Thermal simulation of a complete vehicle using manikin models

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SIMVEC – Simulation und Erprobung in der Fahrzeugentwicklung
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Motivation – Promoted Project STROM

BMBF (German Federal Ministry of Education and Research):

Sponsorship in the topic "Key Technologies for Electromobility (STROM)"

Bundesministerium für Bildung und Forschung

Project group:

Innovative air conditioning and thermal comfort concepts for the range optimization of electric vehicles (E-Komfort)

Time span: 3 years up to June 2014

Partners/

Competence:

- Volkswagen AG → Vehicle OEM
- Fraunhofer IBP → Measurement of thermal comfort (DRESSMAN)
- P+Z Eng. GmbH → Thermal cabin simulation (THESEUS-FE + OpenFOAM)

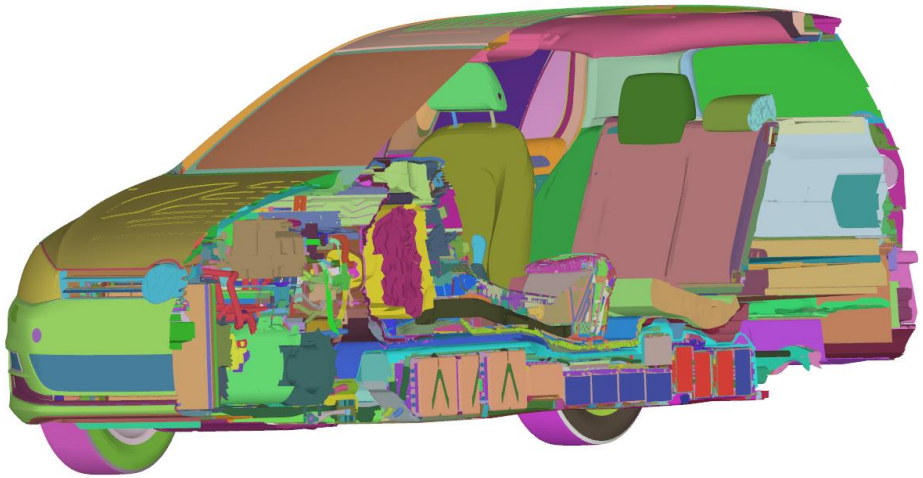
Overview

1. Creation of baseline thermal simulation model
2. Simplified simulation model
3. Concepts for zonal climatization
4. IR radiators and local thermal comfort
5. Validation of coupled cabin simulation

Creation of baseline thermal simulation model

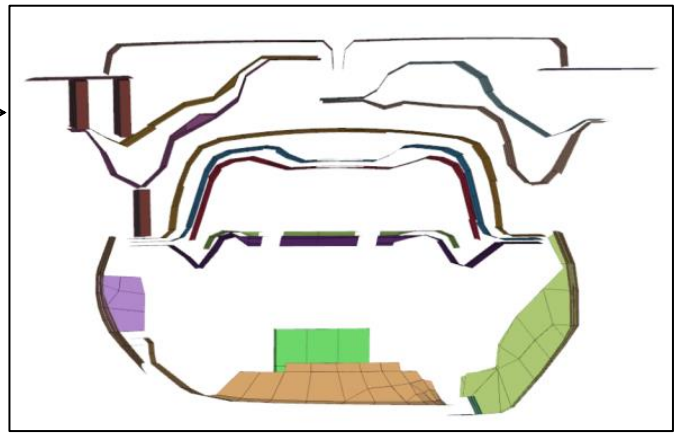
Starting point:

- FE model for side impact crash simulation
- material names, thicknesses, density
- connector elements: welding spots, adhesives



Model enhancement:

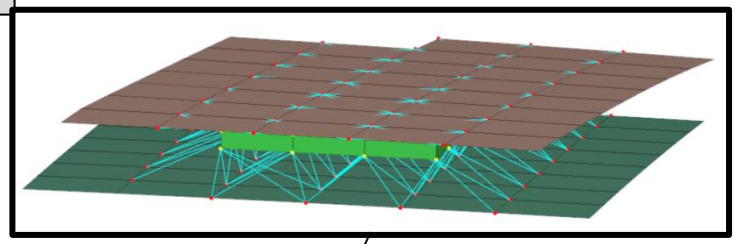
- Remeshing of missing parts
- Volume meshing of important parts
- Thermal contacts and bridges
- Cavity convection effects
- Thermal/solar radiative heat transfer
- Creation of a thermal material database: ρ, λ, c_p, ε, α, τ

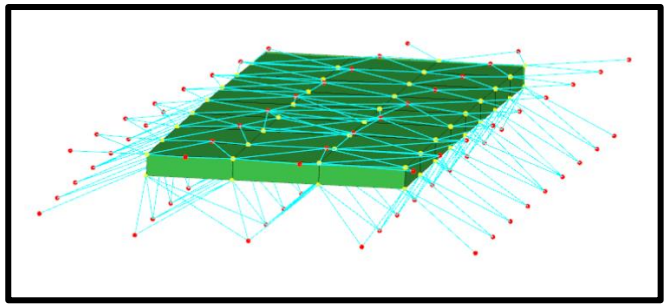


Detail: B-column section

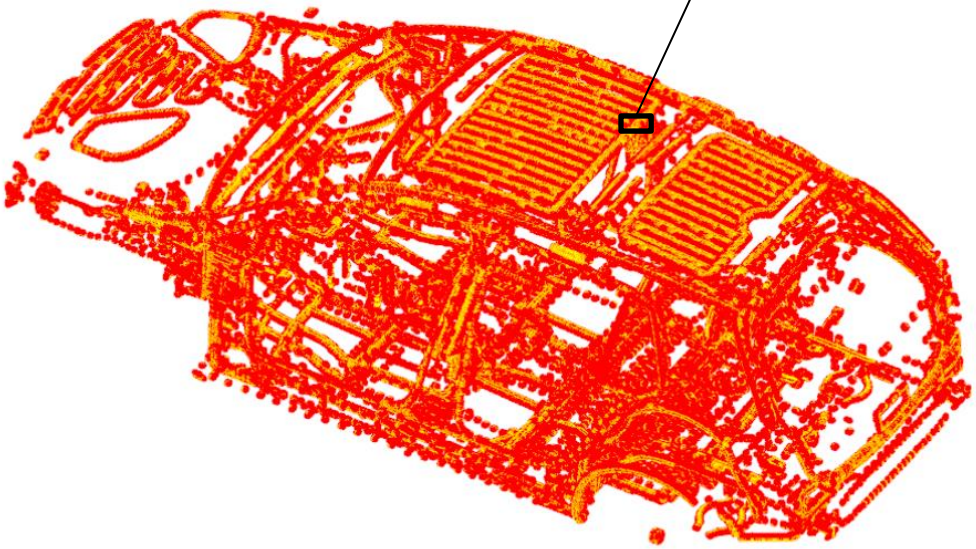
Creation of baseline thermal simulation model

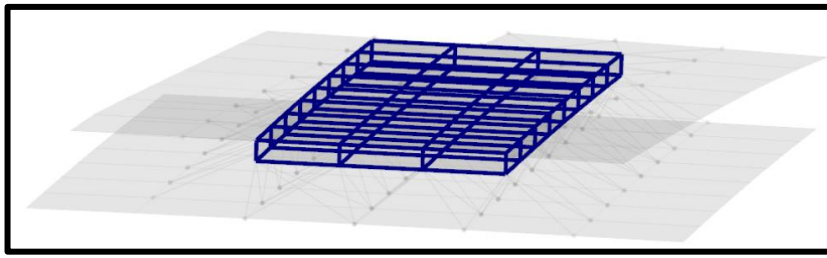
Connector elements
Heat bridges

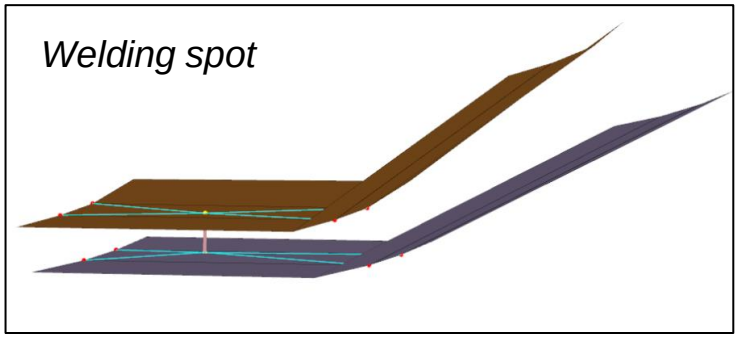




Adhesive lines

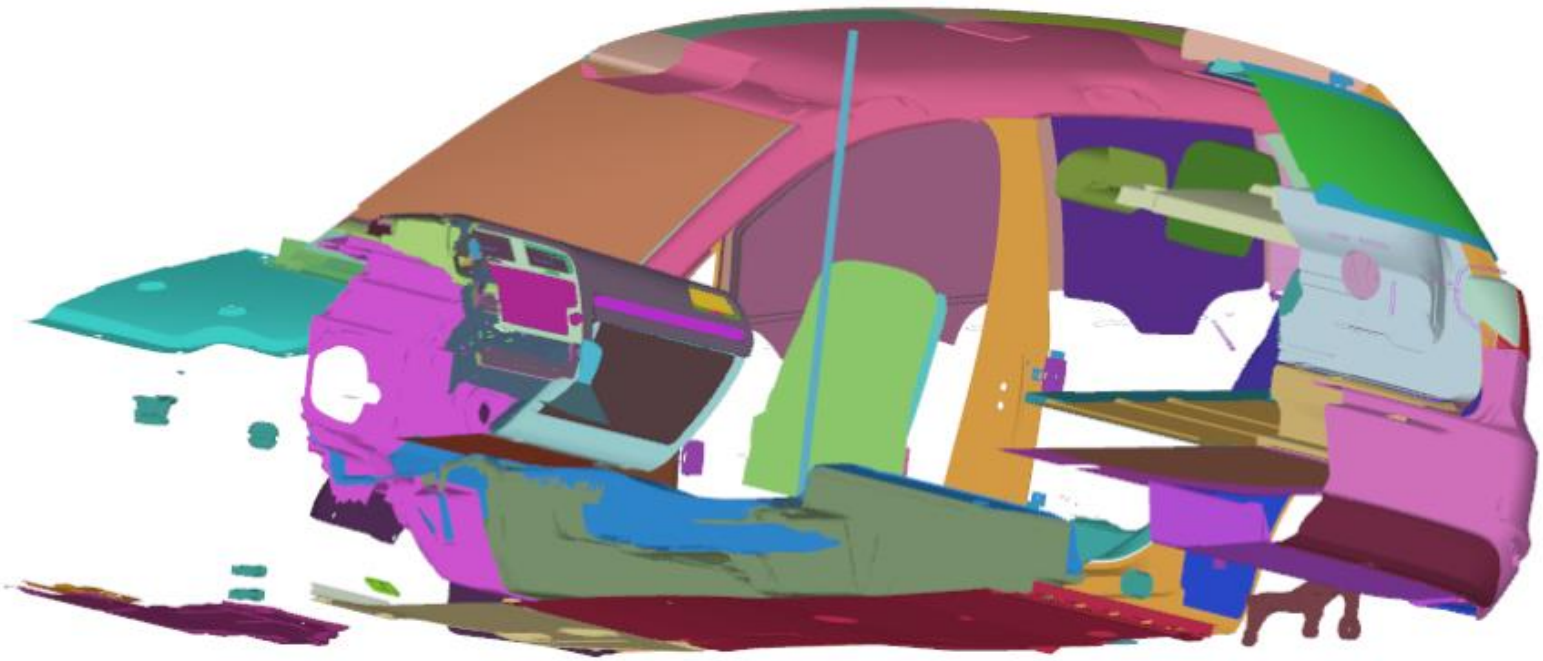






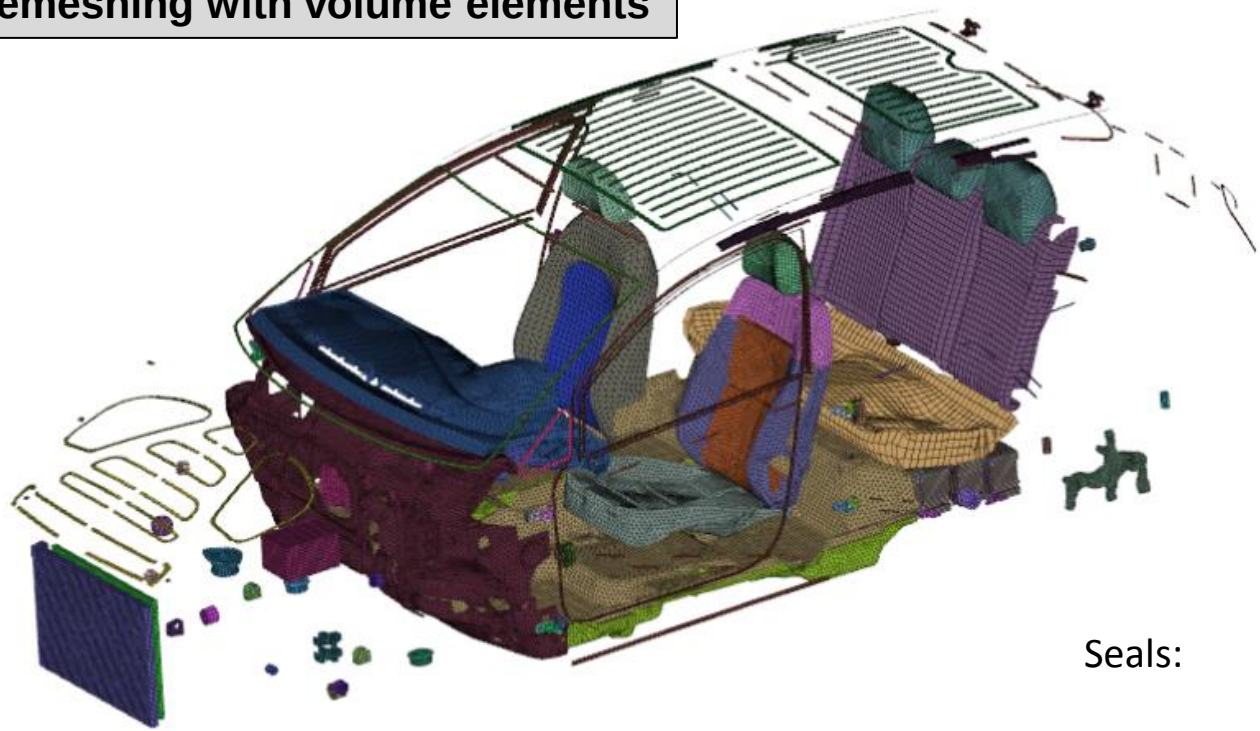
Creation of baseline thermal simulation model

Shell element remeshing

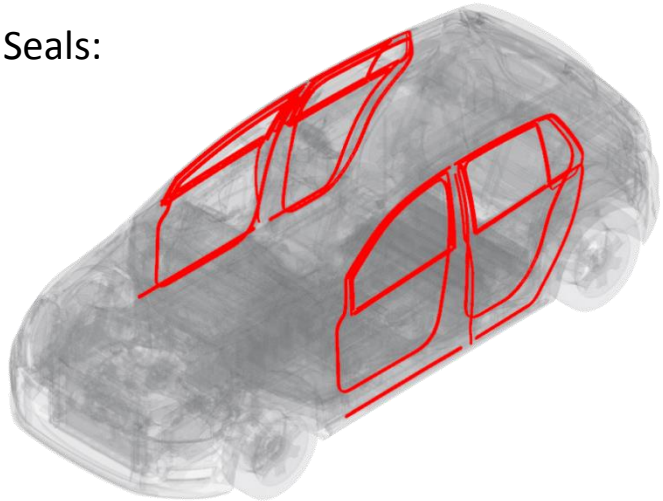


Creation of baseline thermal simulation model

Remeshing with volume elements



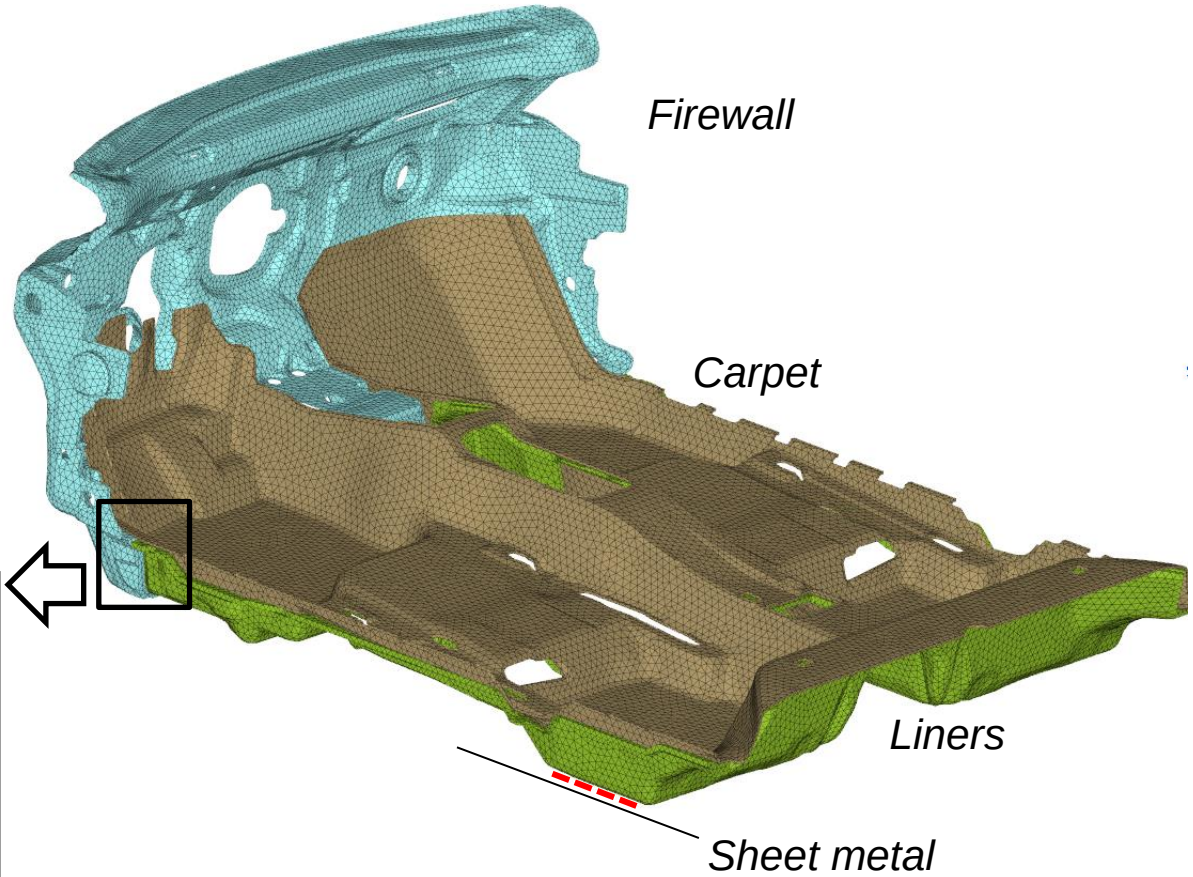
Seals:

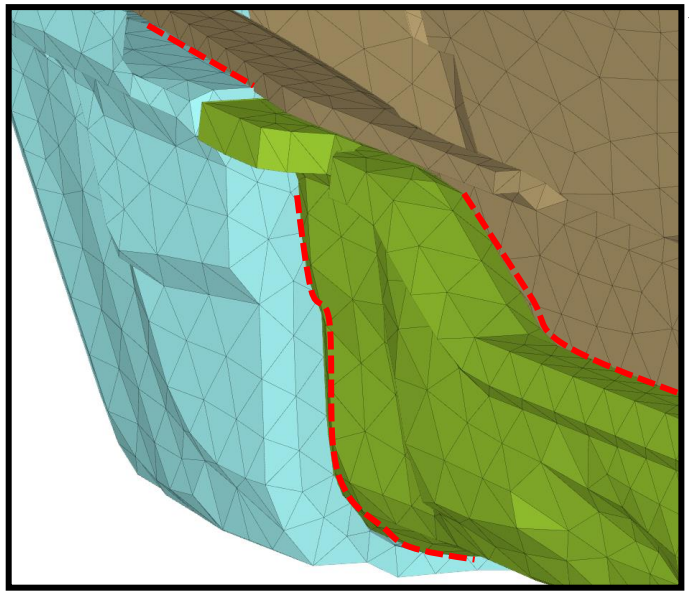


Creation of baseline thermal simulation model

Example of:

- **Volume element meshing**
- **Contacts**

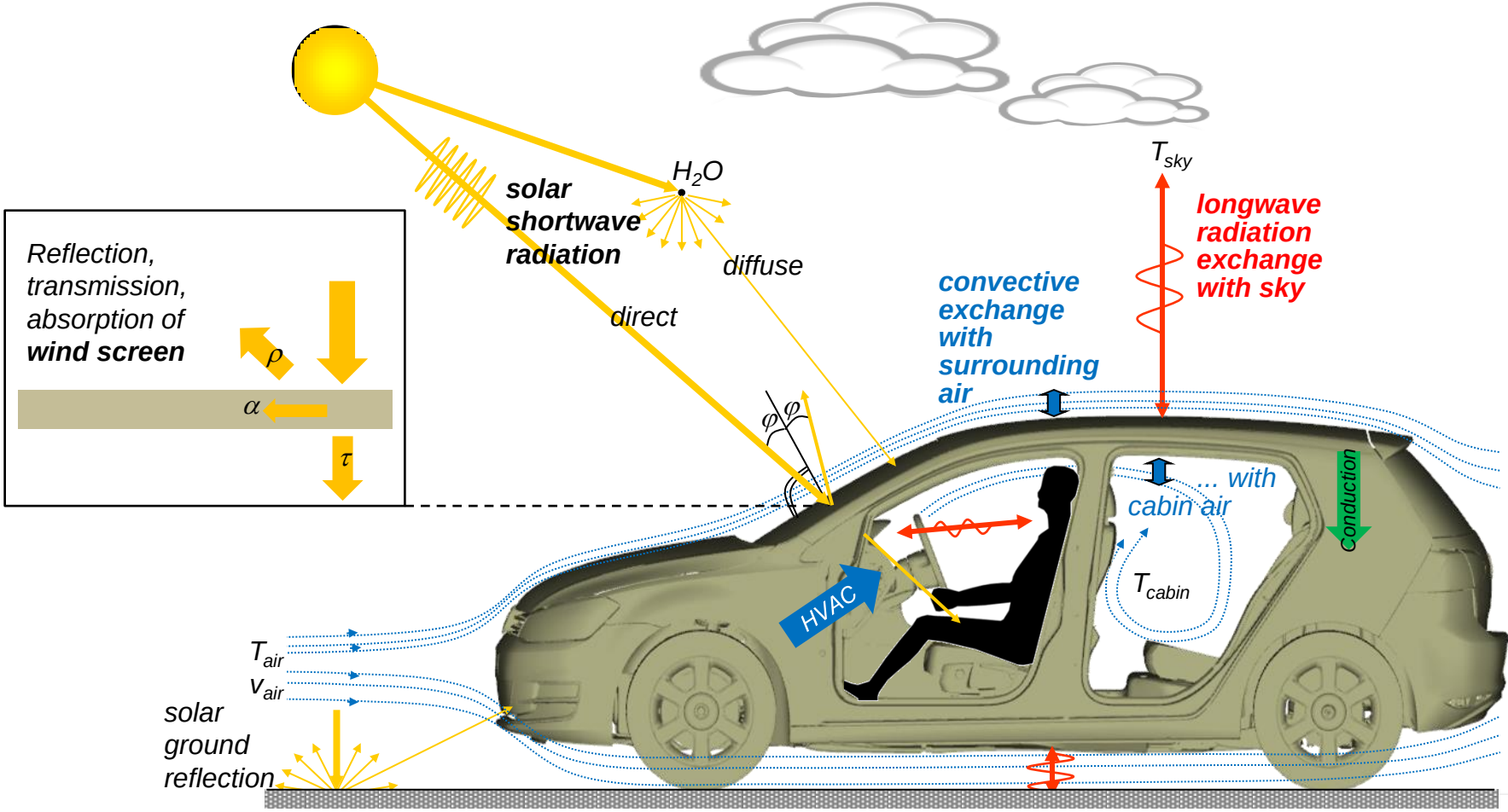




Thermal contacts

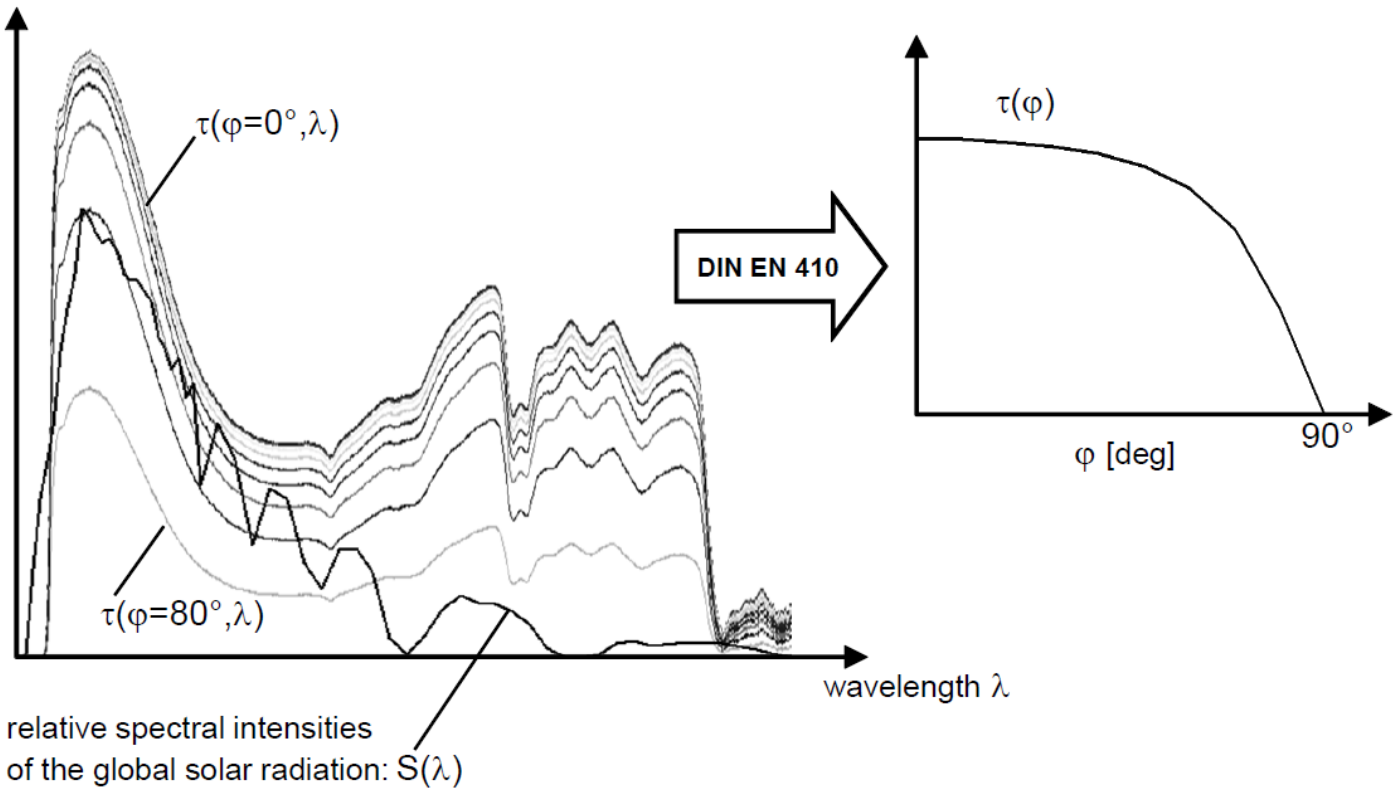
Creation of baseline thermal simulation model

Mechanisms of heat transfer



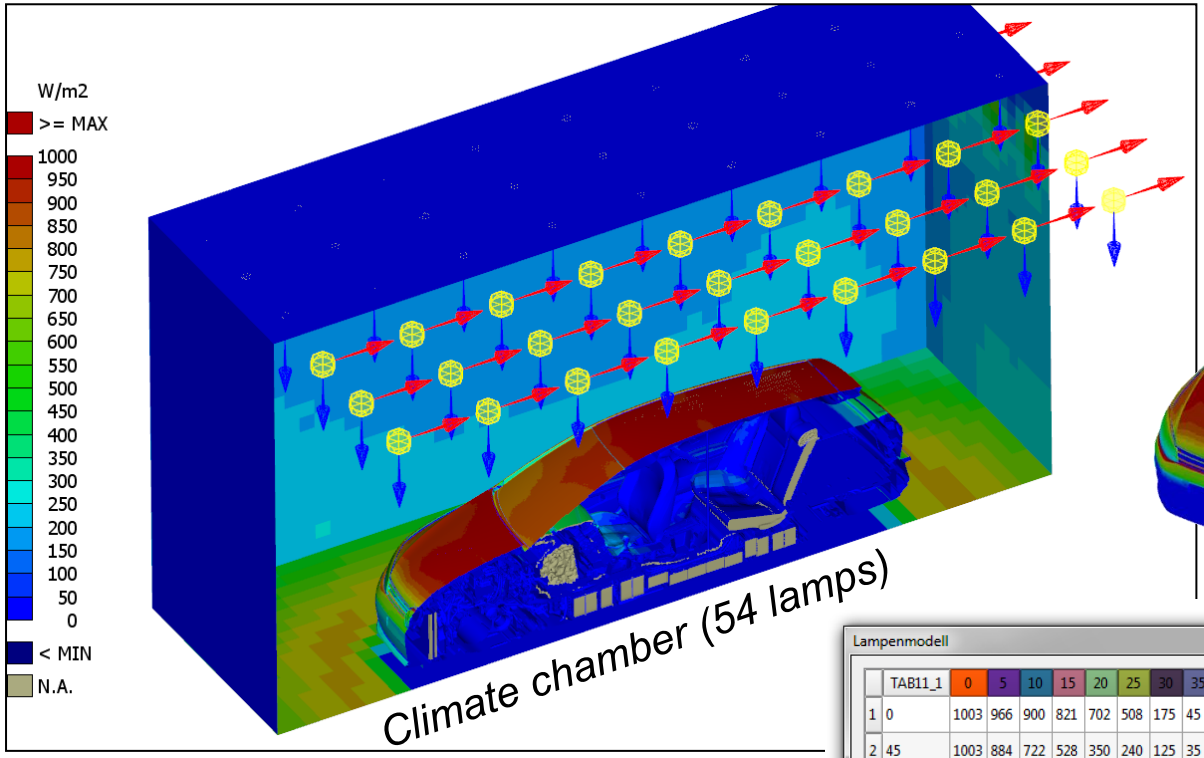
Creation of baseline thermal simulation model

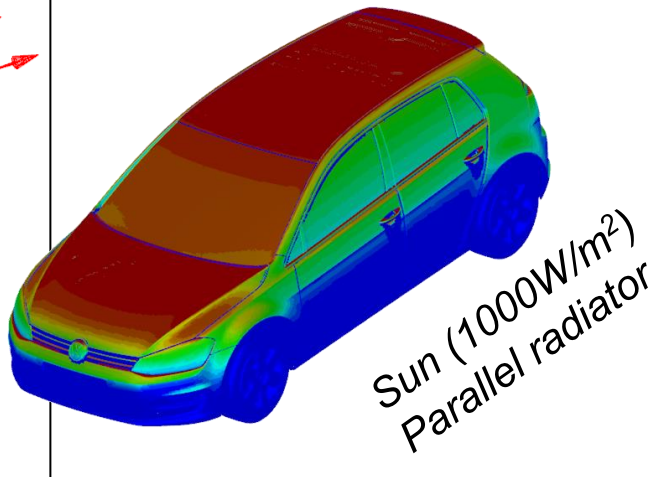
Example:
Transmissivity (standard glass)
dependency on wave length and incidence angle

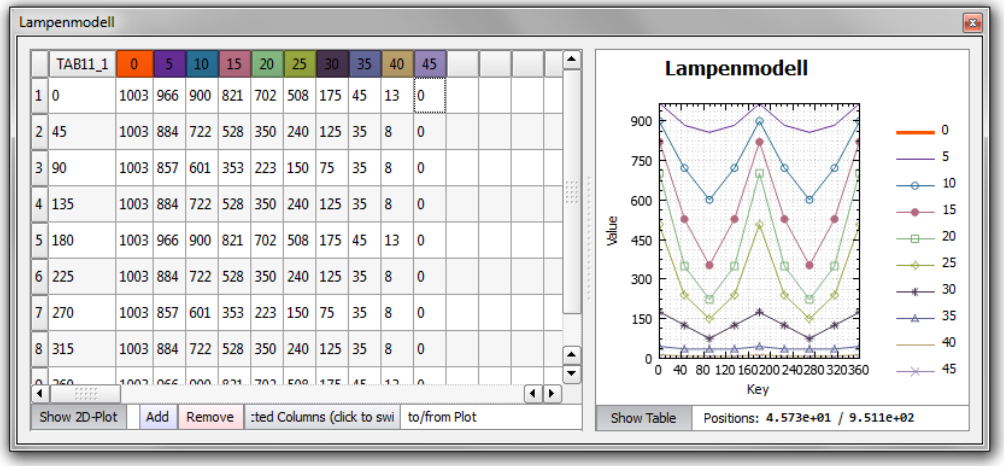


Creation of baseline thermal simulation model

Climate chamber model (summer load case)





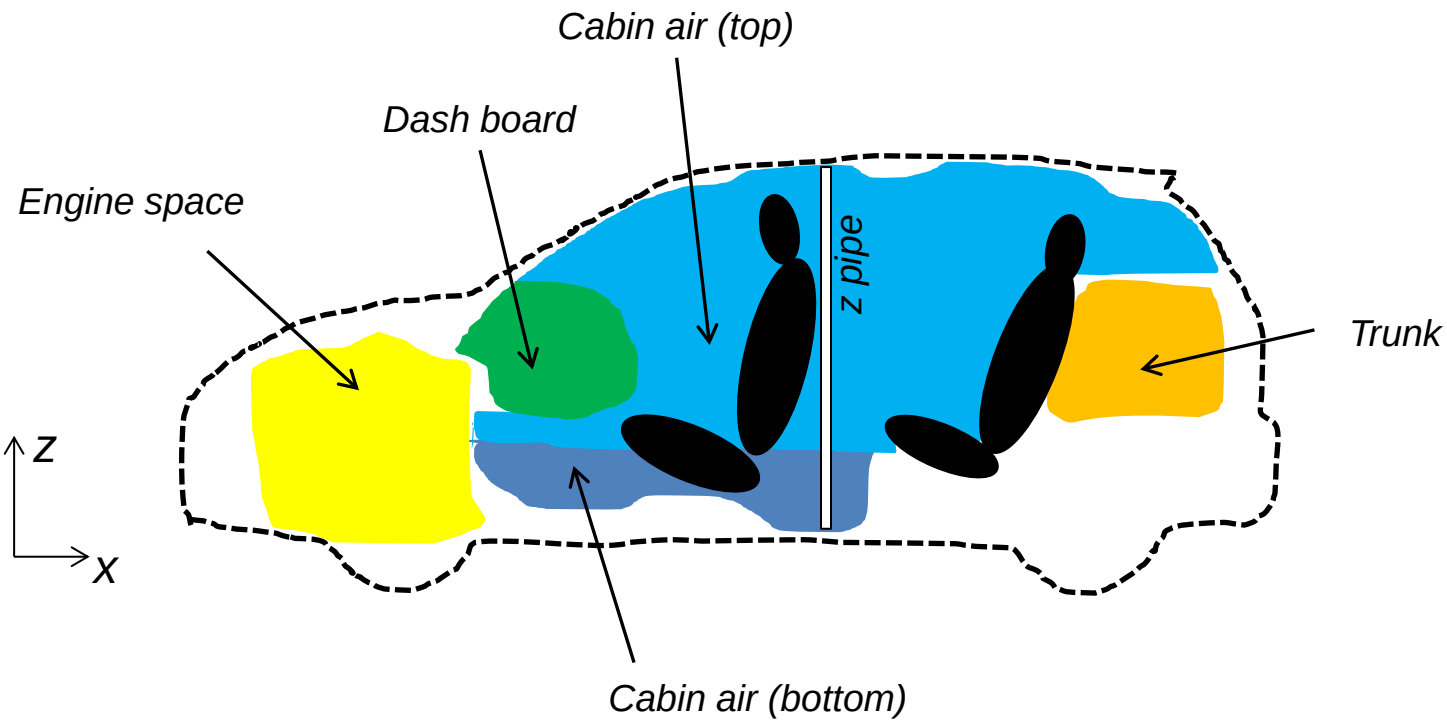


	TAB11_1	0	5	10	15	20	25	30	35	40	45
1	0	1003	966	900	821	702	508	175	45	13	0
2	45	1003	884	722	528	350	240	125	35	8	0
3	90	1003	857	601	353	223	150	75	35	8	0
4	135	1003	884	722	528	350	240	125	35	8	0
5	180	1003	966	900	821	702	508	175	45	13	0
6	225	1003	884	722	528	350	240	125	35	8	0
7	270	1003	857	601	353	223	150	75	35	8	0
8	315	1003	884	722	528	350	240	125	35	8	0

Creation of baseline thermal simulation model

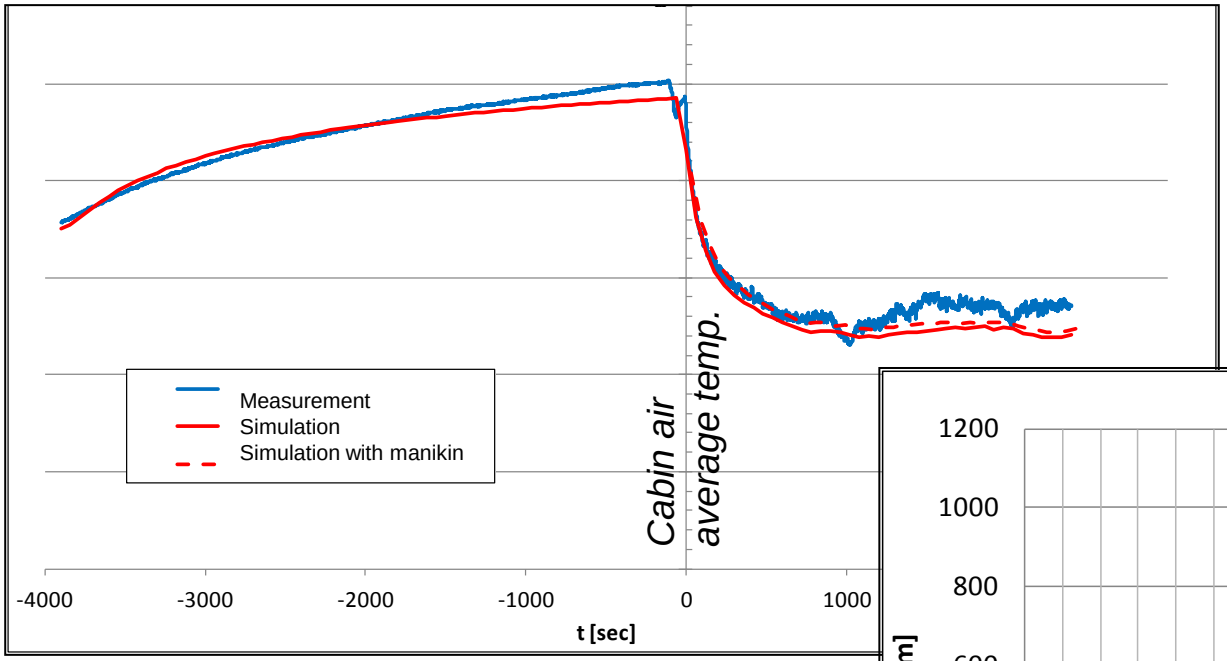
Cabin air zonal modelling

each „airzone“ has an average air temperature and humidity as degree of freedom

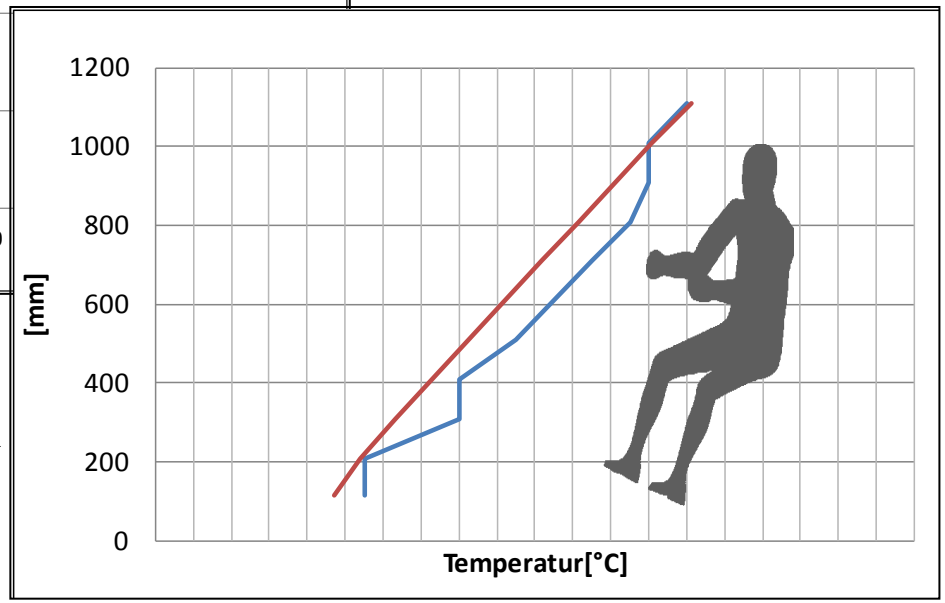


Creation of baseline thermal simulation model

Validation of summer load case „Pull-Down“ - Baseline

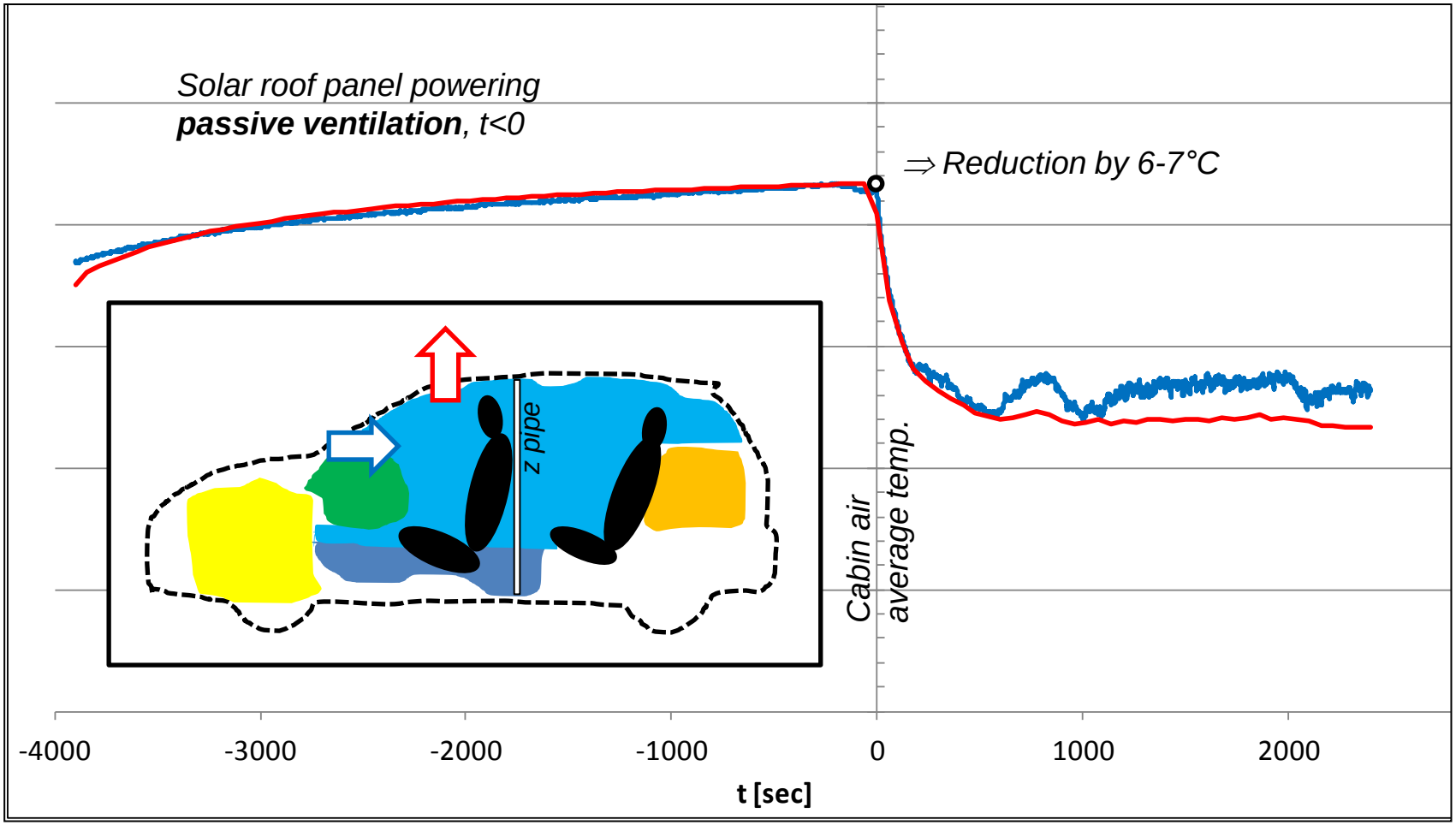


t=0



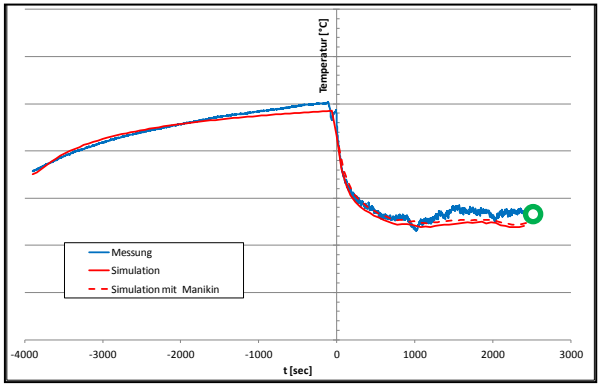
Creation of baseline thermal simulation model

Validation of summer load case „Pull-Down“ - Baseline

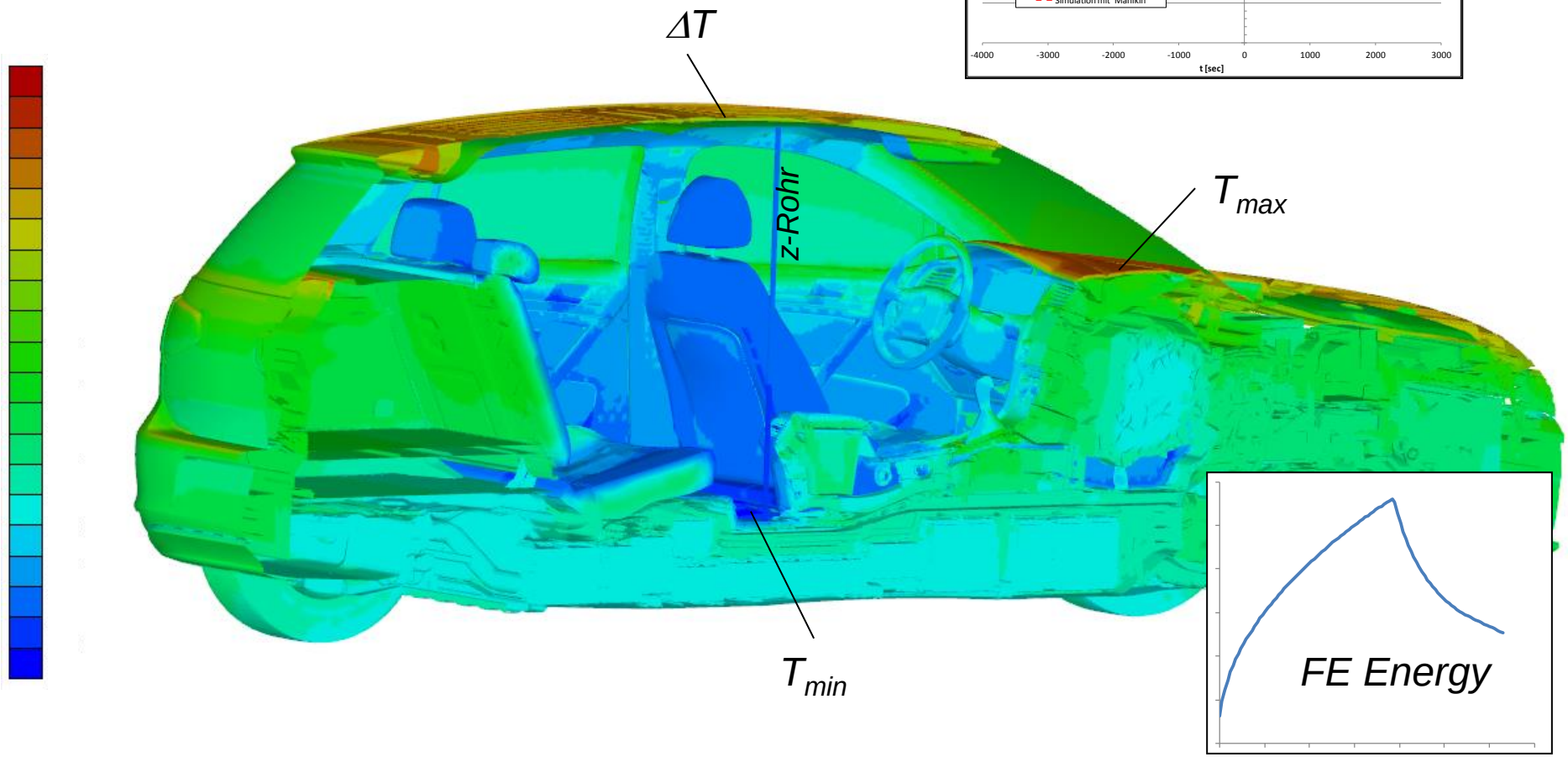


Creation of baseline thermal simulation model

Validation of summer load case
Solid part temperature, $t=t_{max}$
(Simulation)



t_{max}



Creation of baseline thermal simulation model

Baseline model statistics

Number of FEs
 # Shells: 2.1 million
 # Facets: 4.2 million
 # Solids: 1.1 million
 # 1D-Verbindungen: 0.2 million
 # DOF: 4.3 million

Material data
 # Properties: 2.600
 # Materials: 90

Computation time
 # 4 CPUs: 2-5h

Model creation effort
- *Several months, including research of material parameters*

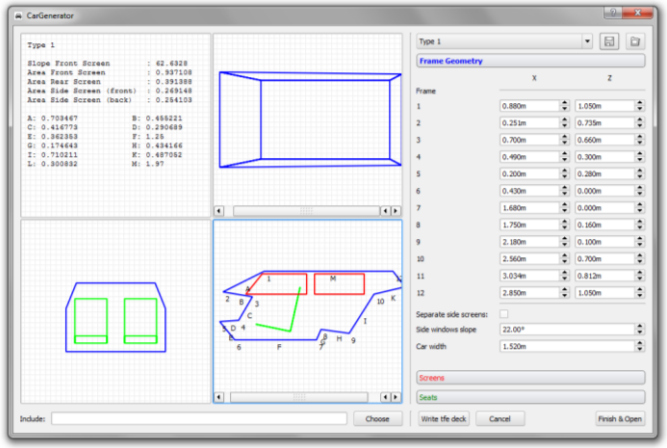
Part 2:

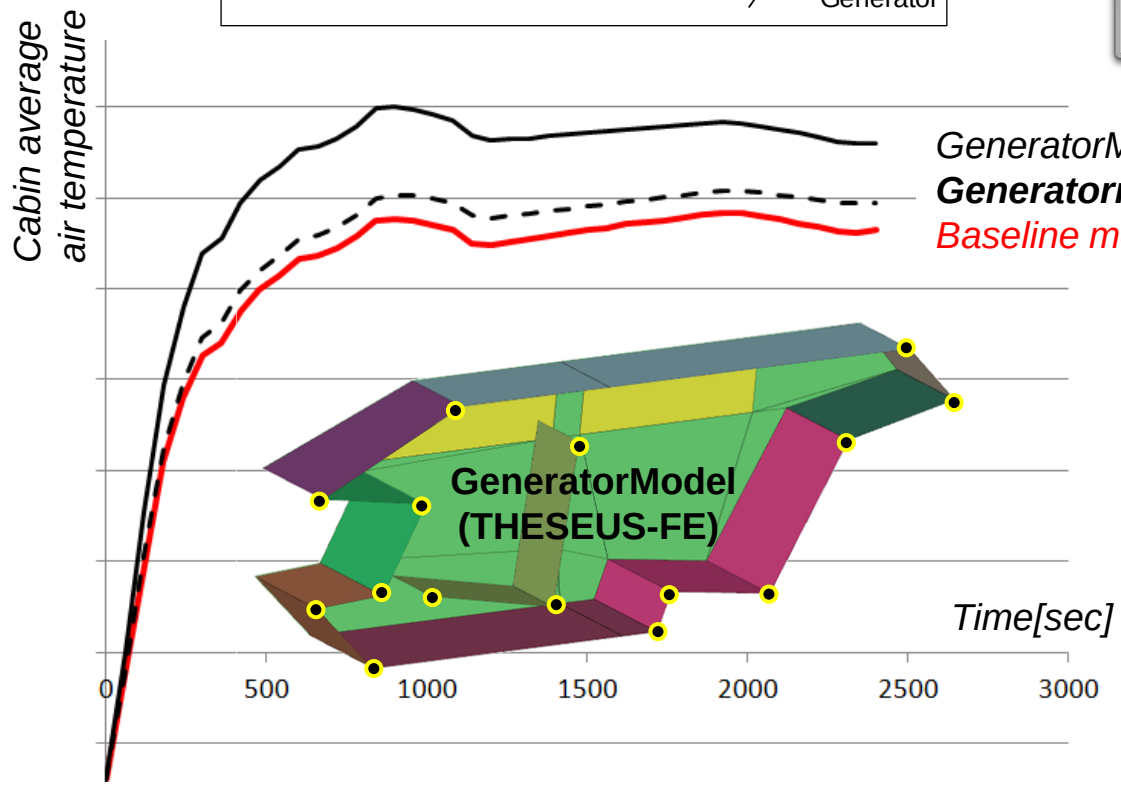
Simplified simulation model

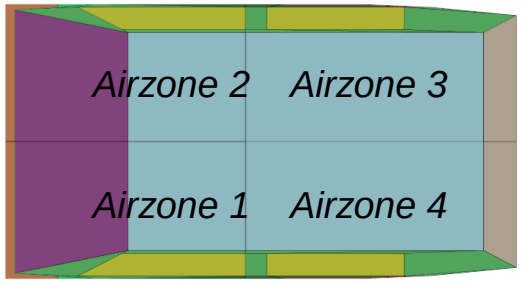
Simplified simulation model

Winter load case "Heat up"

Area correction factor $x = A / A_{Generator}$

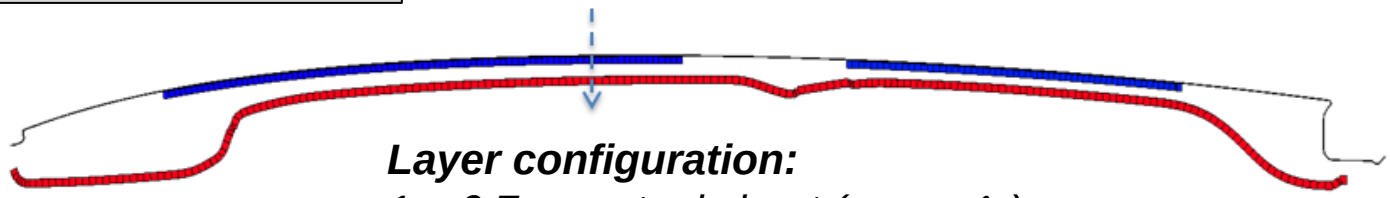






Simplified simulation model

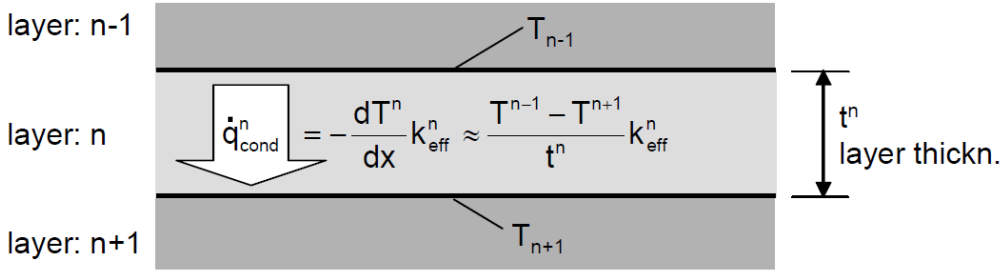
1D heat conduction modelling



Layer configuration:

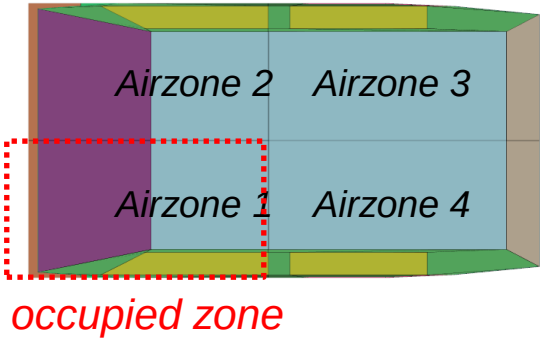
1. *0.7 mm steel sheet (c_1, ρ_1, λ_1)*
2. *8.5 mm liner*
3. *<u>25 mm air</u>*
4. *9.4 mm canvas*

Air layer:



$$k_{eff} = \underbrace{\frac{h_{conv} t_n}{2}}_{convection} + \underbrace{\frac{t^n \sigma}{1/\varepsilon^{n-1} + 1/\varepsilon^{n+1} - 1} \left(\bar{T}^{n-1} + \bar{T}^{n+1}\right)\left[(\bar{T}^{n-1})^2 + (\bar{T}^{n+1})^2\right]}_{radiation}$$

$\bar{T}$ in Kelvin

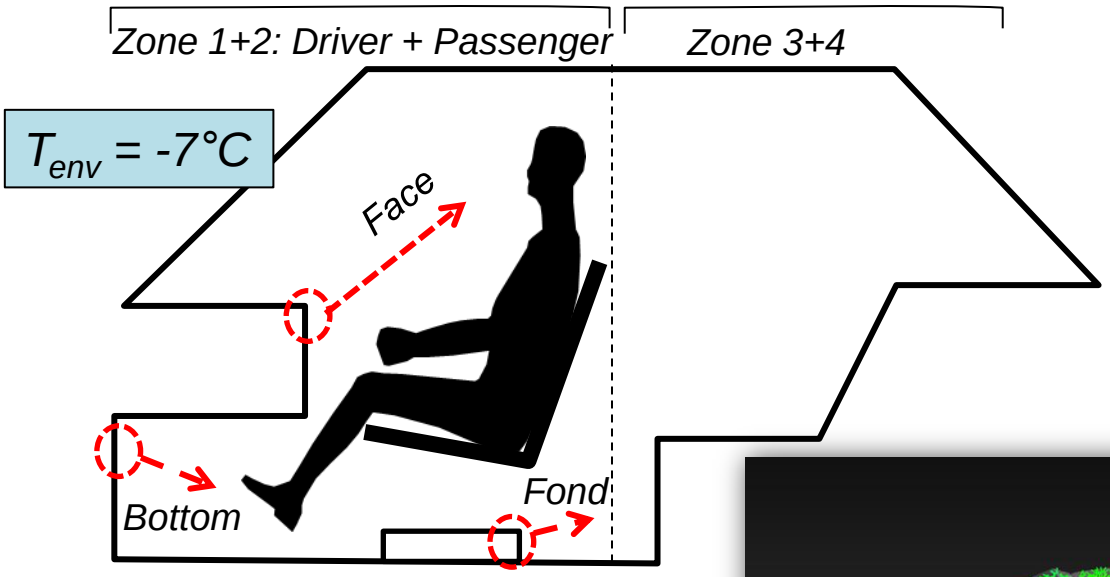


Part 3

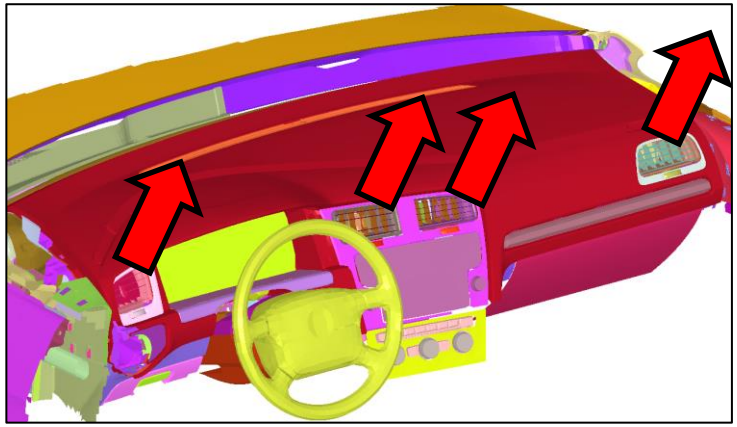
Concepts for zonal climatization

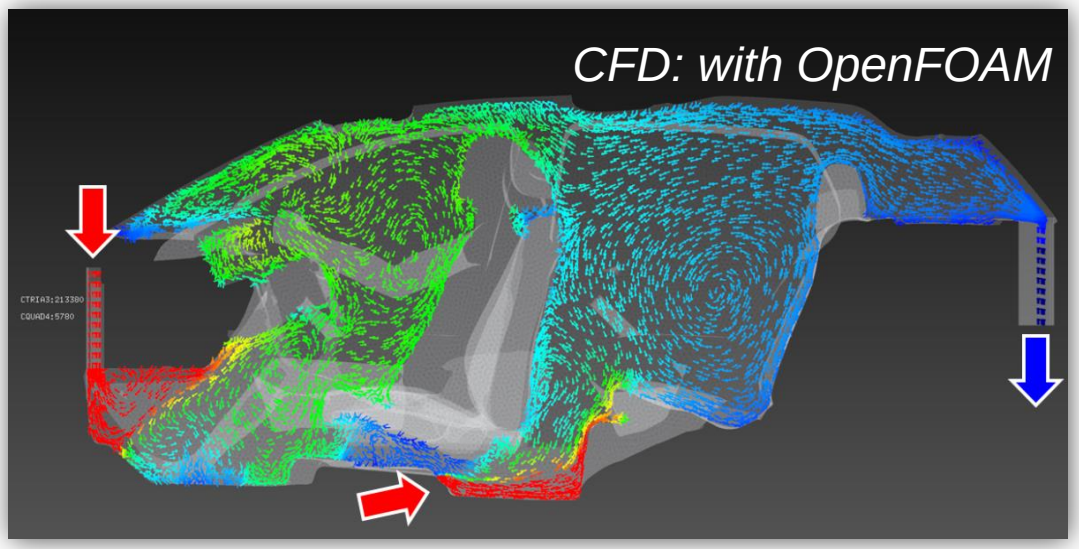
Concepts for zonal climatization

Winter load case "Heat up"



Face outlets

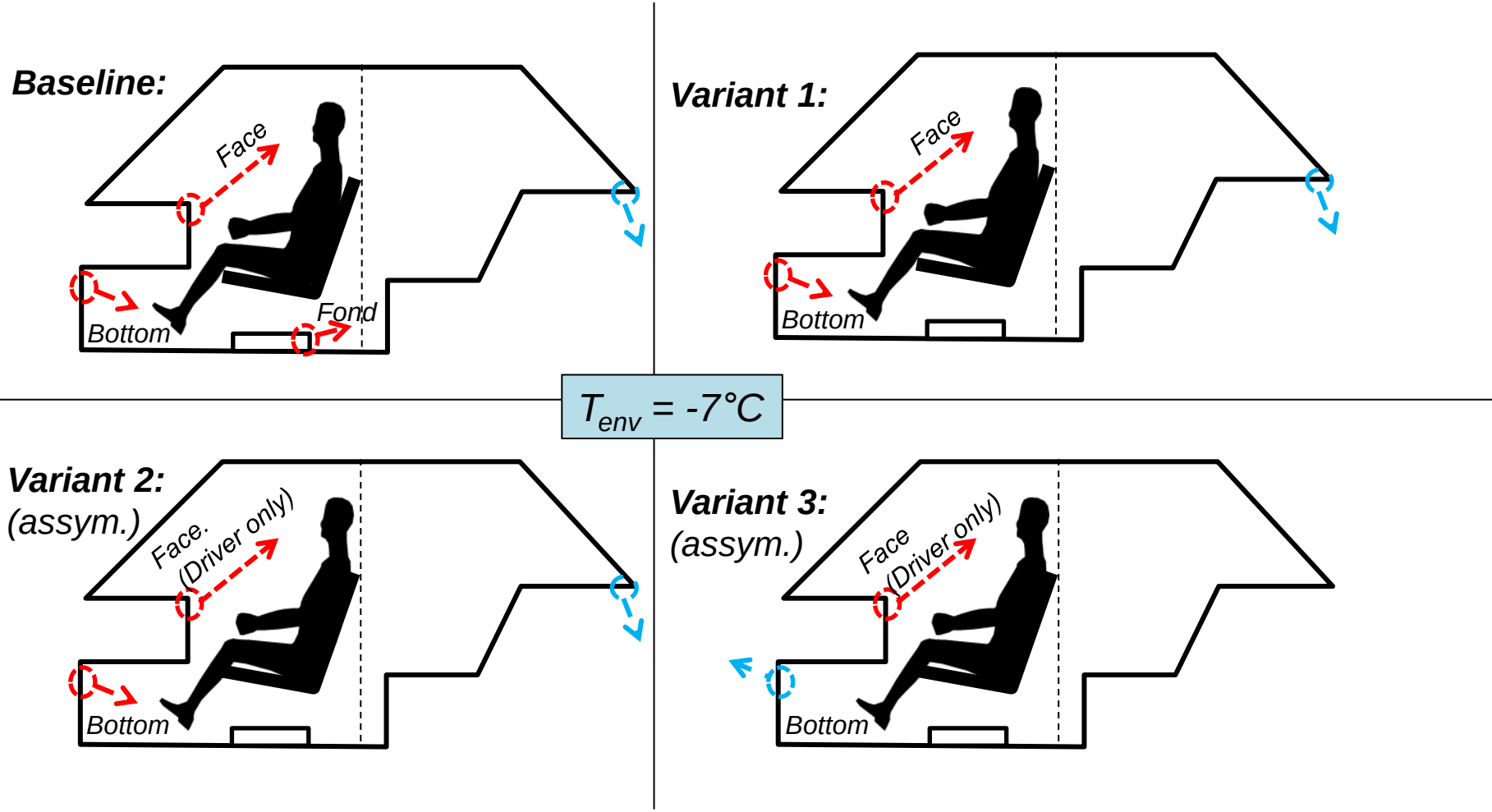




- *Steady-state flow assumed*
- *CFD ⇒ Volume flow rates through zone borders*
- *Constant outlet temperature assumed*
- *Overall goal: raise temperature in driver zone to 24.7 °C after 10 min (corresponds roughly to PMV=0)*

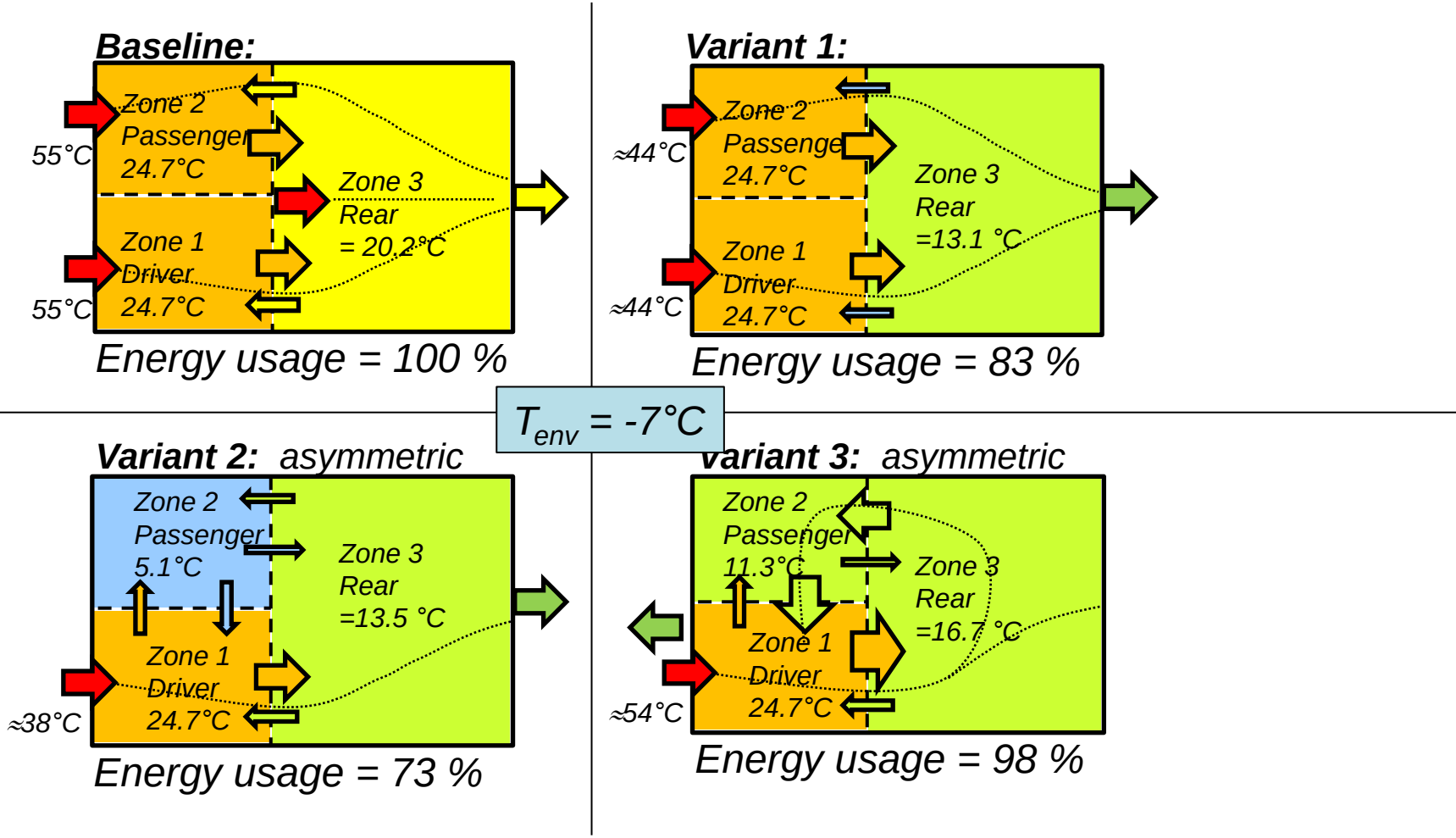
Concepts for zonal climatization

Winter load case
Variants



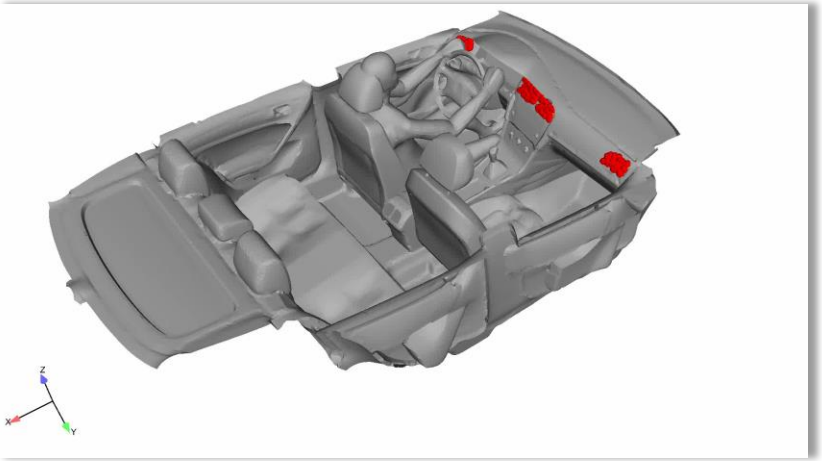
Concepts for zonal climatization

Winter load case
Variants

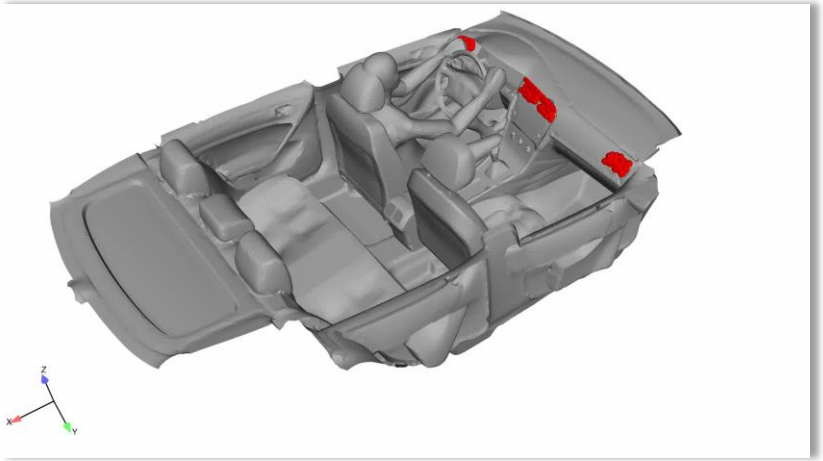


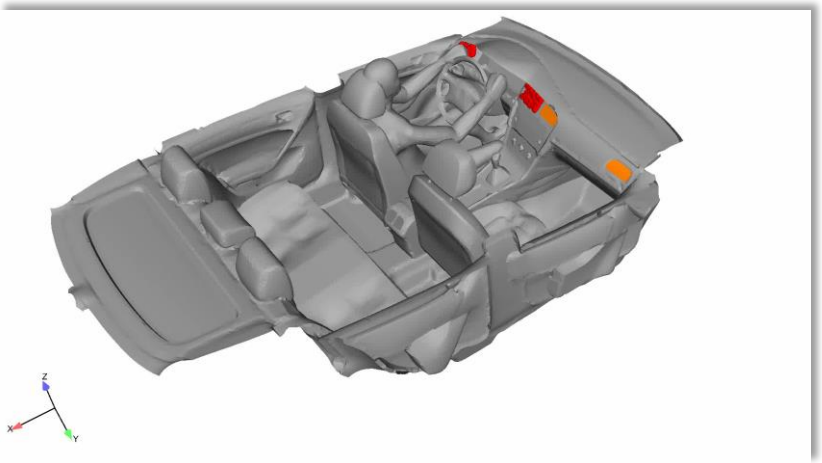
Concepts for zonal climatization

Basis

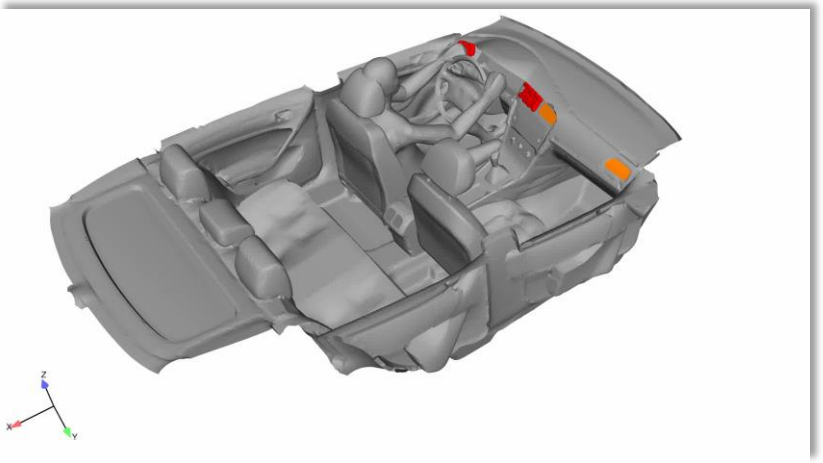


Variant 1





Variant 2



Variant 3

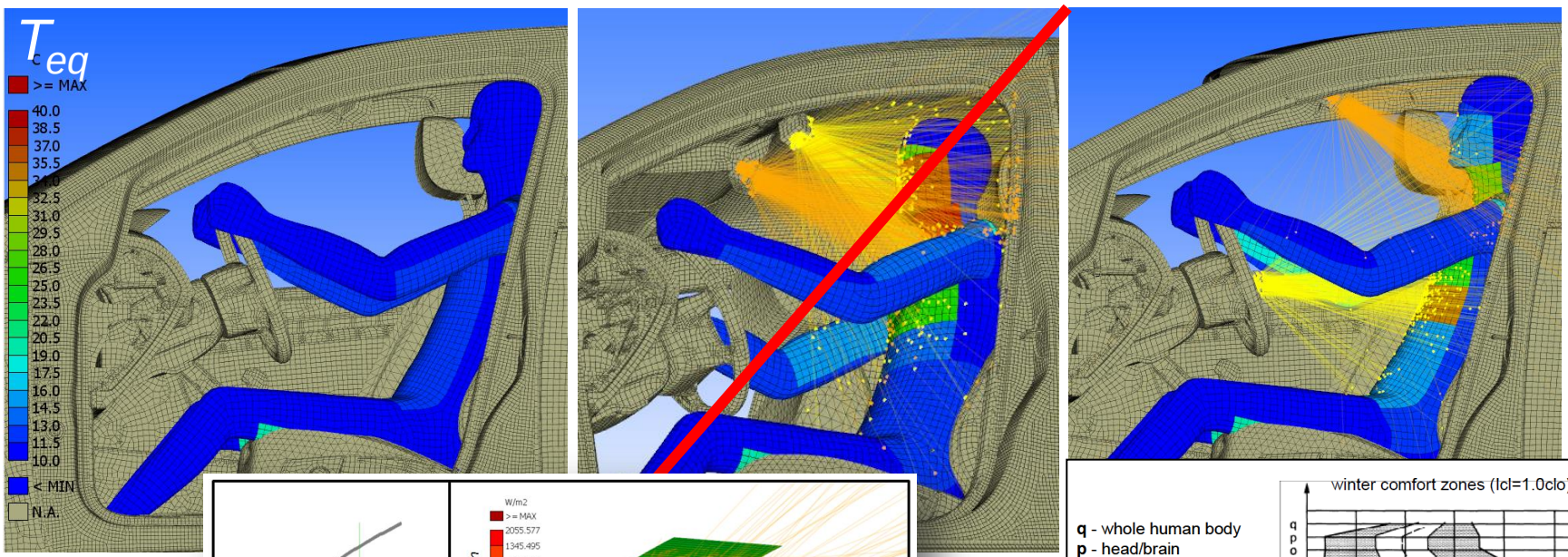
Part 4:

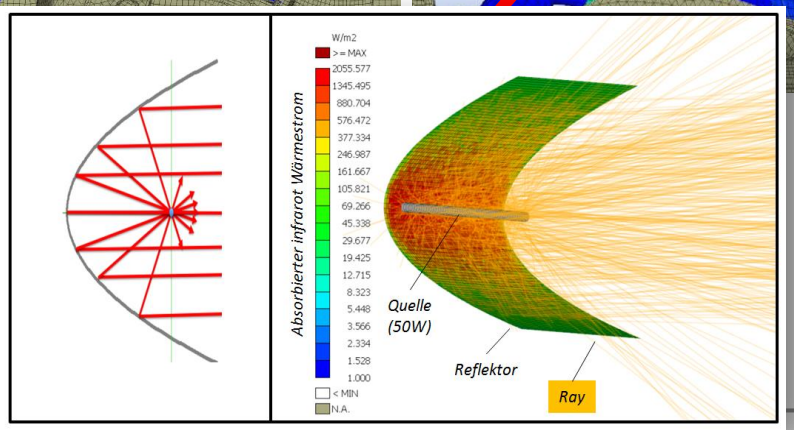
1. IR radiators and local thermal comfort

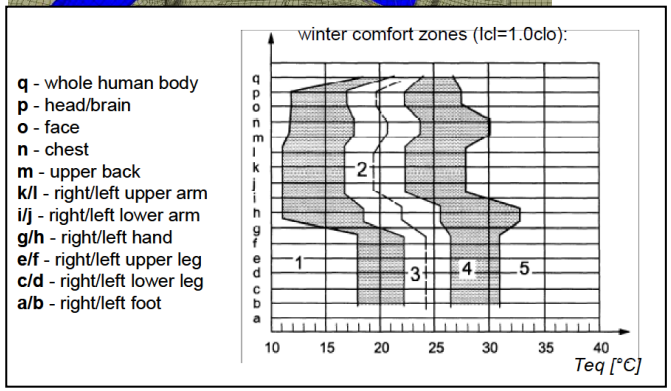
IR radiators and local thermal comfort

Winter load case
Variants with reduced outlet temperature

- *Baseline without IR emitters*
- *Var. 1 with IR emitters above*
- *Var. 2 with IR emitters above and below*







ISO-14505-2

IR radiators and local thermal comfort

Coupled comfort simulations

$$\dot{Q}_{convection} = A \cdot h \cdot \left(T_{fluid} - T_{wall}\right)$$

CFD Simulation (OpenFOAM) $\xrightarrow{h\ ,T_{fluid}}$ *Therm. Simulation (THESEUS-FE)*

CFD Simulation (OpenFOAM) $\xleftarrow{T_{wall}}$ *Therm. Simulation (THESEUS-FE)*

- *Data exchange with **OpenFOAM** via mapping*
- *Thermophysiology model: **FIALA-FE***
  - *Heat conduction within body*
  - *Circulatory system, metabolism, shivering*
  - *Contact heat flow, clothing, respiration, transpiration, sweating (incl. humidity exchange with **OpenFOAM**)*
- *Thermal comfort evaluation for human model **FIALA-FE**: PMV, DTS, Teq, ISO-14505-2, Zhang*
- *3D heat conduction in solids with **THESEUS-FE***
- *3D radiation thermal and solar in **THESEUS-FE***

IR radiators and local thermal comfort

Coupled comfort simulations

What data is exchanged during co-simulation?

Parameter	Units	Source	Target	
Wall temperature T_{wall}	°C	THESEUS-FE	OpenFOAM	field
Local convective coefficient of heat transfer h	$W/(m^2K)$	OpenFOAM	THESEUS-FE	field
Adjacent fluid temperature T_{fluid}	°C	OpenFOAM	THESEUS-FE	field
Current time increment Δt	S	THESEUS-FE	OpenFOAM	scalar
Rate of water vapor generation J	$kg/(m^2s)$	THESEUS-FE	OpenFOAM	field
Mass fraction of water vapor Y_{H2O}	-	OpenFOAM	THESEUS-FE	field
Air pressure p	Pa	OpenFOAM	THESEUS-FE	field
Avg. inlet temperature T_{in}	°C	AC model	OpenFOAM	scalar
Avg. water vapor fraction $X_{H2O,in}$	-	AC model	OpenFOAM	scalar
Avg. outlet temperature T_{out}	°C	OpenFOAM	AC model	scalar
Avg. water vapor fraction $X_{H2O,out}$	-	OpenFOAM	AC model	scalar
PMV (=global comfort index)	-	THESEUS-FE	AC model	scalar

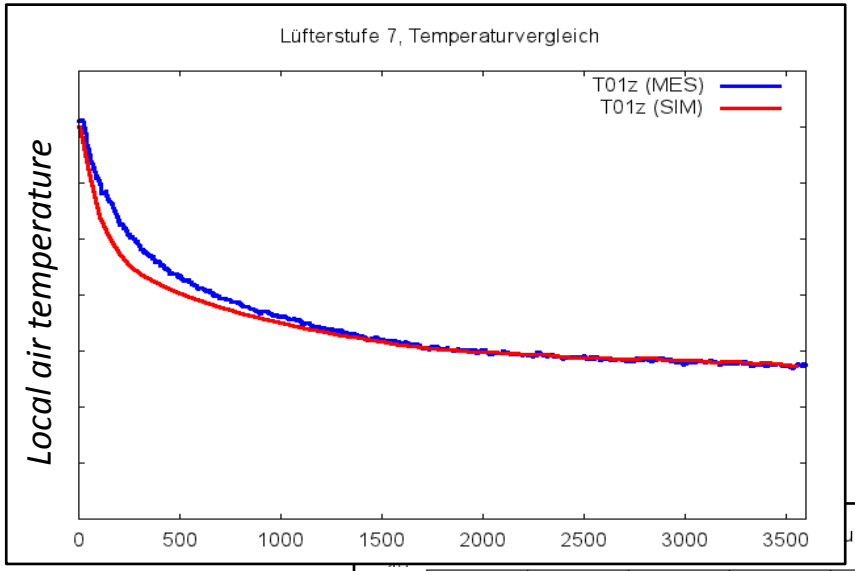
Part 5:

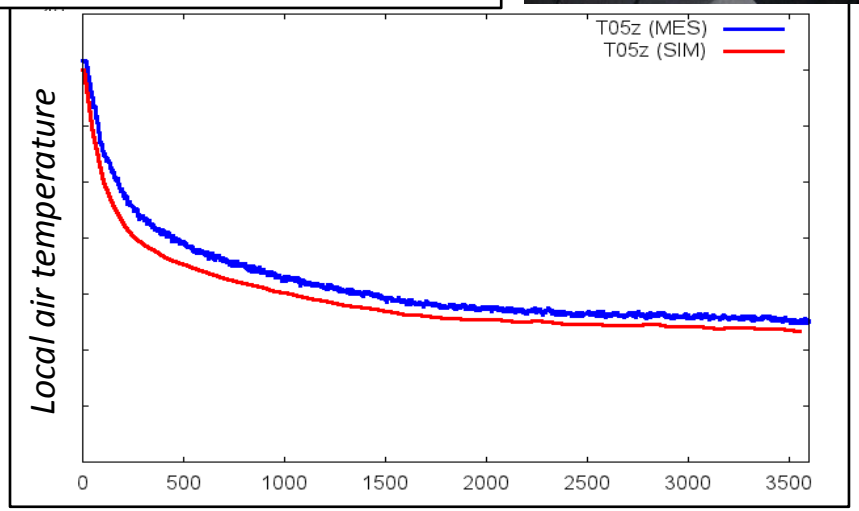
Validation of coupled cabin simulation

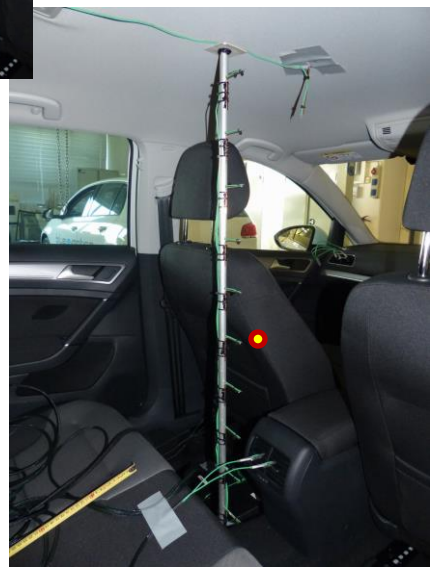
OpenFOAM $\leftrightarrow$ THESEUS-FE

Validation of coupled cabin simulation

Validation summer load case ("pull-down")







Validation of coupled cabin simulation

Validation summer load case