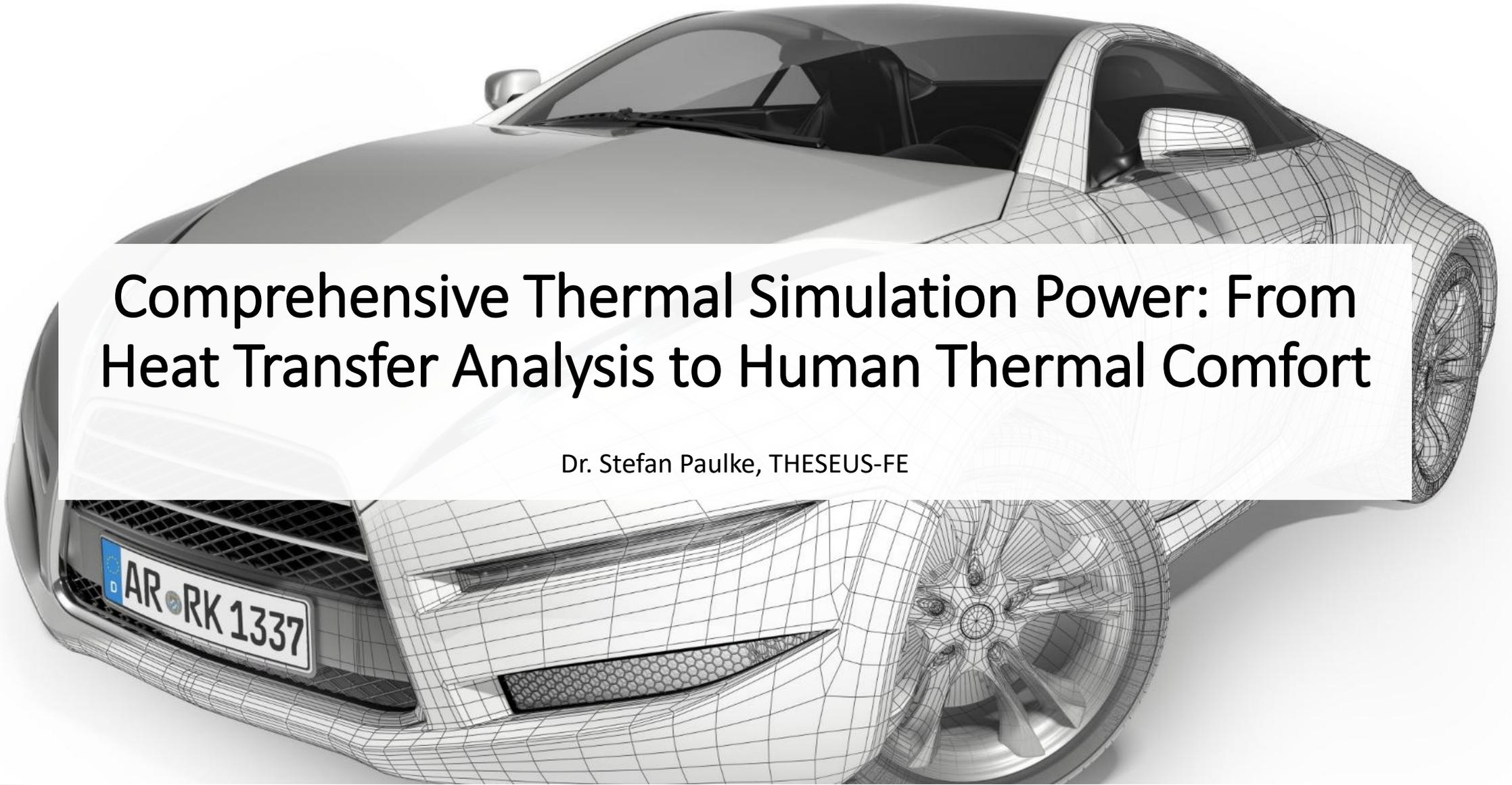




# Comprehensive Thermal Simulation Power: From Heat Transfer Analysis to Human Thermal Comfort

Dr. Stefan Paulke, THESEUS-FE



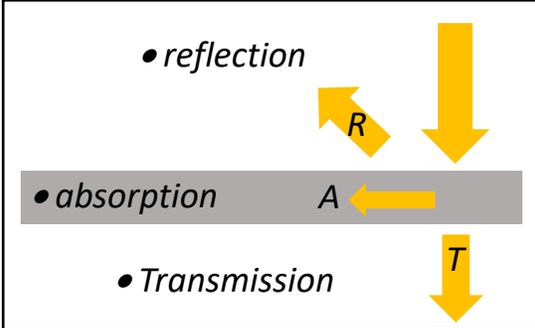


# Introduction To Cabin Simulation



# The General Idea Of Cabin Modelling

## Boundary conditions



solar short wave radiation

direct

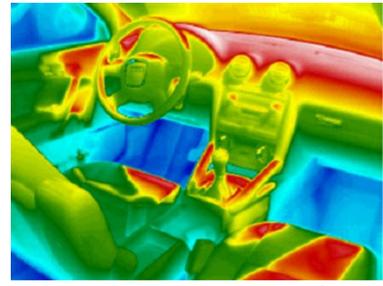


H<sub>2</sub>O

diffusive

T<sub>sky</sub>

long wave radiation heat exchange



Infrared thermography (IRT)

Cabin

T<sub>air</sub>  
v<sub>air</sub>

HVAC

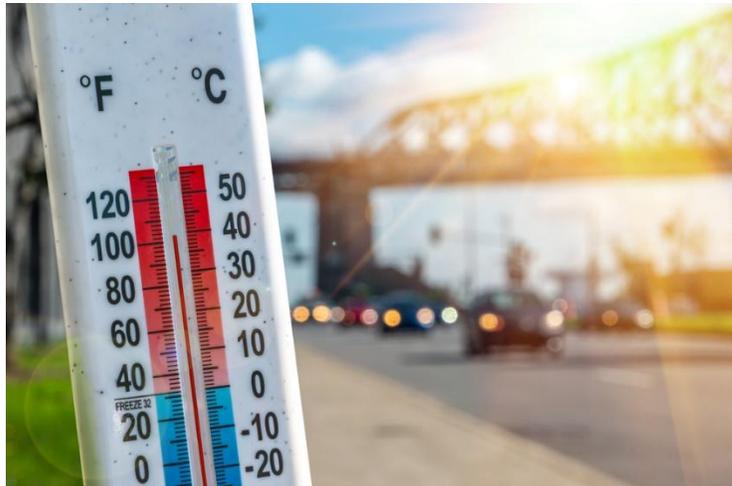
heat conduction

T<sub>air</sub>

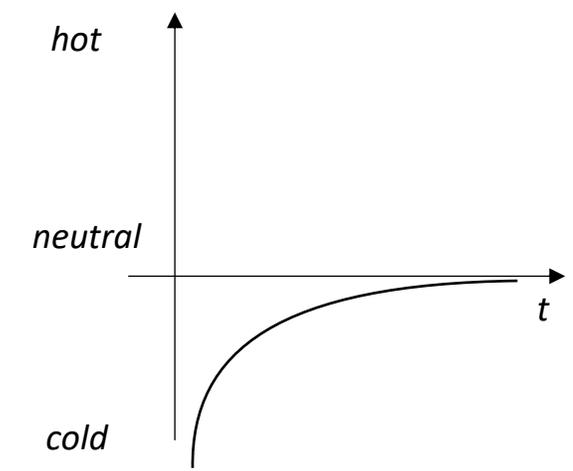
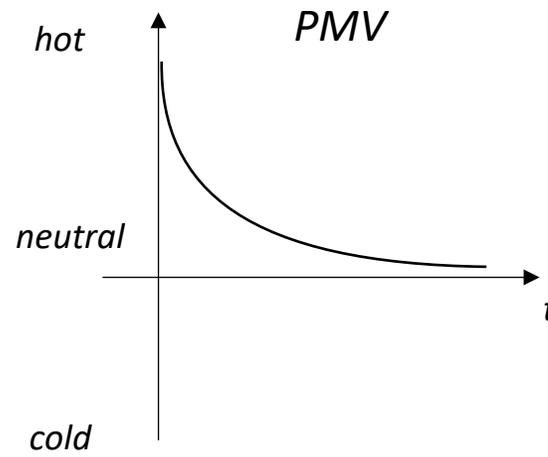
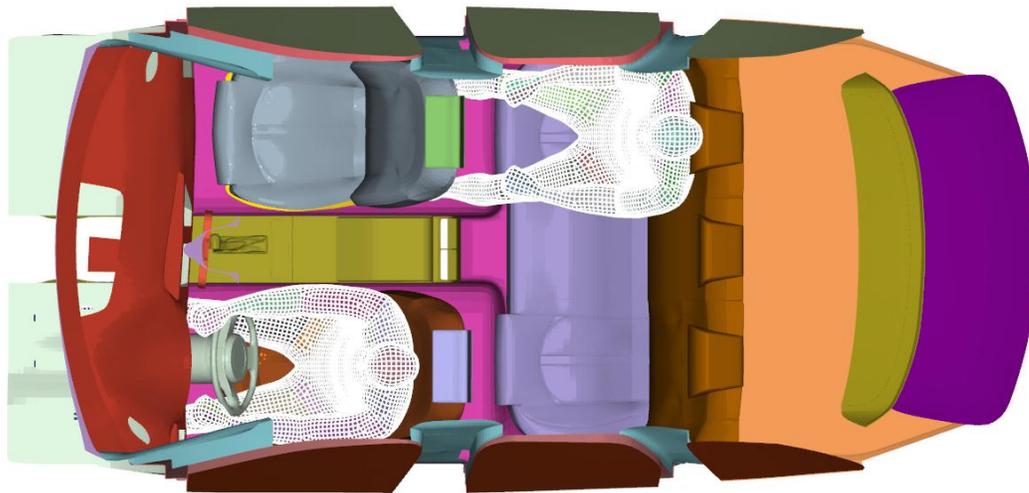


# Prevent Humans From Thermal Discomfort

Summer load case



Winter load case

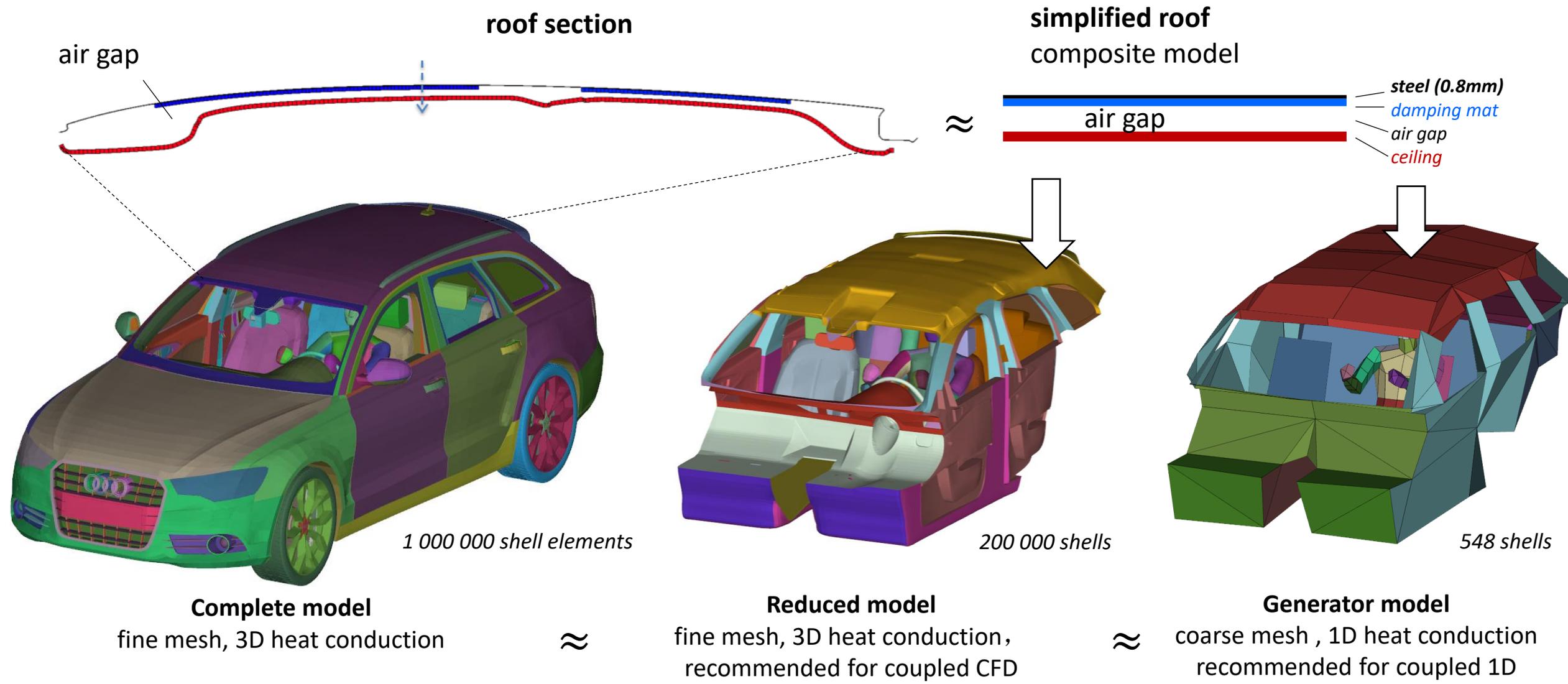




# Outstanding Features of Cabin Simulation with THESEUS-FE



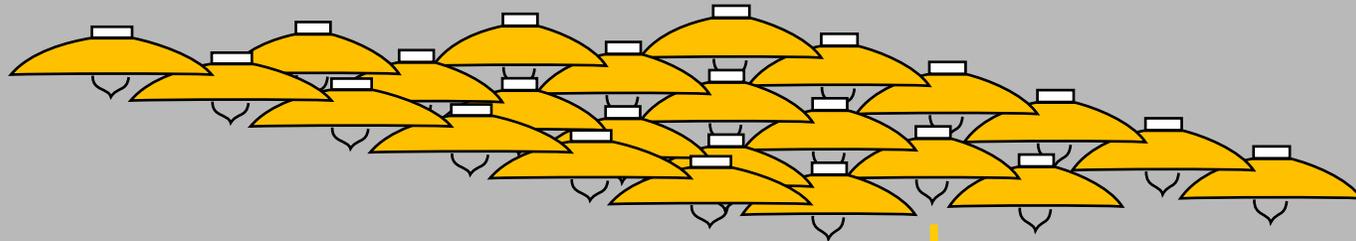
# Different Types of Cabin Models



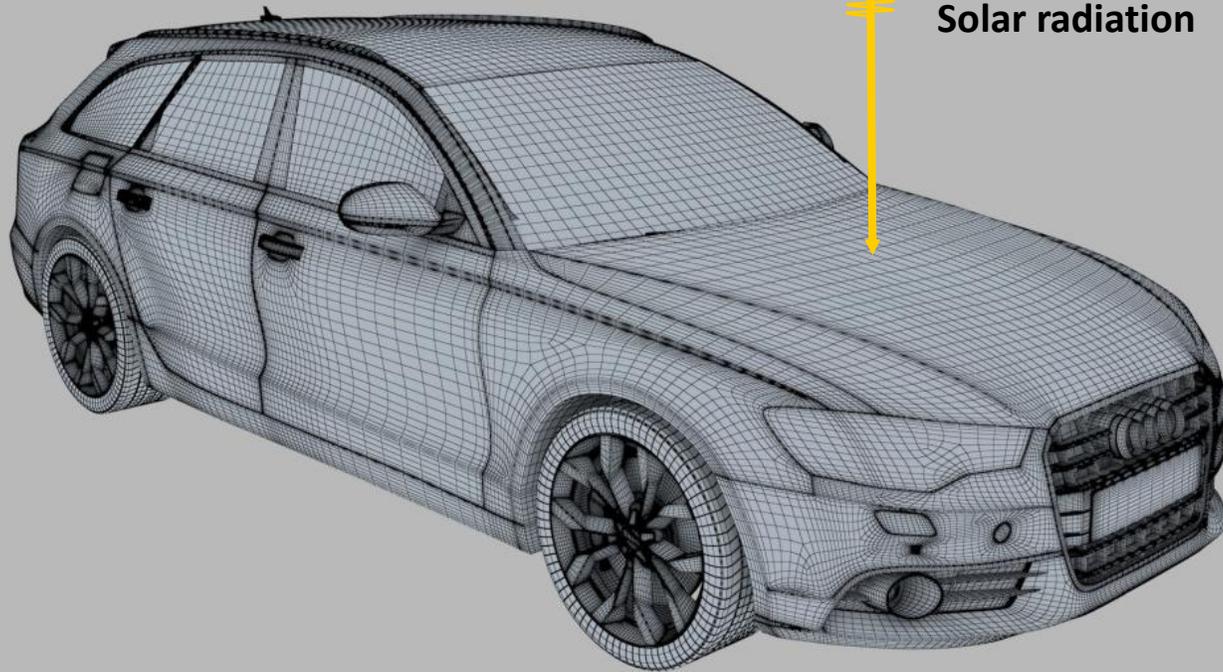


# Climate Chamber Lamp Model

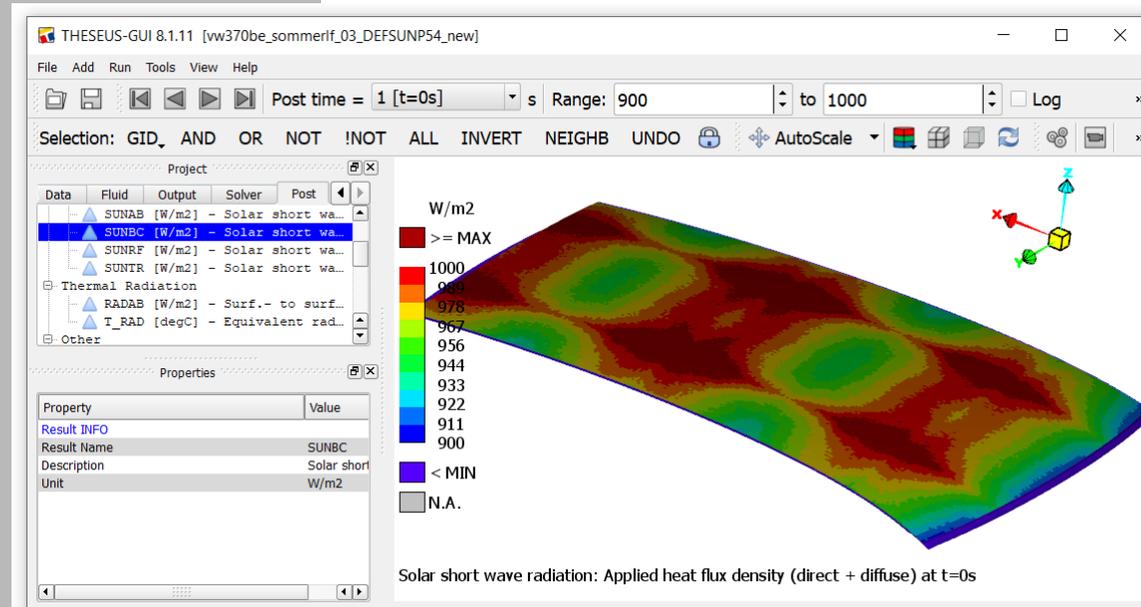
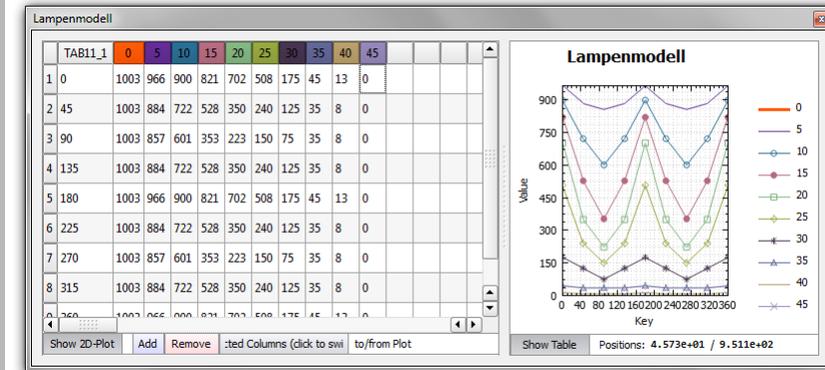
54 lamps



Solar radiation

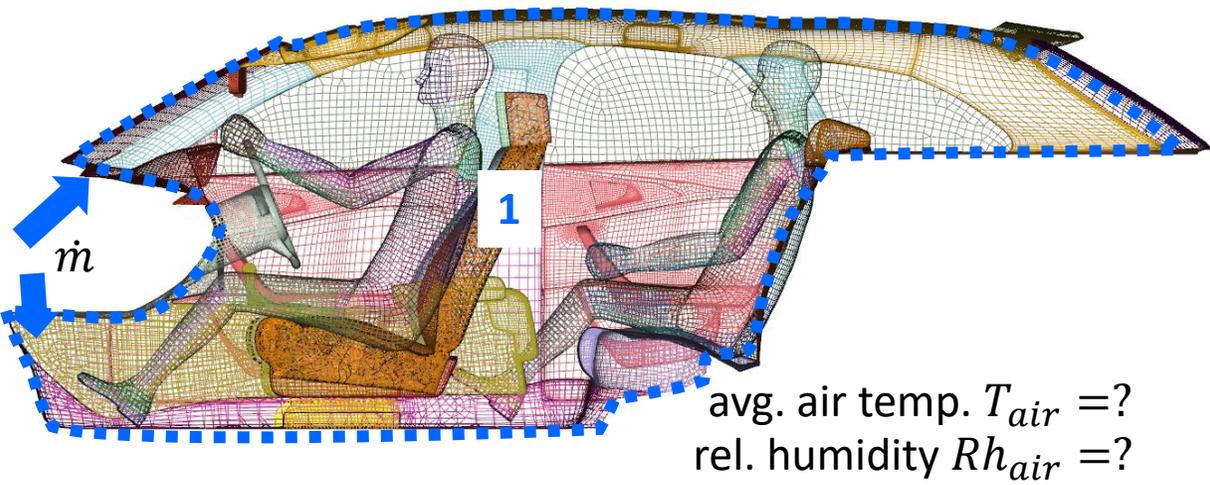


Original VW lamp model

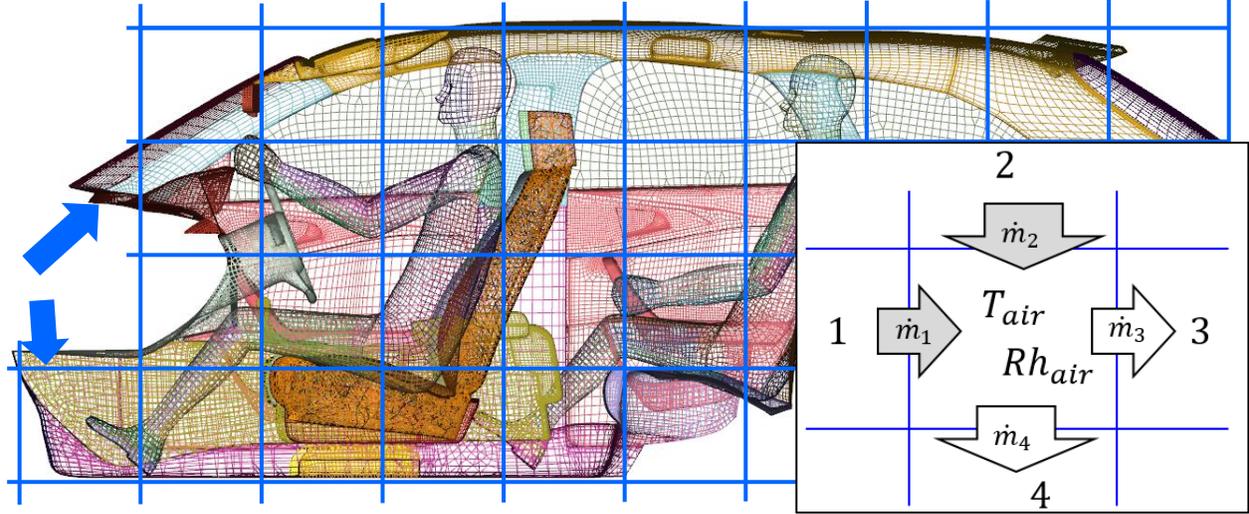


## Single Airzone Model:

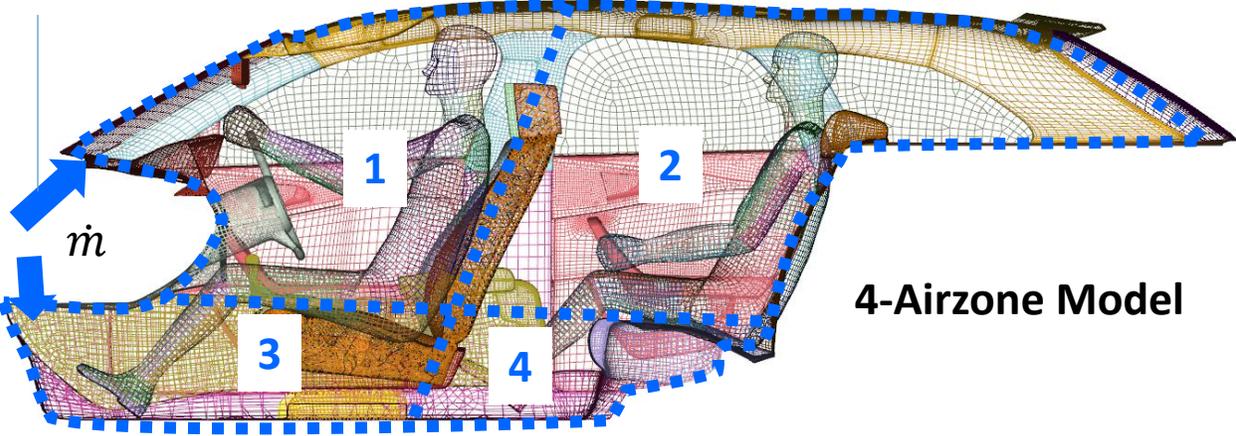
1hr CPU time



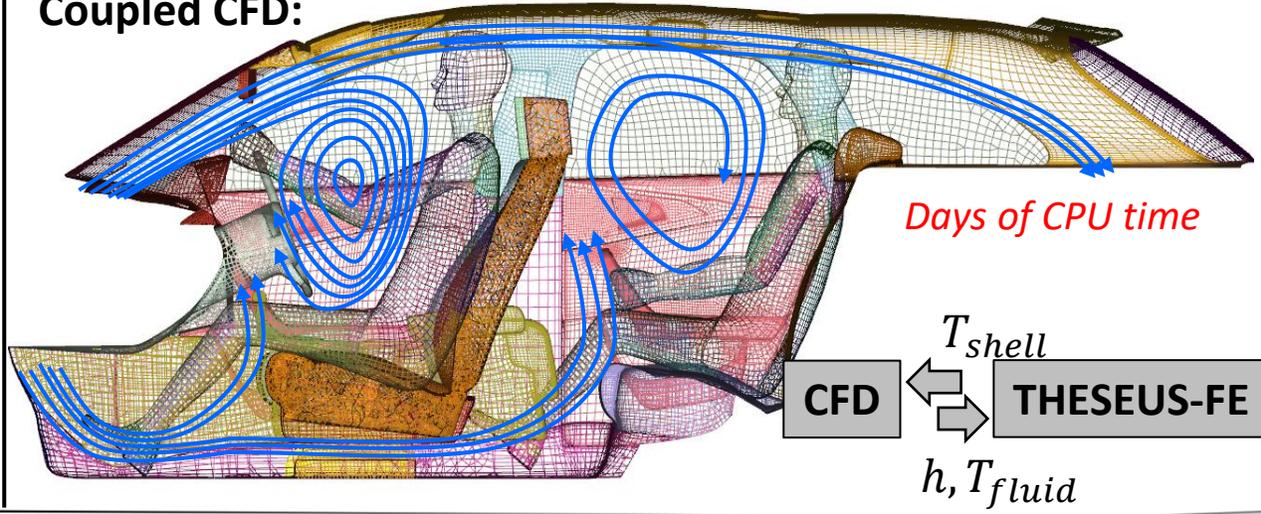
## Multi-Airzone Model (version 9):



## Ventilations



## Coupled CFD:

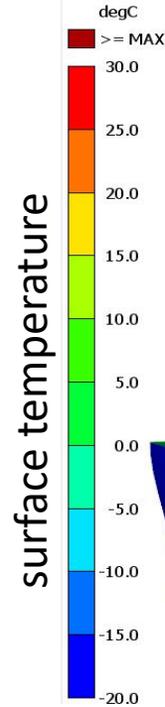
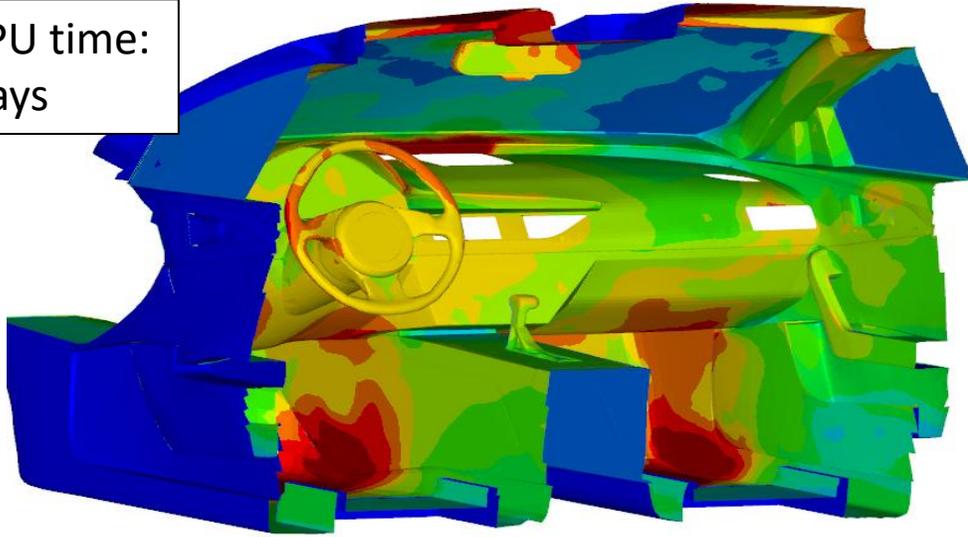




# Winter Load Case

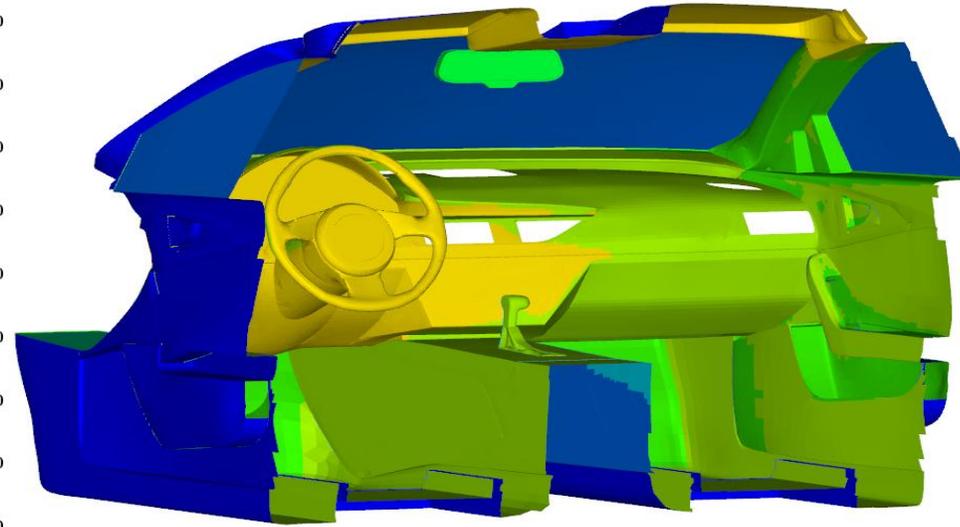
### Coupled CFD:

CPU time:  
Days



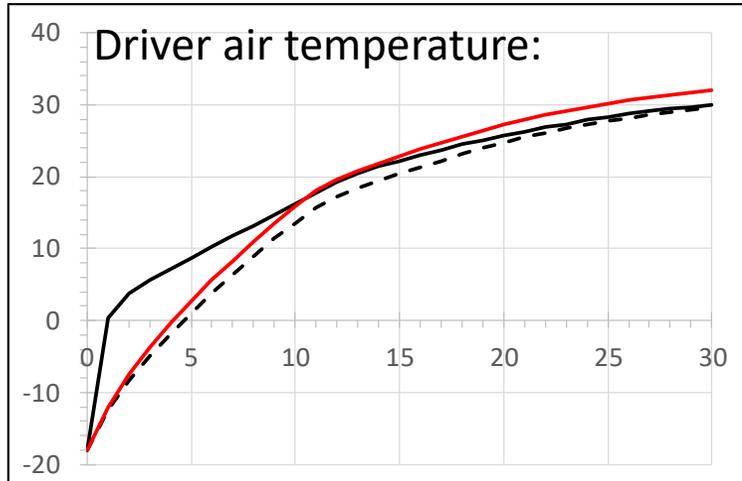
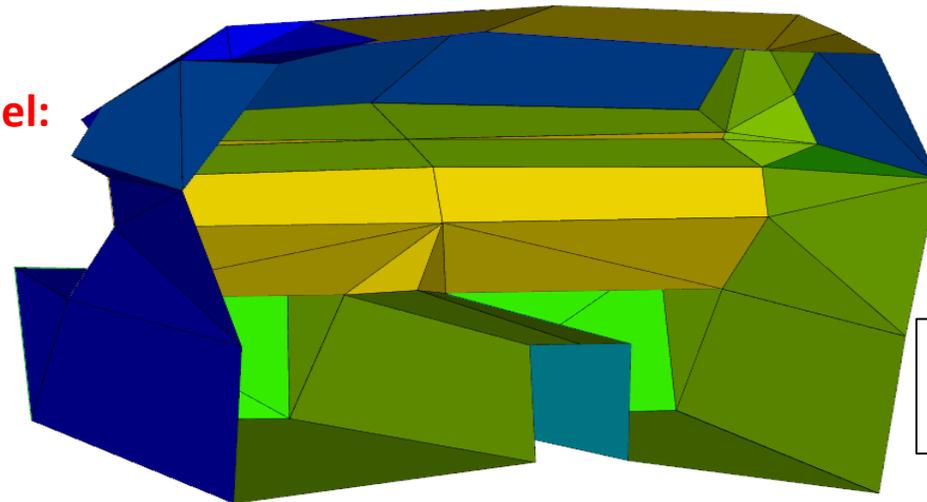
### Single Airzone Model:

CPU time:  
Minutes



### Generator Model:

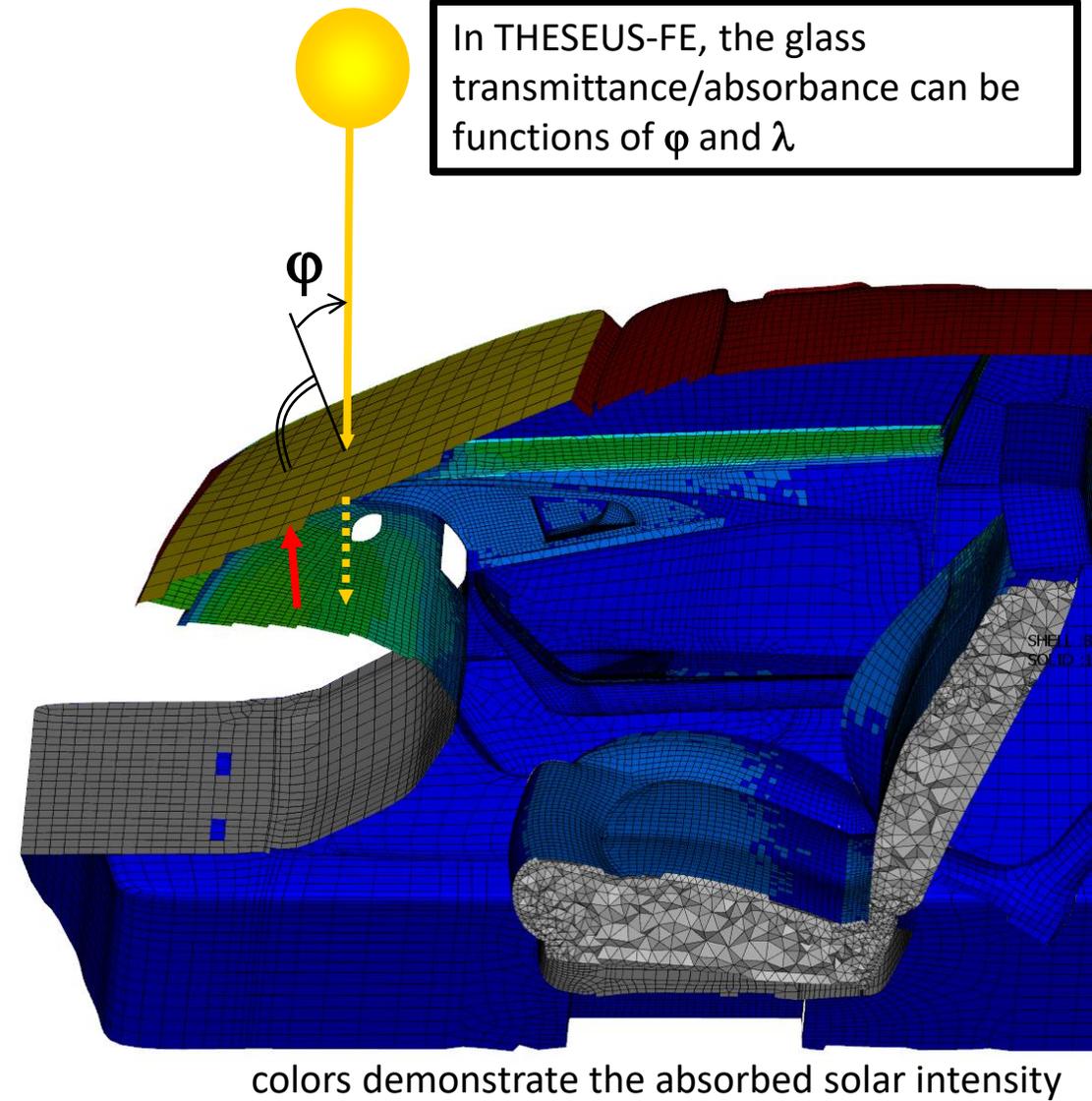
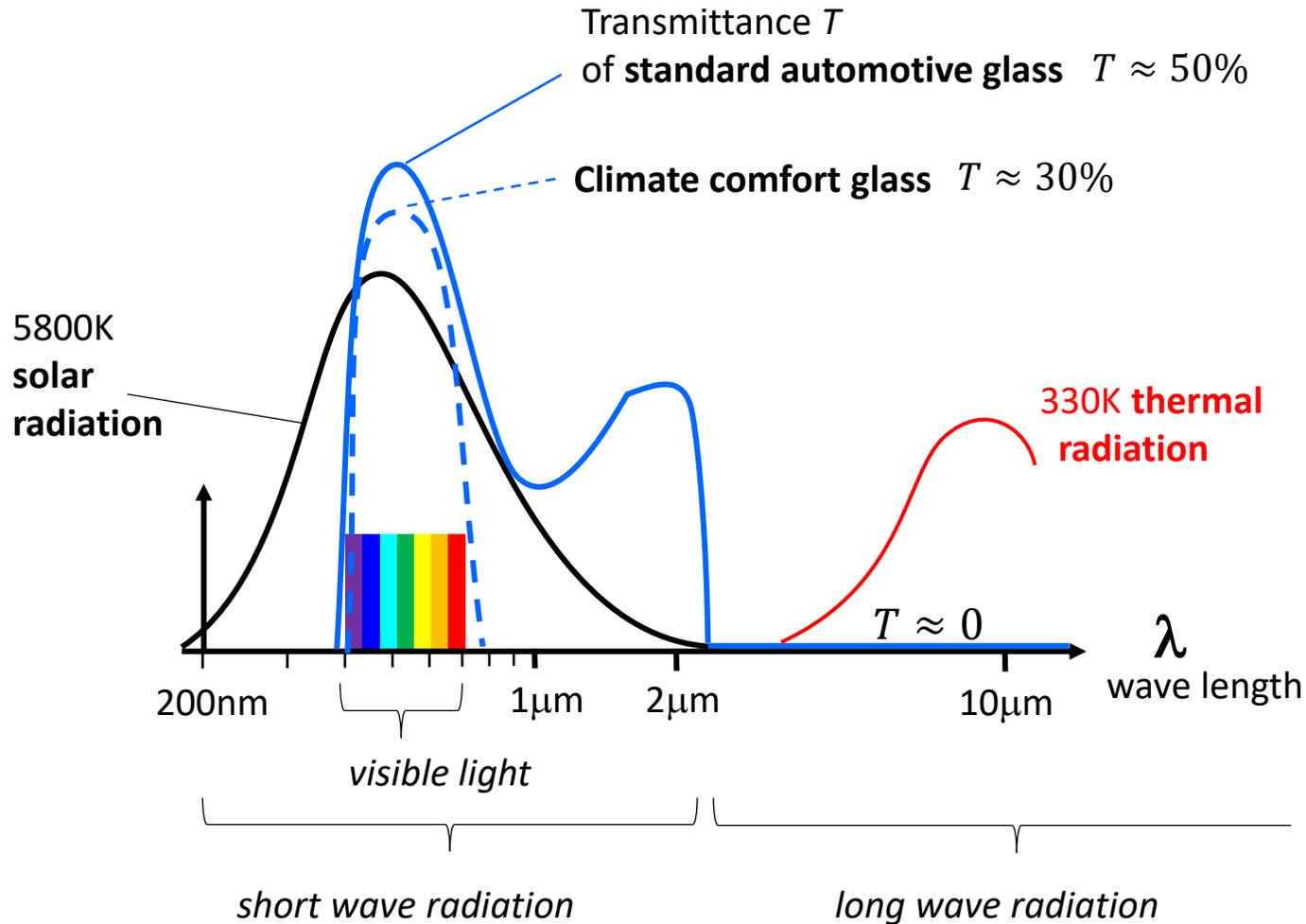
CPU time:  
Seconds



- coupled CFD
- - - Single Airzone Model
- Generator



## Green house effect





# Wave Length Dependencies Of Solar Radiation

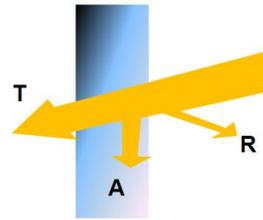
## Customer project

shows the impact of glass transmittance  $T$  on the HVAC energy consumption of a bus

## Side Window Glass Parameters

Solar energy transmission/reflection:

	Transmission T	Reflection R	Absorption A
Standard Glass	59%	19%	22%
Contra Vision 1	29%	55%	16%
Contra Vision 2	41%	37%	22%



Example of Contra Vision coating:



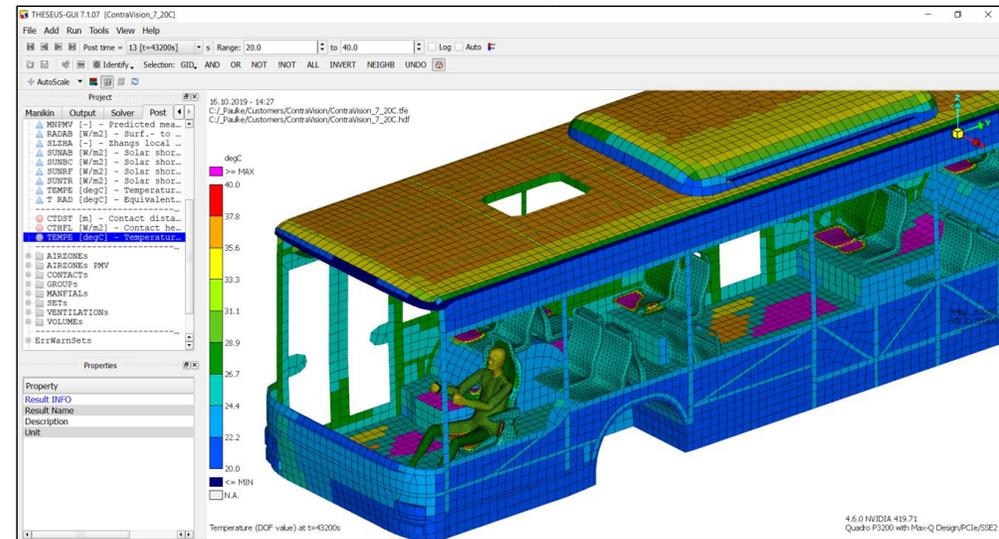
contrAvision®



Summer	load case 1	load case 2
Contra Vision 1 T=29%	35%	11%
Contra Vision 2 T=41%	23%	6%

## THESEUS-FE Simulation results

Temperature results  
for load case LC1: environmental air temperature 20°C, standard glass

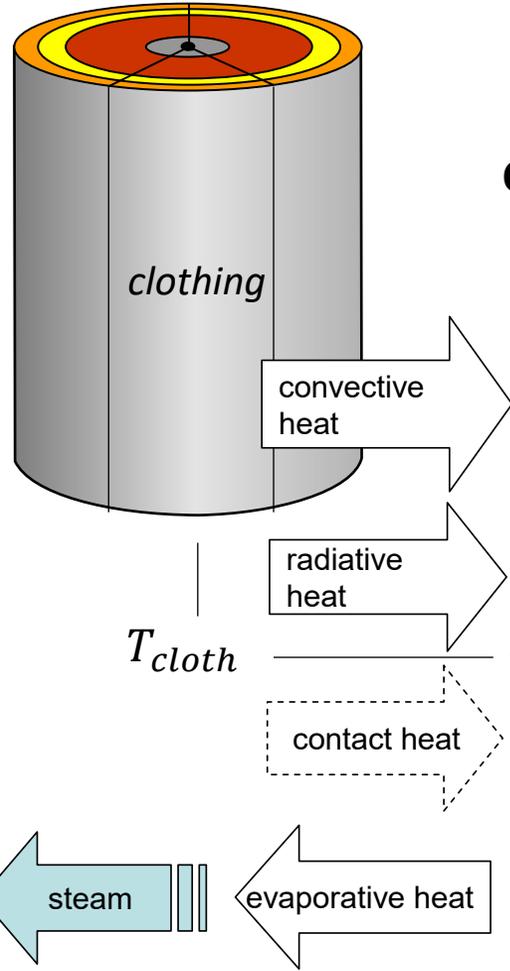


contrAvision®

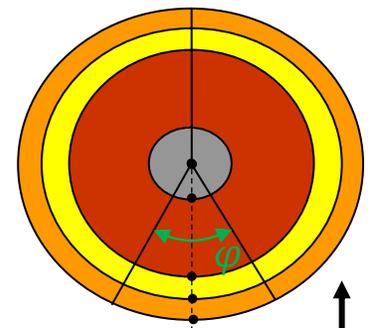
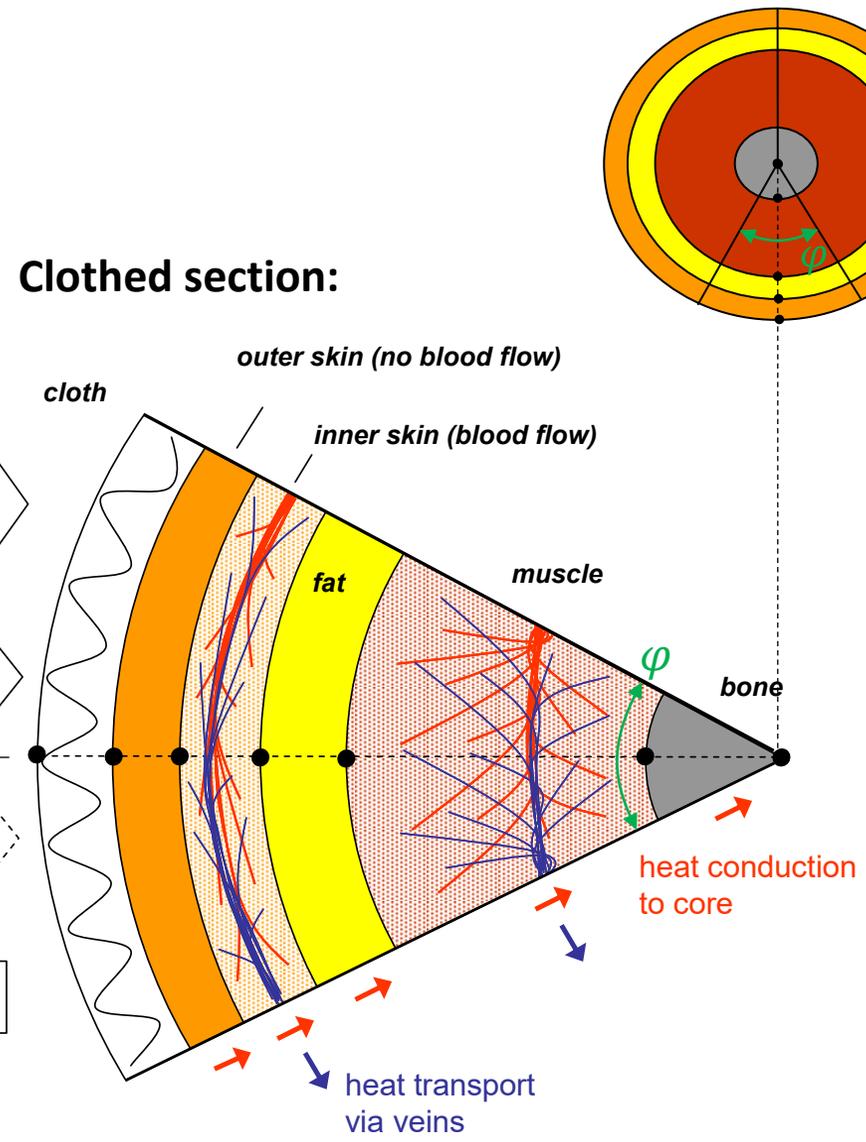


# Thermal manikins and comfort models

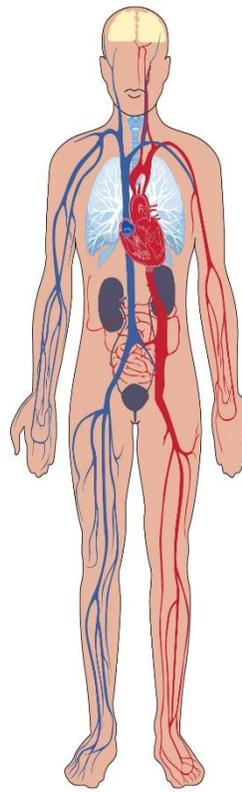
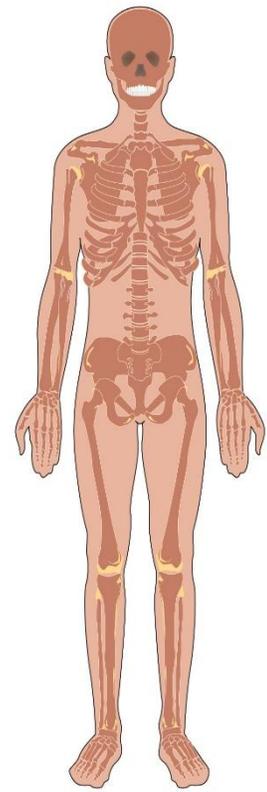
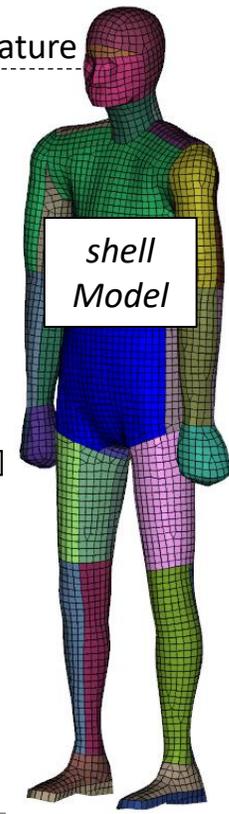
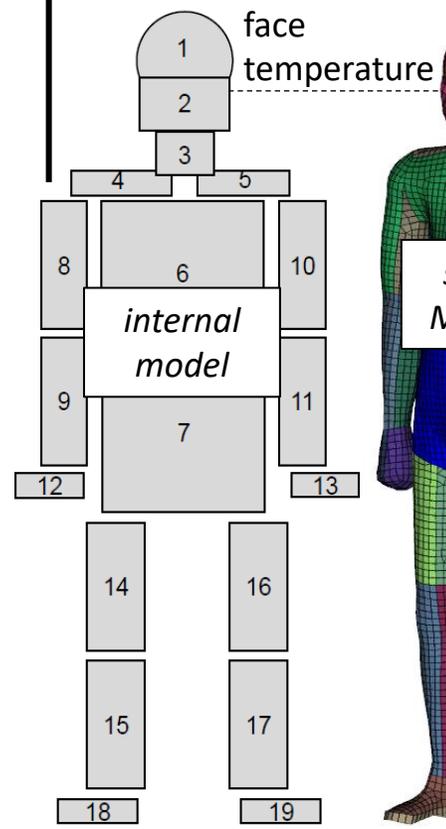
Typical body element:



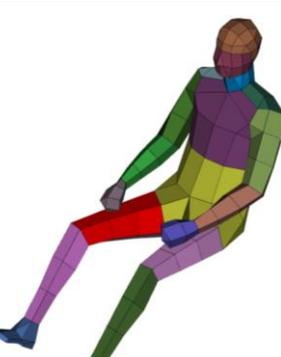
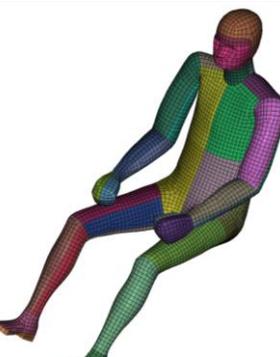
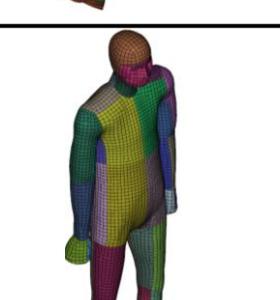
Clothed section:



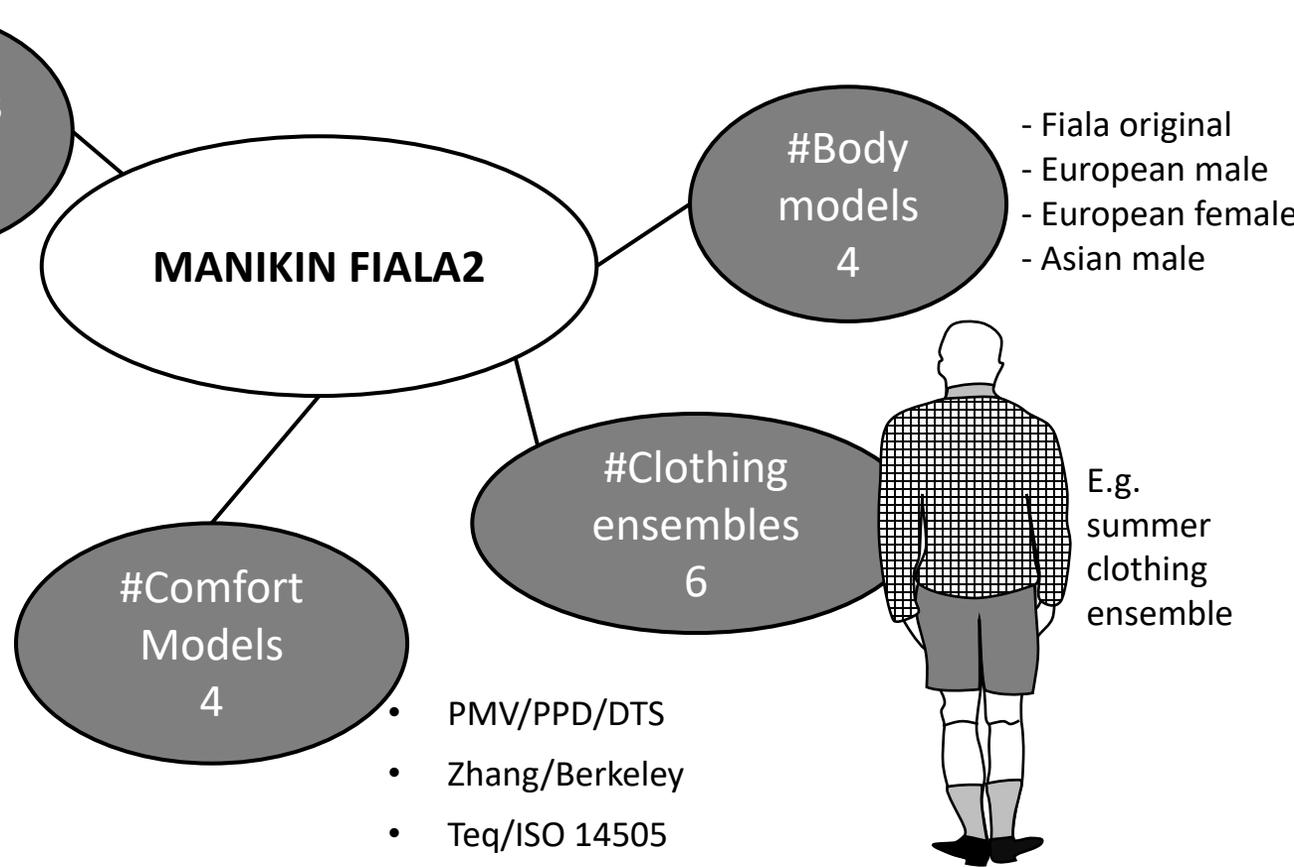
Active system regulations:  
sweating, shivering, vasoconstriction, ...



# Fiala's Thermal Manikin Model (1998)

	Manikin meshes from the install. folder		User-def. meshes
sitting driver			
sitting passenger			
standing			

**Modular system**  
=672 combinations of models



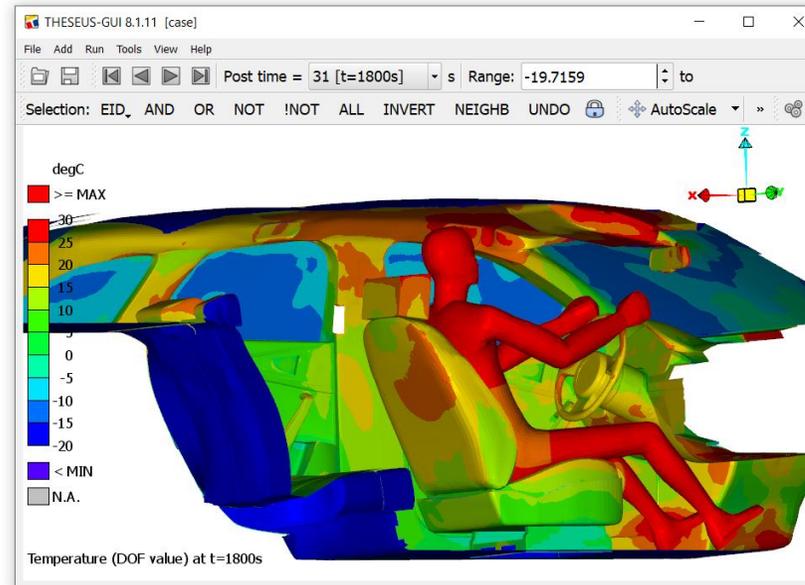


# Winter Load Case: "Heat Up"

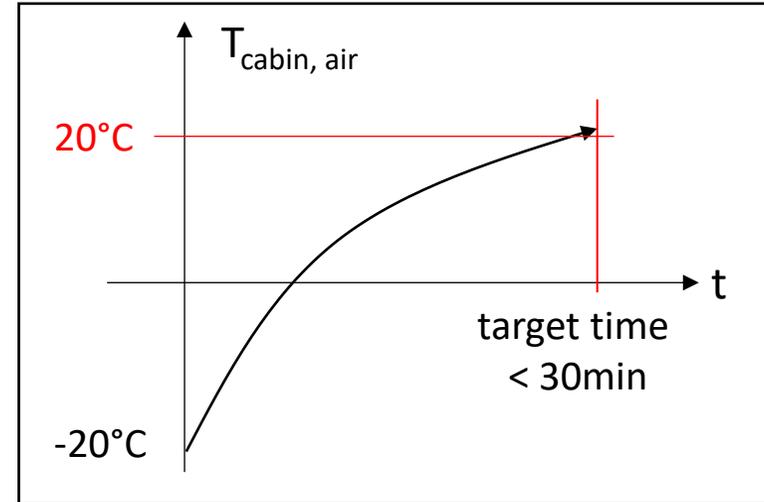


- air temp. : -20°C
- air velocity: 50km/h

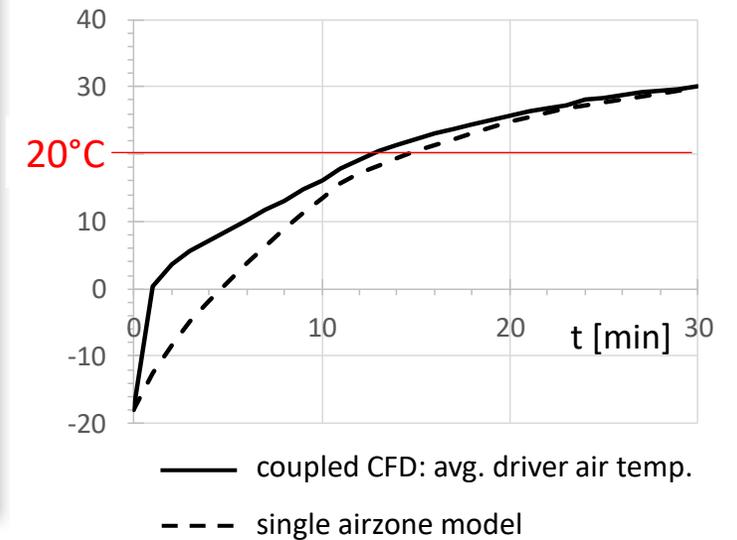
Surface temperatures, t = 30min  
(from coupled CFD)



Requirements from DIN-1496:



Simulated cabin air temperature:

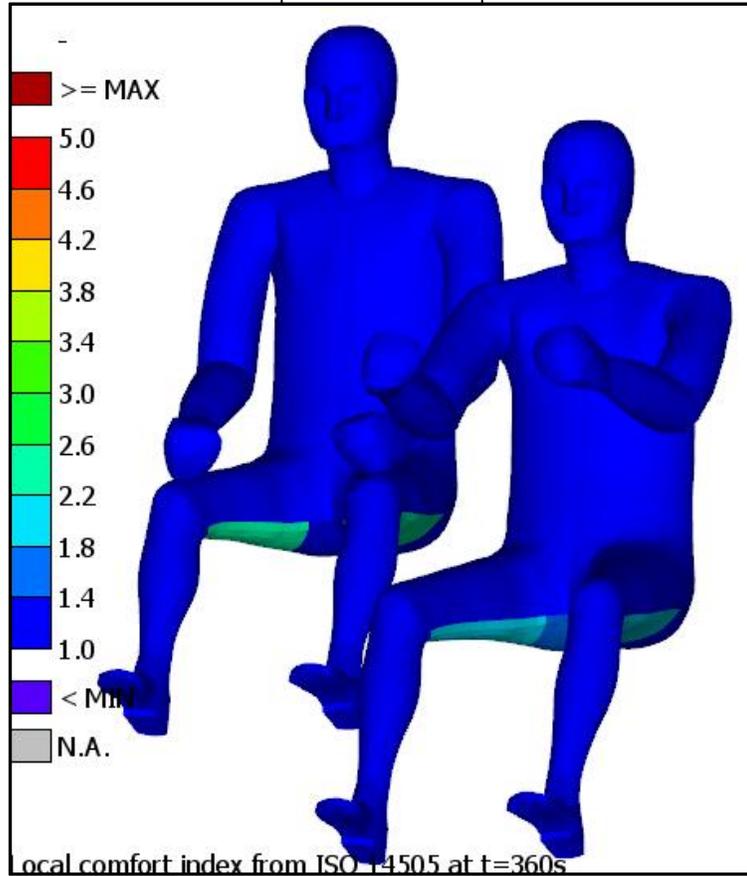




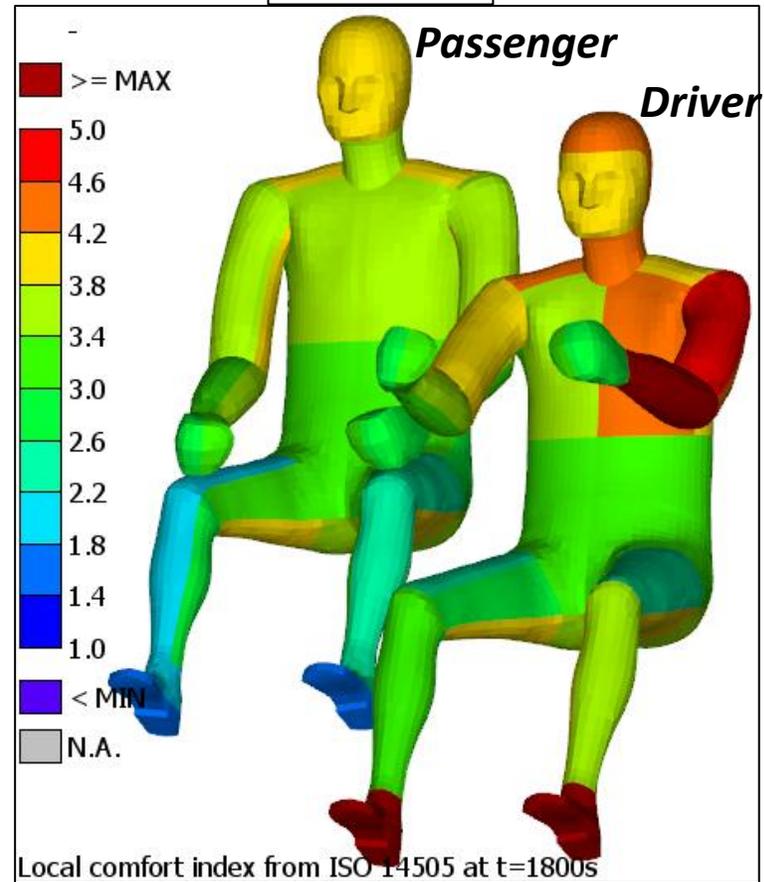
# Winter Load Case: "Heat Up"

## Discussion of local thermal comfort results:

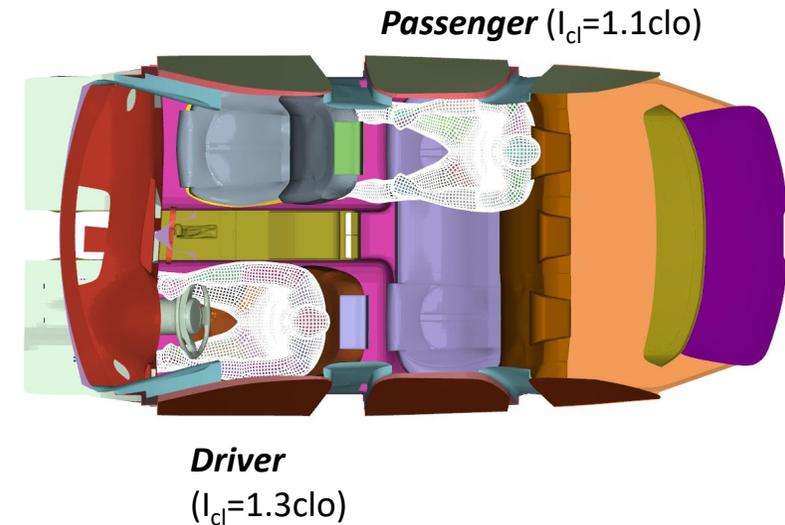
t = 6min



t = 30min



- 1 : too cold (uncomfortable)
- 2 : cold, but comfortable
- 3 : neutral
- 4 : warm, but comfortable
- 5 : too warm (uncomfortable)

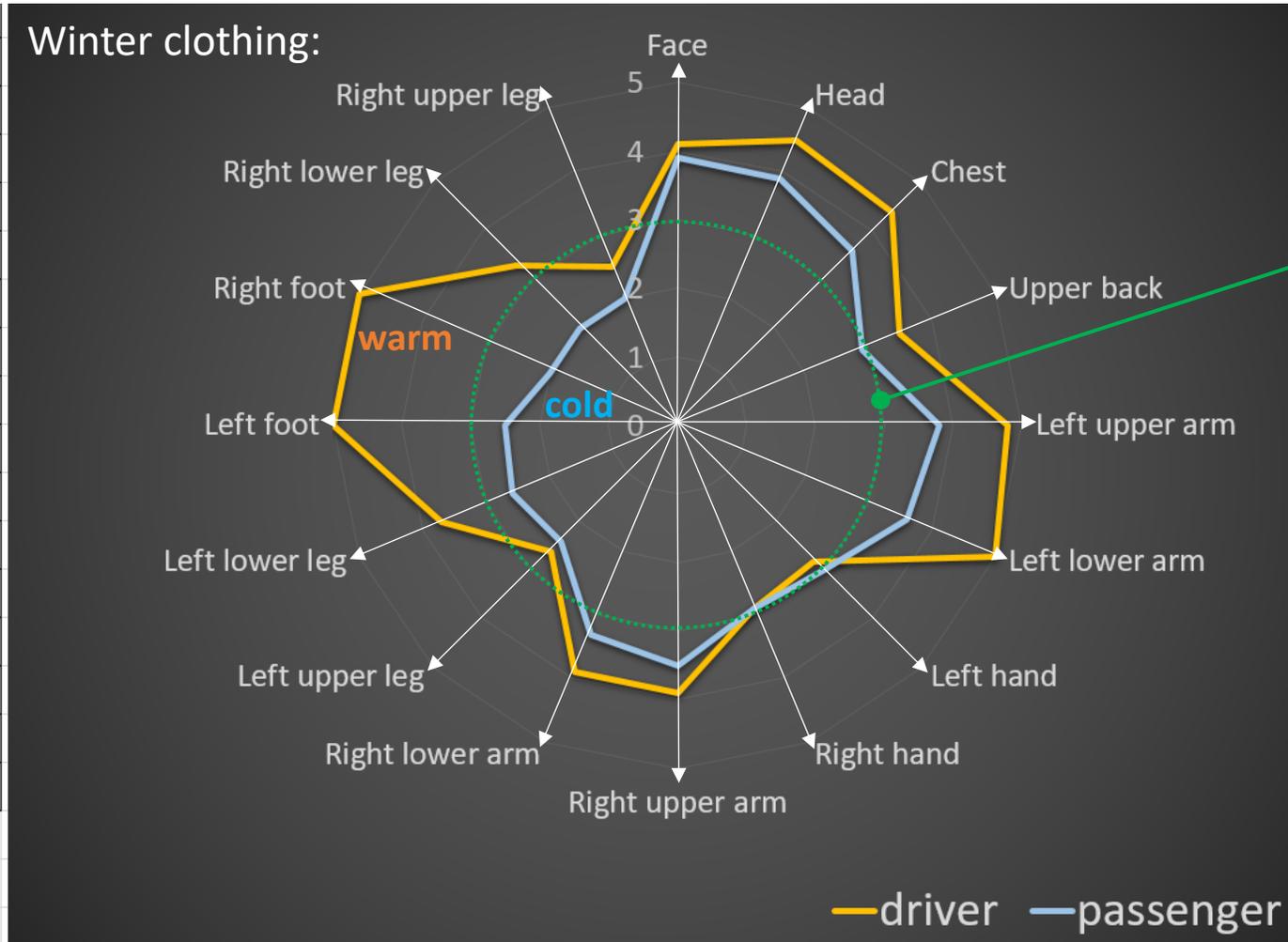




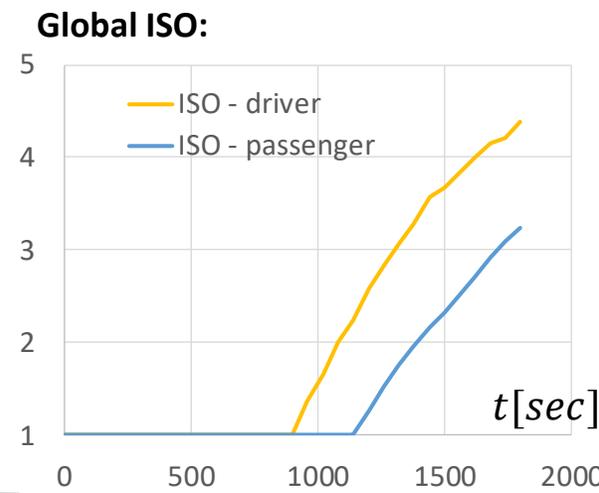
# Winter Load Case: "Heat Up"

## Local comfort index from ISO 14505:

	driver	passenger
Face	4.1	3.9
Head	4.5	3.9
Chest	4.4	3.6
Upper back	3.5	2.9
Left upper arm	4.8	3.8
Left lower arm	5	3.6
Left hand	2.8	3
Right hand	2.9	2.9
Right upper arm	3.9	3.5
Right lower arm	3.9	3.3
Left upper leg	2.6	2.4
Left lower leg	3.7	2.6
Left foot	5	2.5
Right foot	5	2
Right lower leg	3.3	2
Right upper leg	2.5	2



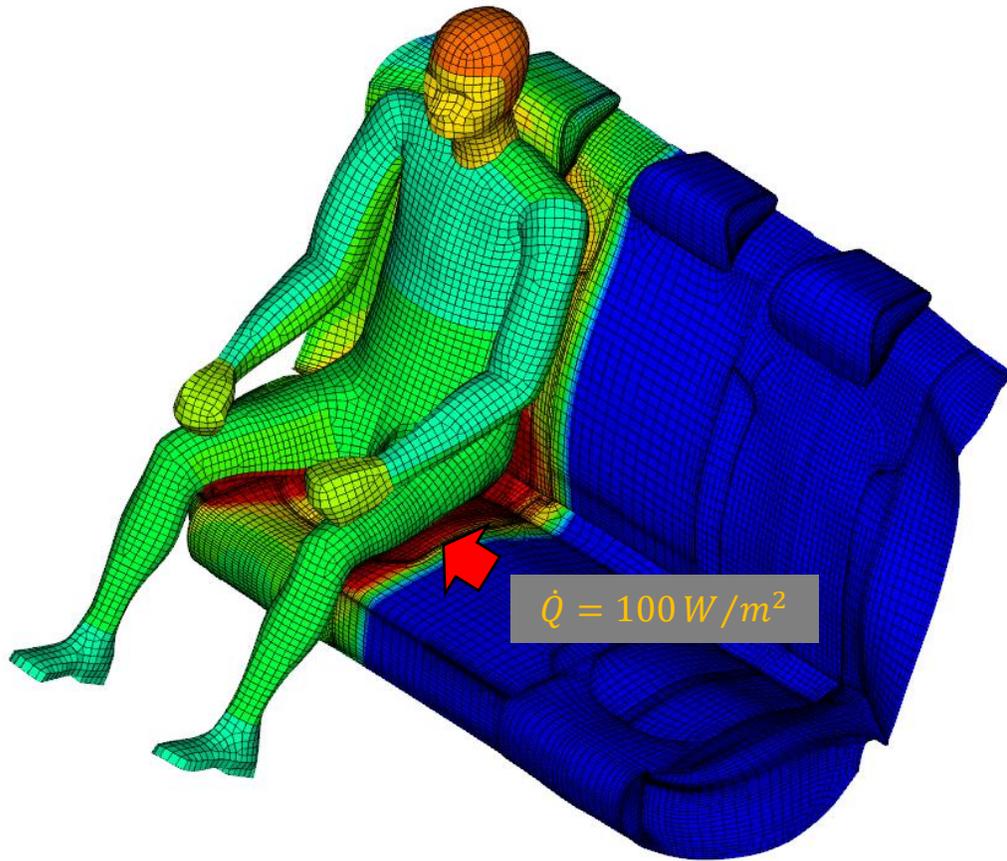
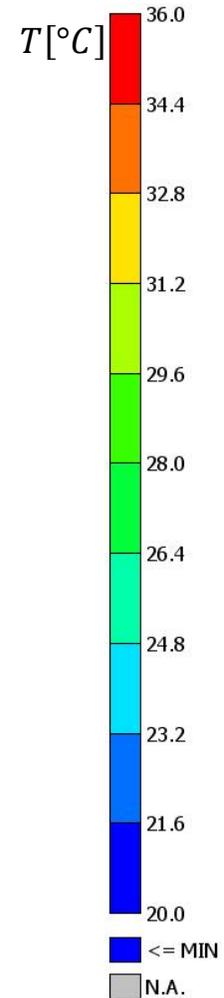
- 1 : too cold (uncomfortable)
- 2 : cold, but comfortable
- 3 : neutral
- 4 : warm, but comfortable
- 5 : too warm (uncomfortable)



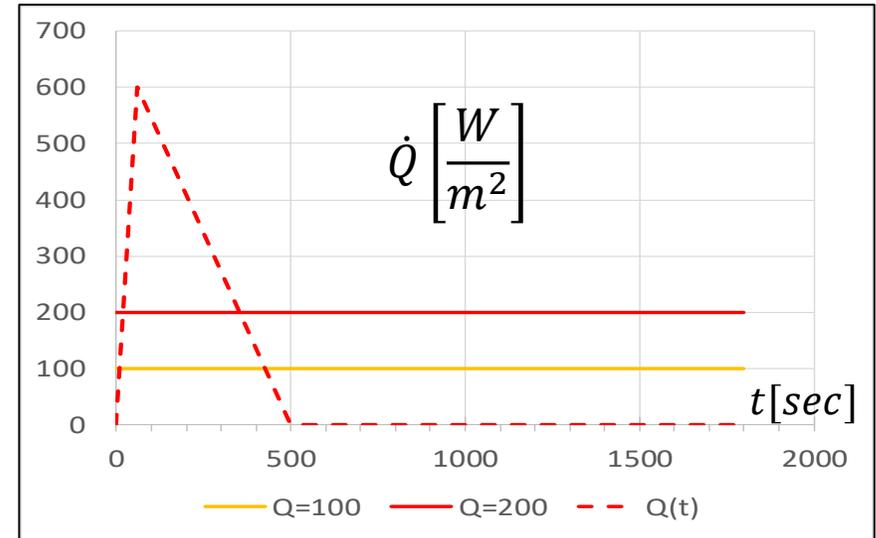


# Winter Load Case: "Heat Up"

Zhang/Berkeley local thermal comfort evaluation for seat heating optimization

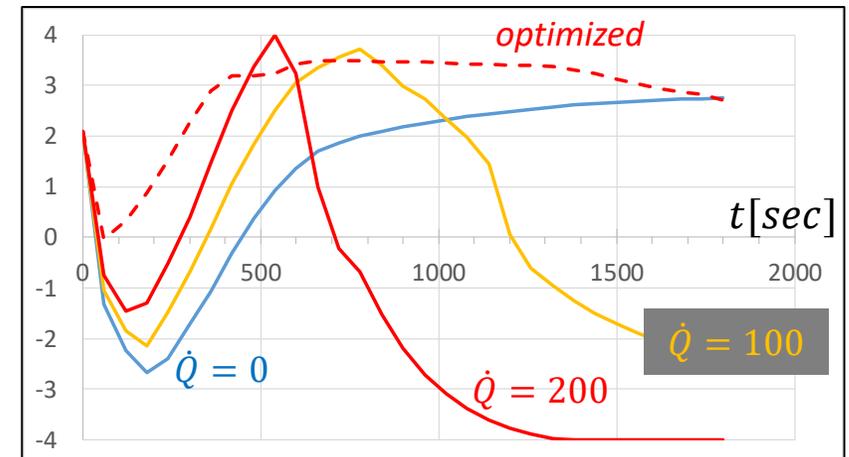


Variants of seat heating power:



Local thermal comfort index:

very comfortable:  
comfortable:  
neutral:  
uncomfortable:  
very uncomfortable:





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