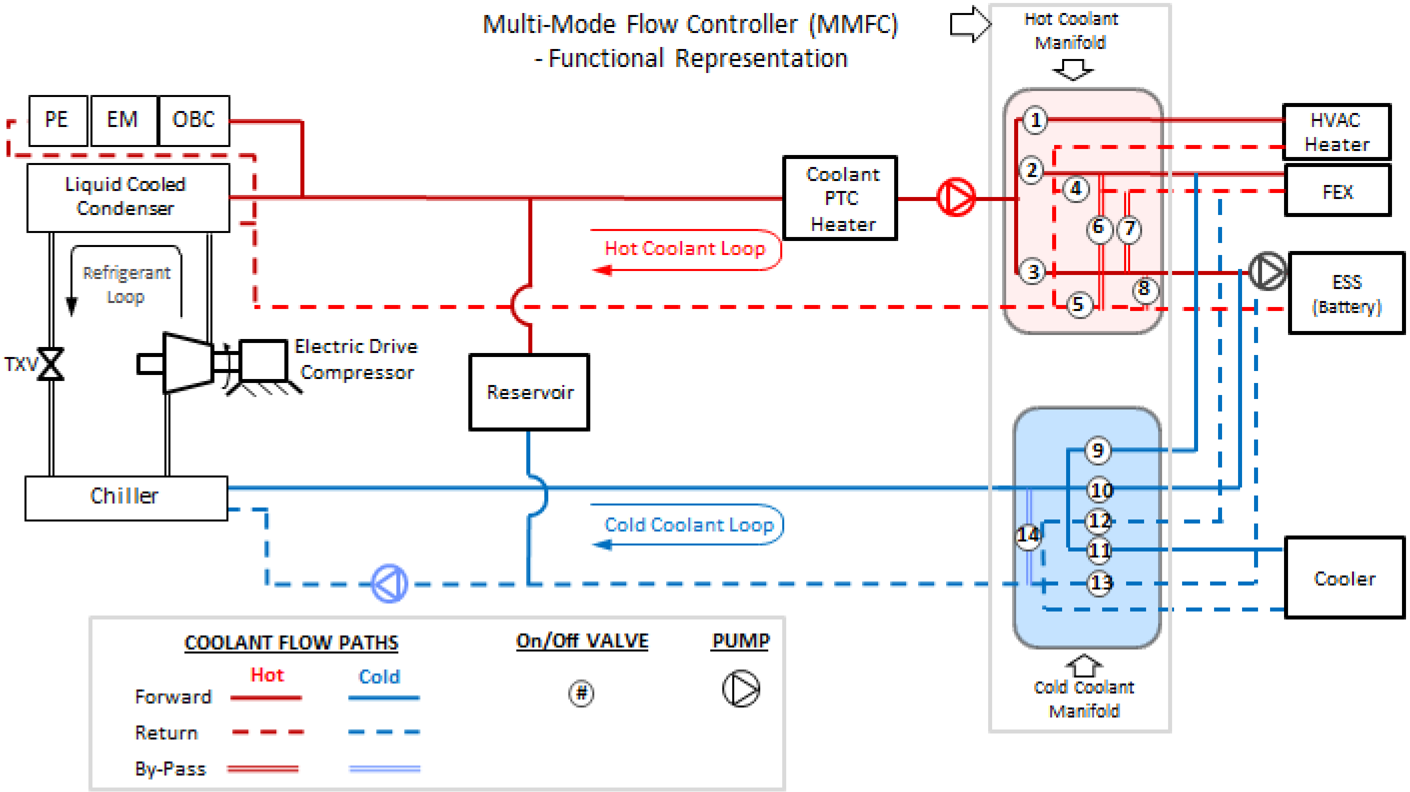
- 9% range improvement on annual basis
- ~12% improvement at -10ºC (components and system not optimized)
- UTEMPRA is targeting to demonstrate 15% at -10ºC for a test cycle similar to SAE J1643 (2012) MCT Cycle

Baseline Range Results

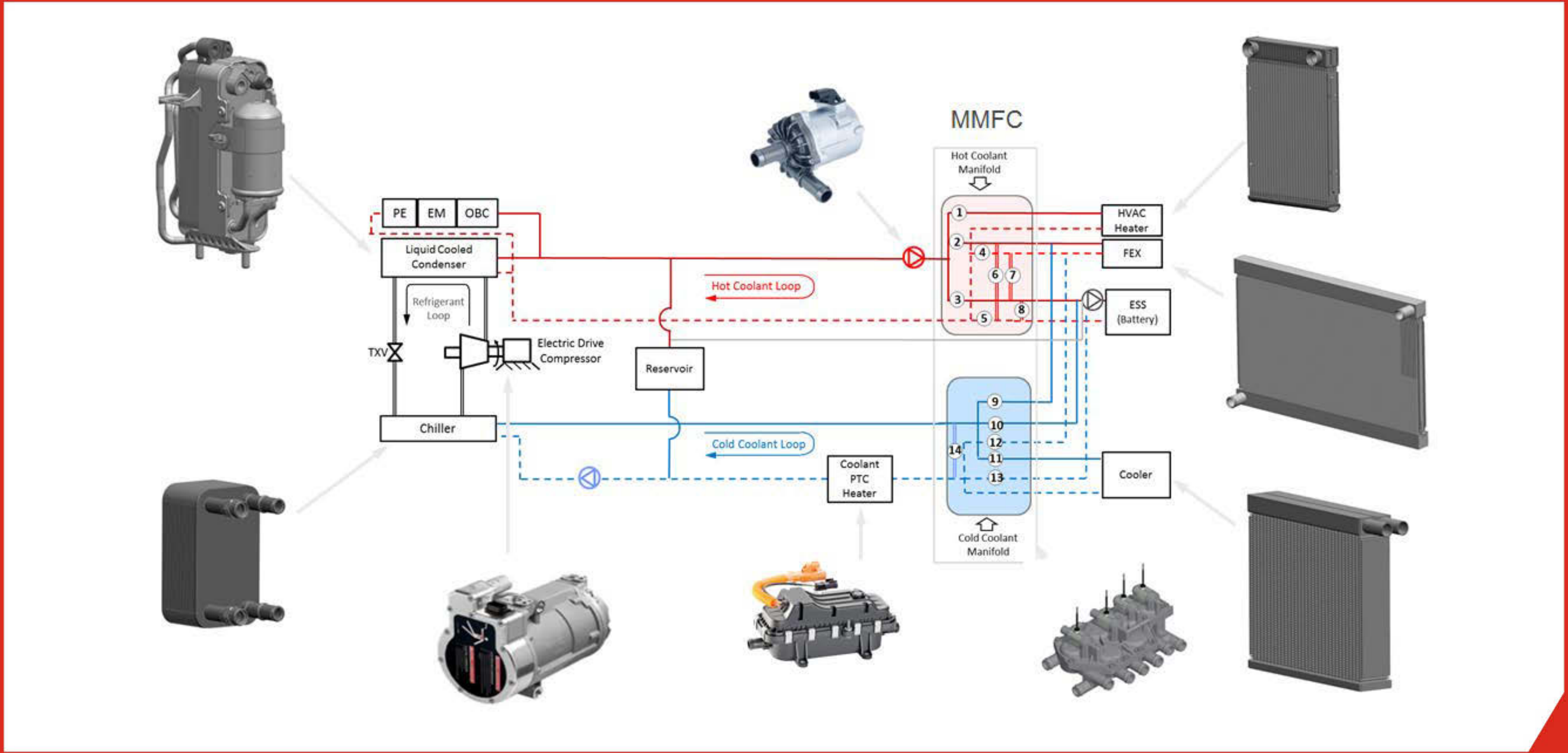


The ACC25 test data was used to estimate the impact of ambient temperature on the vehicle range. These tests were run at a constant 25 mph condition. Three of the tests were run to near full depletion. The range for the other tests are estimated using the Whr/mile energy usage.

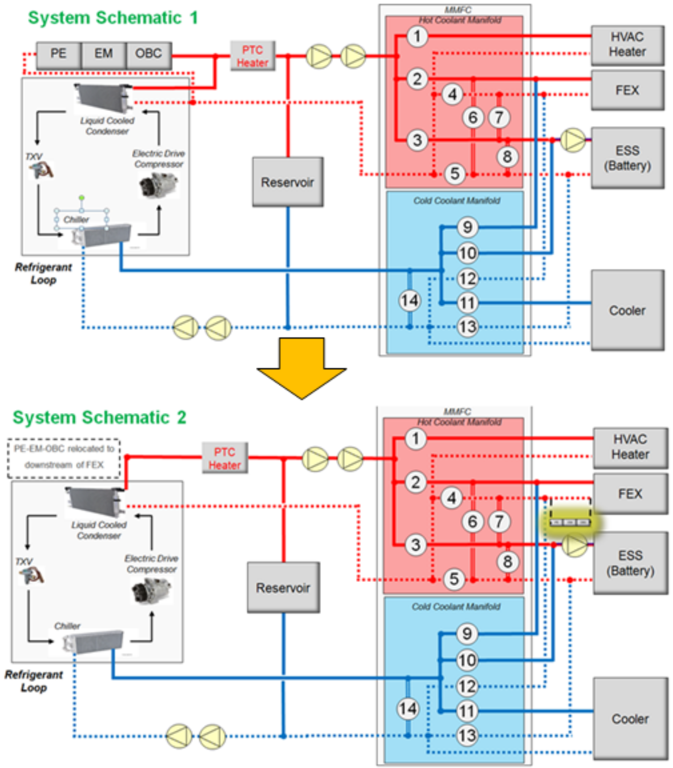
UTEMPRA System – System Schematic 1



UTEMPRA Components



UTEMPRA System Schematic Update



- Relocation of PE-EM-OBC to downstream of FEX significantly improves the performance of the system by eliminating the parasitic effects.

UTEMPRA System Modes

- Cabin Conditioning:
  - Heating: using Heat Pump (HP) with FEX and/or PTC, PEEM heat scavenging
  - Cooling: using A/C with Chiller & Cooler (ultimately FEX rejects heat)
  - Heat-Cool (Dehumidifying/Defogging): using HP/PTC/PEEM + Cooler
  - OFF
- Battery Conditioning:
  - Heating: using HP/PTC/PEEM
  - Passive Cooling: using FEX
  - Active Cooling: using Chiller
  - Temperature equalization: using just battery pump
  - OFF
- PE-EM-OBC Conditioning:
  - Cooling: Hot Loop pump always ON when vehicle is ON/Charging
- FEX De-icing Mode
  - FEX is heated with hot coolant loop. HP is active – PTC heater and Battery is used as temporary heat source for HP
- Fail-Safe Mode (in case MMFC loses power)
  - Valve's normal (unpowered) position allows flow through PE-EM-OBC to FEX and Battery. Battery pump decides if battery gets flow

Baseline BEV has 20 modes of operation

UTEMPRA will have 22 modes including heat pumping, heat scavenging and a fail-safe mode

UTEMPRA System Modes – contd.

Mode Selection Table		Mode Selection		
Mode	**Mode description**	***Battery***	***Cabin***	***PEEM***
1	Fail Safe	Passive Cooling	System Off	Cooling
2	PEEM cooling	System Off	System Off	* Cooling
3	ESS equalization [plus PEEM cooling]	Equalization	System Off	* Cooling
4	ESS equalization and cabin cooling	Equalization	Active Cooling	Cooling
5	ESS equalization and cabin heating	Equalization	Active Heating	Cooling
6	ESS equalization and cabin heating and cabin cooling	Equalization	Dehumidify OR Defrost	Cooling
7	ESS passive cooling	Passive Cooling	System Off	* Cooling
8	ESS passive cooling and cabin cooling	Passive Cooling	Active Cooling	Cooling
9	ESS passive cooling and cabin heating	Passive Cooling	Active Heating	Cooling
10	ESS passive cooling and cabin heating and cabin cooling	Passive Cooling	Dehumidify OR Defrost	Cooling
11	ESS active cooling	Active Cooling	System Off	Cooling
12	ESS active cooling and cabin cooling	Active Cooling	Active Cooling	Cooling
13	ESS active cooling and cabin heating	Active Cooling	Active Heating	Cooling
14	ESS active cooling and cabin heating and cabin cooling	Active Cooling	Dehumidify OR Defrost	Cooling
15	ESS active heating	Active Heating	System Off	Cooling
16	ESS active heating and cabin cooling	Active Heating	Active Cooling	Cooling
17	ESS active heating and cabin heating	Active Heating	Active Heating	Cooling
18	ESS active heating and cabin heating and cabin cooling	Active Heating	Dehumidify OR Defrost	Cooling
19	ESS NTM and cabin cooling	System Off	Active Cooling	Cooling
20	ESS NTM and cabin heating	System Off	Active Heating	Cooling
21	ESS NTM and cabin heating and cabin cooling	System Off	Dehumidify OR Defrost	Cooling
22	De-ice	Active Cooling	Active Heating	Cooling

NREL Bench Testing with MAHLE Components

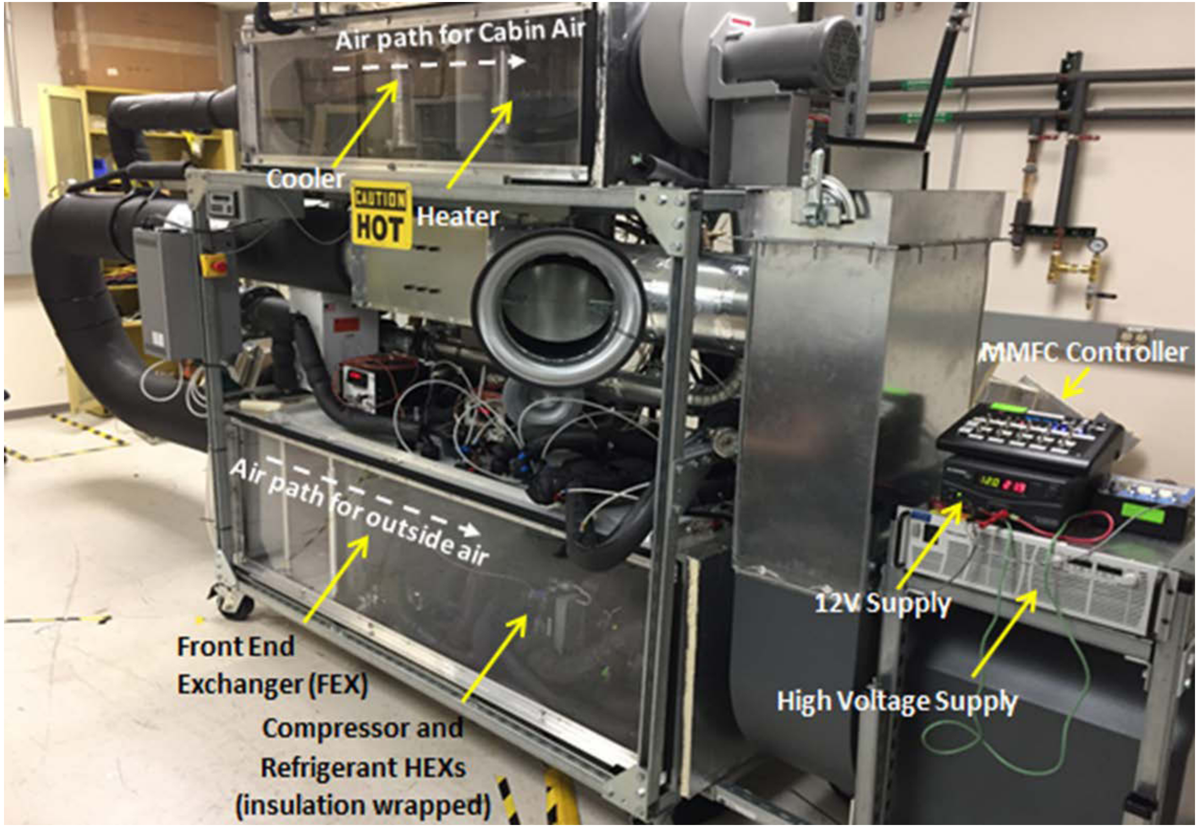
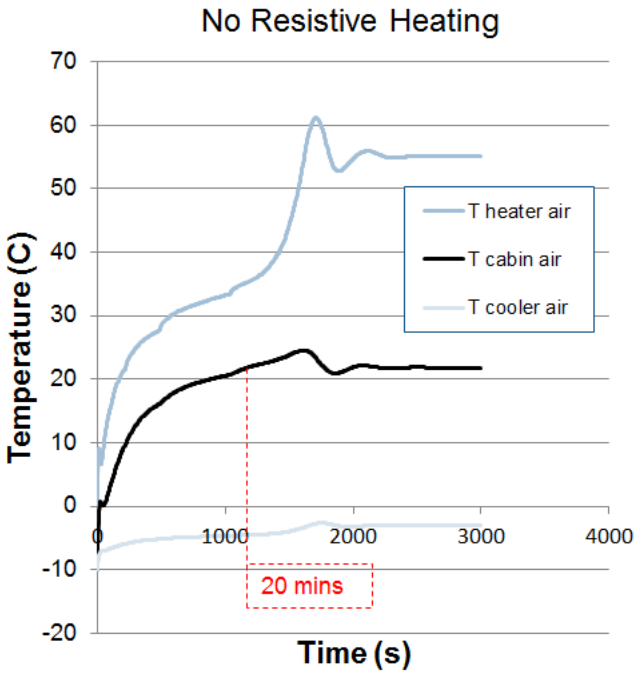
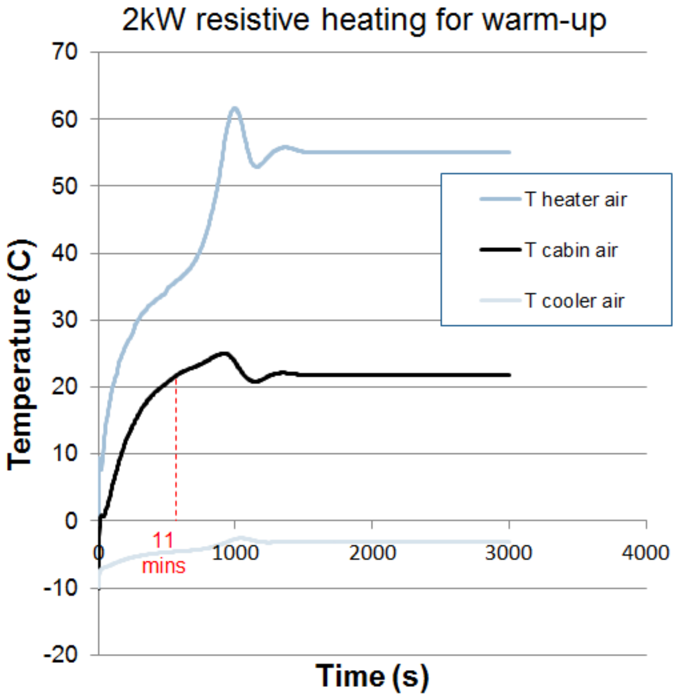


Photo by Daniel Leighton, NREL

Projected Data - Ambient -10°C

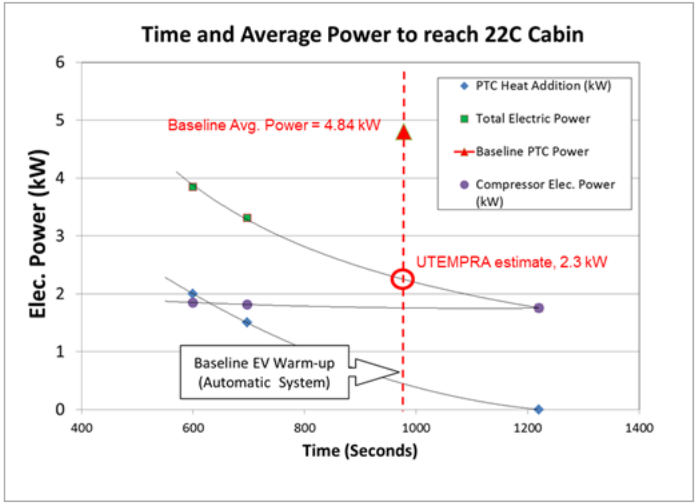
Mode 17 ESS and Cabin Heating (NREL Model)



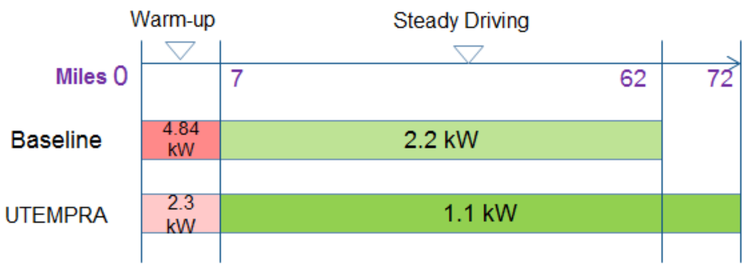


Projected Range Impact at Ambient -10ºC

Mode 20 ESS-NTM and Cabin Heating, 40 km/h (NREL Model)

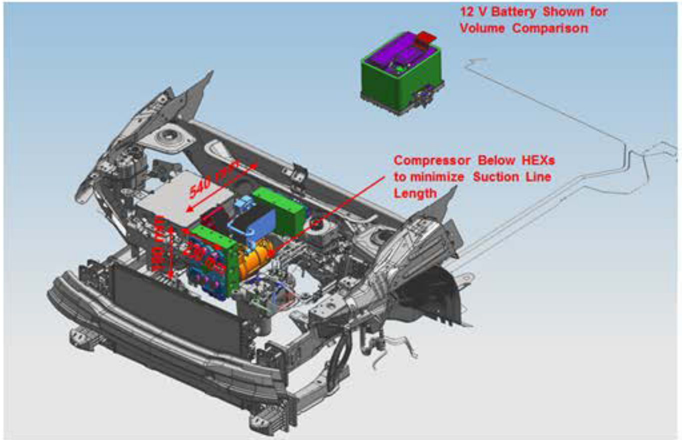


Climate Control Electric Power at -10ºC



- ❑ Estimated Electric Power Savings:
  - ▪ Cabin Warm-up Period, 16 mins @ 2.5 kW is 2.5x16/60 = 0.67 kWh
  - ▪ Steady State Period, 133 mins @1.1 kW is 1.1 x 133/60 = 2.44 kWh
- ❑ Baseline vehicle has 3.08 miles/kWh; this produces extra 9.6 mile
- ❑ Baseline vehicle range at -10ºC is 62 miles; therefore, range increase is 15.5%

UTEMPRA Vehicle Packaging

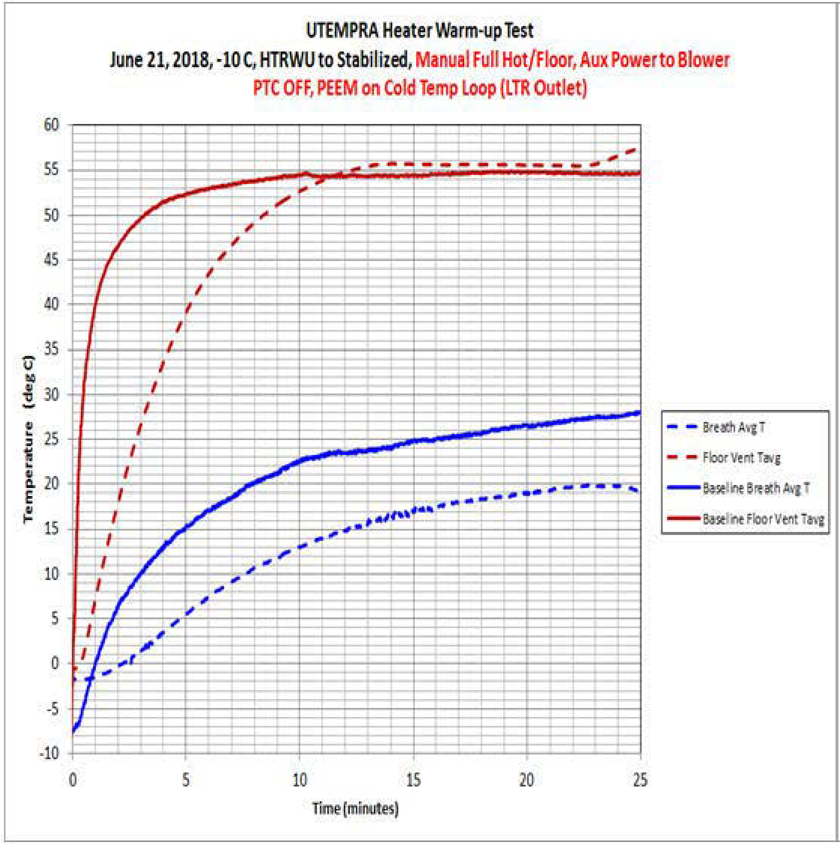


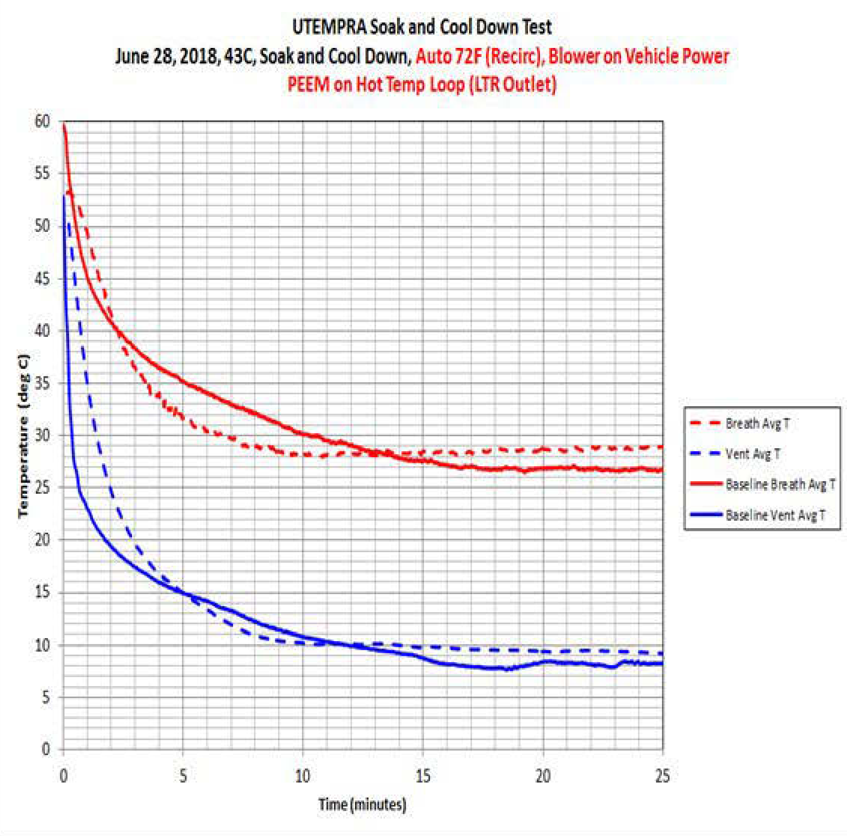
- Highly complex packaging due to retro-fitting a sub-compact underhood space & instrumentation requirements

Photos by MAHLE

Preliminary Test Data of Baseline Fiat 500e vs. UTEMPRA

Warm up and Cool Down with Manual Control





Conclusions and Next Steps

- UTEMPRA system is demonstrated on bench and in simulation to meet target range benefit
- UTEMPRA vehicle is built and currently being testing with initial testing results showing target is achievable
- A semi-automatic controller with logic is being implemented for
  - energy optimization strategy (using NREL Model)
  - Mode selection based on external (ambient) and internal (i.e. vehicle components) inputs
- Final testing and energy assessment will be performed in Nov. 2018 – Feb. 2019
  - A baseline vehicle (production) & UTEMPRA vehicle will be tested at FCA and compared for range gain and performance capabilities.