2021 ECS SIMULATION CONFERENCE

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# Occupants Nose Level Air Temperature Prediction through 1D CAE Advance Cabin Simulation

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# Outline

- Introduction
- Simple Cabin Model Vs Advance Cabin Model
- Inputs For Advance Cabin Modelling
- Advance Cabin Modelling Along with Complete AC System
- Correlation With Physical Test
- Summary

Deck of 14 slides

# MAC Performance Validation (Digital, Physical)

- During vehicle development front loading through digital validation is vital
- Work happens on both sides digital as well as physical, digital load cases are closely mapped with physical validation

<table>
<tr><th>MAC system has to provide year round cabin comfort to all occupants</th><th>Digital</th><th>Physical</th></tr>
<tr><td>Severe/ high ambient<br></td><td rowspan="3">Following parameters are predicted by deploying 1D CAE and 3D CFD:<br>i. Average vent temperature (1D Simple Cabin)<br>ii. Average cabin temperature (1D Simple Cabin)<br>iii. Refrigerant pressures and compressor power consumption (1D Simple Cabin)<br>iv. All occupant face and chest level velocities (CFD)<br>v. Air discharge at all AC vents (CFD)<br>vi. Occupant ear level climate noise (CFD and CAE)</td><td rowspan="3">Performance is validated for following parameters:<br>i. All AC vent temperatures<br>ii. All occupant nose level temperatures<br>iii. Refrigerant pressures and compressor power consumption<br>iv. All occupant face and chest level velocities<br>v. Air discharge at all AC vents<br>vi. Occupant ear level climate noise</td></tr>
<tr><td>Moderate/ low ambient<br></td></tr>
<tr><td>High humid and low ambient<br></td></tr>
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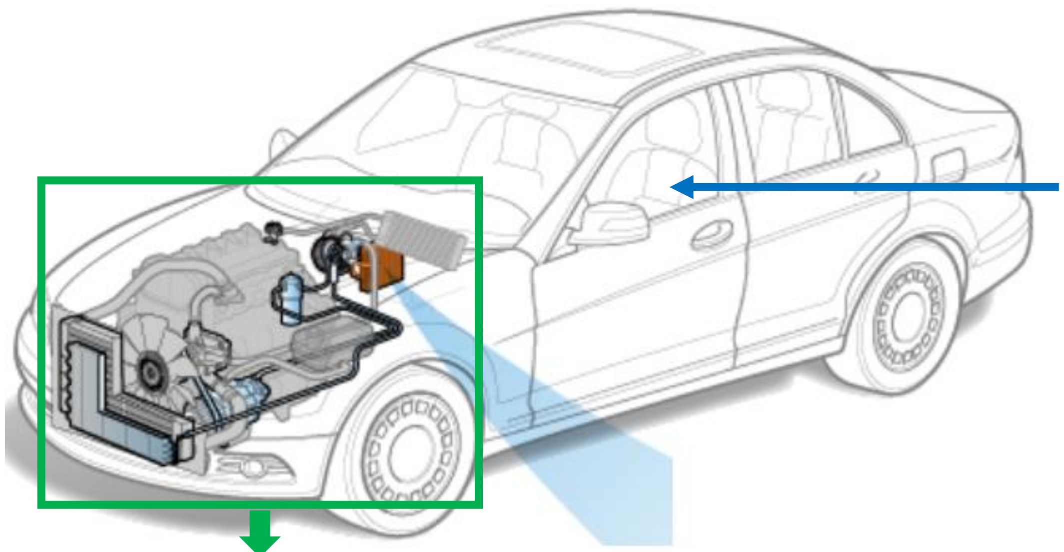
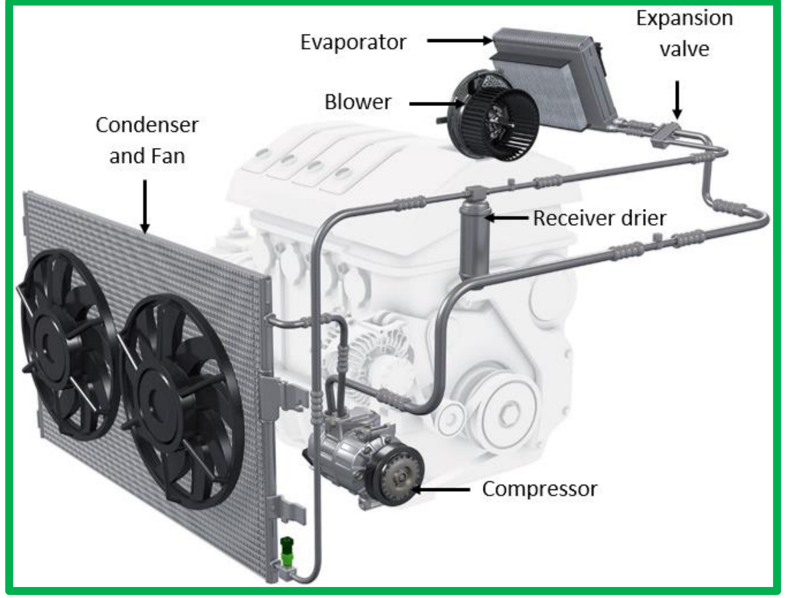
# Mobile Air Conditioning (MAC) System with SIMPLE CABIN Model (1D)

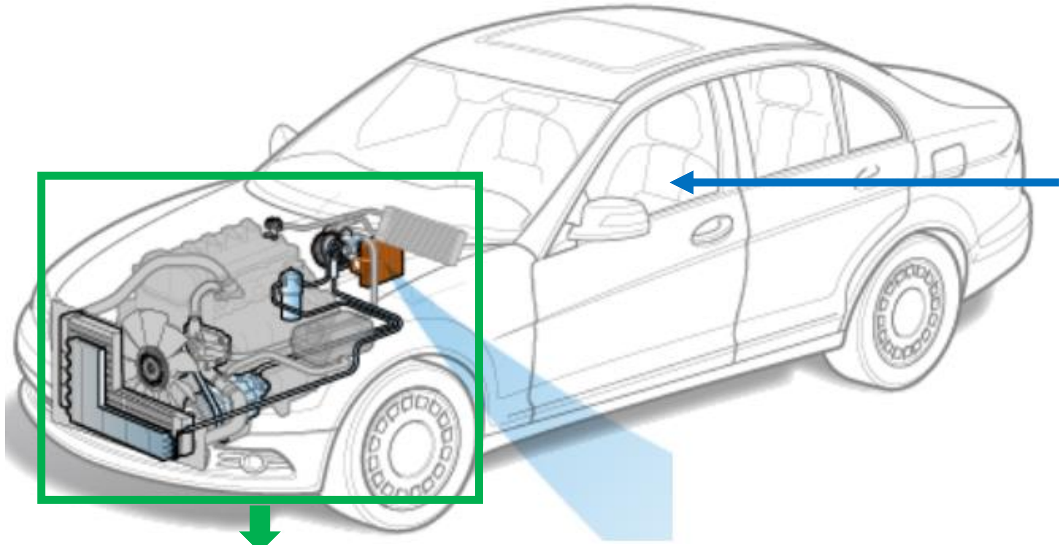


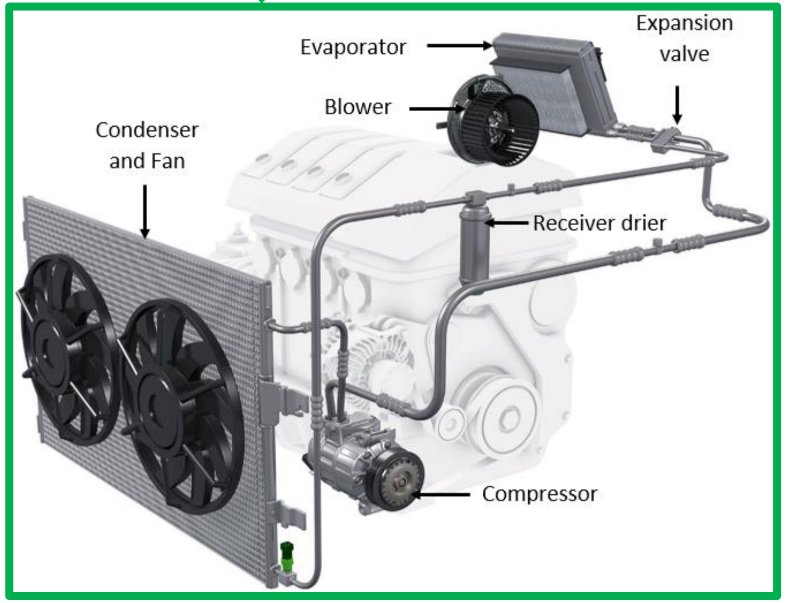



| MAC System Components | Types |
|---|---|
| Passenger cabin | • **Single, two and three row cabin is modelled as SIMPLE CABIN**<br>• **Average vent and average cabin temperature prediction is possible** |
| Fan and Blower | Brushed and Brushless |
| Expansion device | Block type, Angle type |
| Evaporator | Tube and Fin, Plate and Fin, Serpentine… |
| Compressor | • Fixed Displacement<br>  ○ Swash/ Wobble reciprocating<br>  ○ Scroll<br>  ○ Vane<br>• Variable Displacement<br>  ○ Internally Controlled<br>  ○ Externally controlled |
| Condenser | Tube and Fin, Serpentine, electric |
| Receiver drier | Integrated and Remote |

# Mobile Air Conditioning (MAC) System with ADVANCE CABIN Model (1D)





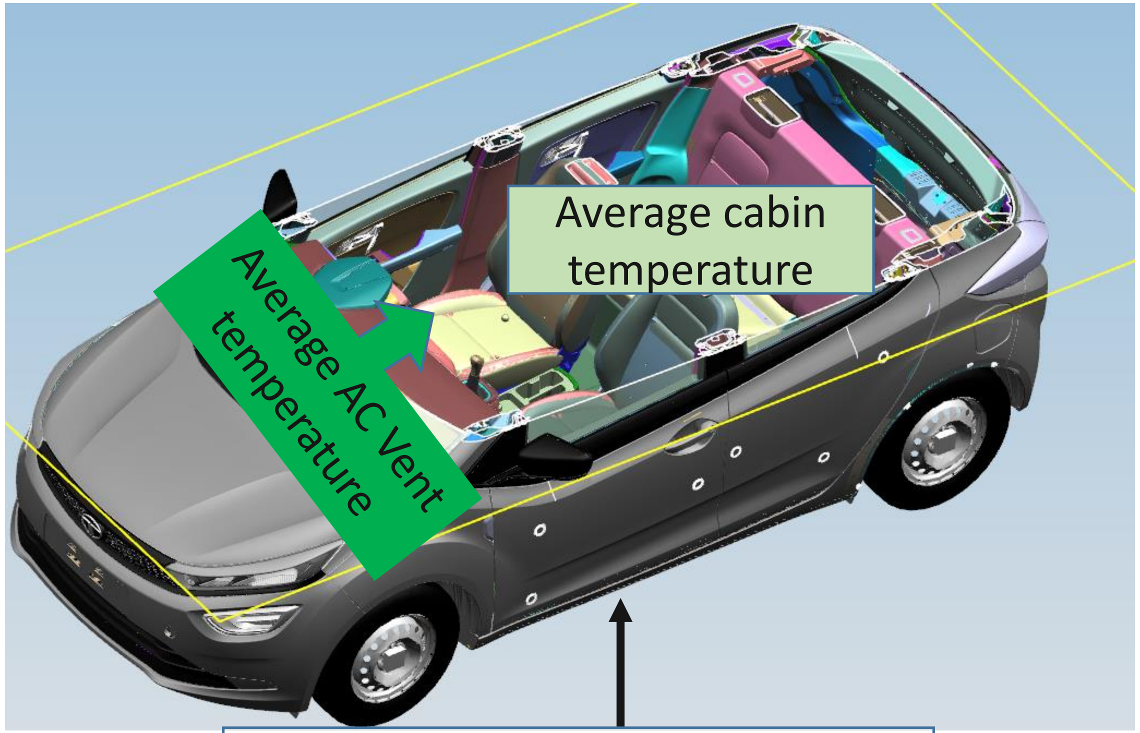



| MAC System Components | Types |
|---|---|
| Passenger cabin | • Single, two and three row cabin is modelled through ADVANCE CABIN<br>• Individual AC vent and each nose level temperature prediction is possible |
| Fan and Blower | Brushed and Brushless |
| Expansion device | Block type, Angle type |
| Evaporator | Tube and Fin, Plate and Fin, Serpentine… |
| Compressor | • Fixed Displacement<br>○ Swash/ Wobble reciprocating<br>○ Scroll<br>○ Vane<br>• Variable Displacement<br>○ Internally Controlled<br>○ Externally controlled |
| Condenser | Tube and Fin, Serpentine… |
| Receiver drier | Integrated and Remote |

# Simple Cabin Model Vs Advance Cabin Model

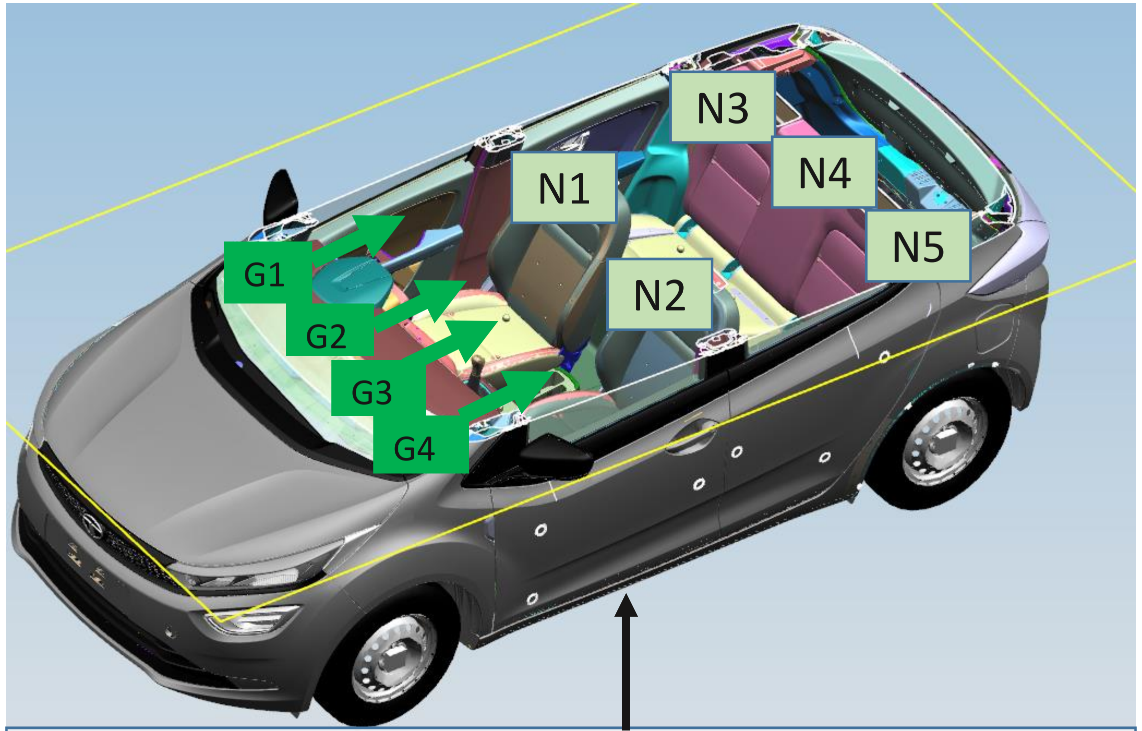


Simple cabin model




Cabin modelled as lumped mass

Advance cabin model




Detailed modelling of cabin geometry, wall layers and glasses with conditioned air flow distribution

G1, G2, G3 and G4: AC Vent temperatures
N1, N2, N3, N4 and N5: Nose level temperatures

- Currently with simple cabin model, only average vent and average cabin temperatures can be predicted
- In order to predict individual AC vent and nose level temperatures, advance cabin modelling is necessary

# Inputs for Advance Cabin Modelling

← Carryover inputs
☐ Additional inputs

| Inputs required | Simple cabin model | Advance cabin model |
|---|---|---|
| Compressor | Isentropic and volumetric efficiency curves for different compressor RPM and refrigerant pressure | ← |
| Condenser | Geometrical and component level performance data | ← |
| Evaporator | Geometrical and component level performance data | ← |
| Thermal Expansion Valve (TXV) | TXV 4 quadrant data | ← |
| AC plumbing | Geometrical data (inner diameter, length and angle of bends) | ← |
| Cabin | • Cabin volume and total surface area<br>• Window surface area and incidence angle<br>• Mass in Passenger compartment | • Cabin volume and total surface area<br>• Cabin geometric details<br>• Cabin wall properties (for glass, door, floor, roof, etc..) |
| Conditioned Air flow | Air flow over evaporator ($m^3$/hr) | • Air flow over evaporator ($m^3$/hr)<br>• Mass flow and diffusion coefficients from 3D CFD simulation |

# Inputs for Advance Cabin Modelling

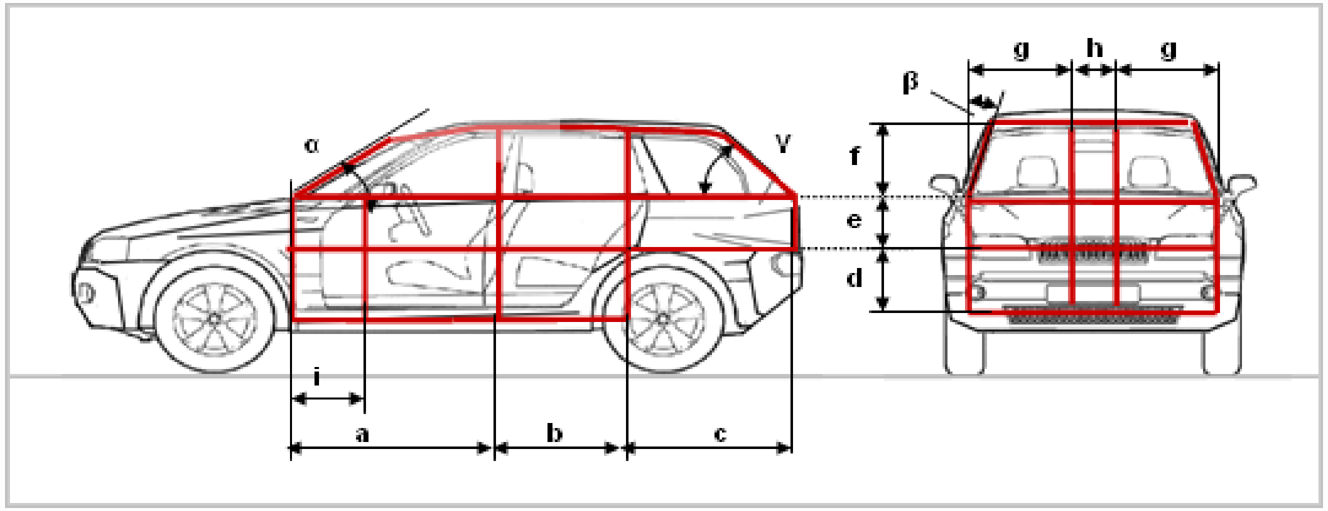
## Cabin geometric details

- Vehicle cabin is divided into number of zones to capture conditioned air temperature in each zones
- Also windshield, window and rear glass angles are given as input for modelling of heat ingress from glass surfaces

General data | Geometric properties | Wall Properties | Pressure Loss

Vehicle volume [m³]: 5.11

| ID | Wert |
|---|---|
| a [m] | 1.11 |
| b [m] | 0.99 |
| c [m] | 0.8 |
| d [m] | 0.3 |
| e [m] | 0.38 |
| f [m] | 0.45 |
| g [m] | 0.62 |
| h [m] | 0.33 |
| i [m] | 0.42 |
| alfa [°] | 18 |
| beta [°] | 47 |
| gamma [°] | 40 |



# Inputs for Advance Cabin Modelling

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## Cabin wall properties

Cabin wall material and thermal properties input are keyed in for detailed modelling of the cabin

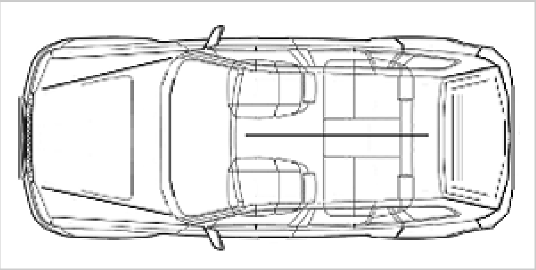
General data | Geometric properties | Wall Properties | Pressure Loss

- General
  - Windscreen
  - Firewall
  - Roof
  - Floor
- Front
  - Window Front Left
  - Window Front Right
  - Door Front Left
  - Door Front Right
- Rear
  - Window Rear Left
  - Window Rear Right
  - Door Rear Left
  - Door Rear Right
- Trunk
  - Window Trunk Left
  - Window Trunk Right
  - Window Trunk Back
  - Door Trunk
- Inner Walls (interior)
  - Inner Wall Dashboard
  - Inner Wall All Seats

Windscreen

Comment: Glass 5.1 mm - composite

Area [m²]: 1
Absorption coefficient: 0.36
Transmission coefficient: 0.56
Emission coefficient Ambient: 0.8
Emission coefficient Inside: 0.8



Layers

Outside --> Inside

| Material | Wall Thickness [mm] | Density [kg/m³] | Heat capacity [J/kg/K] | Heat conductivity [W/m/K] |
|---|---|---|---|---|
| Glass | 2.17 | 2563 | 800 | 0.9 |
| PVB Film | 0.76 | 1100 | 1200 | 0.2 |
| Glass | 2.17 | 2563 | 800 | 0.9 |

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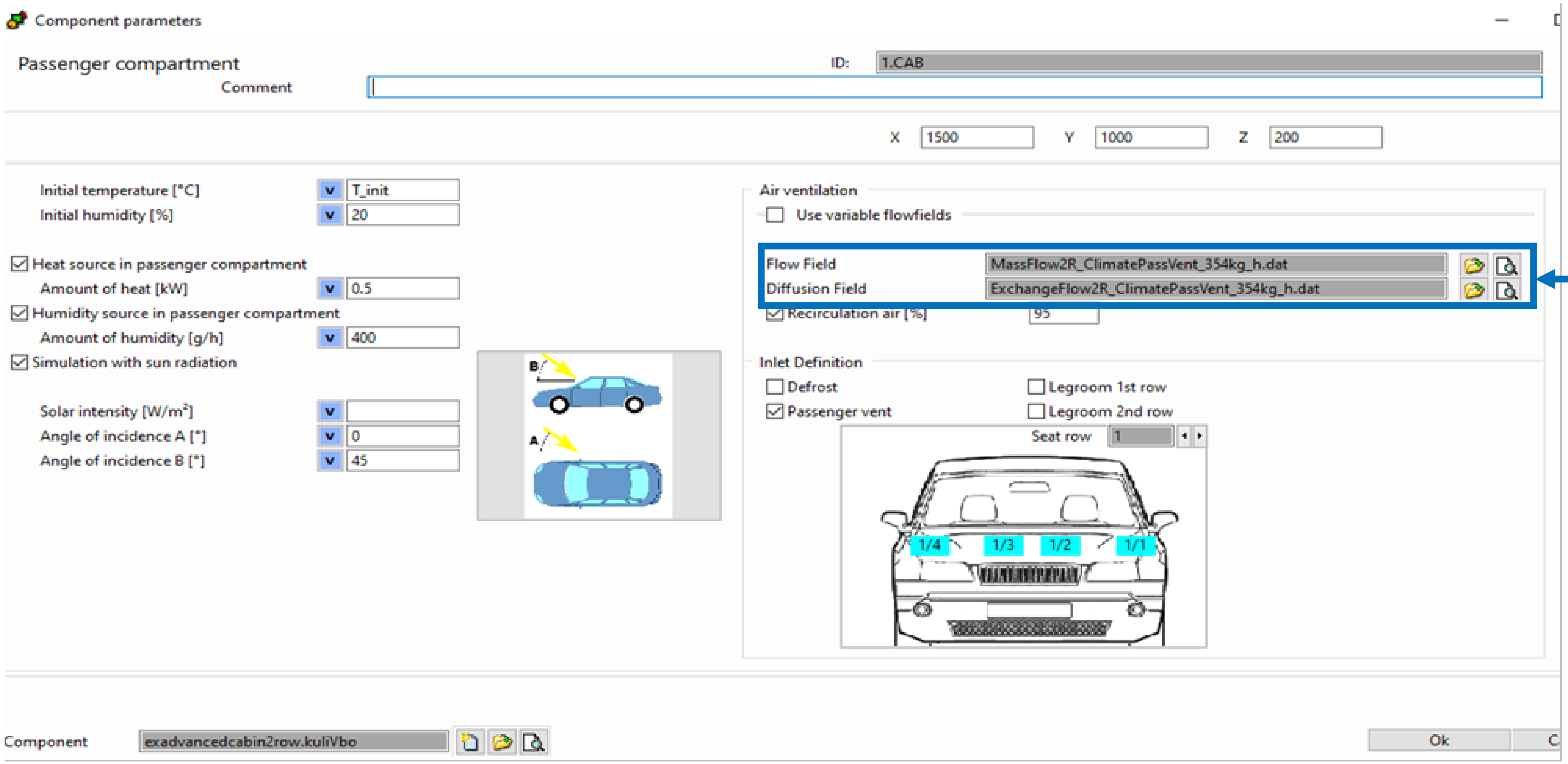
# Inputs for Advance Cabin Modelling

## Mass flow and diffusion field coefficients

3D CFD simulation outcome will be given as input for advance cabin model in terms of mass flow and diffusion field coefficients




Mass flow and diffusion field input from 3D CFD

# Advance Cabin Modelling Along with Complete AC System

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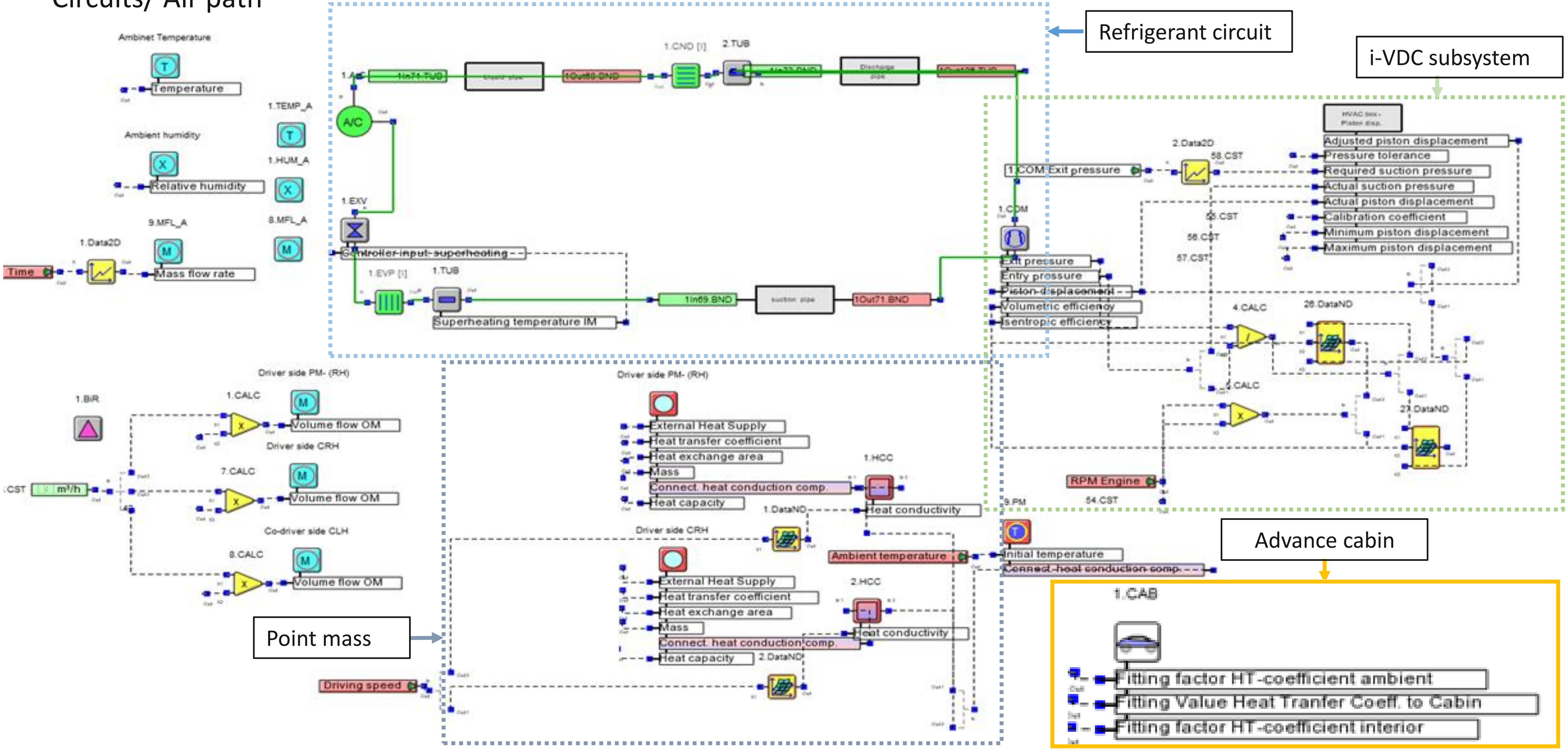
Circuits/ Air path



# Advance Cabin Modelling Along With Complete AC System

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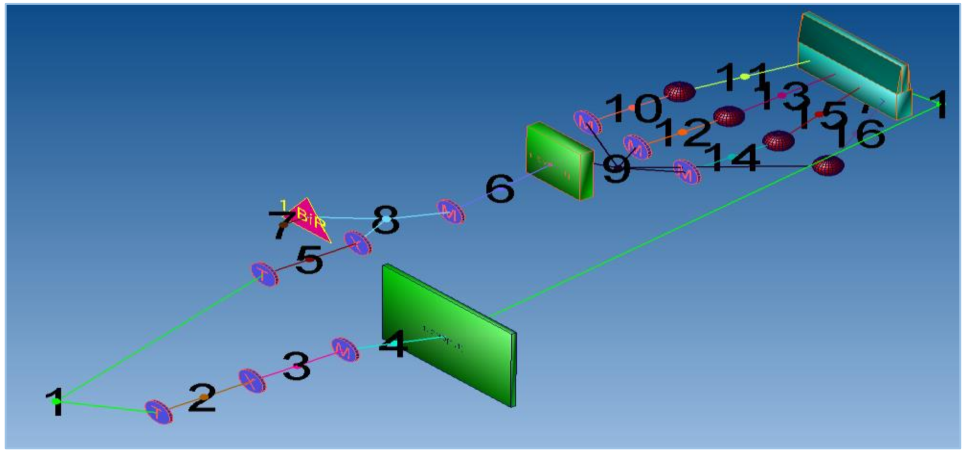
## Air side, nodes and transient simulation parameters

- In air side, cabin inlets (CAB [1,4], CAB [1,3], CAB [1,2] and CAB [1,1]) representing the AC vent in cabin are connected to the four duct point masses
- Simulation parameters are set to perform transient cooldown simulation

Air side




Nodes

| Nodes | Previous | Next |
|---|---|---|
| 1 | 1.CAB[Discharge];1.CND[1,1] | 1.TEMP_A;2.TEMP_A |
| 2 | 2.TEMP_A | 2.HUM_A |
| 3 | 2.HUM_A | 9.MFL_A |
| 4 | 9.MFL_A | 1.CND[1,1] |
| 5 | 1.TEMP_A | 1.HUM_A |
| 6 | 8.MFL_A | 1.EVP[1,1] |
| 7 | 1.CAB[Recirc] | 1.BiR |
| 8 | 1.BiR;1.HUM_A | 8.MFL_A |
| 9 | 1.EVP[1,1] | 4.PM;1.MFL_A;2.MFL_A;3.MFL_A |
| 10 | 1.MFL_A | 1.PM |
| 11 | 1.PM | 1.CAB[1,4] |
| 12 | 2.MFL_A | 2.PM |
| 13 | 2.PM | 1.CAB[1,3] |
| 14 | 3.MFL_A | 3.PM |
| 15 | 3.PM | 1.CAB[1,2] |
| 16 | 4.PM | 1.CAB[1,1] |

Simulation parameters

General data | Circuits / Air Path | Air side | Simul. param.

Type

- ○ Steady state
- ◉ Transient

Transient

| | |
|---|---|
| Start time [s] | 0 |
| End time [s] | 5000 |
| Time step [s] | 5 |
| AC/ST Time step [s] | 5 |

Constant during simulation

| Air humidity [%]... | Ref.press. for humidity [hPa]... | Ref.temp. for humidity [°C]... | T_init [°C]... |
|---|---|---|---|
| 50 | 1013 | 40 | 55 |

Variable during simulation

| Time [s]... | RPM Engine [1/min]... | Driving speed [km/h]... | Warm-up temperature [K]... | Ambient temperature [°C]... | Comment | A/C on |
|---|---|---|---|---|---|---|
| 0 | 2000 | 80 | 3 | 40 | | On |
| 10 | 2000 | 80 | 3 | 40 | | On |
| 55 | 2000 | 80 | 3 | 40 | | On |
| 1800 | 2000 | 60 | 3 | 40 | | On |
| 1801 | 2200 | 60 | 3 | 40 | | On |
| 3000 | 2200 | 60 | 3 | 40 | | On |

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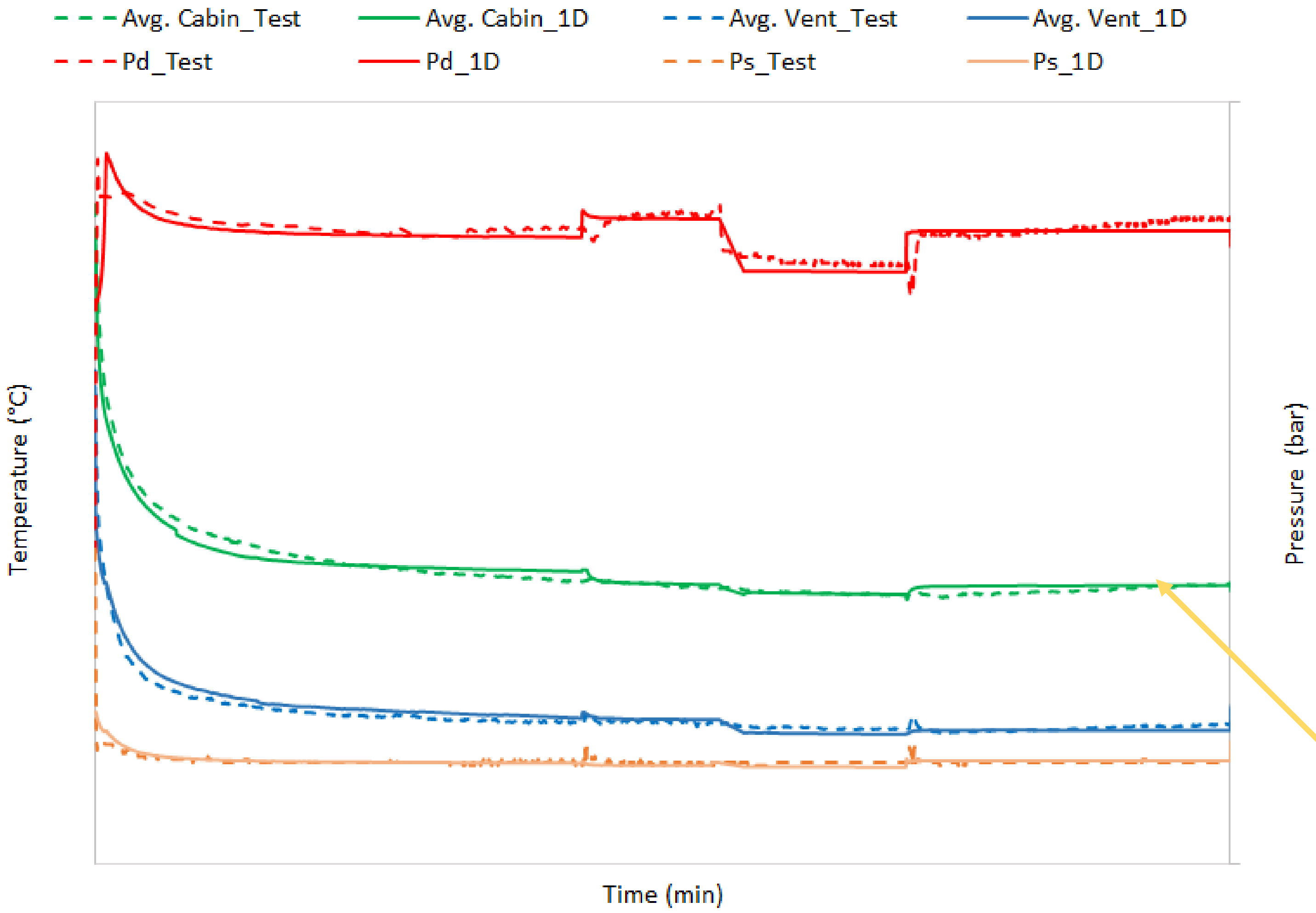
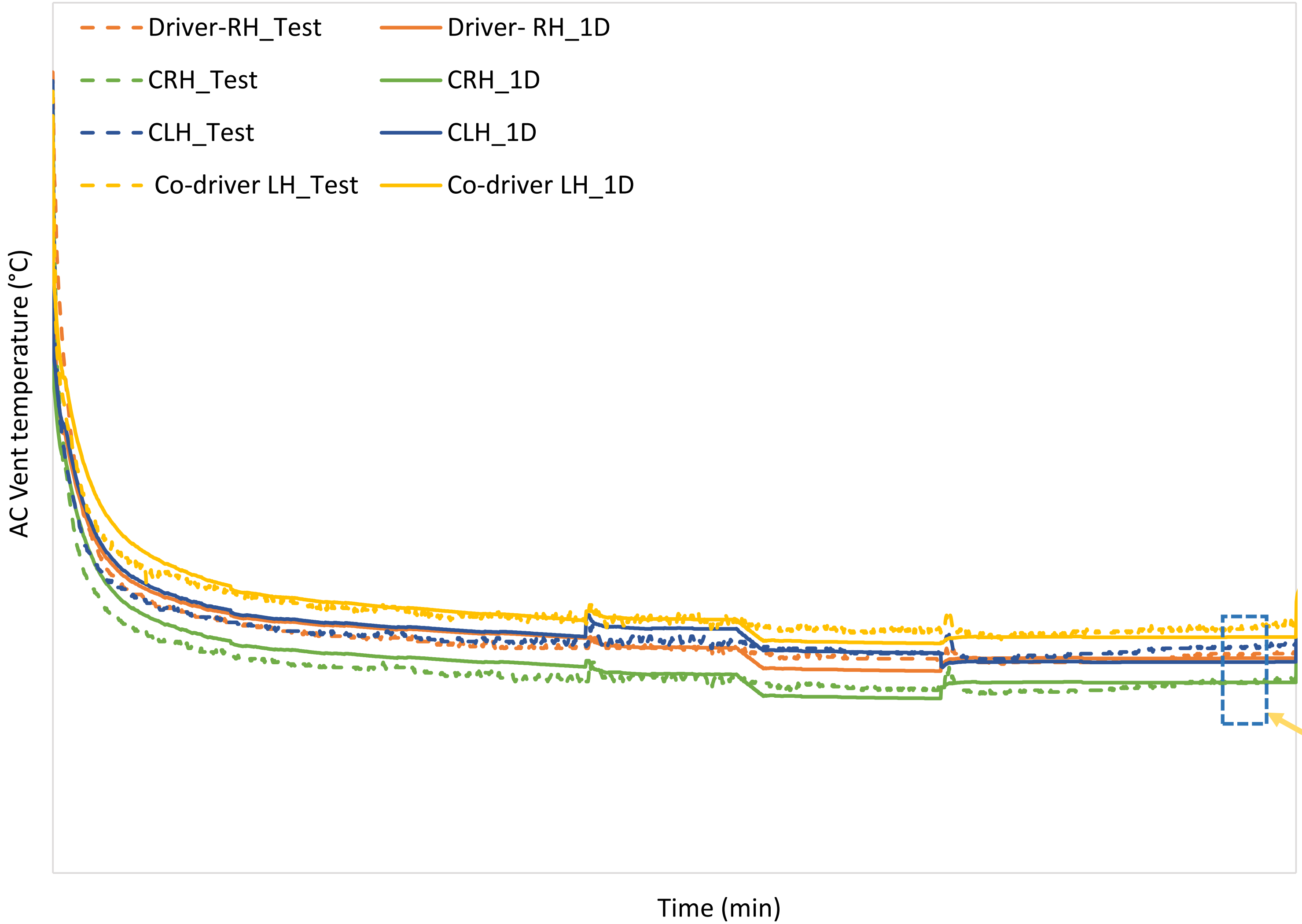
Correlation Case Study

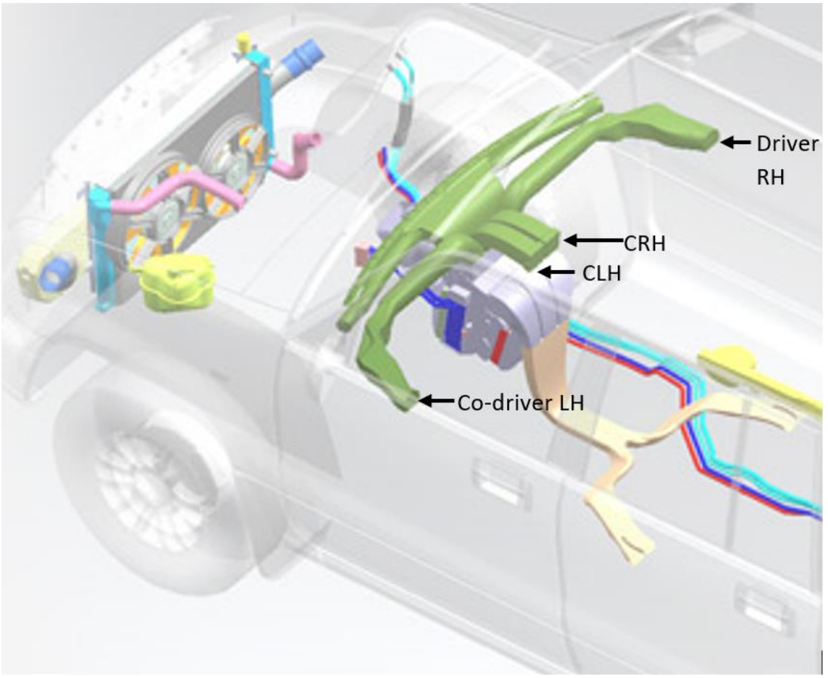
# Correlation with Physical Test: AC performance (Average Vent and Average Cabin)




Average cabin temperature correlation is achieved within accuracy of 97%

# Correlation with Physical Test: Individual AC Vent Temperature




AC vent temperature correlation is achieved within deviation of -1.0°C to 1.3°C with respect to physical test result

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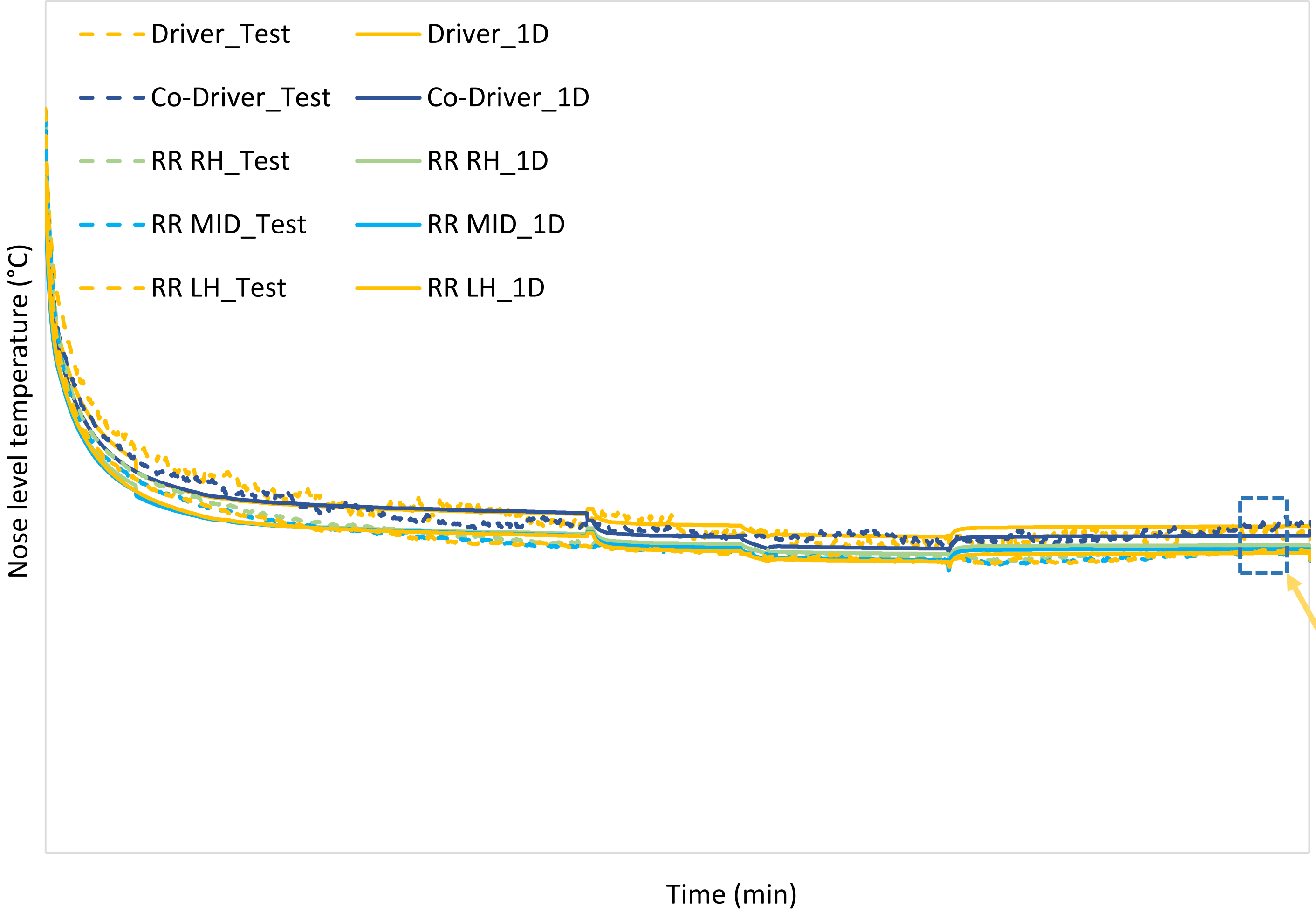
# Correlation with Physical Test: Each Nose Level Temperature





| Nose level temperature | |
|---|---|
| T1 | Driver |
| T2 | Co-driver |
| T3 | RR-RH |
| T4 | RR-MID |
| T5 | RR-LH |

Nose level temperature correlation is achieved within deviation of ±1.0°C with respect to physical test results

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# Summary

- 1D CAE simulation tools are widely used for MAC cooldown performance prediction
- Simple cabin modelling helps to predict average vent and average cabin temperatures
- In real scenario, temperature of air inside the cabin is non-uniform, hence it is essential to predict the cabin air temperature distribution
- In order to predict individual vent temperature and each nose level temperature, detailed modelling of vehicle cabin (Advance Cabin) is vital
- Necessary inputs for Advance Cabin modelling are-
    - Thermo-physical properties of cabin material
    - Detailed cabin geometry
    - Conditioned air velocity profile inside the cabin
    - Mass flow and diffusion field coefficients
- Initially multiple iterations are required to get good correlation for each nose level temperature with physical test outcome and also for making model robust
- Accuracy of component functional data (>97%) helps to get better correlation and allows predicting results close to real world scenario

# Acknowledgement

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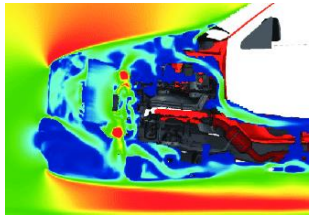
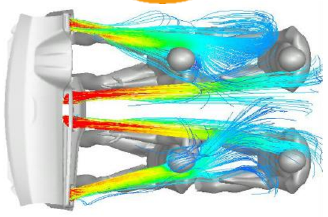


**Aerothermal CAE, TML**

Mr. Rajesh Pawar
Mr. Preetam Ghodake



**Cabin CFD, TML**

Mr. Mustafa Nomani
Mr. Sujit Shelar
Mr. Ambadas Kandekar

# Thank you for your attention…

# Questions?