Comparative comfort simulations for winter load cases using global and local comfort models (2019)

HdT: 3. Tagung Fahrzeugklimatisierung

Kühlen, Heizen und Komfort – Zukunftsorientierte Konzepte (07.05.19)

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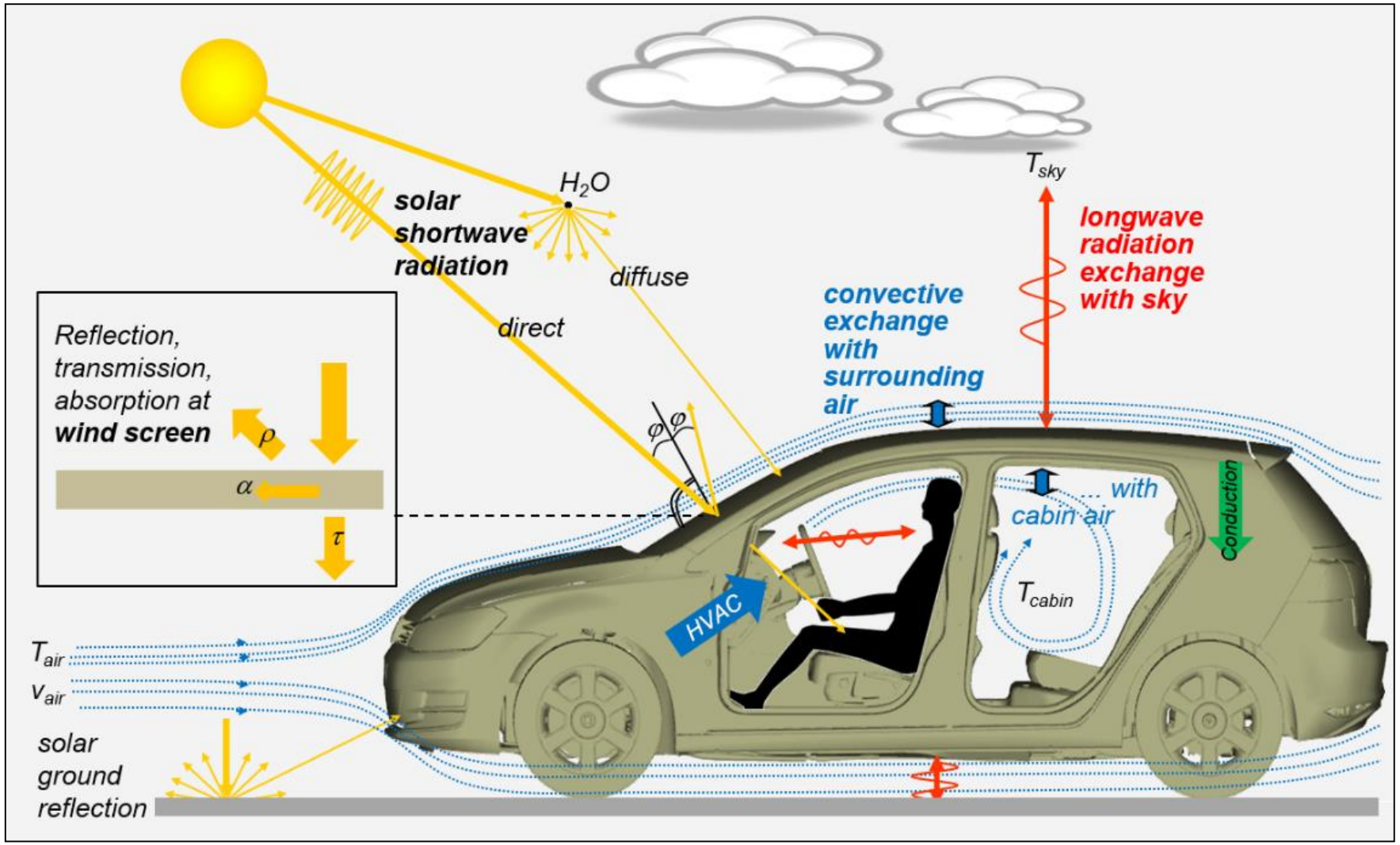
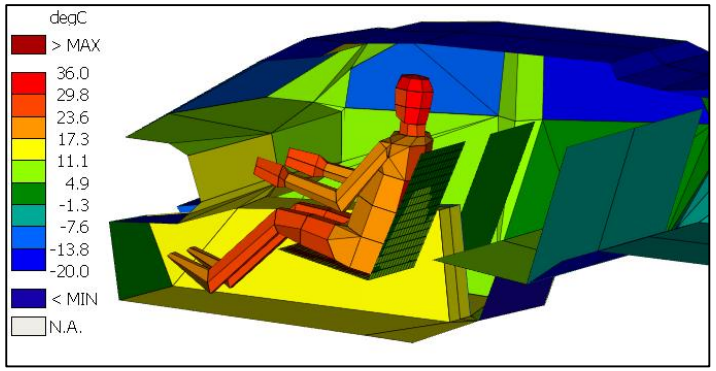
Mechanisms of Cabin Heat Transfer

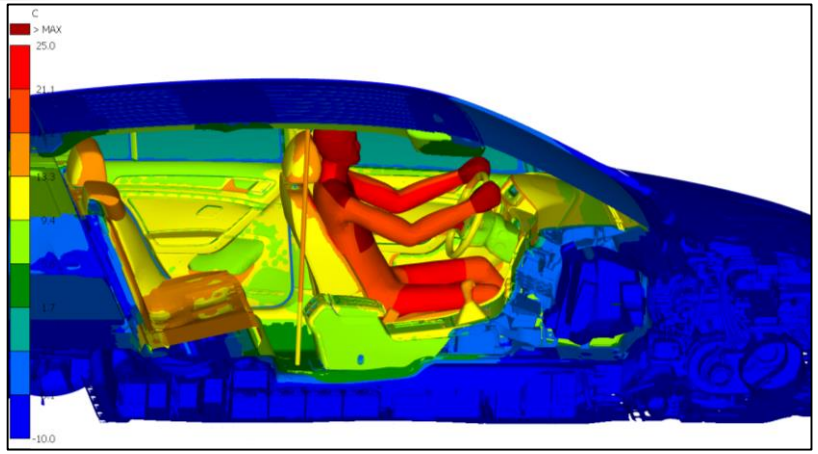
- Solar radiation (short wave)
- Thermal radiation (long wave)
- Multi layer conduction
- Contact
- Convection
- HVAC ventilations & humidity



Environmental thermal bound. cond.

Simplified Model Creation



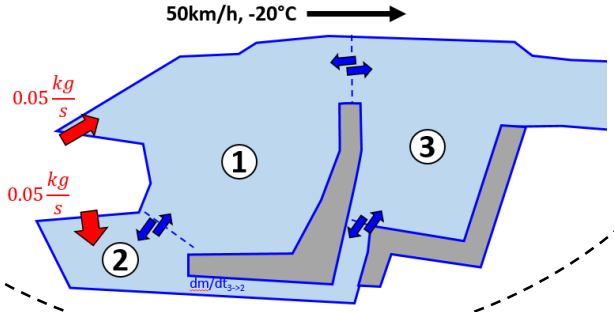


CPU time: **Seconds** **Minutes** **Hours** **Days** **Weeks**

100 Elm. **1 Mio Elm.** **10 Mio Elm.** **100 Mio Elm.**

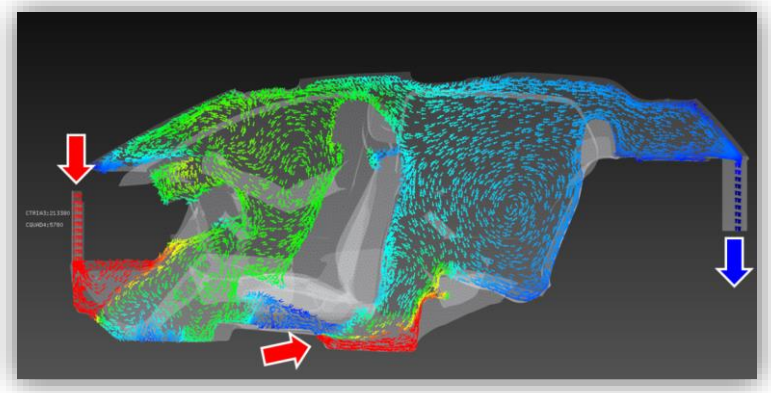
1D Conduction

Air zone model:



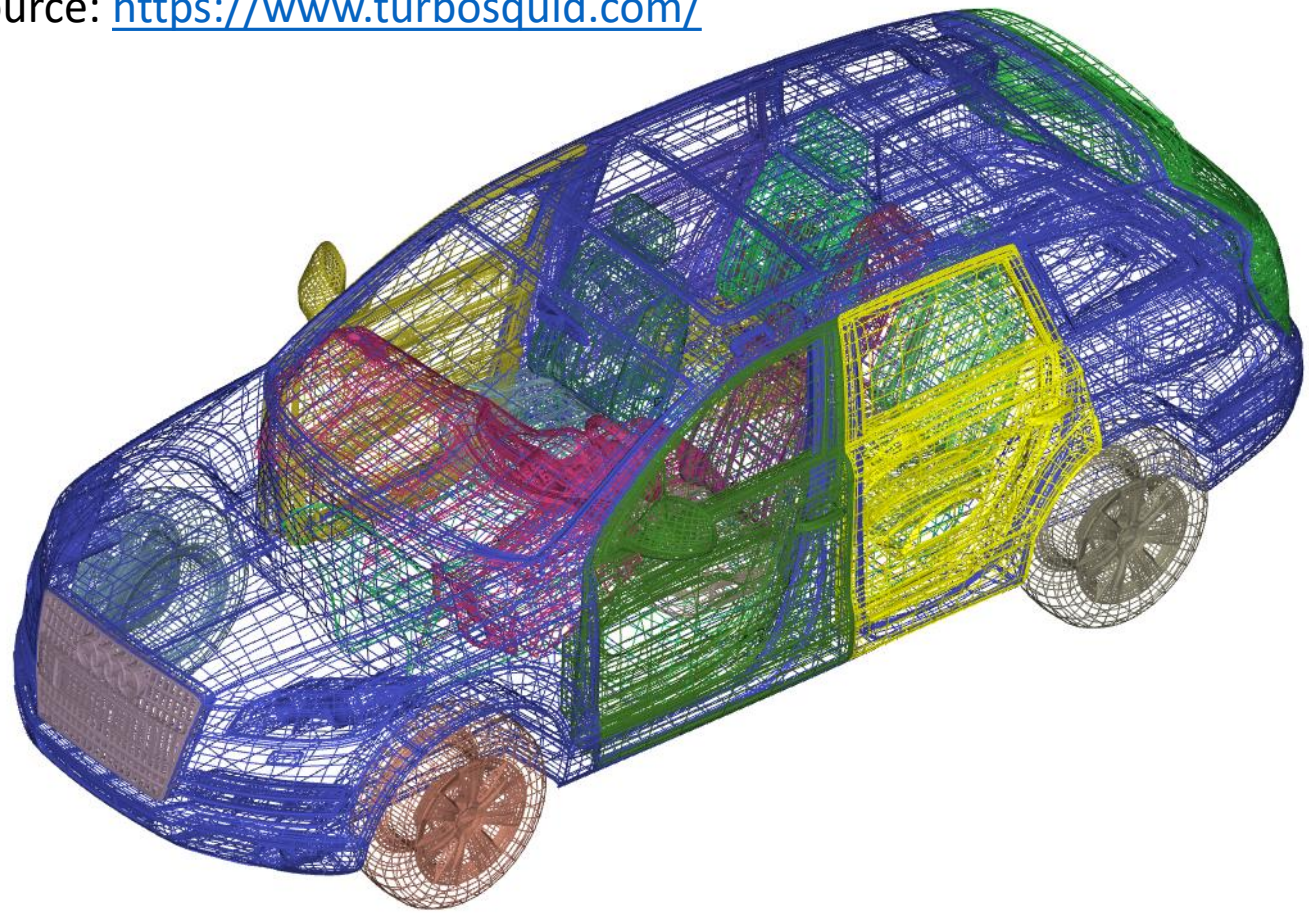
3D Conduction

Fully Coupled 3D CFD



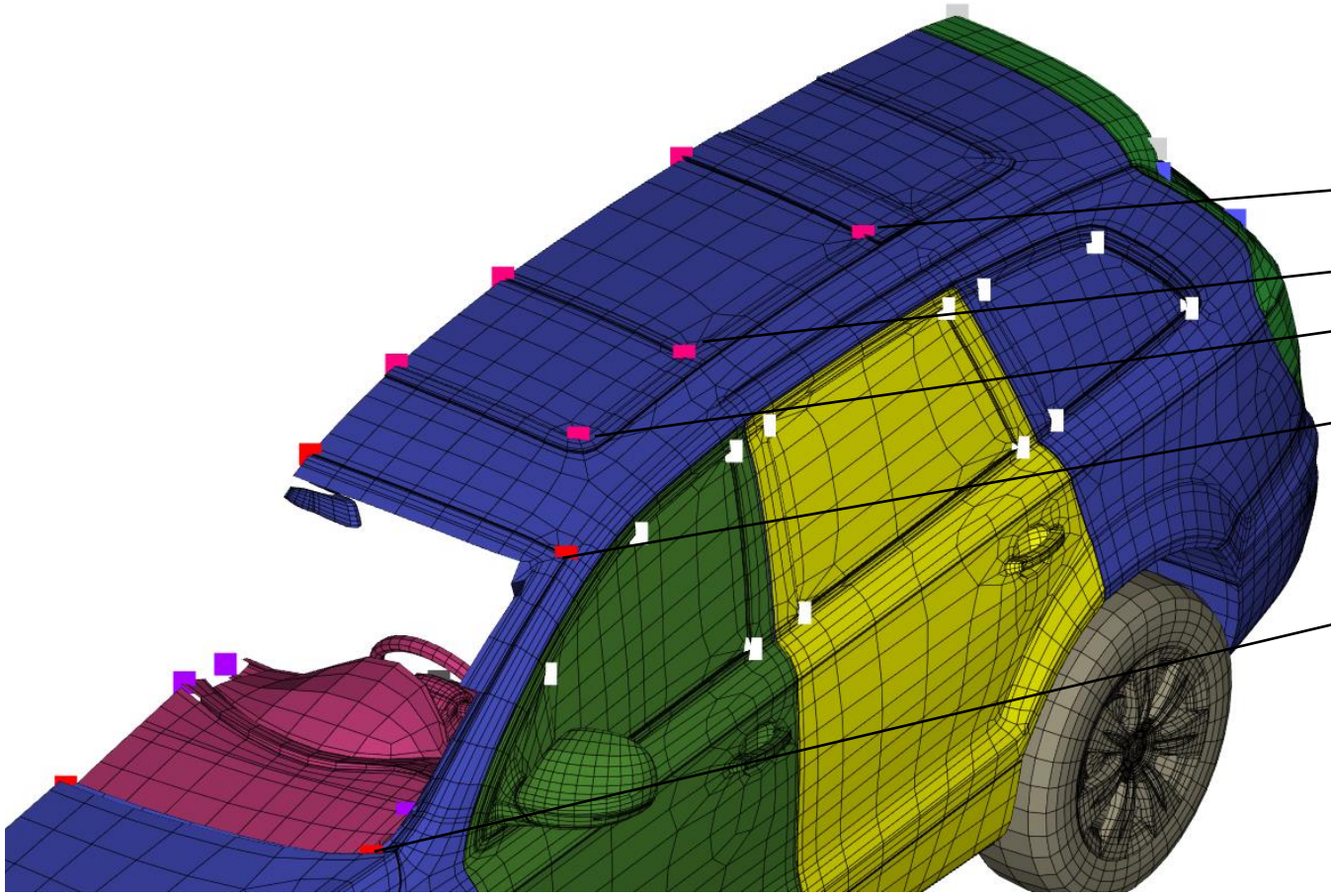
Audi-Q7

Source: https://www.turbosquid.com/

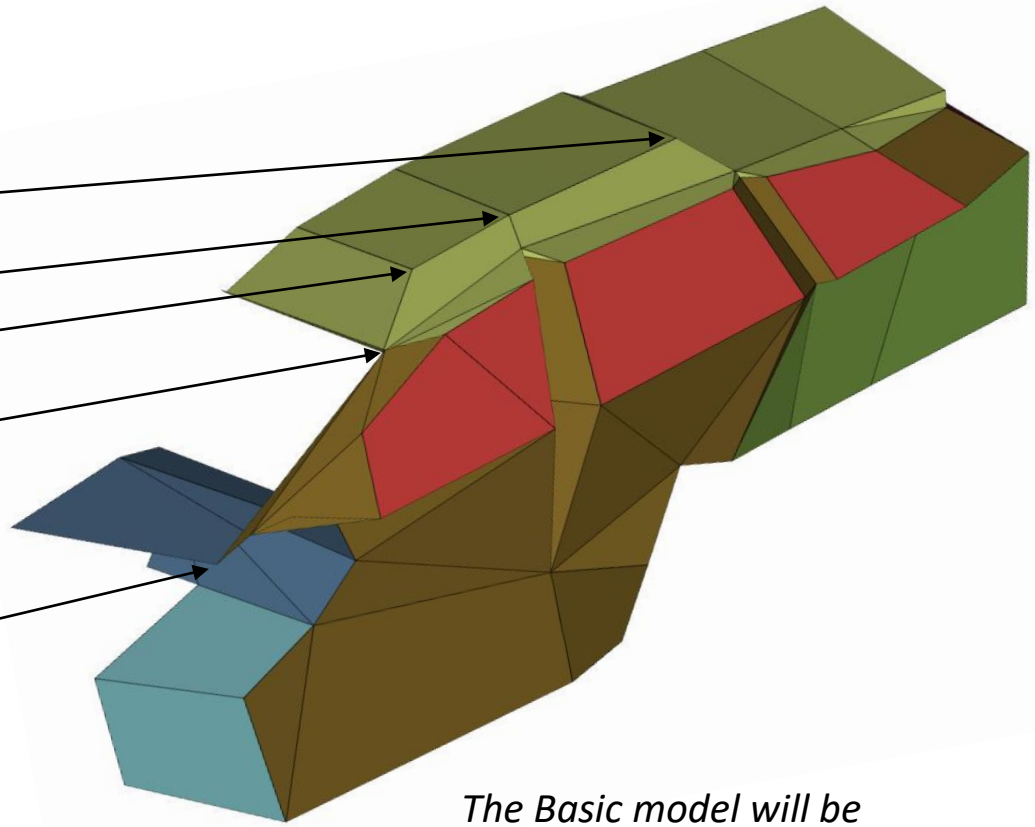


Geometry & Generator Model

Q7 original Geometry



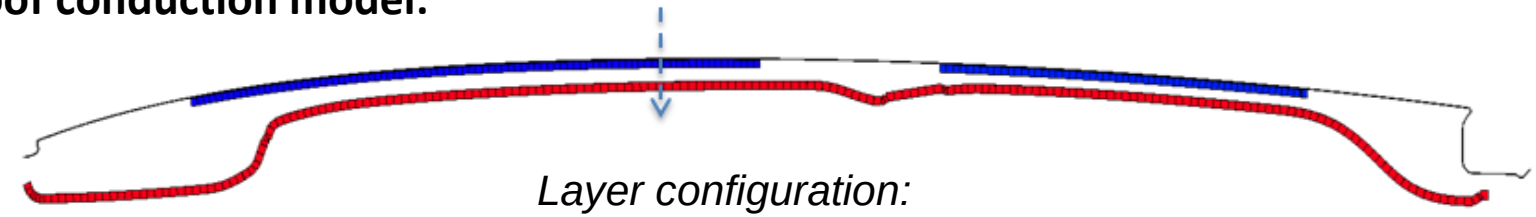
Generator Model



The Basic model will be without panorama screen!

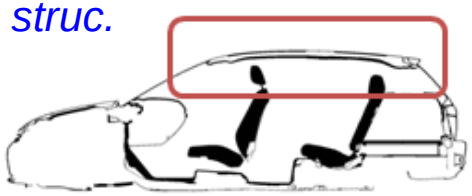
Simplified 1D Conduction

Roof conduction model:

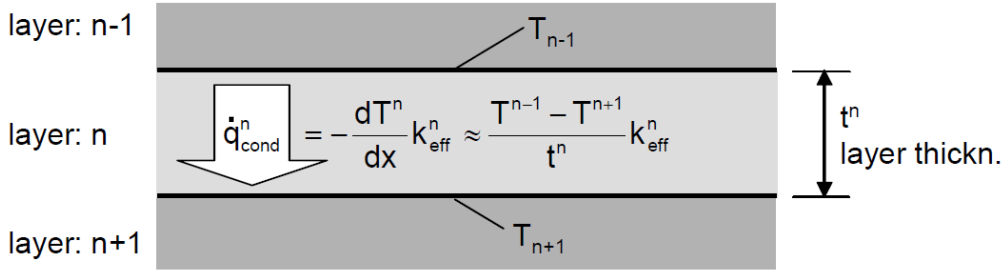


Layer configuration:

- *0.7 mm - Steel*
- *8.5mm - Sandwich struc.*
- *20 mm - Air gap*
- *9.4 mm - Ceiling*



Simplified air gap model:



Assumptions:

$$h_{conv} \approx 3 \frac{W}{m^2 K}$$
$$\varepsilon \approx 0.9$$

Effective conductivity:

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

$\bar{T}[K]$

Floor conduction model:

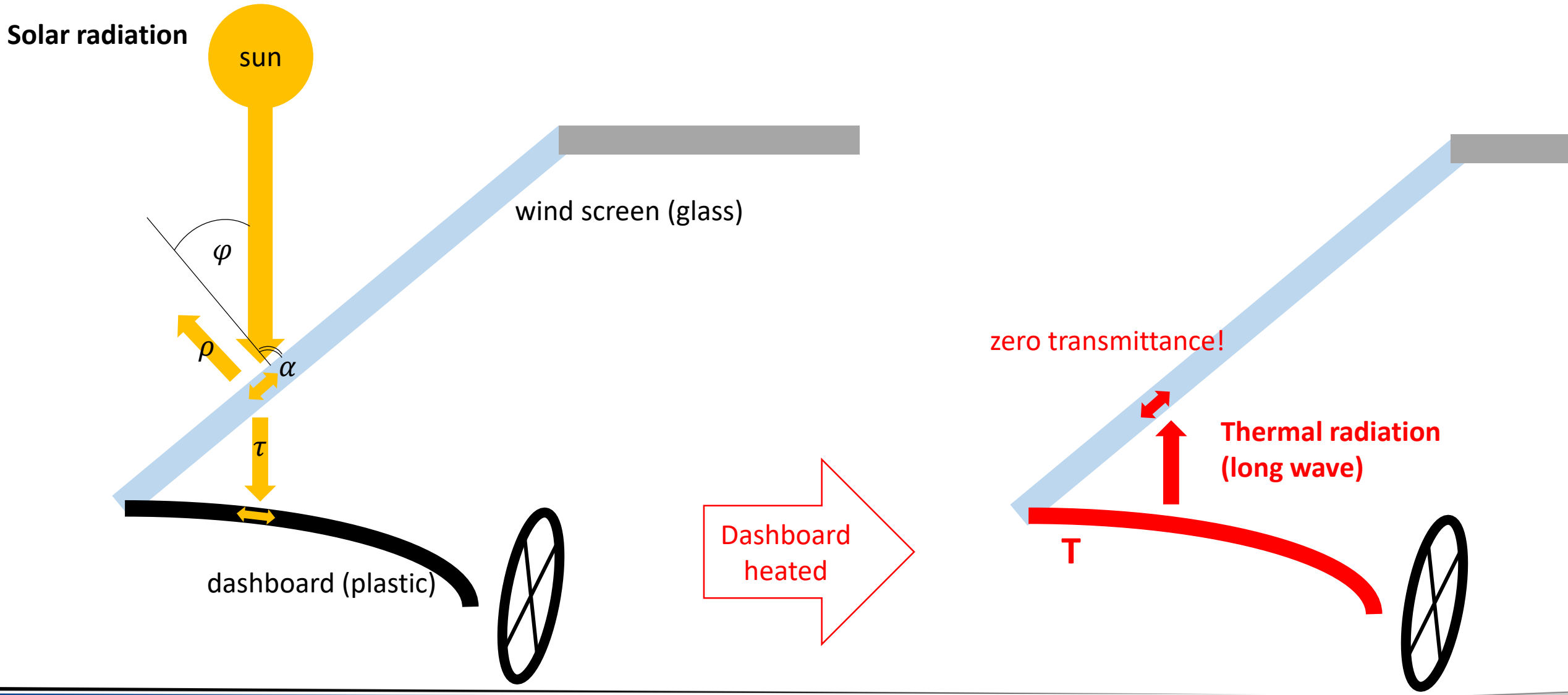
Inside cabin

Carpet + mat ≈ 10mm
EPDM ≈ 3mm
Foam ≈ 25mm
Plastic ≈ 10mm
Air gap 50mm
Metal sheet ≈ 1mm

outside

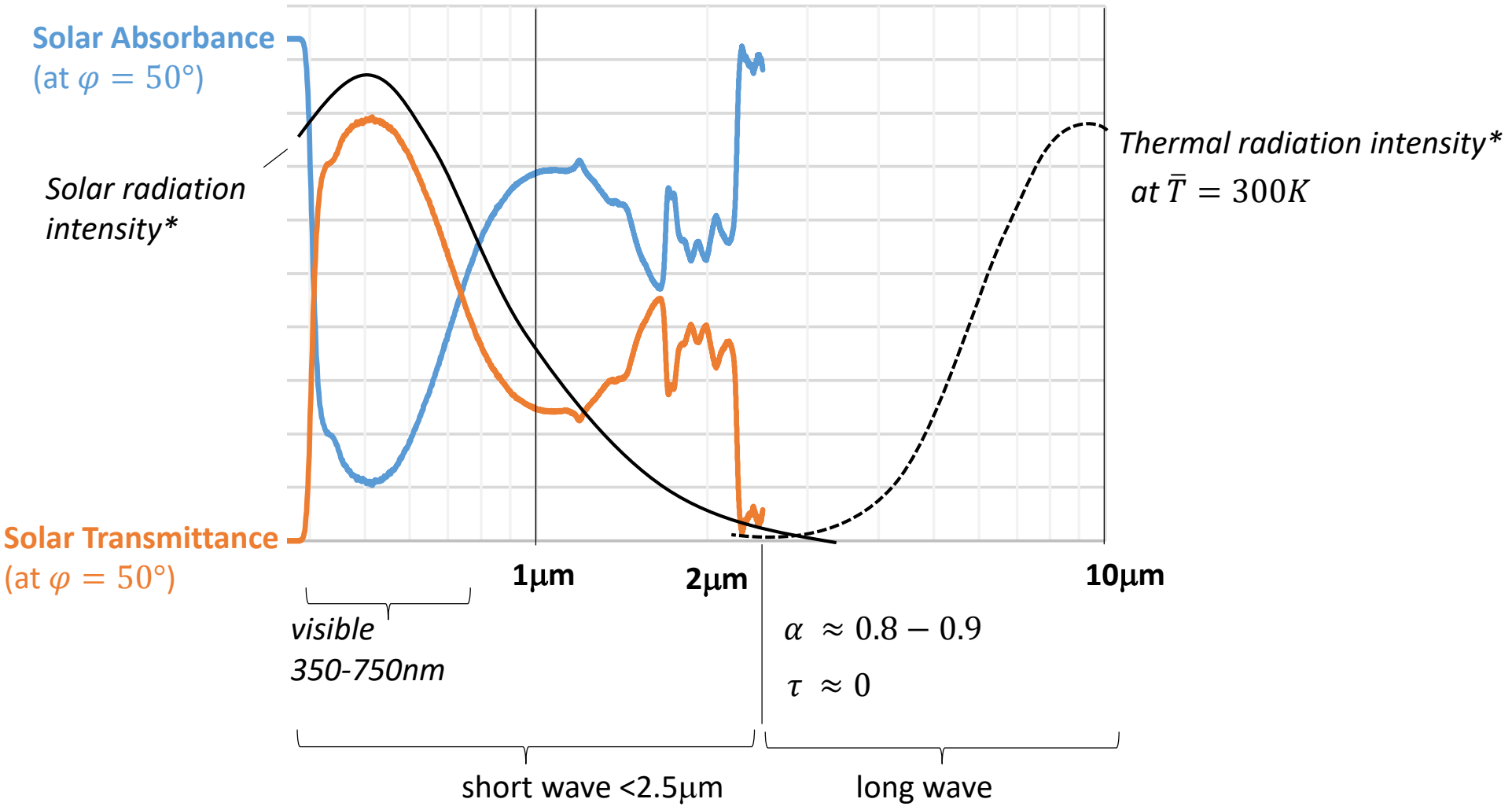
street

Green House Effect



Typical VSG-Windshield Radiation Properties

Wave length dependencies:



*Planck (normalized)

Human Thermal Physiology Model (Fiala)

Passive system:

- Metabolism
- Heat conduction
- Blood circulation
- Contact heating
- Evaporation
- Respiration
- Radiation
- Convection

Active system:

- Shivering
- Sweating
- Vasoconstriction & -dilatation

Clothing:

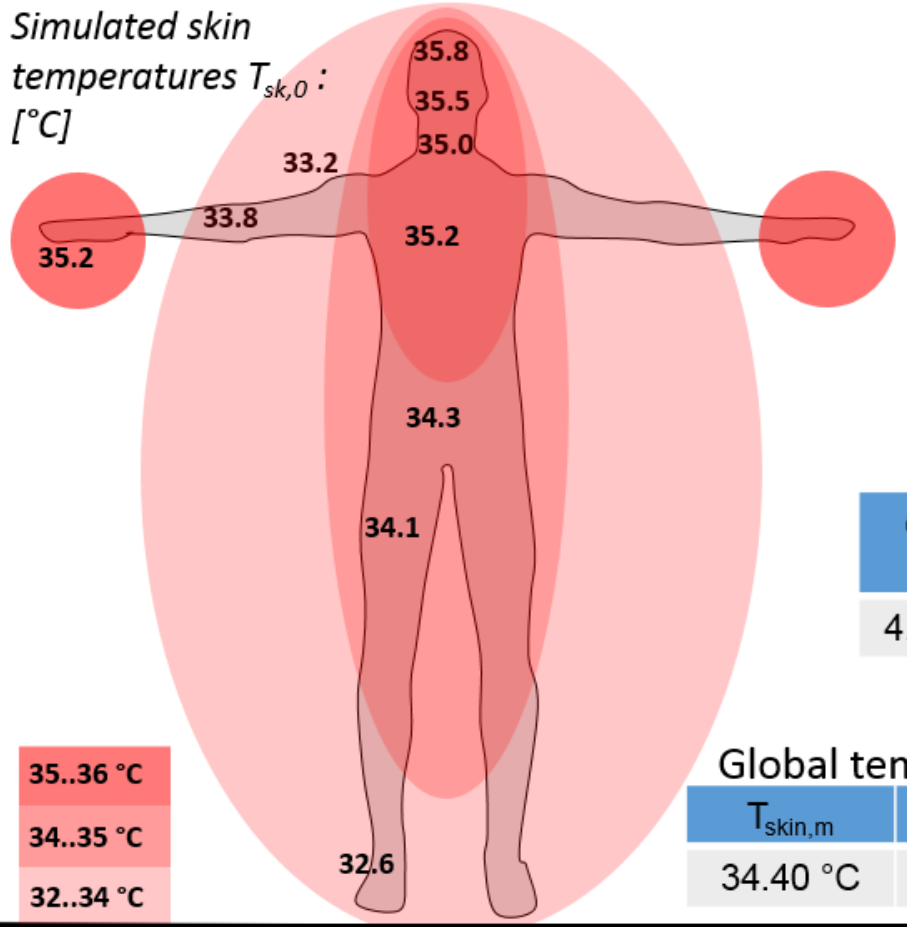
- Local clothing parameters: I_{cl}, i_{cl}, f_{cl}

The reference state for comfort = Thermal. Neutrality

Boundary conditions of unclothed manikin

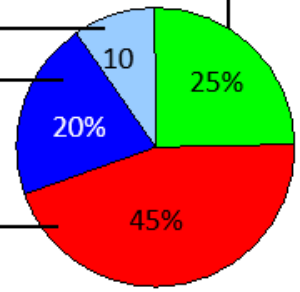
T_{air}	T_{wall}	v_{air}	humidity	metabolism
30.0 °C	30.0 °C	0.05 m/s	40 %	≈87 W

Simulated skin temperatures $T_{sk,0}$: [°C]



In the quasi-stationary state of neutrality the inner heat production is equal to the outer **heat loss** from

- convection
- respiration
- evaporation
- radiation



cardiac output	skin blood flow	mass loss
4.9 ltr/min	24.3 W/K	0.73 g/min

Global temperatures:

$T_{skin,m}$	$T_{muscle,m}$	$T_{hypothalamus}$	T_{rectal}
34.40 °C	36.20 °C	37.00 °C	36.88 °C

Human Thermal Comfort Models

The **PMV** is the most common and simplest thermal comfort model based on a global energy balance.

DTS is based on global skin and core temperatures to be simulated by the manikin passive/active system.

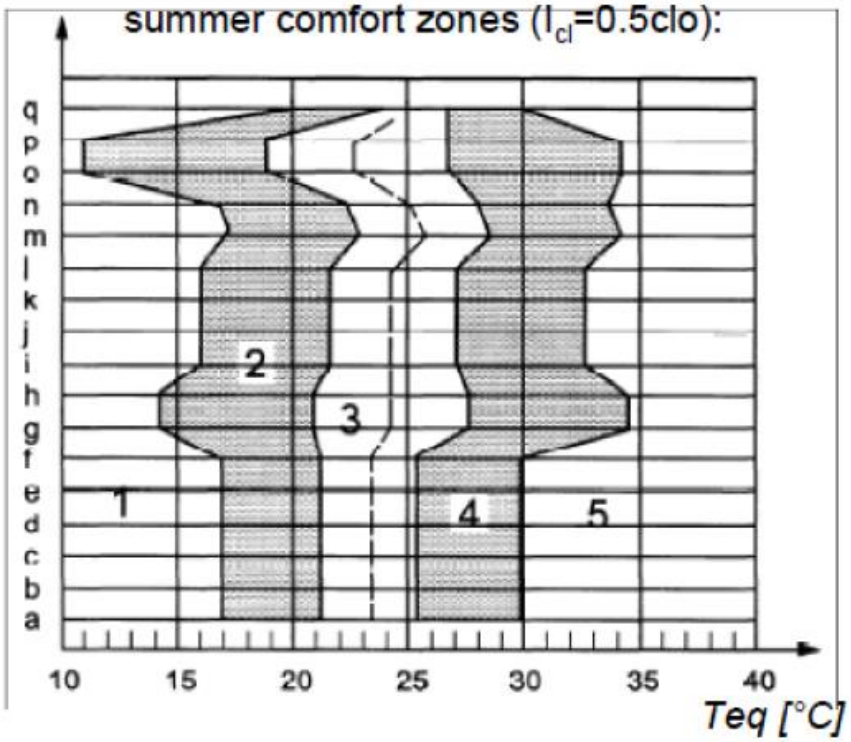
Equiv. temperatures are based on local heat fluxes (also see next slide).

Zhang Model is based on local skin and global core temperature changes* to be simulated by the manikin passive/active system.

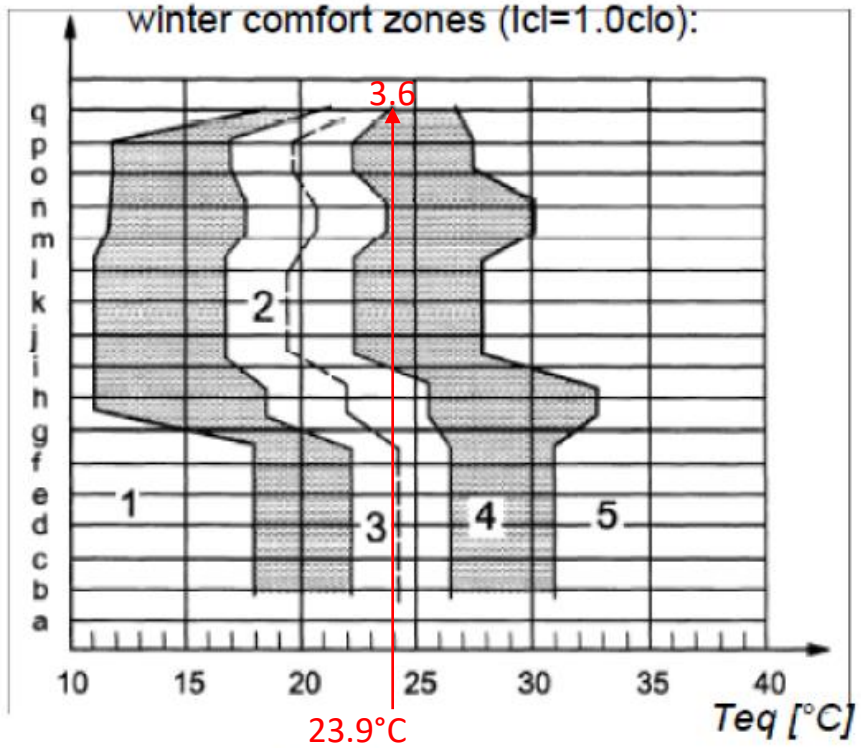
	Fanger (1970) **PMV-Index**	Fiala (1998) **DTS-Index**	**Equivalent temp. T_eq** (EN ISO 14505-2)	**Zhang** (2003) Local comfort model
Input	activity level global boundary conditions: air- and wall temperature, air-velocity, humidity clothing	mean skin temperature core temperature.	local heat loss values	locale skin temperatures mean skin temperature core temperature
Validity	stationary, global	dynamic global	stationary, local + global 6 assessment regions	dynamic, local + global 13 body parts
Remarks	not coupled with thermal manikin response	DTS similar to PMV	differing assessment for summer and winter clothing	model provides max. thermal comfort value => applicable for optimization
Problems	not applicable for contact boundary conditions model requires global clothing definition (clo-value)	less validated for dynamic load cases	compared with Zhang: locale comfort predictions are quite undifferentiated	very complex model results sometime not transparent ("black box")
Output (Indices)	<u>global therm. sensation</u> on a 7-step-scale -3 .. cold -2 .. cool -1 .. slightly cool 0 .. neutral +1 .. slightly warm +2 .. warm +3 .. hot		<u>local therm. sensation and comfort</u> on a 5-step-scale 1 .. to cold (uncomfortable) 2 .. cold (but comfortable) 3 .. neutral (comfortable) 4 .. warm (but comfortable) 5 .. to warm (uncomfortable)	<u>global and local therm. sensation</u> on a 9-step-scale, from -4 (very cold) to +4 (very hot) <u>thermal comfort</u> on a 9-step-scale, from -4 (very uncomfortable) to +4 (very comfortable)

*towards neutrality

Equivalent temp. T_eq (EN ISO 14505-2)



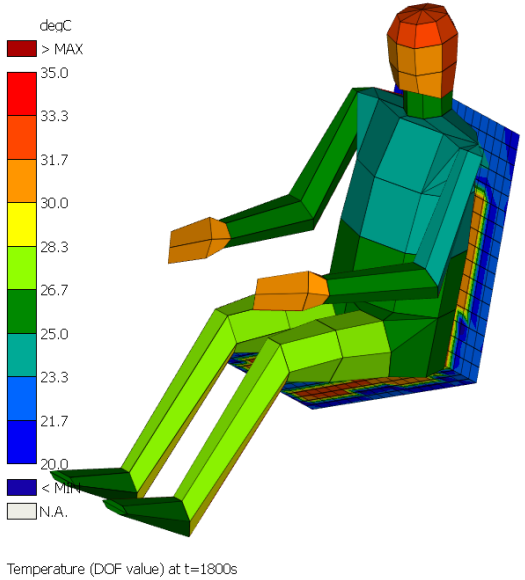
q - whole human body
p - head/brain
o - face
n - chest
m - upper back
k/l - right/left upper arm
i/j - right/left lower arm
g/h - right/left hand
e/f - right/left upper leg
c/d - right/left lower leg
a/b - right/left foot



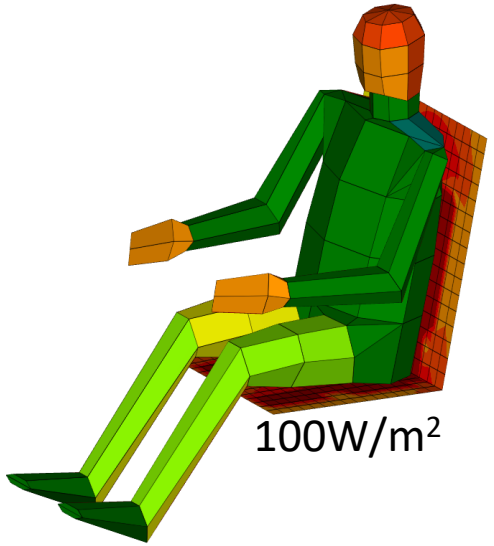
1 - too cold (uncomfortable), **2** - cold, but comfortable, **3** - neutral, **4** - warm, but comfortable, **5** - too warm (uncomfortable)

Simulation Results of a Winter LC

Basic:



Variant 1: with seat heating

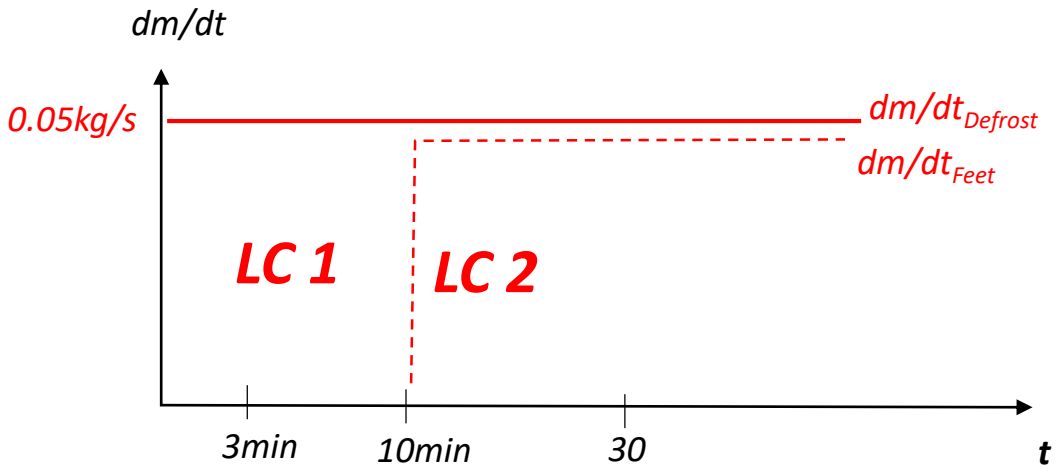


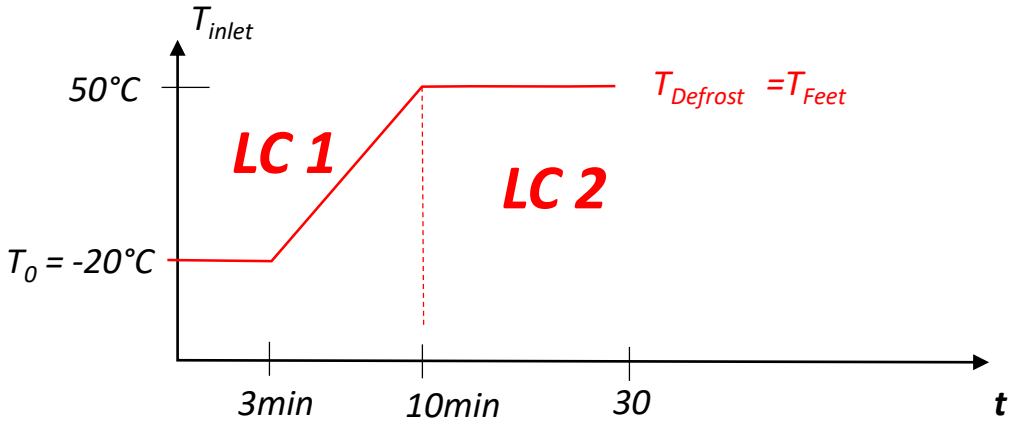
Winter Load Case Description

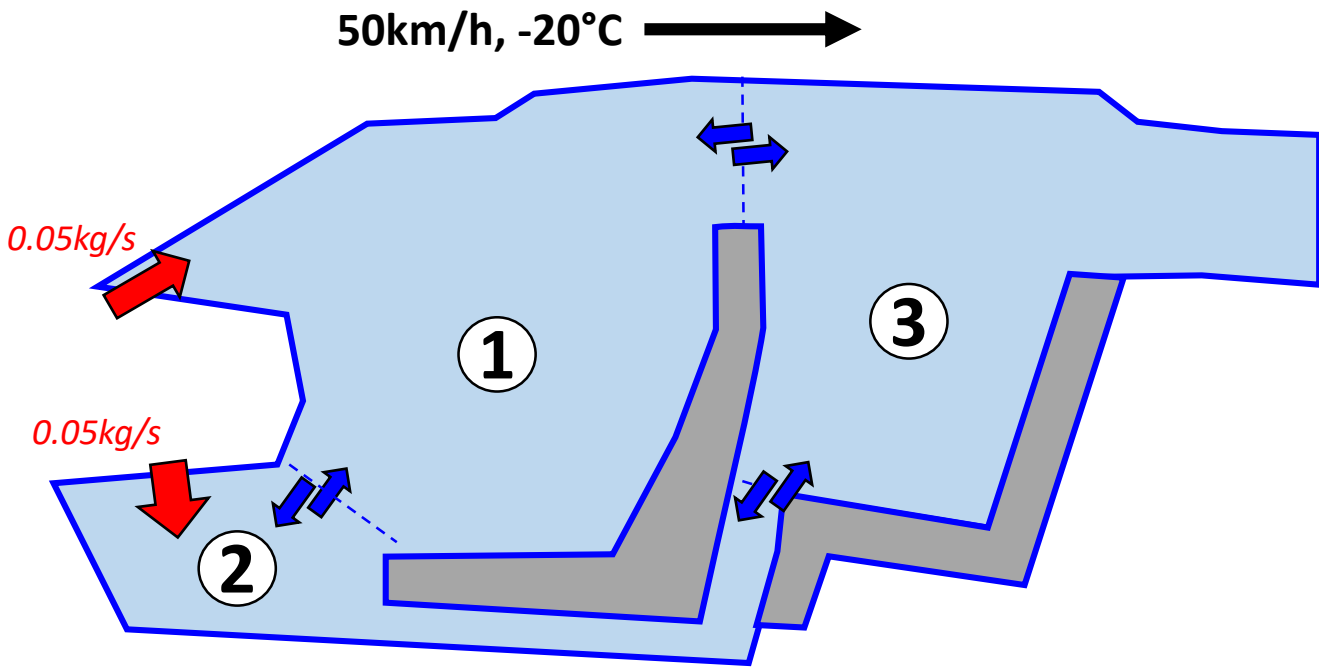
1. Initial & environmental temperature: -20°C
2. External air flow speed: 50km/h
3. HVAC: defrosting starts immediately with 0.05kg/s
4. HVAC: warm air at feet outlet starts after 10 minutes
5. Reach comfortable conditions after 20 minutes

HVAC & Air Zone Model

- Load case 1: only defrost outlet
- Load case 2: both outlets active



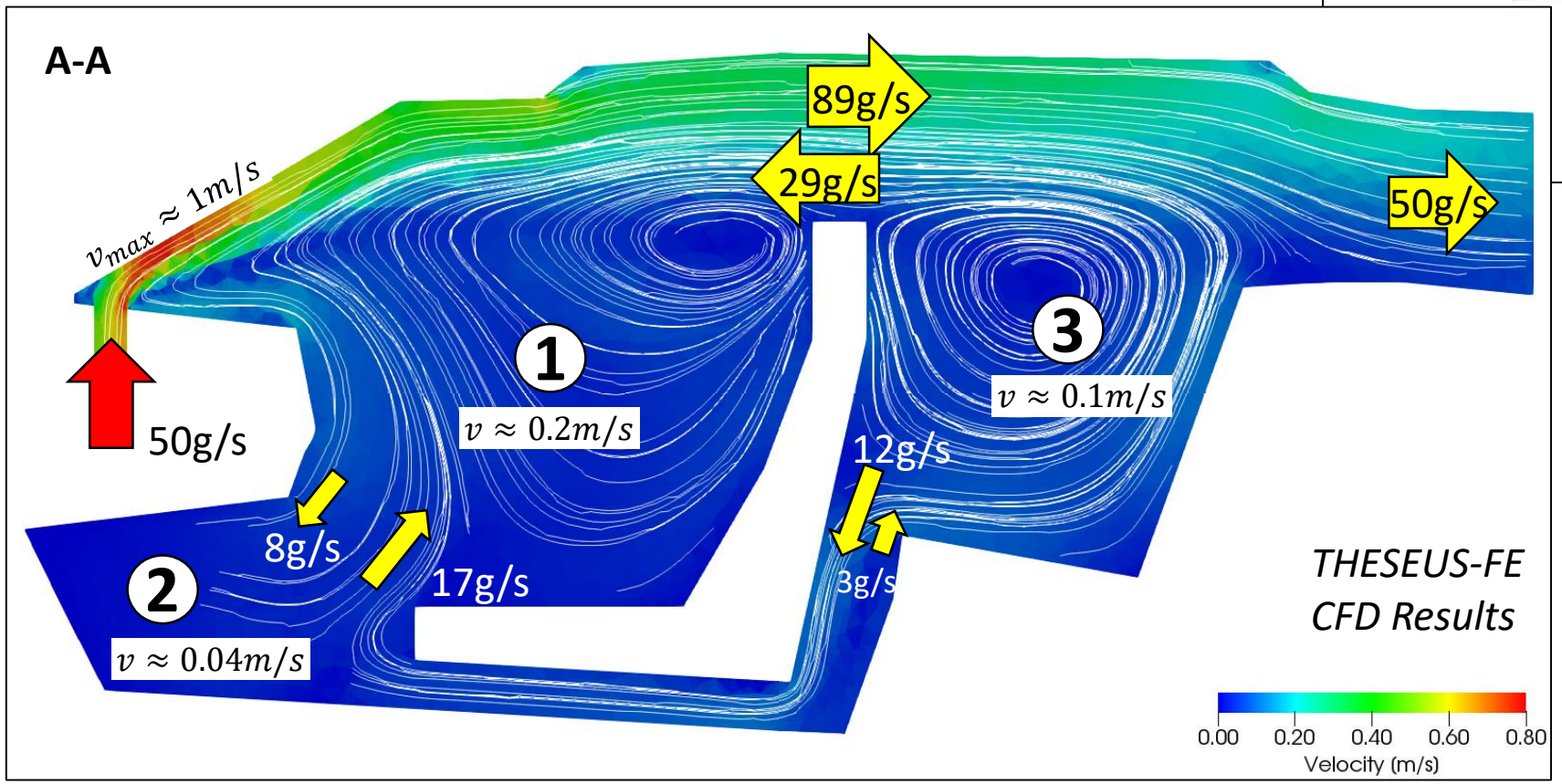


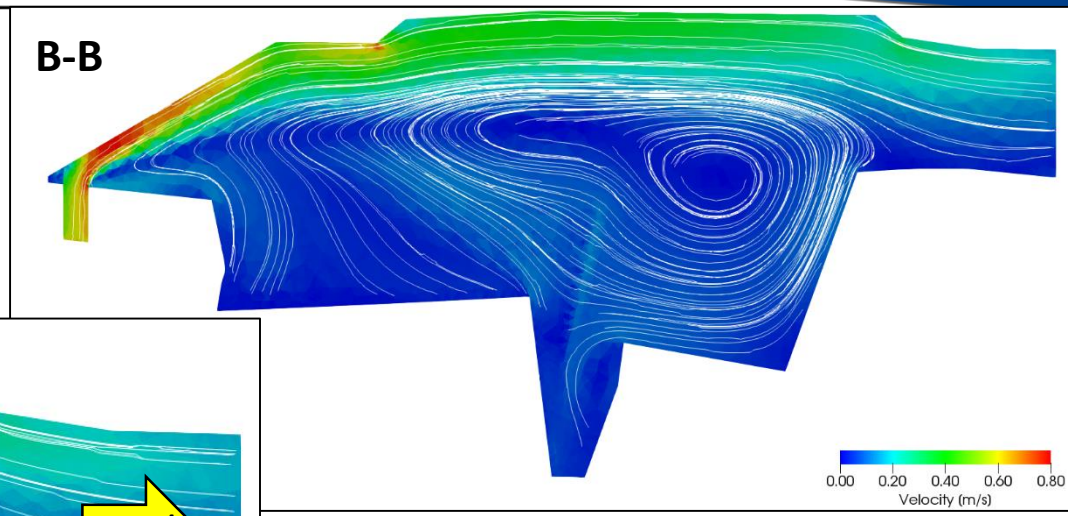


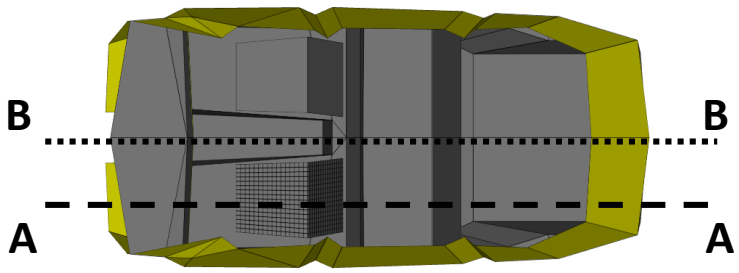
Unknown mass exchange rates between air zones (to be calculated via CFD)

Cabin Mass Flow for Winter LC 1

THESEUS-CFD Results for* ***LC 1***



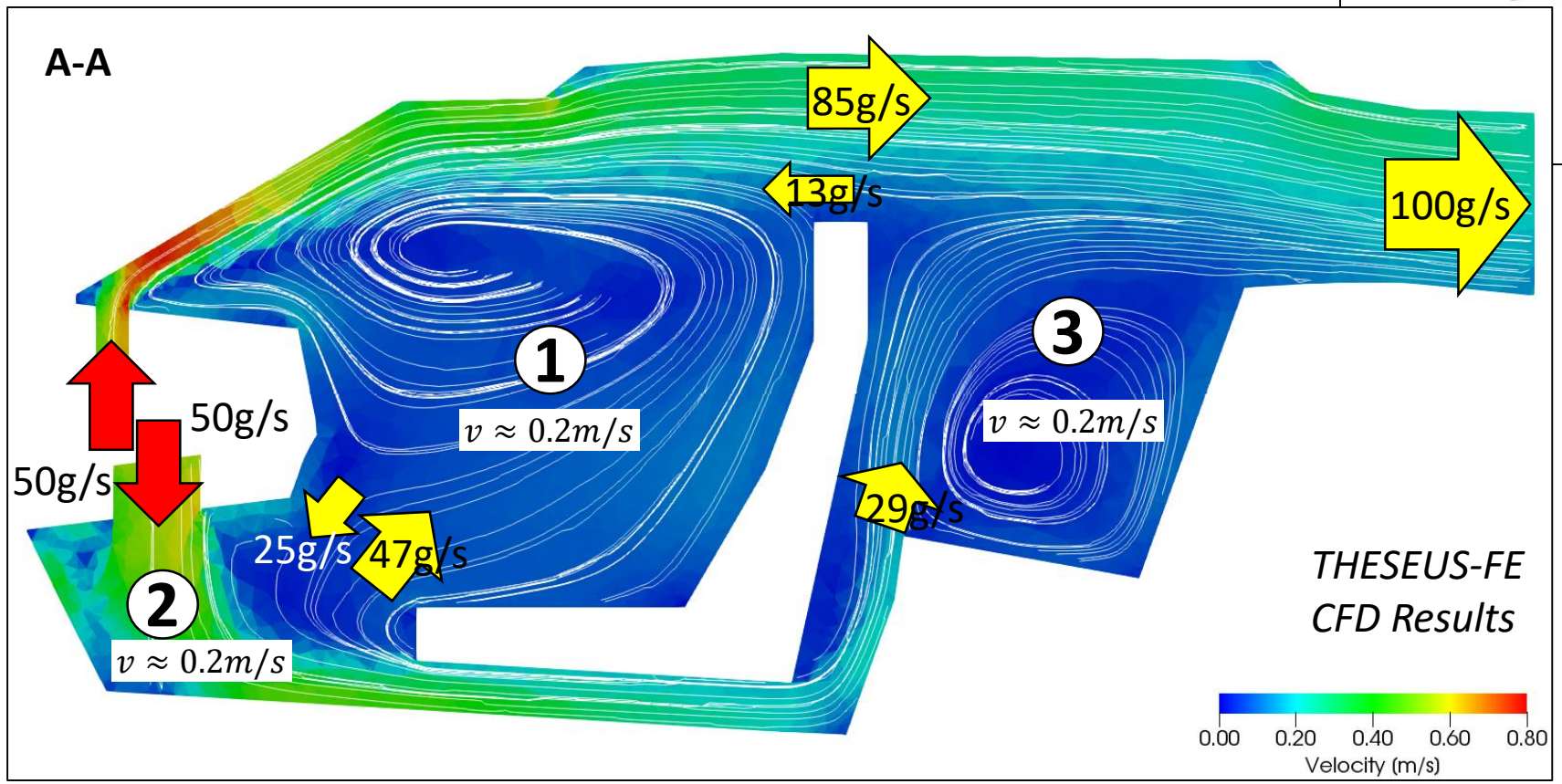


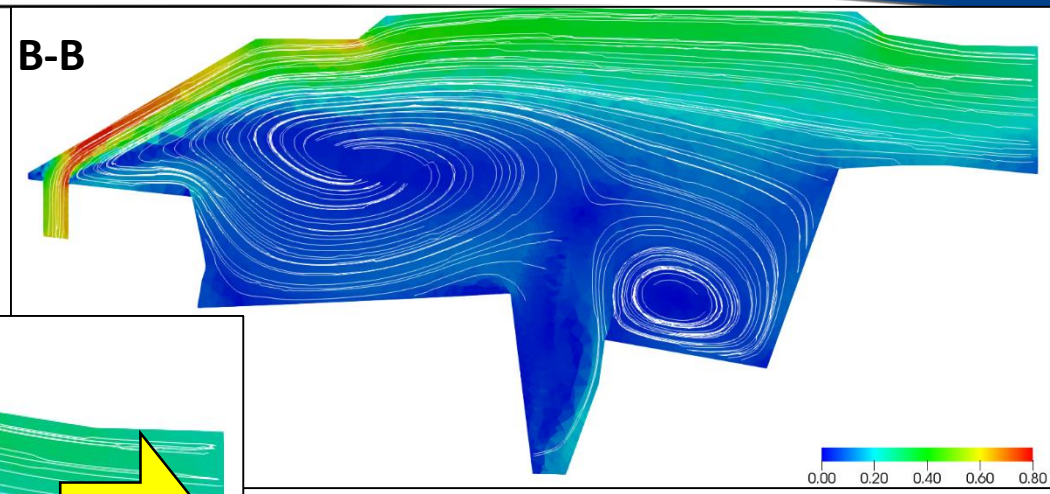


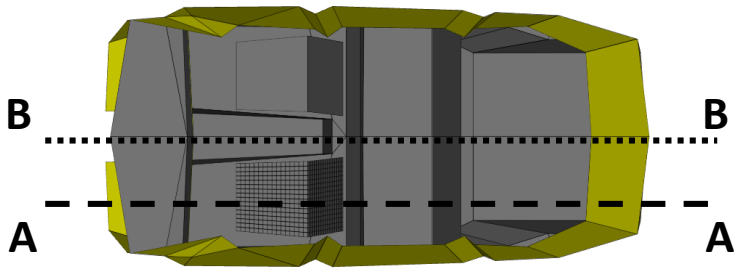
*without manikin because of easier mesh creation

Cabin Mass Flow for Winter LC 2

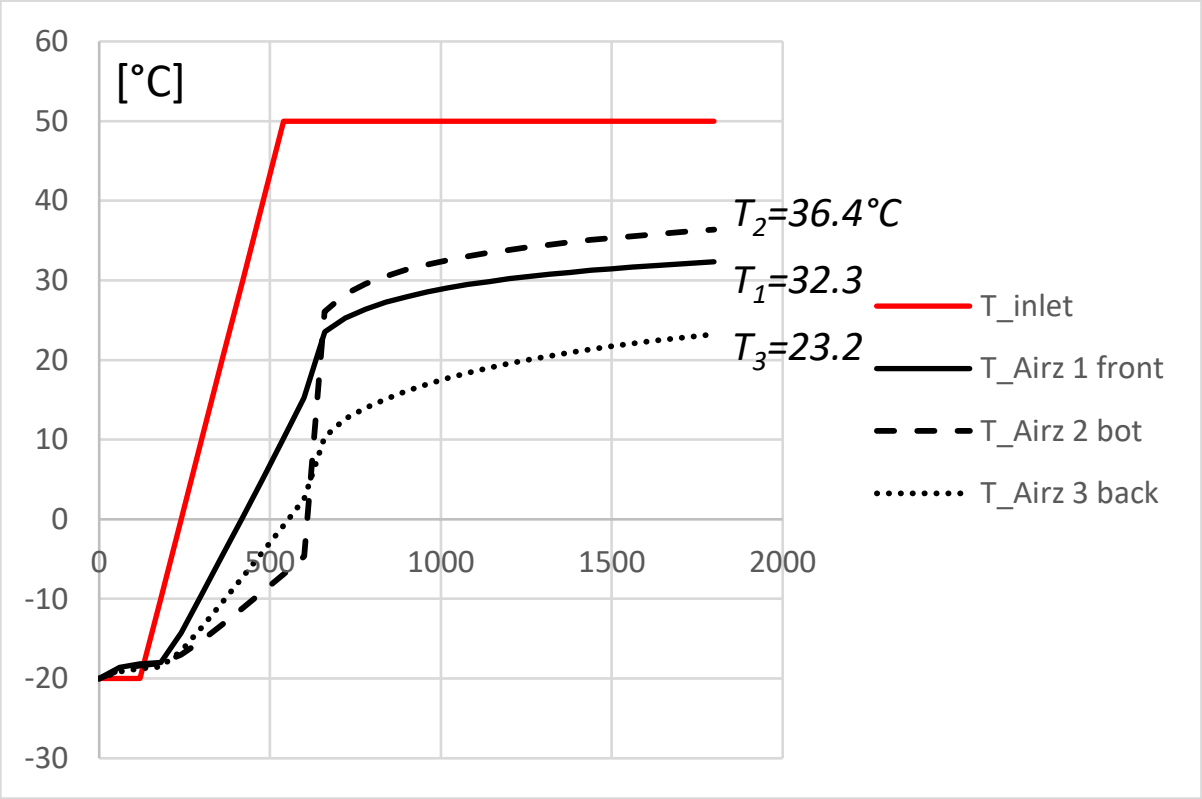
THESEUS-CFD Results for ***LC 2***



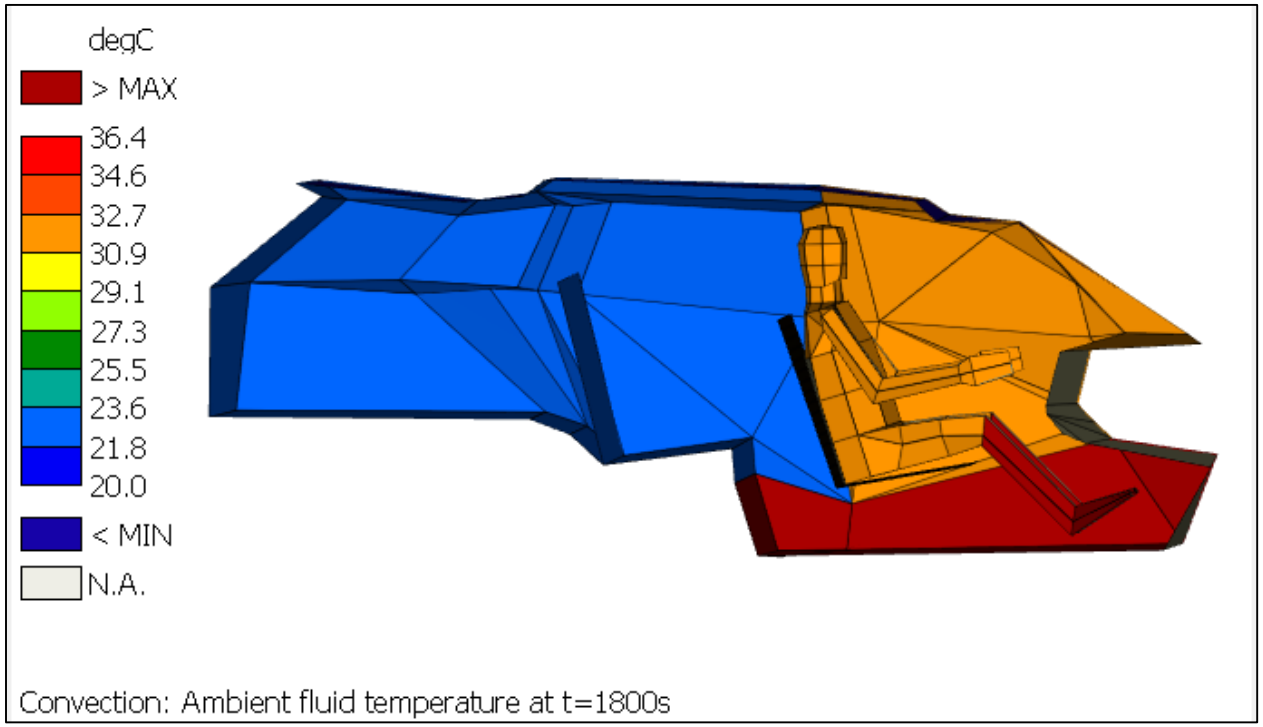




Results: Air Zone Temperatures

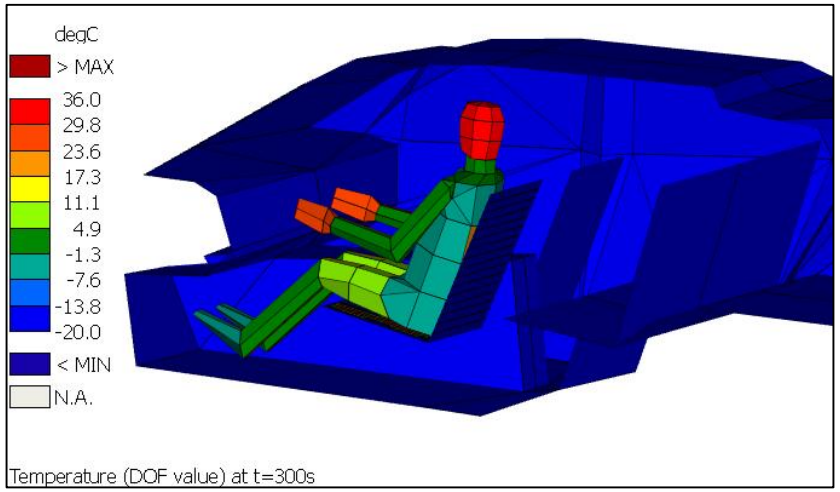


Air zone temp. after 30min

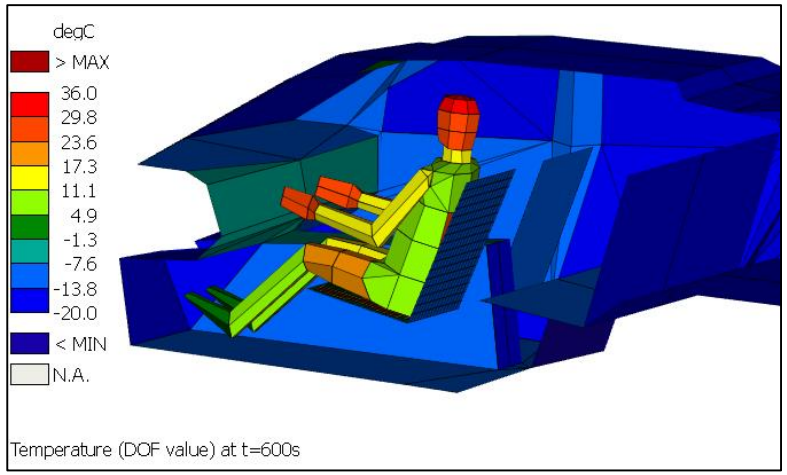


Results: Part temperatures

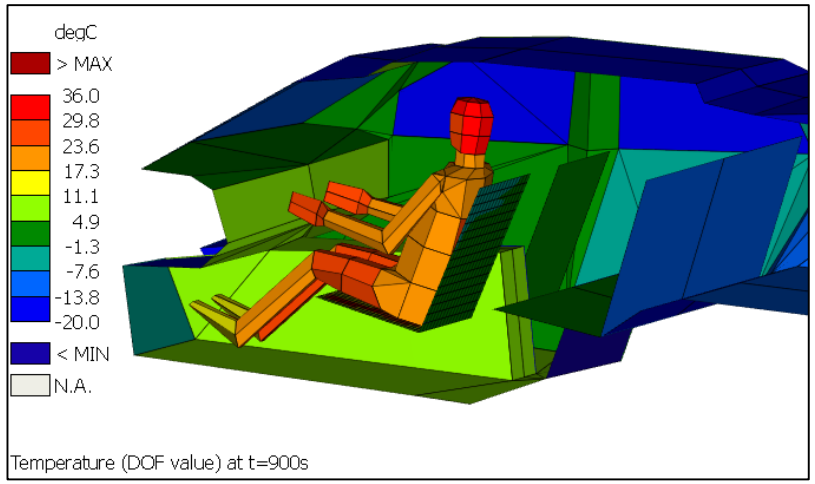
5min



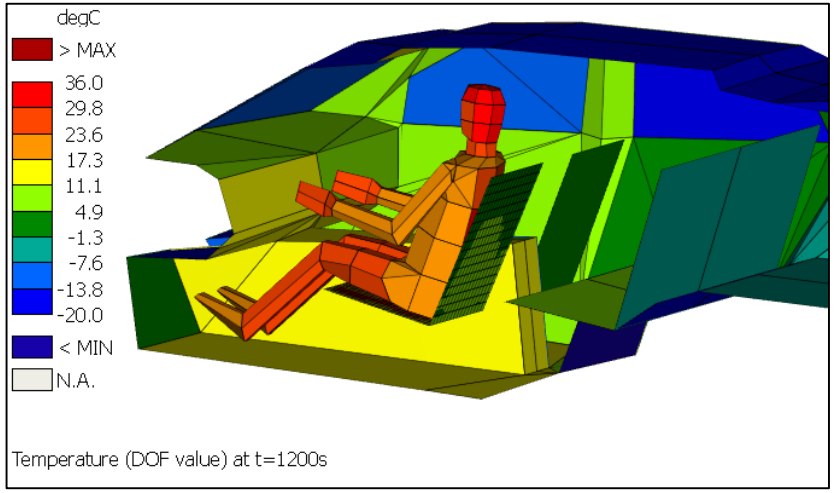
10min



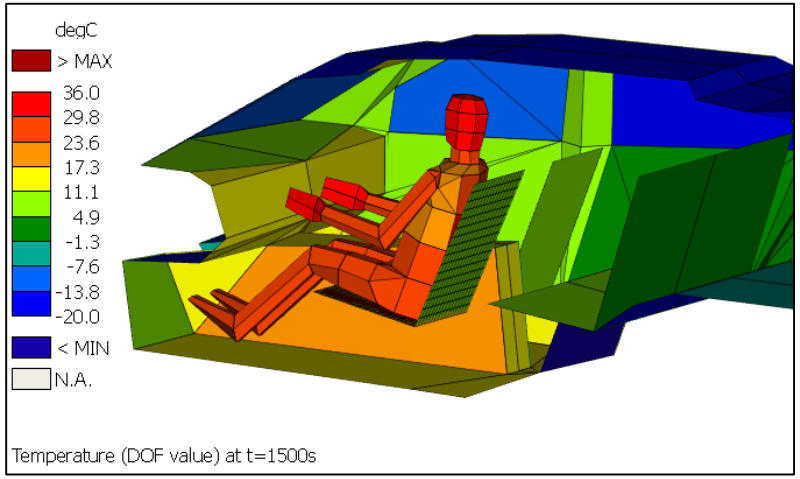
15min



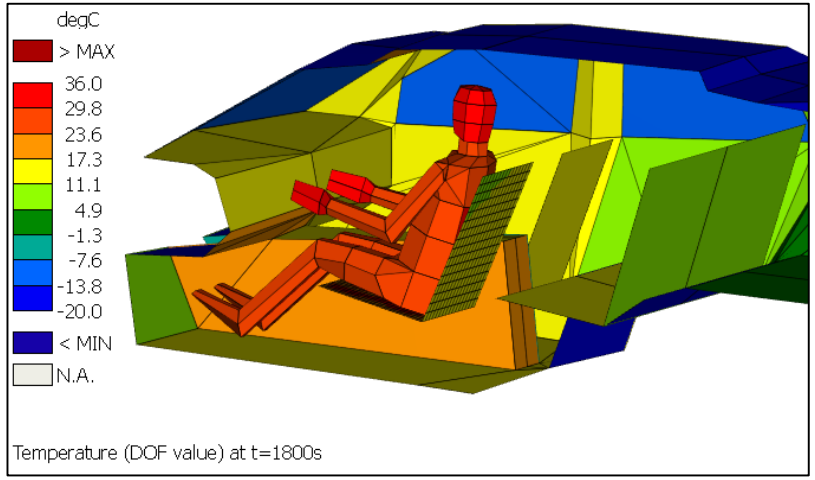
20min



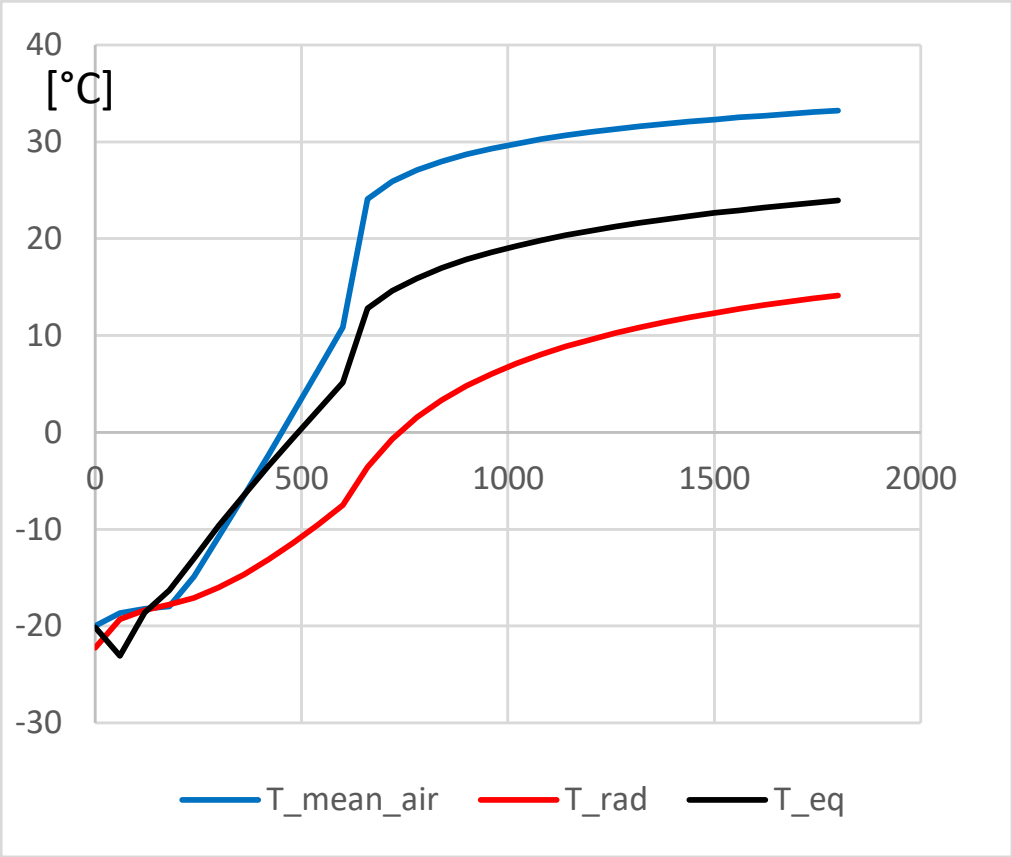
25min



30min



Results: Global Temperatures Acting on the Manikin



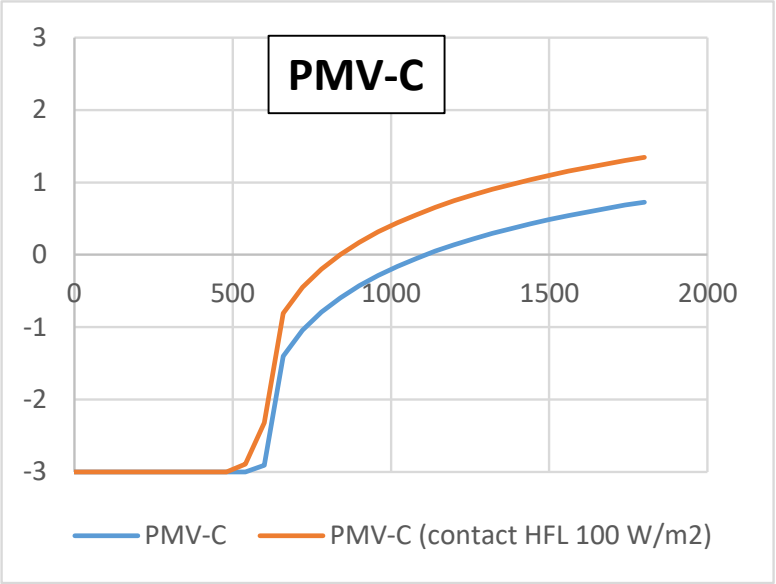
33.2°C - mean air temp. on manikin

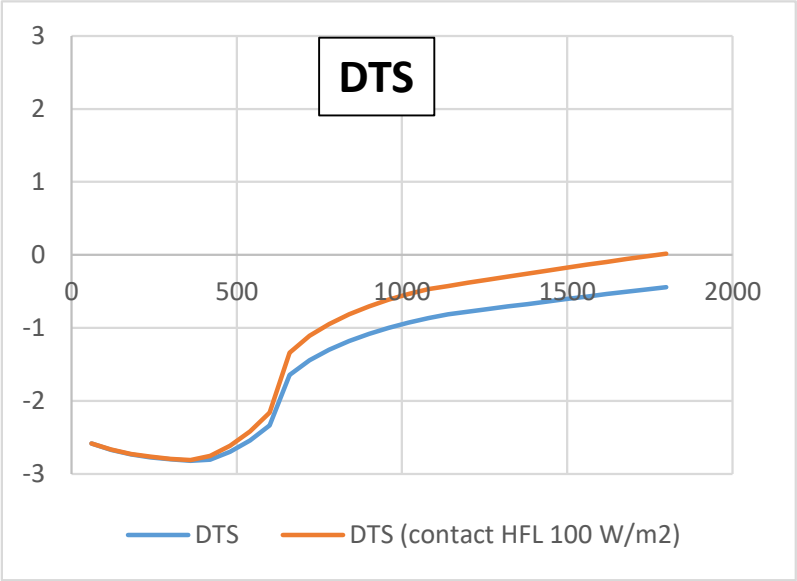
23.9°C - mean equivalent temp. on manikin

14.2°C - Mean radiation temp. on manikin

Results: Manikin Global Comfort Indices

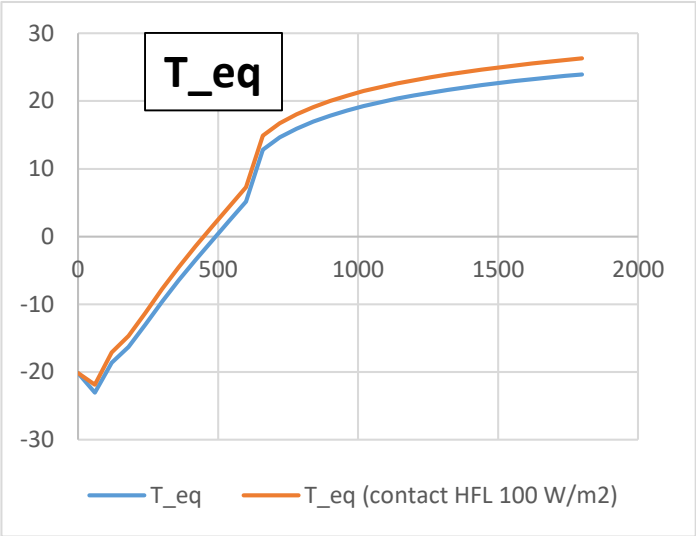
Hot
Warm
Slightly warm
Neutral
Slightly cool
Cool
Cold



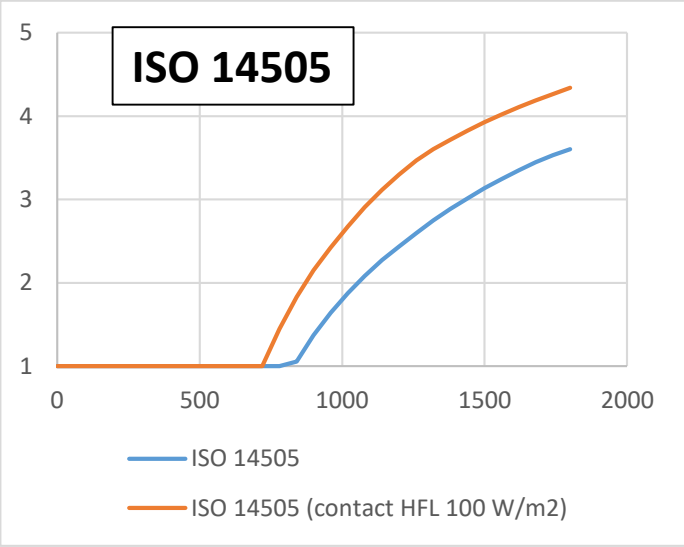


PMV-C is a modified PMV calculation considering the contact region a global energy balance.

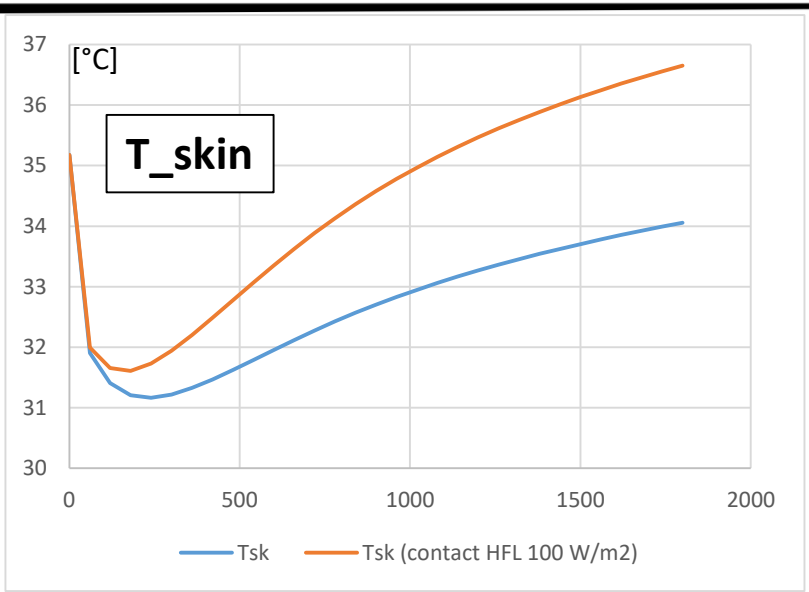
[°C]

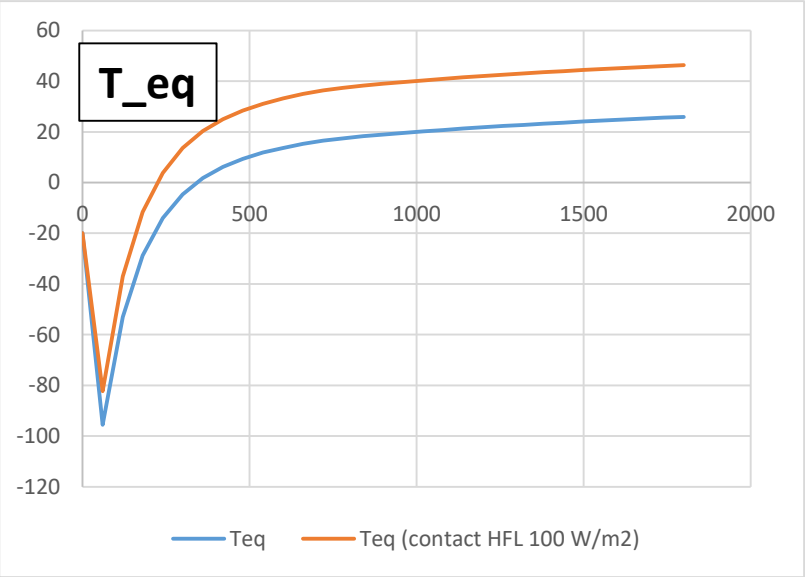


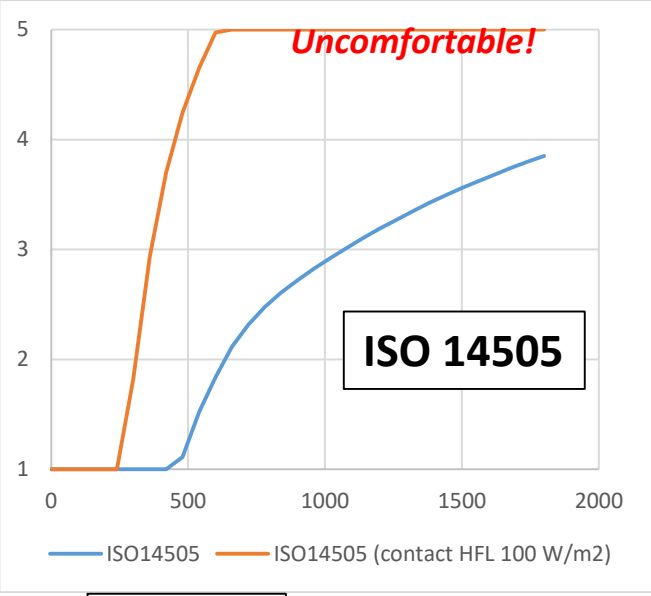
Too warm (uncomfortable)
Warm (but comfortable)
neutral
Cold (but comfortable)
Too cold (uncomfortable)

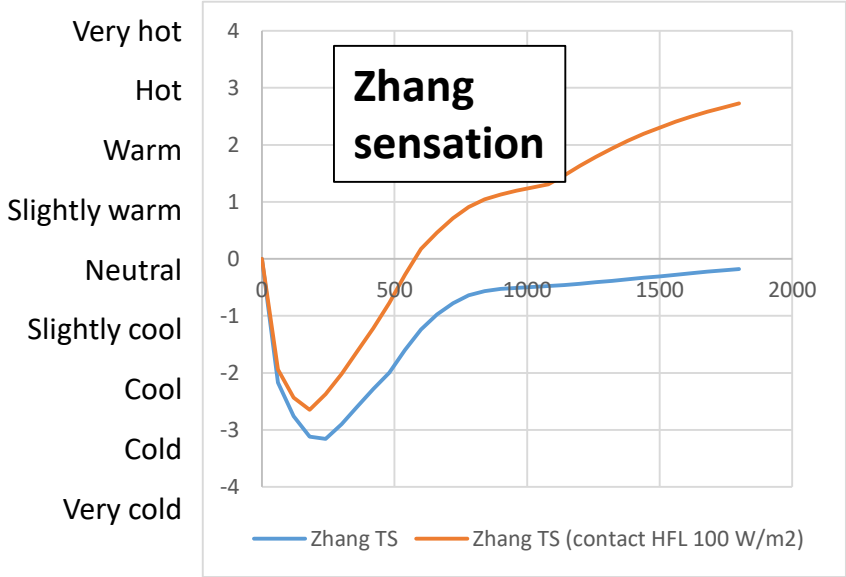


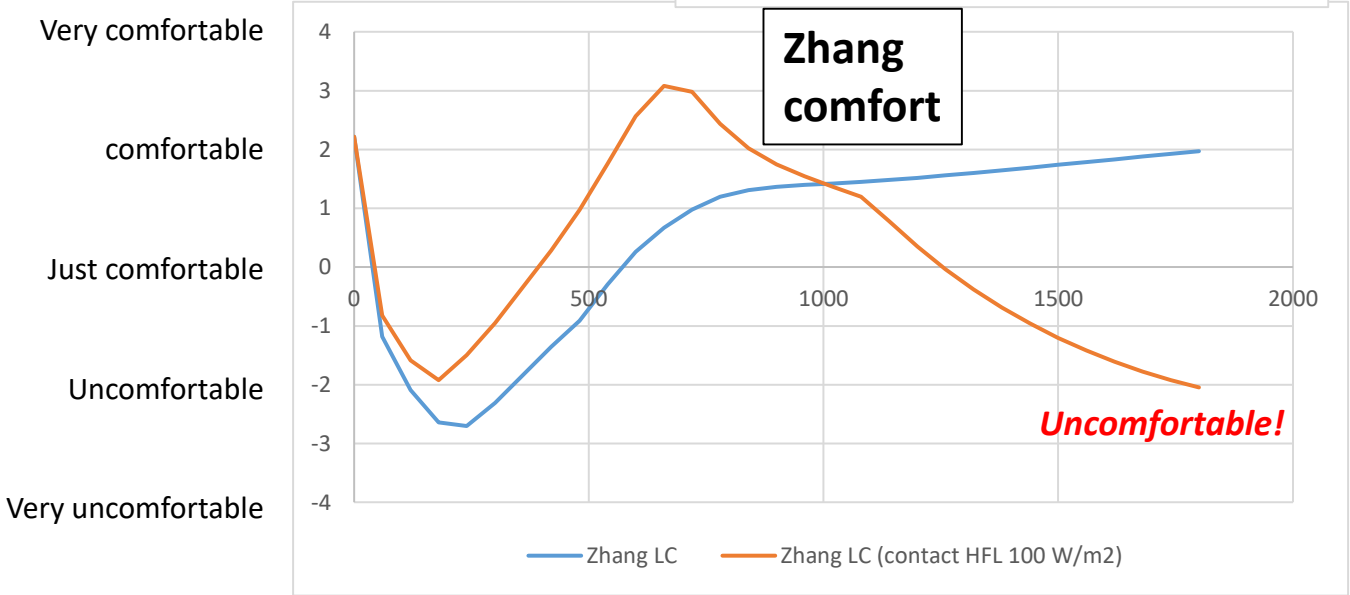
Results: Manikin Local Comfort Indices (Back)





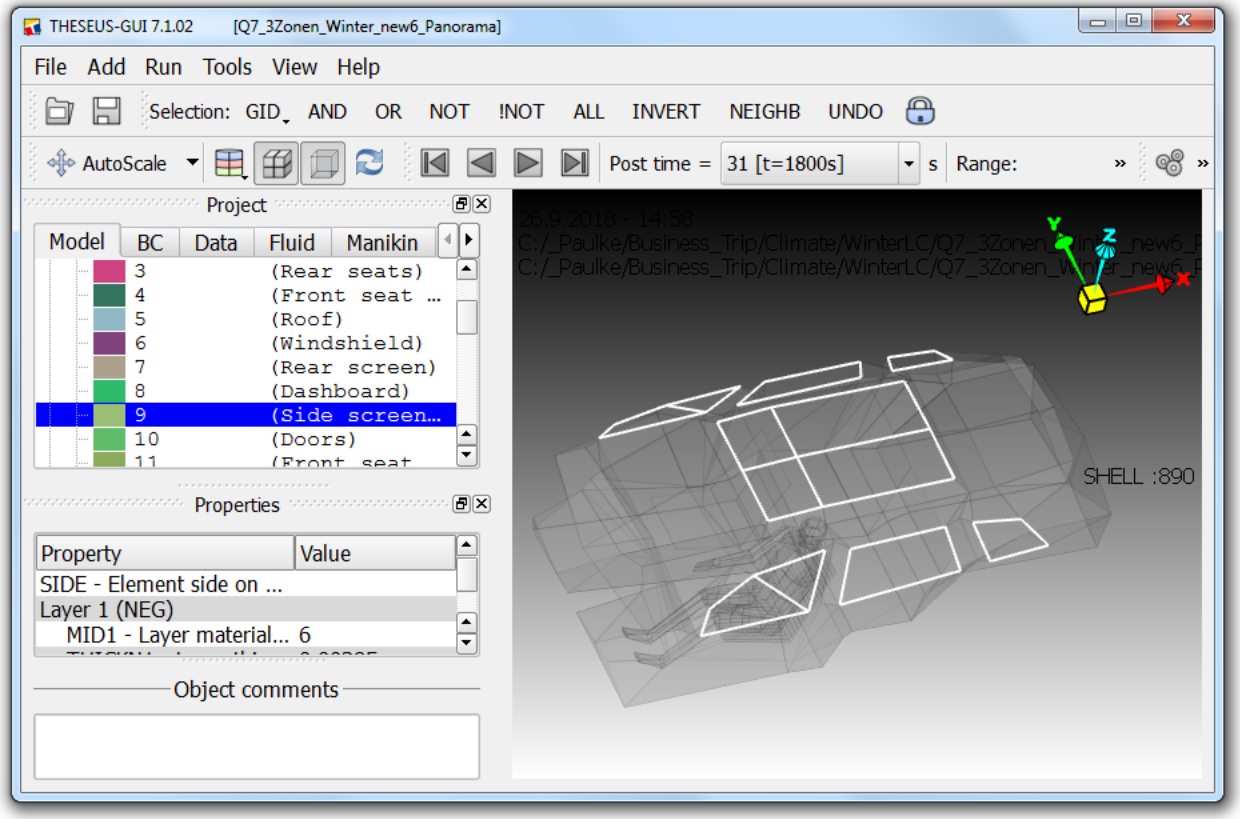






Influence of Panorama Screen

To analyse the effect of a panorama screen for the winter load case we replace the original material/thickness by those of the side screen.



The influence on the air zone temperatures is marginal

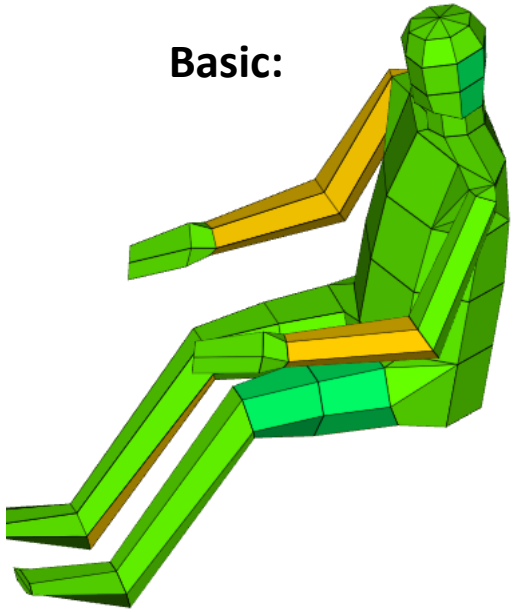
Front :	*32.3 => 31.4 °C*
Bottom :	*36.4 => 36.0 °C*
Back :	*23.2 => 21.6 °C*

Influence of Panorama Screen

ISO 14505

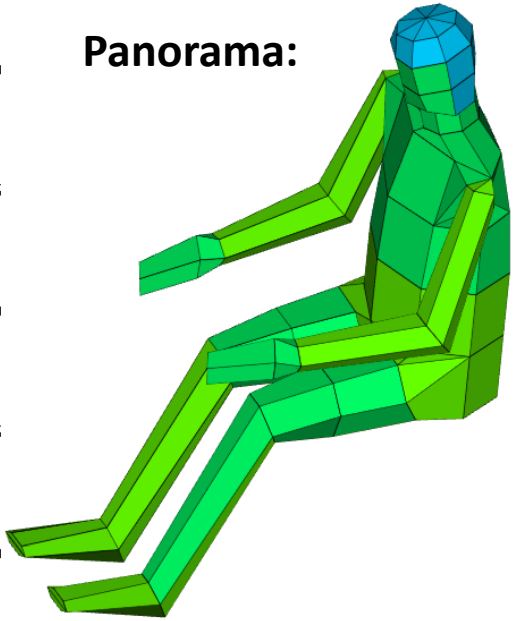
≈3 : neutral

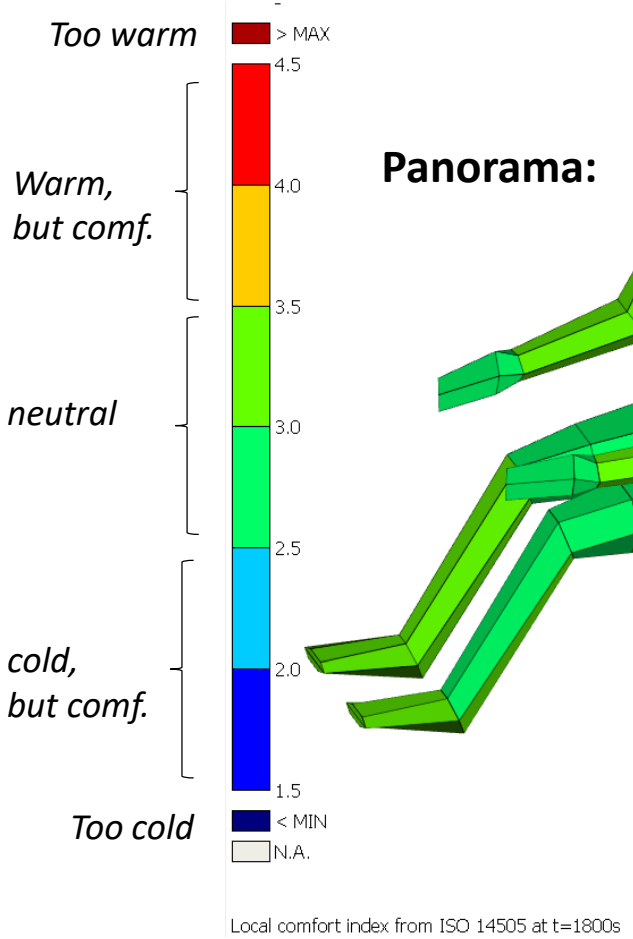
Basic:



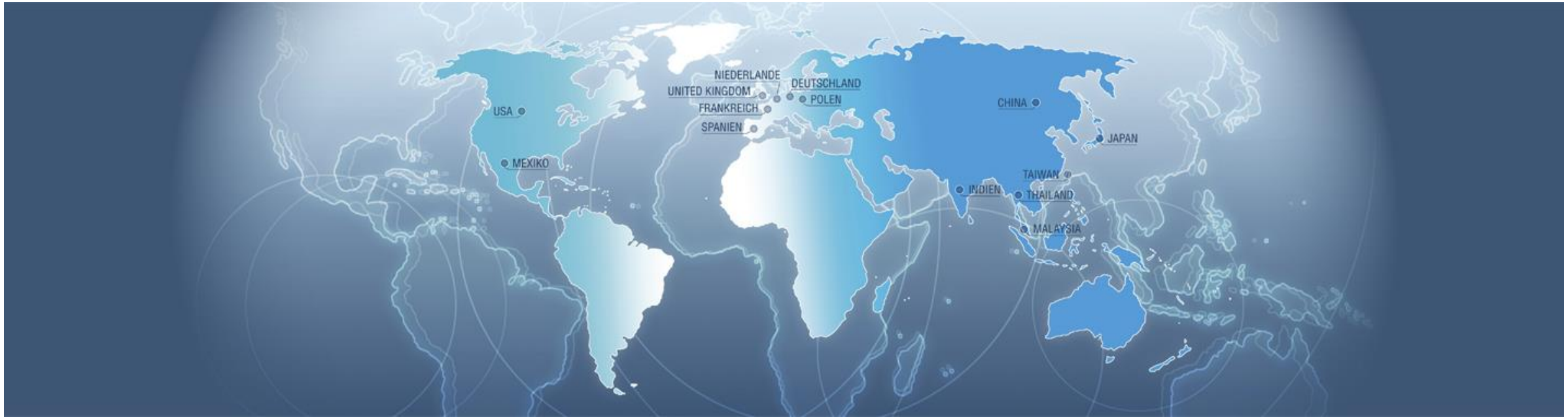
≈2.3 : cold, but comfortable

Panorama:





Kontaktdaten



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