Secondary Loop Mobile Air Conditioning Systems (SL-MACs)

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Institute for Governance & Sustainable Development (IGSD)

CCAC Sustainable Technologies for Air Conditioning Workshop, November 18, 2017, Montreal, Canada

TATA MOTORS

MAHLE

Driven by performance

IGSD

Implications of Kigali Amendment to MACs

HFC-134a will be abandoned in all markets worldwide

Global automakers prefer the most affordable technical option delivering the highest energy efficiency and lowest carbon footprint

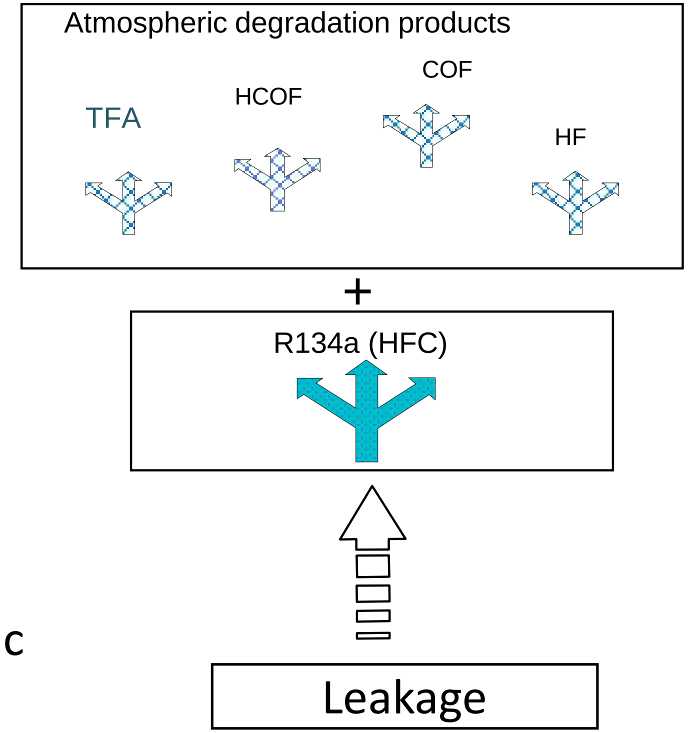
Vehicle owners prefer lower first cost, lower service cost, and fuel-saving advantages of deceleration cooling, prolonged idle stop, and powered cooling at high engine efficiency

Thus, both global automakers and vehicle owners will favor SL-MACs

Atmospheric Impact of Mobile Air Conditioning

<u>Direct Greenhouse Gas (GHG) emissions</u>

Leakage of high Global Warming Potential (GWP) refrigerant to the atmosphere (through AC Hoses / Joints / Servicing / Accidents / End-of-Life)



<u>Indirect GHG emissions</u>

CO_2 from exhaust

(About 4% to 20% of fuel use is for air conditioning; depending on climate and traffic congestion)

<u>Atmospheric Degradation Products</u>

COF, HCOF, HF, TFA

Technical Options to Replace HFC-134a in MACs

- Three refrigerant replacements approved by the US EPA SNAP also satisfy the EU F-Gas Directive (GWP*<150)

SNAP / F-Gas Option	GWP	Efficiency	TFA	Flammable	Application Patent
HFO-1234yf	< 1	Good	Yes	Slightly	Yes
Carbon Dioxide - CO_2	= 1	Poor @ High Ambient	No	No	No/Expired
HFC-152a	= 138	Better	No	Mildly	No

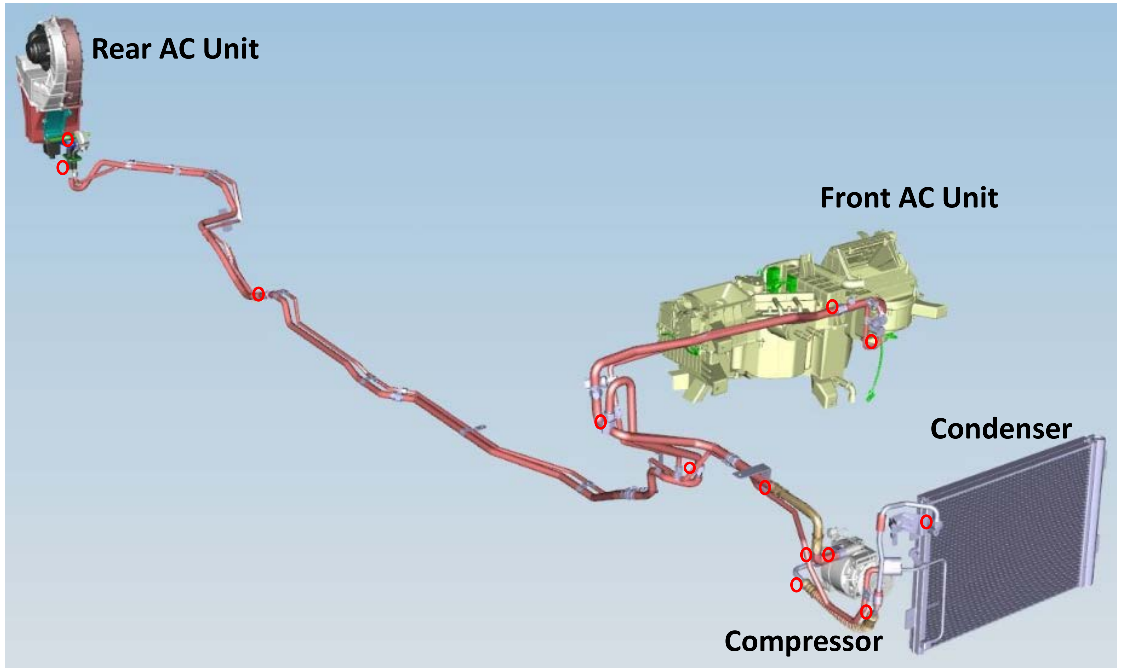
- Automobile companies know how to safely use flammable fluids (fuel, hydraulic fluid, motor oil, brake fluid, antifreeze, and windshield cleaning fluid are all flammable)

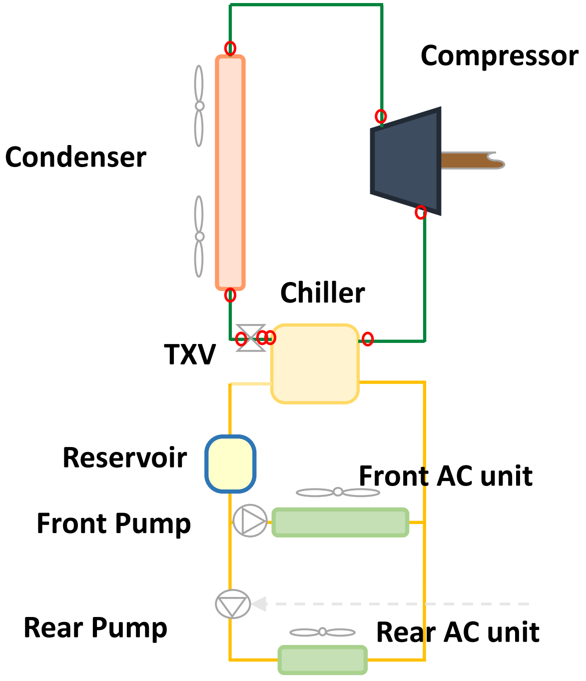
Lower Refrigerant Charge & Fewer Joints ⇒ Reduced Direct Emissions

System Type	Refrigerant Charge (grams)	% Reduction
Baseline DX System (R134a; GWP: 1300)	1000	-
Proposed SL-MAC System (R1234yf; GWP: <1)	610	39.0%
Proposed SL-MAC System (R152a; GWP: 138)	494	50.6%

Joints in primary loop (potential for leak)

- Baseline DX System (R134a): 25 Joints
- Proposed SL-MAC System (R1234yf/R152a): 8 Joints





Results: System Bench Test of Cooling Capacity and Power Consumption

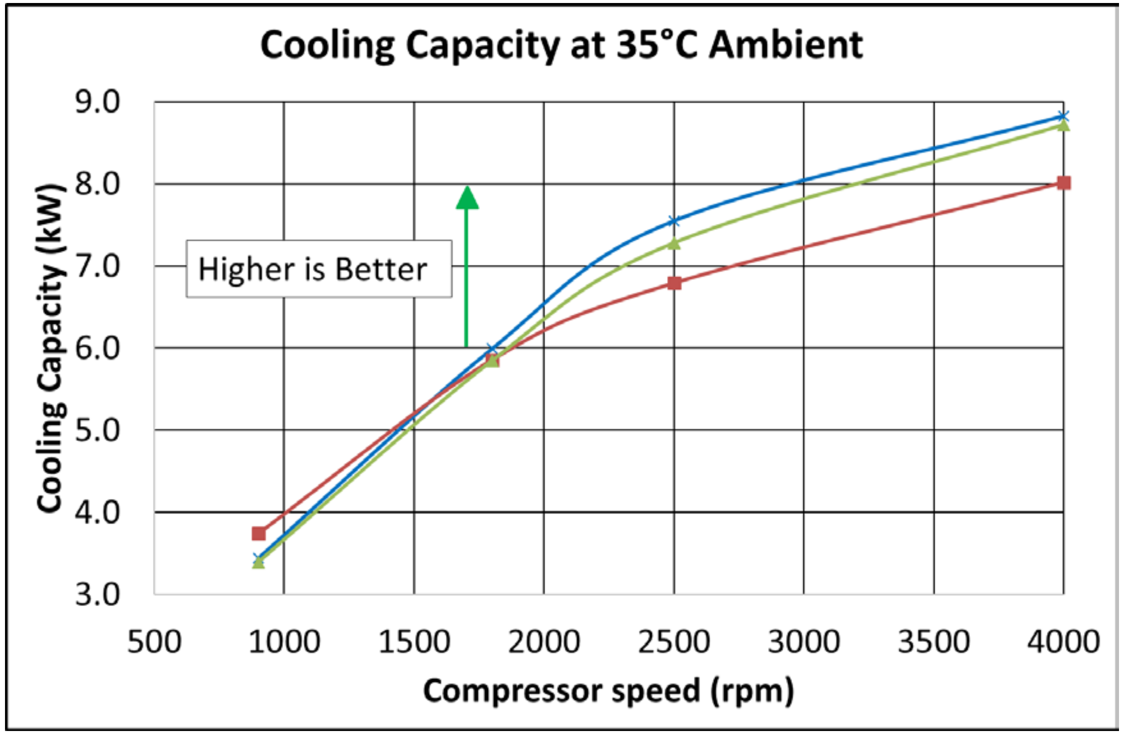
- **Cooling Capacity: ''Higher'' is Better**

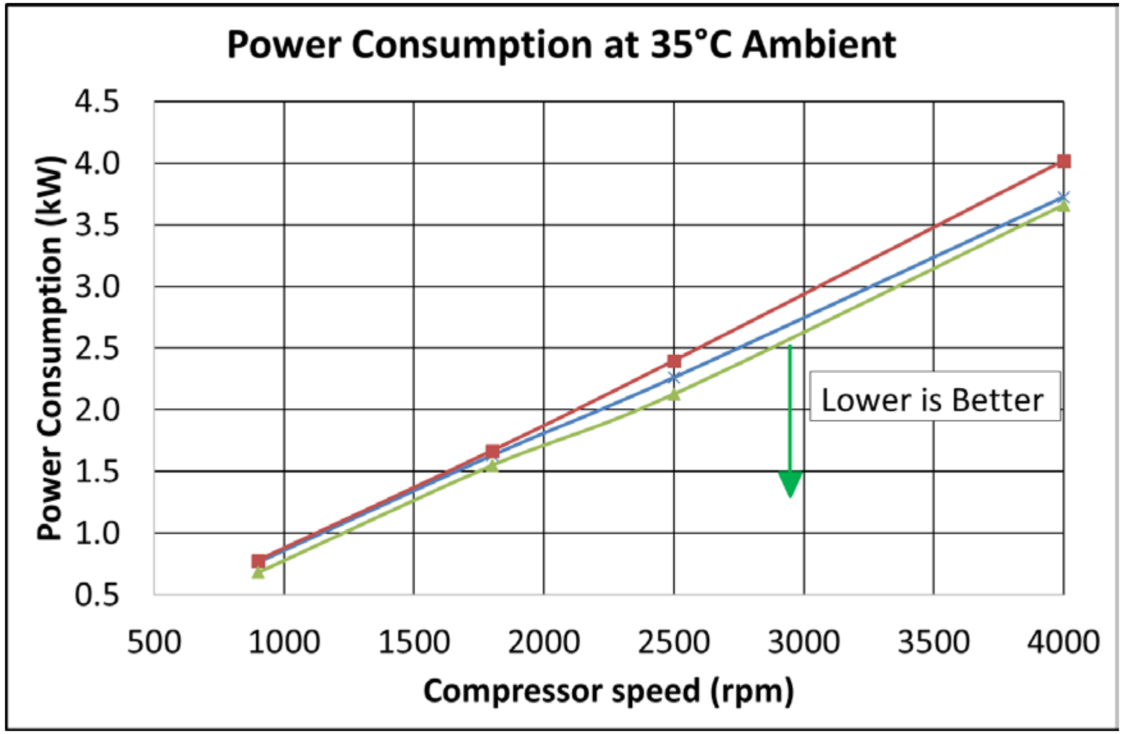
  Baseline DX R134a > Proposed SL-MAC R152a >> Proposed SL-MAC R1234yf

- **Power Consumption: ''Lower'' is Better**

  Proposed SL-MAC R1234yf >> Baseline DX R134a > Proposed SL-MAC R152a

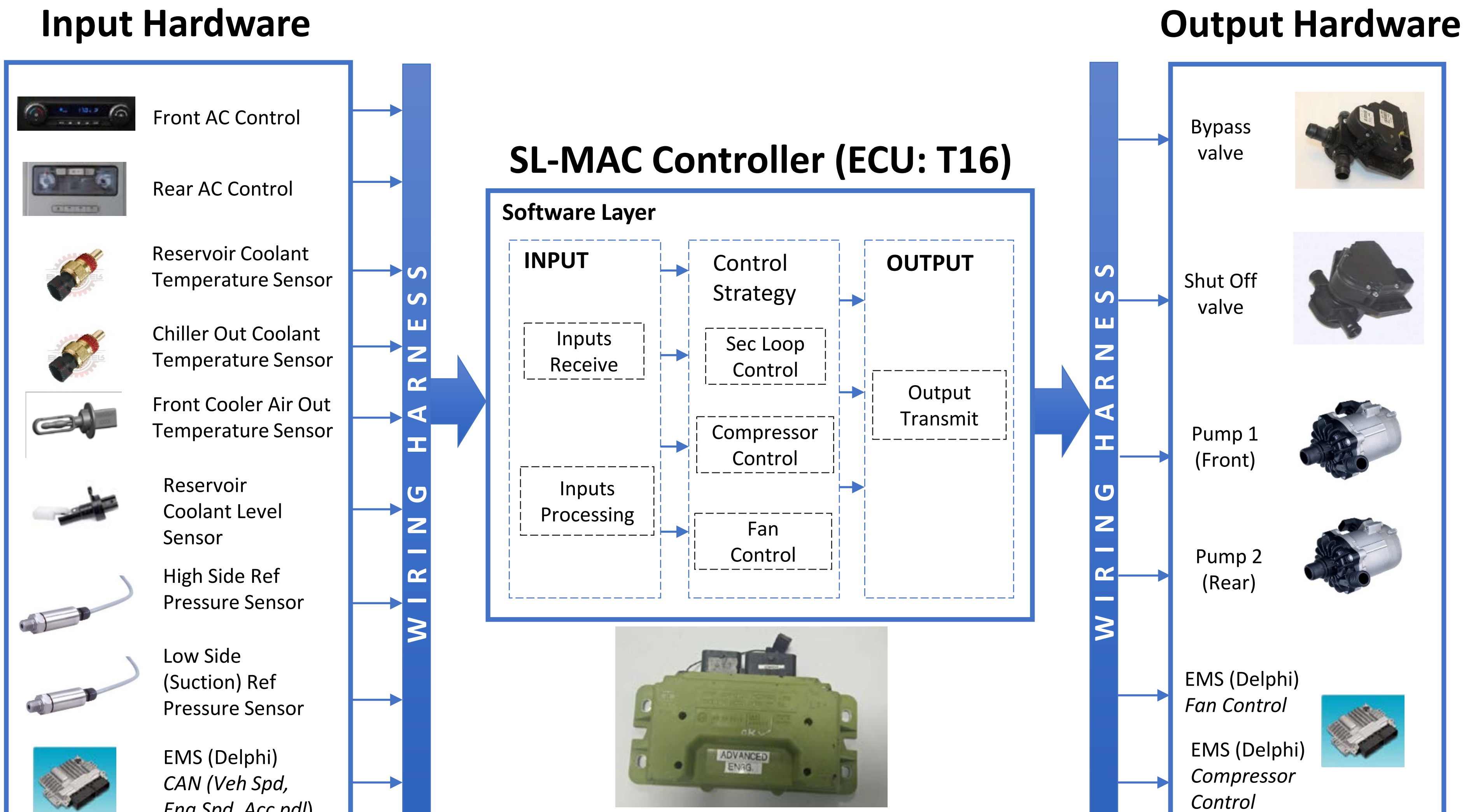
  (This data does not include pumps power consumption for SL-MAC system)





Baseline DX system (R134a) Proposed SL-MAC system (R1234yf) Proposed SL-MAC system (R152a)

Optimising Energy Efficiency: SL-MAC Control System Architecture



Electronic Control Unit (ECU): T16

Logic Summary:

AC cut-off: Compressor OFF

If the reservoir is sufficiently cold

1. Vehicle idle (traffic/signals)
2. Sudden acceleration

AC cut in: Compressor ON

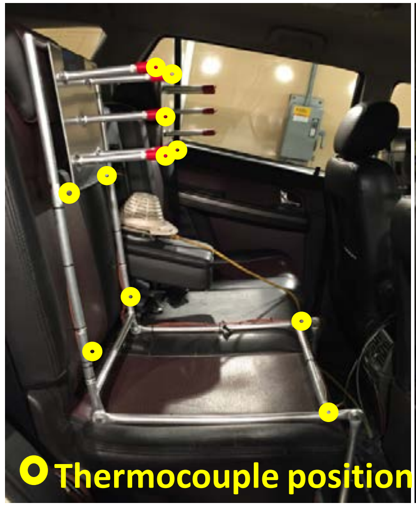
Regenerative cooling

1. Downhill
2. Deceleration

Bypass valve & Pump:

1. For quick cooling during high hot soak condition→ bypass the reservoir and cool the coolant in pipeline

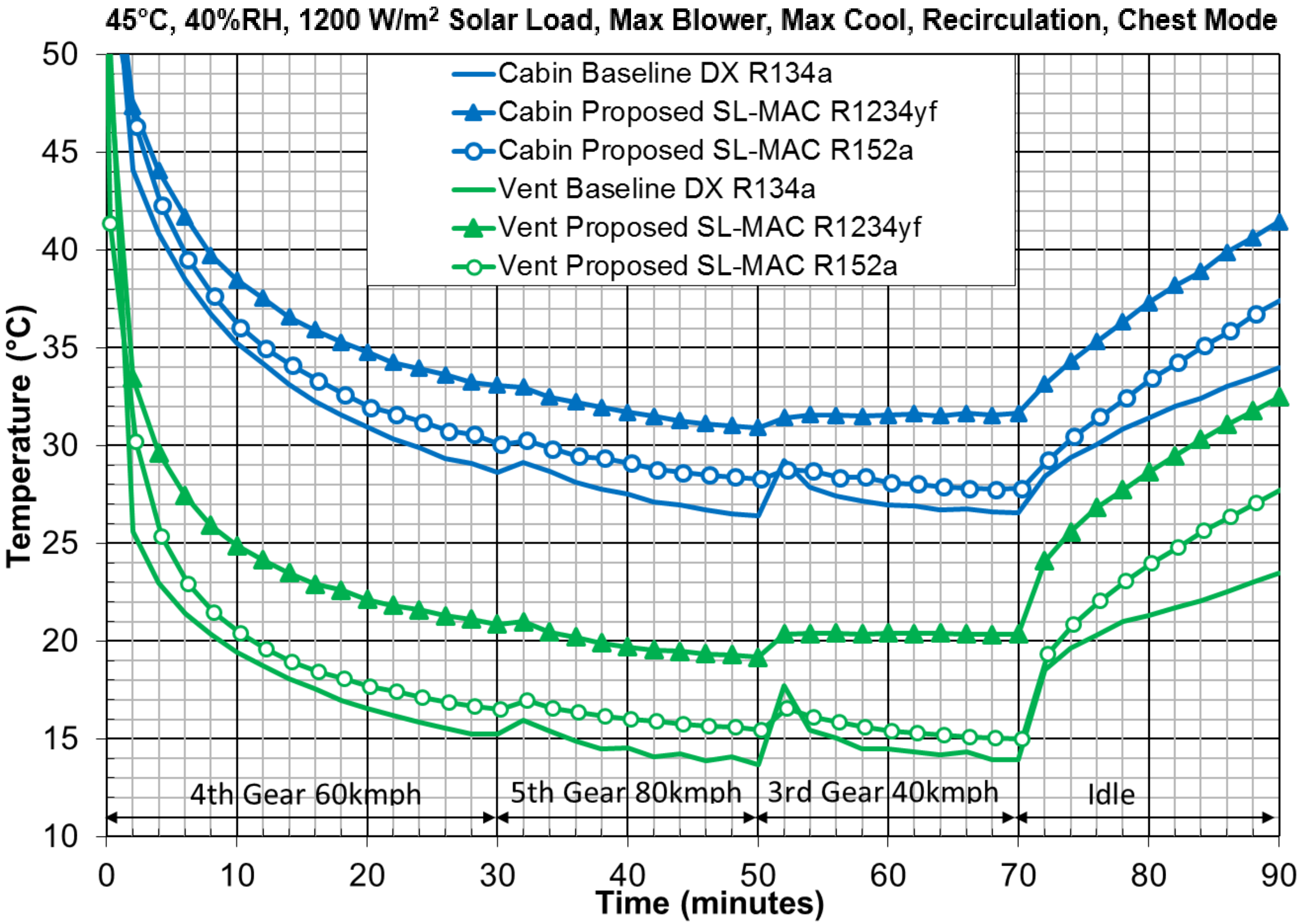
Instrumented Demonstrator Vehicle Inside Wind Tunnel Facility

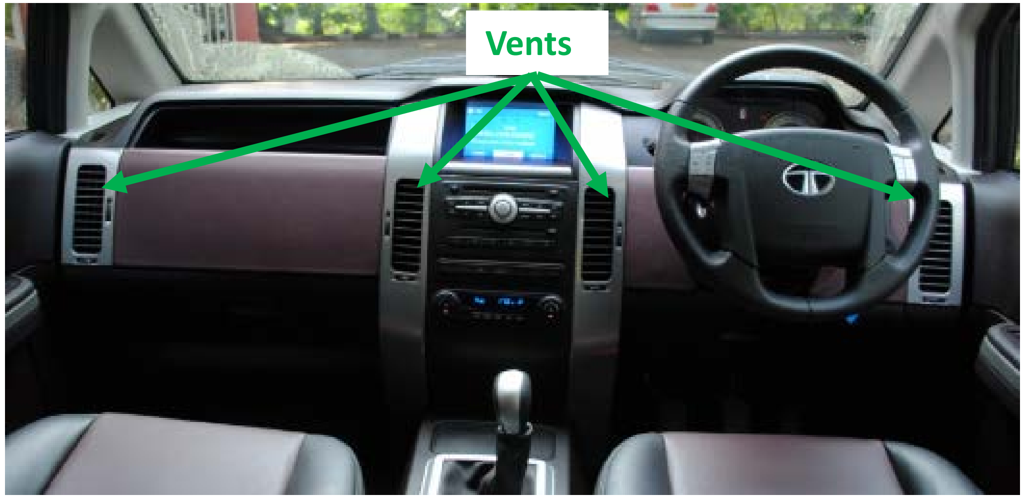


Vehicle Trials Under Simulated Ambient Conditions

Transient hot soak and severe ambient cool down test

- Proposed SL-MAC System (R152a) within 1.5°C of Baseline DX system (R134a), except at idle conditions
- Proposed SL-MAC System (R152a) significantly better (by 2 to 4°C) than the proposed SL-MAC System (R1234yf)

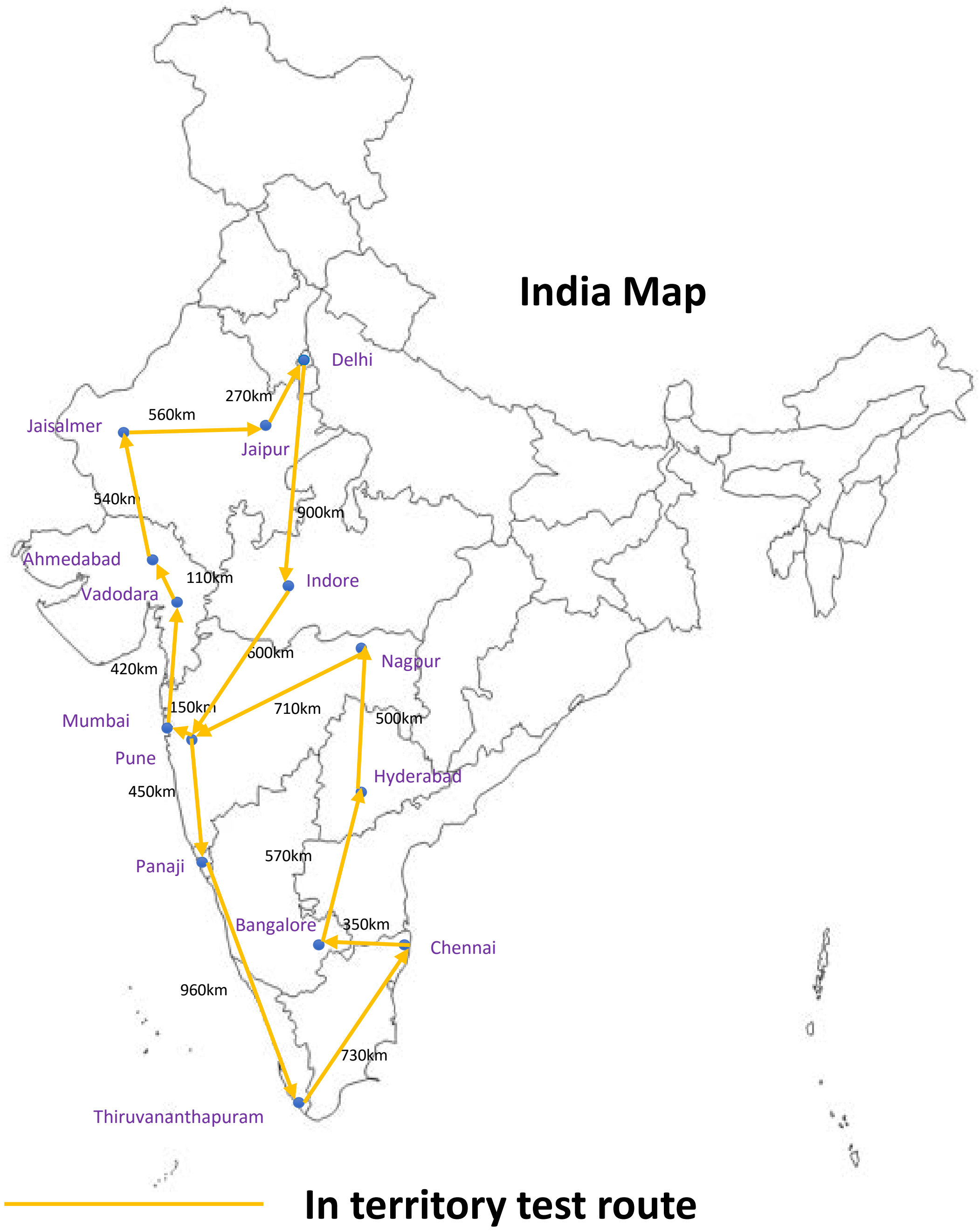




Way Forward

Milestone 4: (completion by June 2018)

- Vehicle Level Performance Testing in TML India facility with new refrigerants R-152a and R-1234yf from December 2017 onwards
- Powertrain logic and results of functional testing
- Rigorous road trials (~15,000 kms) with both refrigerants in hot and humid ambient conditions in different climate zones in India from 1st Mar, 2018 to 30th May 2018
- Report on tunnel and road testing in India, June 2018



Thank you for your attention!

Questions?

Backup Slides Follow

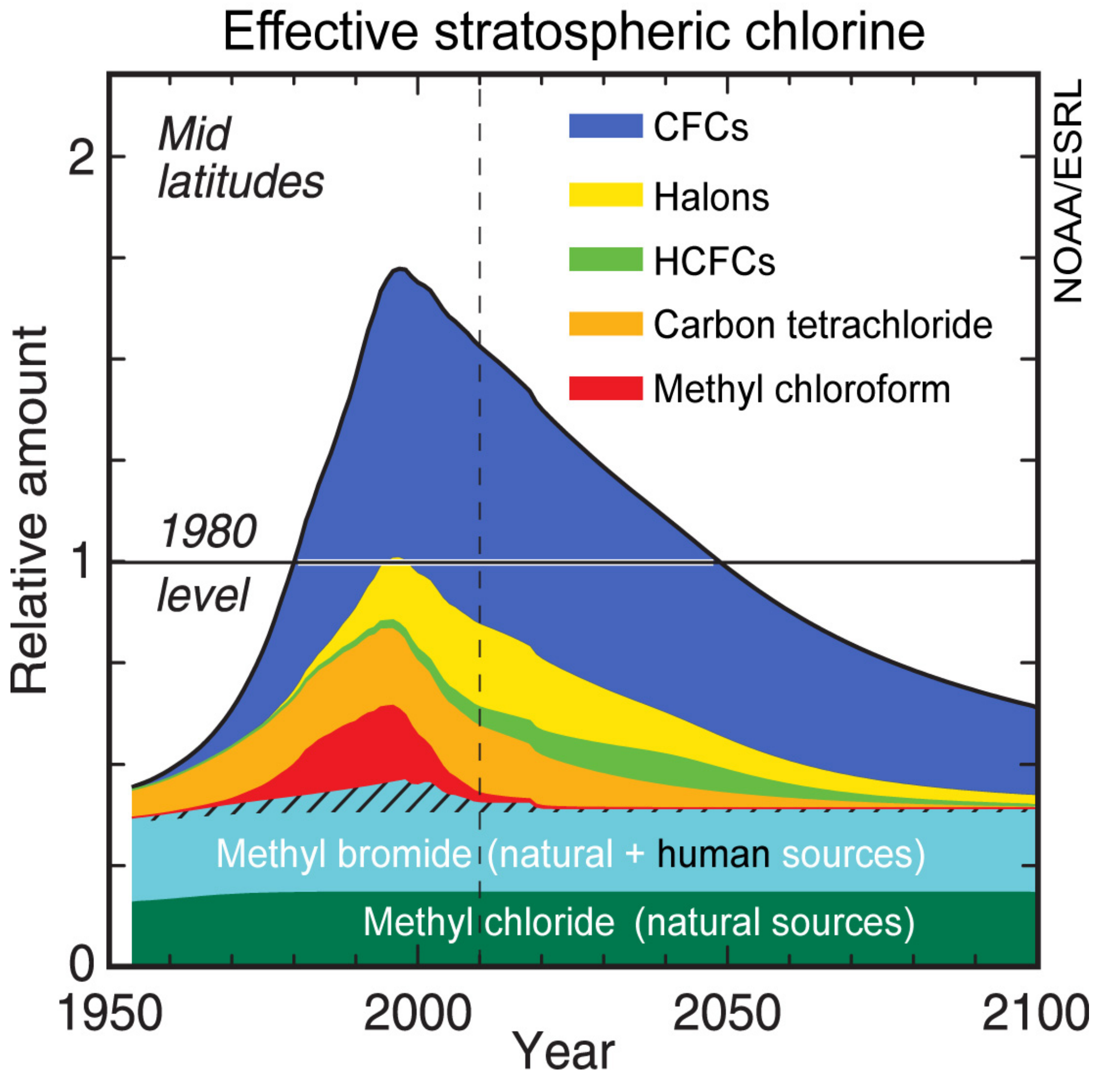
- SL-MAC Demonstration Project Team and Technical Advisors
- Science behind Montreal Protocol and the HFC phasedown
- SL-MAC Project Background
- Project Status

Technology Demonstration: Secondary Loop for Flammable Refrigerants

- Project Team
  - TATA: Sangeet Kapoor, Prasanna Nagarhalli, and Jagvendra Meena
  - MAHLE: Sourav Chowdhury, Timothy Craig, and Lindsey Leitzel,
  - IGSD: Stephen O. Andersen, Nancy J. Sherman, and Melinda Soffer
  - JAB: James Baker

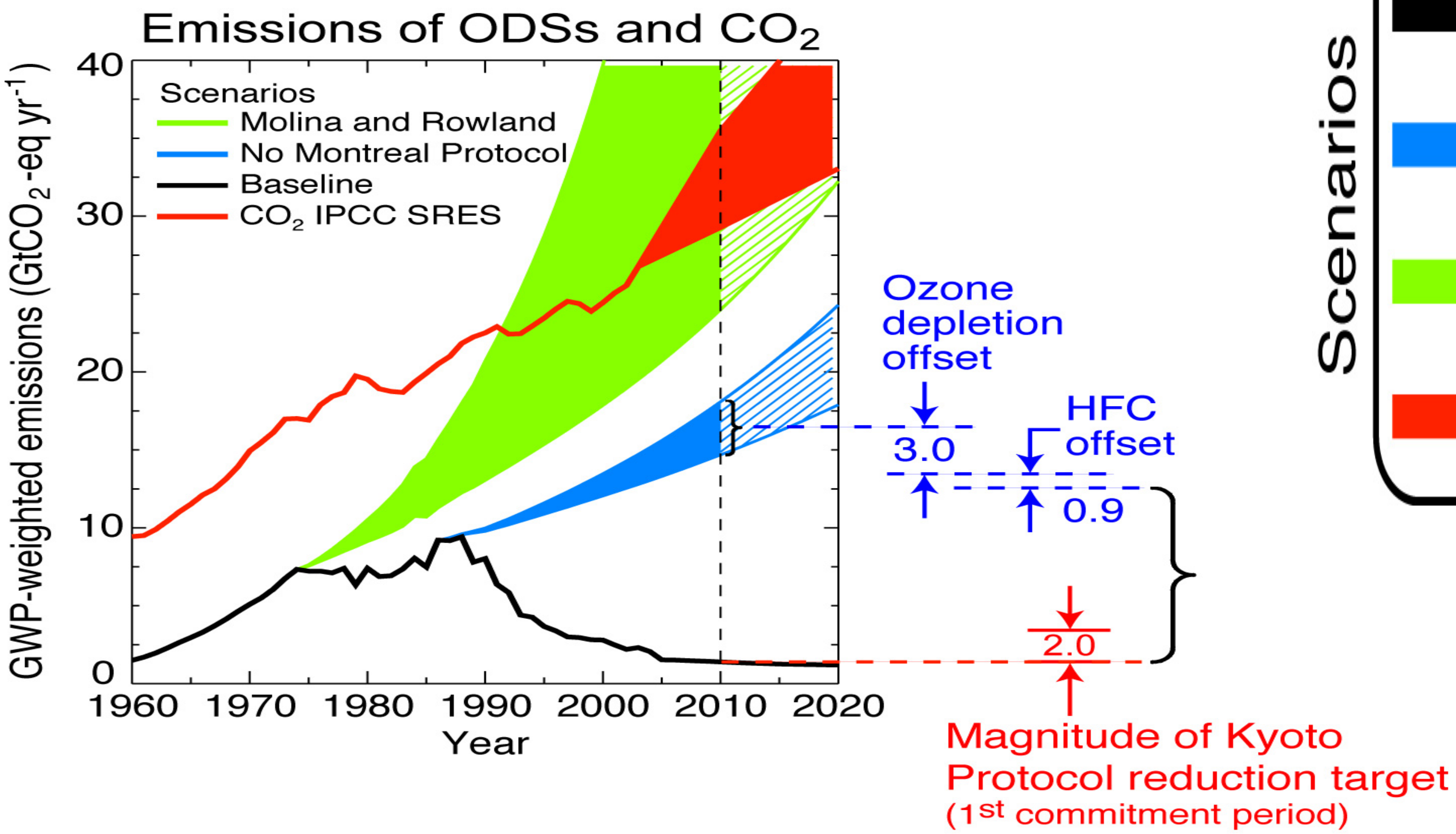
- Technical Advisors
  - California Air Resources Board (CARB), Chemours, Chrysler, Fiat, General Motors, Jaguar Land Rover, Neutronics Refrigerant Analysis, HF Consultancy, Natural Resources Defense Council (NRDC), Mobile Air Conditioning Society Worldwide (MACs), SAE International, Sun Test, TERRE Policy Centre, National Renewable Energy Laboratory (NREL), University of Maryland, and Valeo.

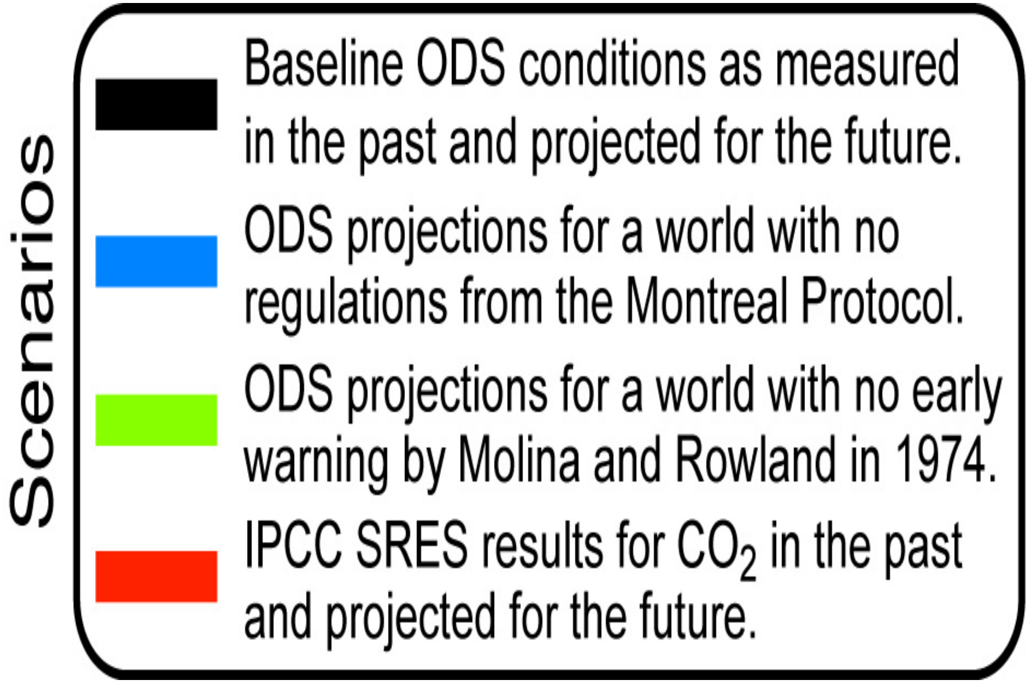
The Montreal Protocol Phase-out of Ozone-Depleting Substances (ODSs)



The Montreal Protocol has slowed and reversed the accumulation of ozone depleting substances (ODSs) in the stratosphere, as measured by effective stratospheric chlorine amounts.

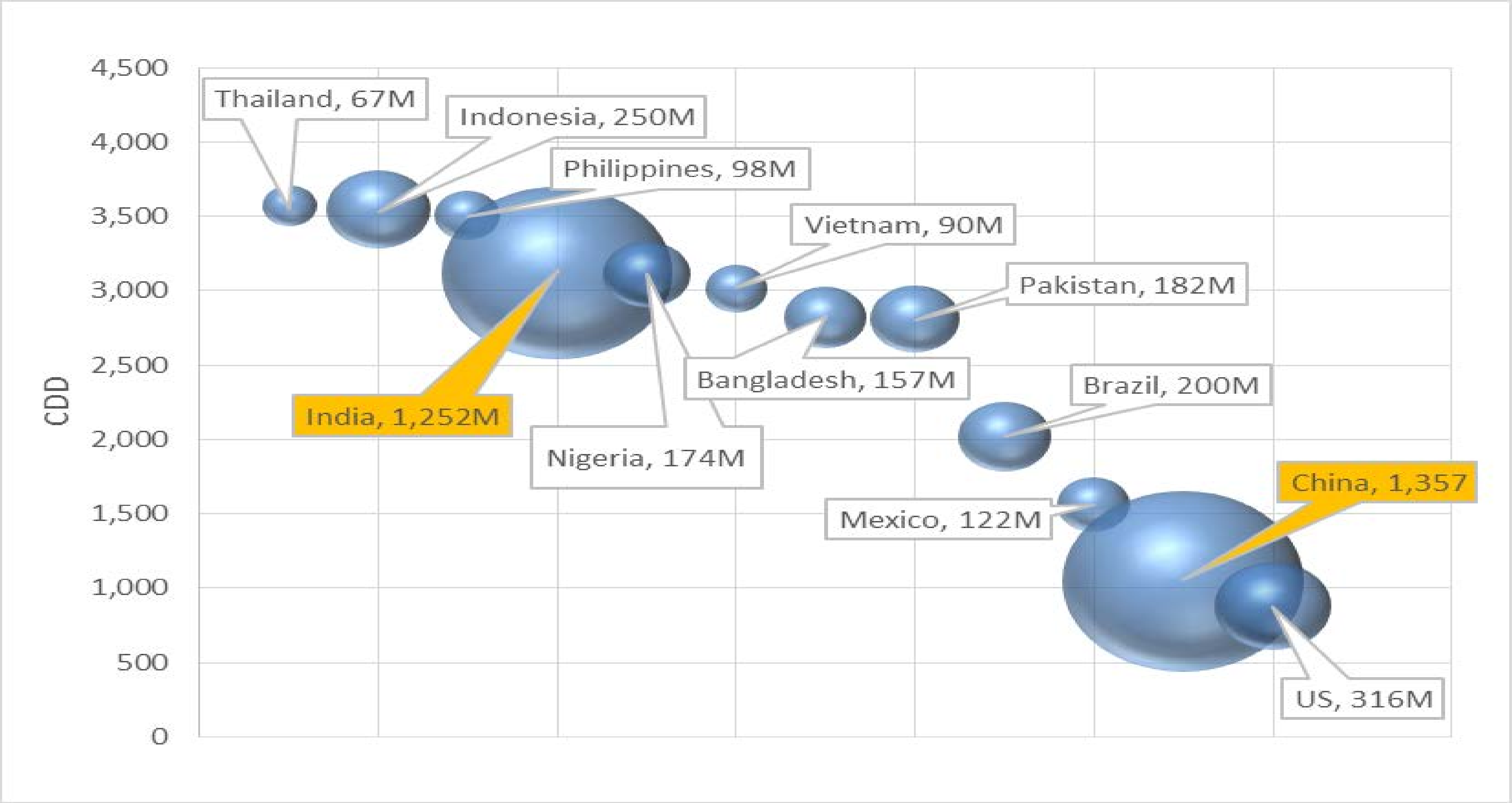
The Montreal Protocol Also Protects Climate!





The Montreal Protocol reduced net GWP-weighted emissions from ODS in 2010 by 11 Gt CO2-eq yr^{-1}. This is 5-6 times the reduction target of the first commitment period (2008-2012) of the Kyoto Protocol.

Cooling Degree Days & Population



Source: Davis et al, Proceedings of the National Academy of Sciences, 2015

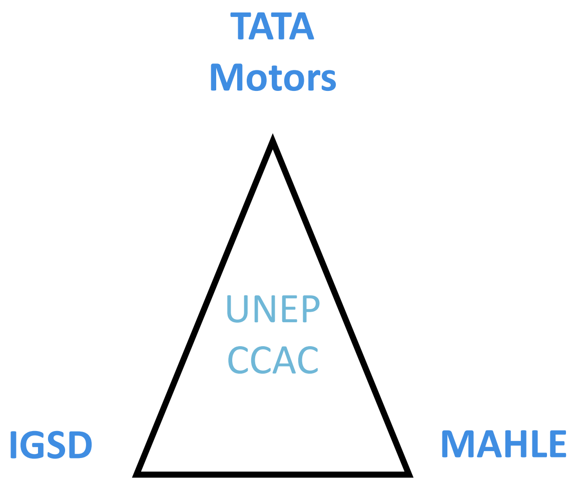
Bench and Wind Tunnel Tests Do Not Capture Deceleration and Power Management Gains

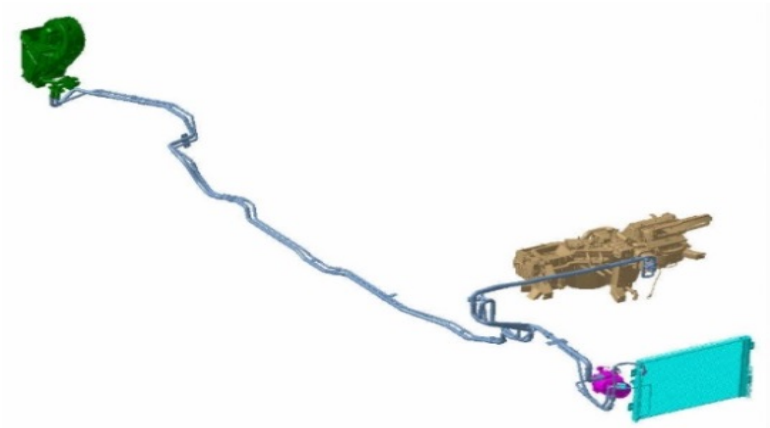
Air conditioning during deceleration is zero net carbon as inertia is converted into cold that can be accumulated in the coolant and used later when needed

The thermal ballast of the coolant allows powered air conditioning to occur when the engine is at lowest carbon intensity

Comfort in the cabin is automatically controlled by managing the powered cooling, coolant pump speed, and volume and velocity of cold air circulation

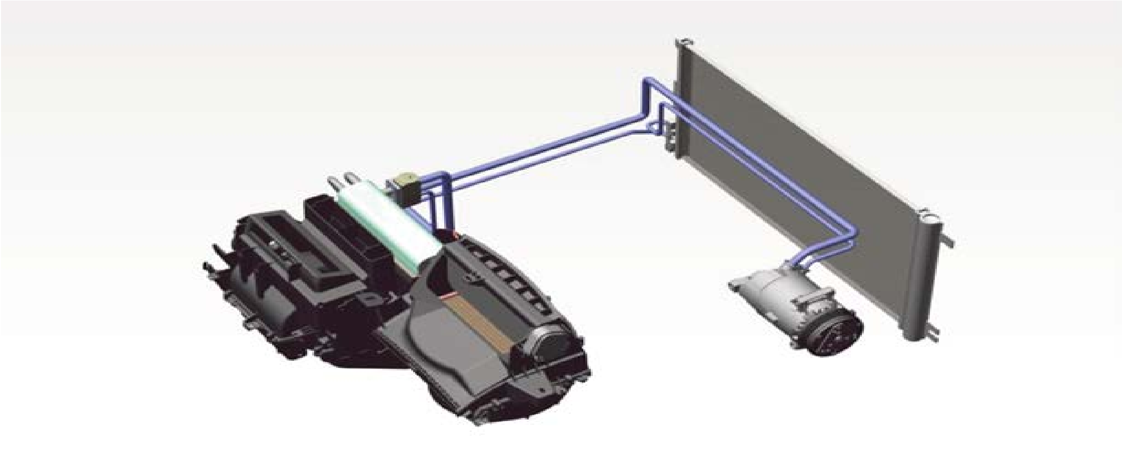
Technology Demonstrator: Secondary Loop for Flammable Refrigerants



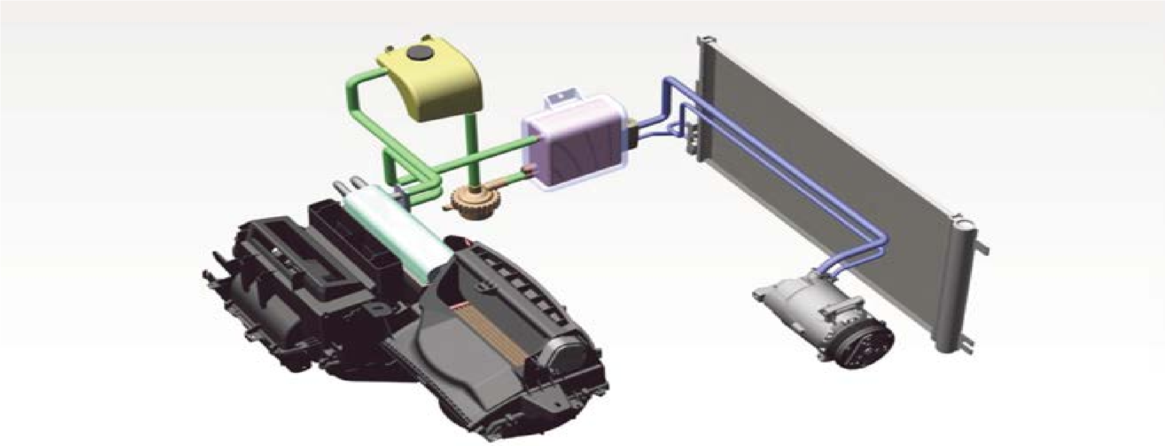


- Apply SL-MAC system with improved power train control logic to reduce Short-Lived Climate Pollutants and maximize energy efficiency advantage
- Financial support by UNEP, as part of a climate change project of the Climate and Clean Air Coalition (CCAC)
- TATA Aria 2.2L Dicor is selected vehicle with front and rear A/C system

Secondary Loop System vs Direct Expansion System



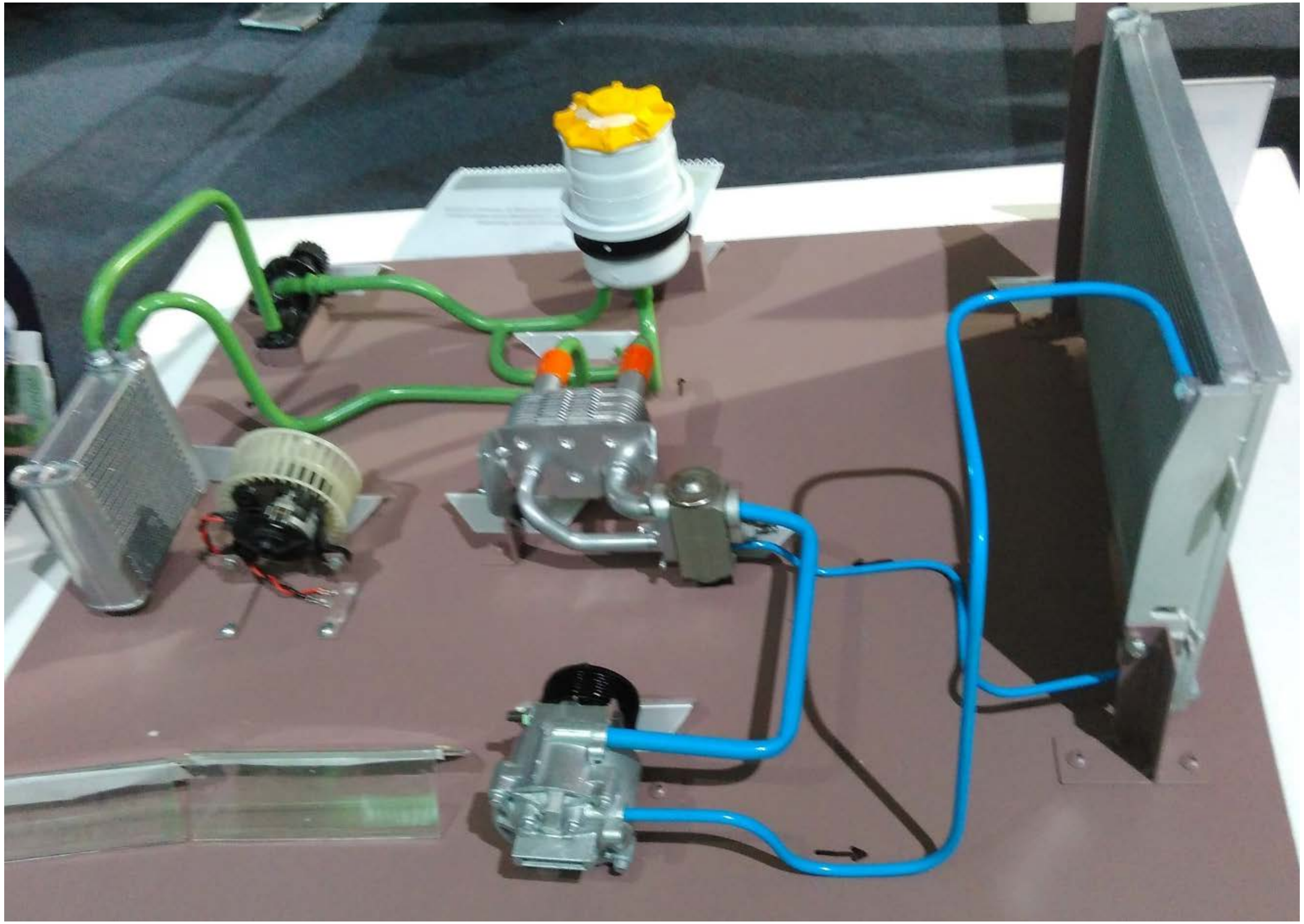
Direct expansion system
Andersen et al., 2014



Secondary loop system
Andersen et al., 2014

SL-MACs use refrigerant to chill a fluid (coolant) that is circulated inside the car for comfort. A reduced charge of flammable refrigerants can be used more safely in systems with less emissions from fewer fittings and shorter refrigerant hoses.

Concept Demonstration Model



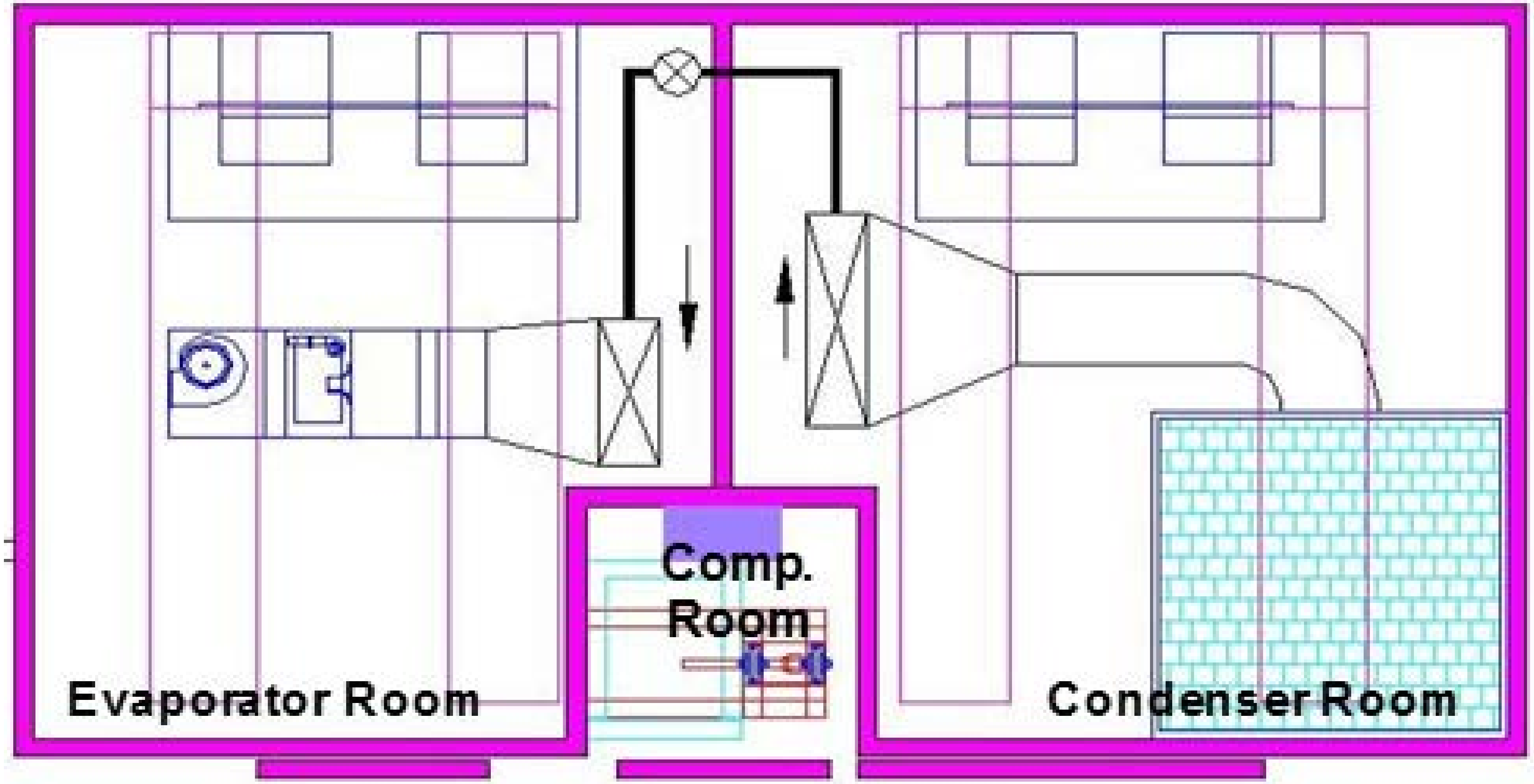
Green hoses – coolant (passenger cabin)

Blue hoses – refrigerant (engine compartment)

Yellow capped canister is the coolant reservoir

Model created by engineers at Tata Motors, Pune, India

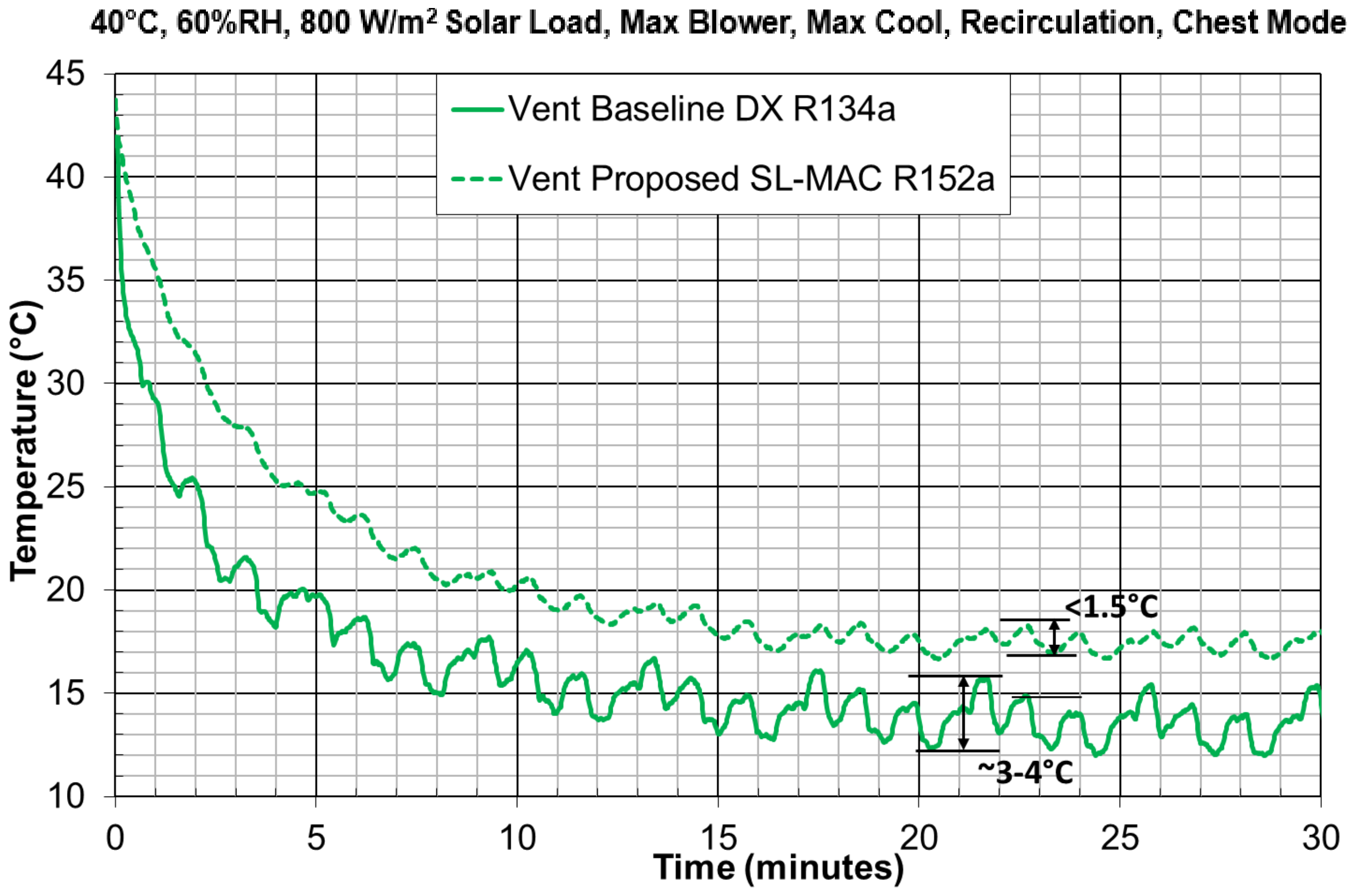
Bench Test Calorimeter



Vehicle Trials Under Simulated Ambient Conditions

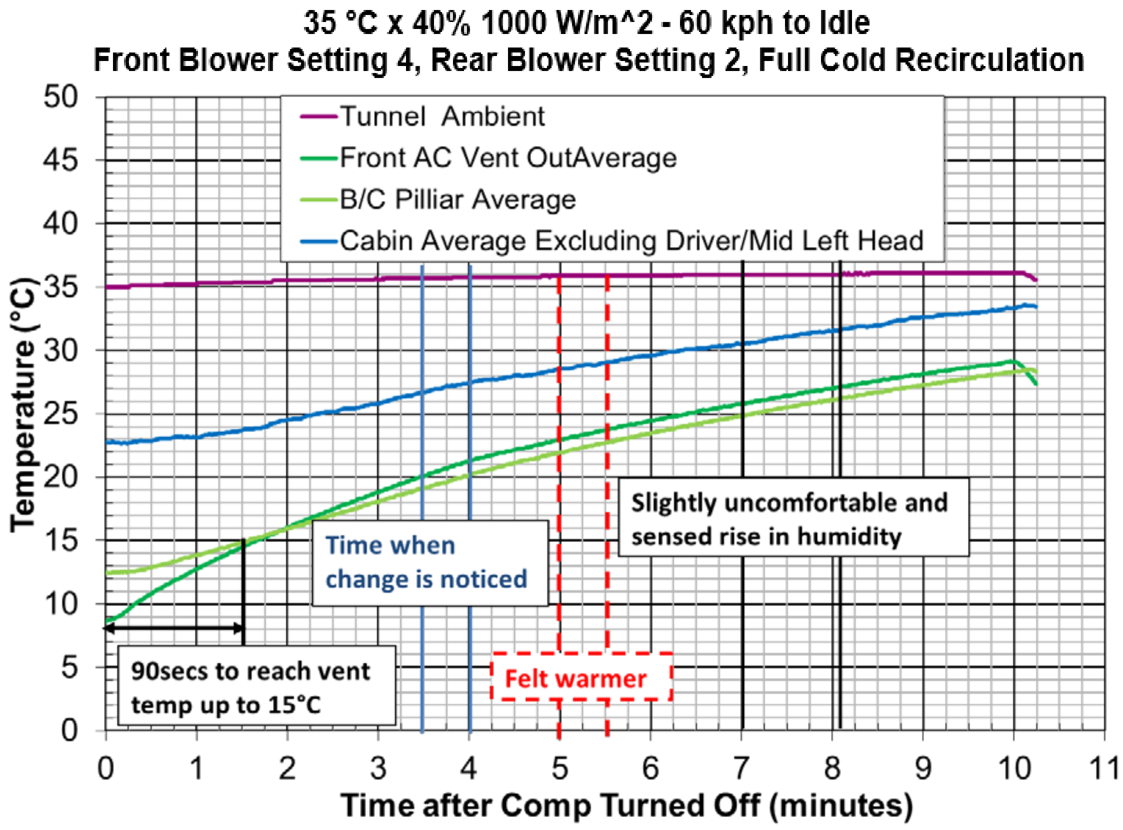
Mumbai City Drive Test

- The vent/grill temperature fluctuation for proposed SL-MAC R-152a system is reduced to 1.5°C against 3-4 °C for the Baseline DX R-134a system



Maximum OFF Time Test (SL-MAC R-152a)

- For the moderate ambient conditions, temperature rise was experienced 3 to 4 minutes after compressor turned off.
- The rise in vent temperature up to 15 °C took about 90 seconds.

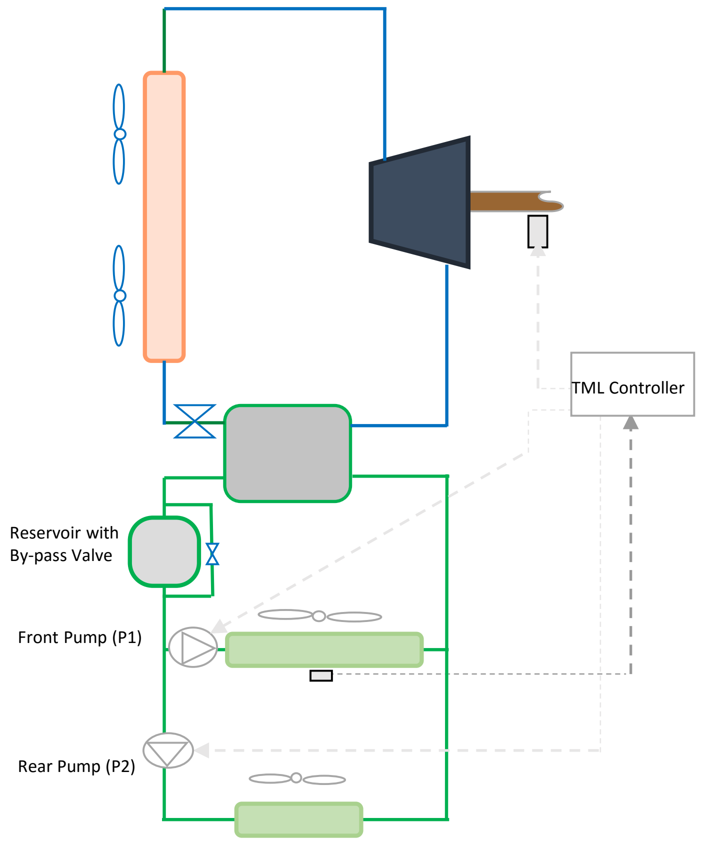


Vehicle As Built

- Set up with 2-pumps for development

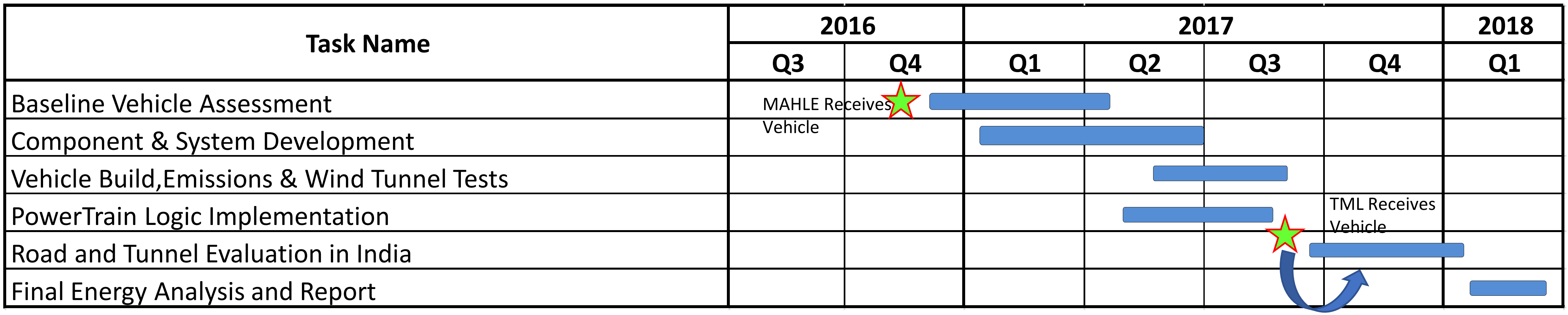
- Flow balance achieved:
- Front: 60%
- Rear: 40%

- Flow rate targets achieved, 50/50 EGW



Sr. No	Parameter	Current	Target
1	Refrigerant (GWP)	R134a (1430)	R152a (124) HFO1234yf (<1)
2	Charge quantity	800gms (±20gms)	@40% reduction
3	Average Cabin Temperature at 25th min in 35^0C 40%RH Solar Load 1000W/m2	21.8°C	21±1
	Average Cabin Temperature at 25th min in 45^0C 40%RH Solar Load 1200W/m2	28.9	28±1
4	Compressor Power Consumption	6KW at @1500erpm	5~8% reduction
5	Rise in Grill temp – City cycle tests	$\leq 4^0$C	$\leq 2^0$C
6	Fuel Economy -Indian Drive Cycle (ARAI) (With AC ON and windows closed)	12.55Kmpl	~3% Improvement

Tasks and Timeline



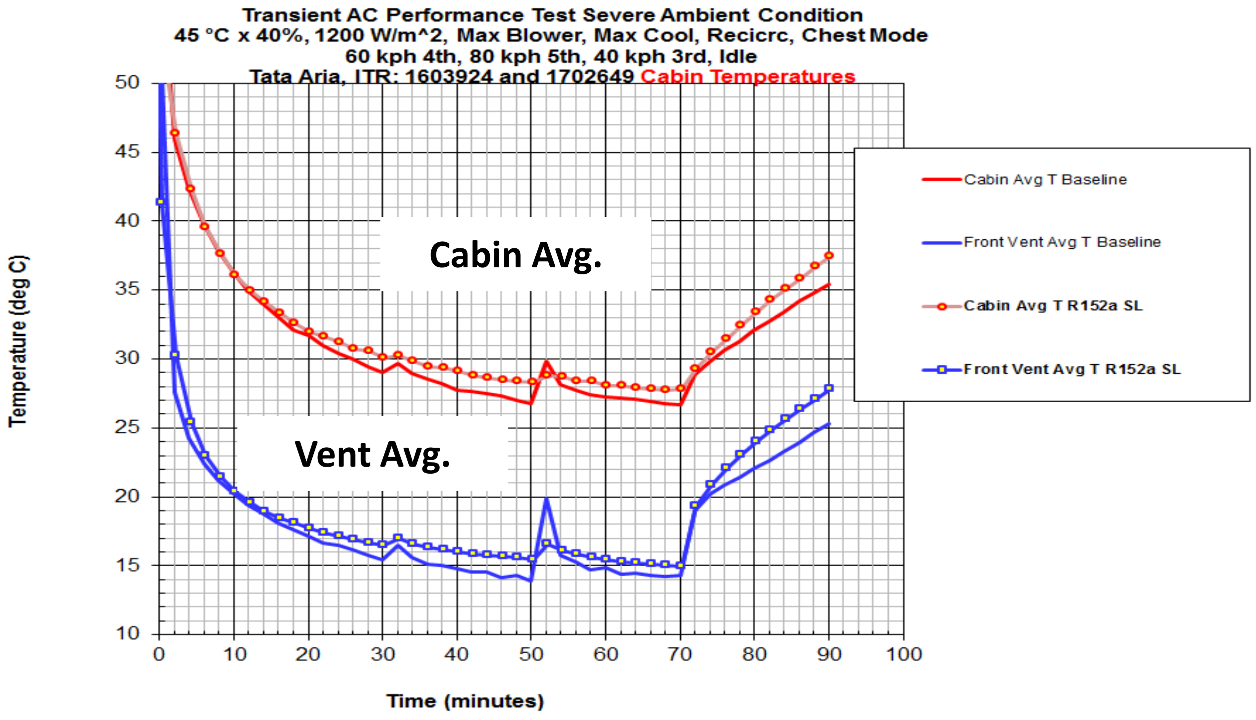
Tata Aria with prototype SL-MAC system was shipped back to TML in India in November

Expected Outcomes

- Vehicle manufacturers able to use HFC-134a alternatives, including flammable refrigerants
- Manufacturers can use cheaper and non-patent-protected refrigerants
- Energy savings

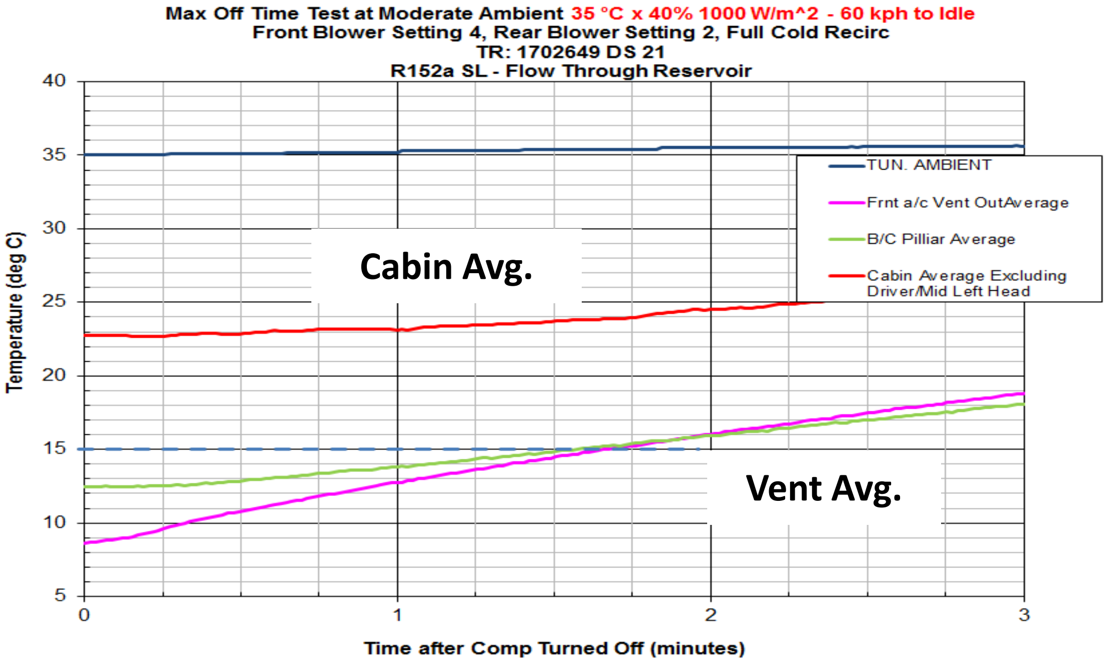
  + Energy saving refrigerant usage

  + Engineering solutions, such as compressor turned off during acceleration and hill ascent.
- Greater passenger comfort through faster cool down after short stops due to cold retention in system.
- Fewer refrigerant leaks due to fewer and tighter fittings.



Boundary Conditions:

1. Production A/C compressor
2. Production condenser & fan



Hot Soak + Cooldown

- R152a (o) vs. R134a (-)
- Driving temps within ~1 deg. C
- At end of Idle temps within ~2 deg. C

Cold Storage: Off-time @ 35C Ambient

- Comfort > 2 minutes after compressor off