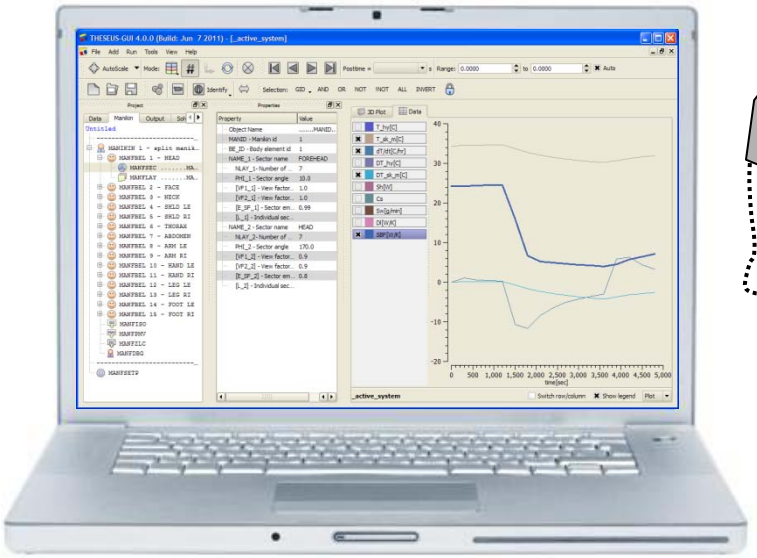
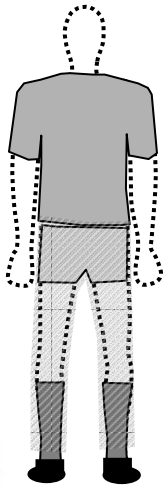
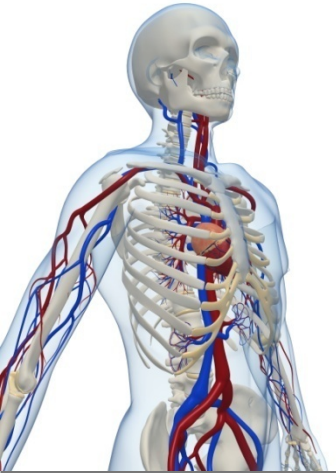
Workshop:
Thermal Manikin FIALA-FE (decoupled modus)

Software Version: THESEUS-FE v.4.0
(bugfix in UserManfialaZhangSL.dll)





summer clothed



To start the model file *sphere.tfe* from the command line...

theseus job=sphere [inter] [fiala]

- the option *inter* starts the job in an interactive modus
- the option *fiala* is required for customers that license the manikin module “FIALA-FE”

Requirements

- **Manuals:** Keyword M., Validation M., Theory M.
- **HDFViewer**
- **MS Excel**
- **Paper:** D. Fiala, K. J. Lomas and M. Stohrer: A computer model of human thermoregulation for a wide range of environmental conditions: the passive system

http://jap.physiology.org/content/87/5/1957.full.pdf+html?maxtoshow=&HITS=10&hit

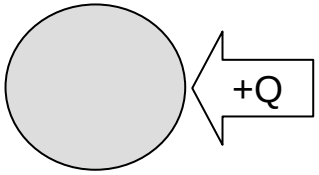
Workshop - contents

- General notes
- Spherical body element
- Cylindrical body element with metabolism and blood perfusion
- Symmetric Manikin - Thermal neutrality
- Symmetric Manikin: Active system simulation in a cool environment
- Asymmetric Manikin: Thermal neutrality
- Asymmetric Manikin: Active system simulation - clothing
- Asymmetric Manikin: Active system simulation - comfort prediction
- Asymmetric Manikin: Active system simulation - MANFSBC

General notes

THESEUS-FE uses

- SI units (W, m, s, J, kg, ...)
- Temperatures in °C. For radiation the solver automatically converts to temperatures in Kelvin.
- Heat fluxes absorbed on body elements are positive.
- „$\dot{Q}$“ or simply „Q“ denotes heat flows in [W]
- „$\dot{q}$“ or simply „q“ denotes heat fluxes in [W/m^2]



Files:

tfe-file (suffix .tfe)	-	ascii	-	thermal model (solver reads and checks for errors and warnings)
hdf-file (...)	-	binary	-	contains results (open with HDFView)
rpt-file (...)	-	ascii	-	contains errors und warnings (and convergence behaviour)
rst-file (...)	-	binary	-	contains temperatures at end of job (use for restarts)
stp-file (...)	-	binary	-	contains setpoint temperatures (use for simulations in active mode)

General remarks

The thermal manikin model **FIALA-FE** is based on the famous PhD-thesis of Dr. Dusan Fiala.

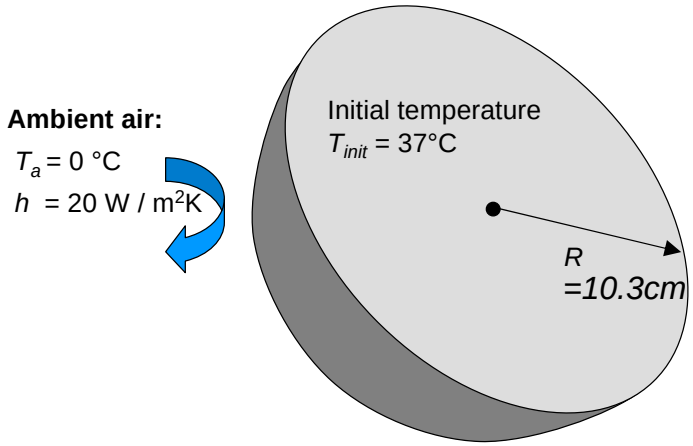
Dynamic Simulation of Human Heat Transfer and Thermal Comfort
by Dusan FIALA

June 1998
Institute of Energy
and Sustainable Development
DE MONTFORT UNIVERSITY LEICESTER

- The implementation in THESEUS-FE was done with consulting by Dr. Fiala.
- The model is <u>not gender-specific</u> but mixes thermal behaviour of both genders
- The thermoregulation model is tuned to achieve good fit with a number of temperature measurements on real people under variable thermal boundary conditions.
- Special emphasis was placed on good results for local and average skin temperatures in time-varying thermal boundary conditions.
- All of Dr. Fiala's documented validations were recalculated using the model FIALA-FE and are documented in a special validation manual.

Spherical body element

- A manikin model will be calculated with just one body element.
- The model is stored in the file *sphere.tfe*



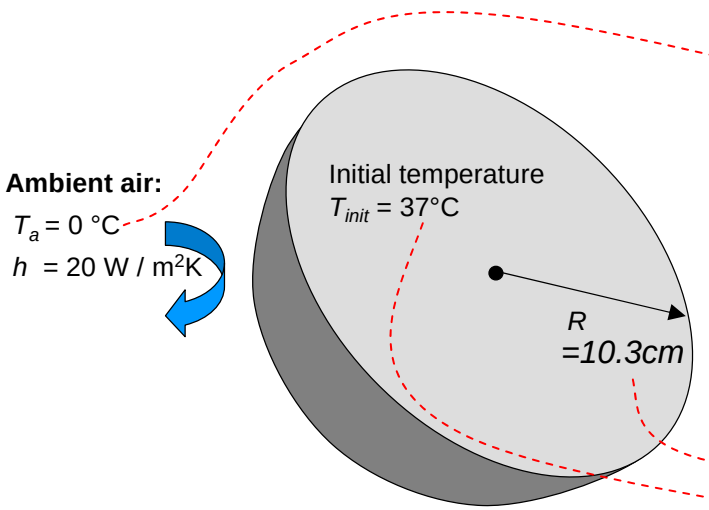
thermal material properties:

Brain:

conductivity:	k = 0.49 W/mK
density:	ρ = 1080 kg/m³
specific heat:	c = 3850 J/kgK

Spherical body element

- The tfe-file contains keywords (e.g. MANIKIN) and comment lines ($...).
- The order of the keywords is unimportant (exception: MANIKIN must be defined before MANFBEL).
- All entry fields have a fixed length of 8 characters.
- The Keyword Manual provides a detailed description of all keywords.



8 characters

sphere.tfe - Editor

Datei Bearbeiten Format Ansicht ?

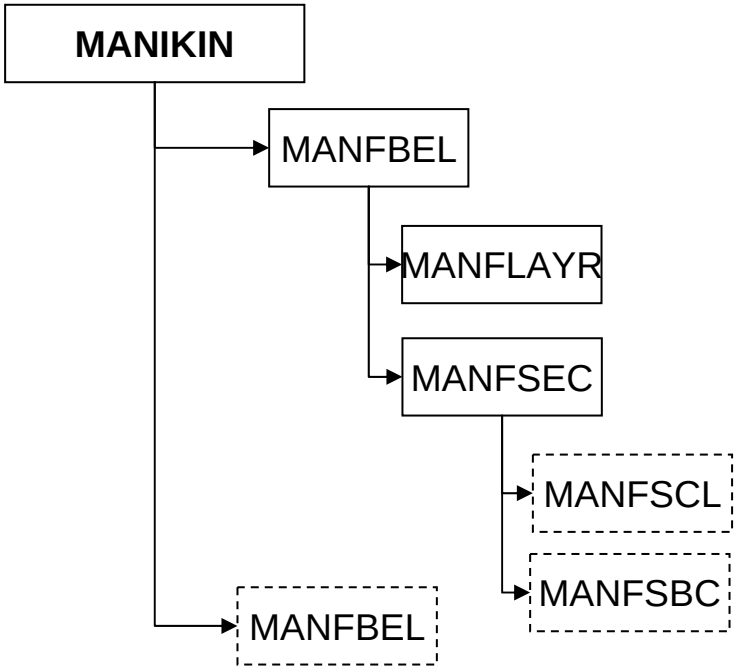
```
$        2        3        4        5        6        7        8        9       10
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
$
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ Man with single spherical body element
MANIKIN 1        FIALA   UNCPLD  PASSIVE STND    1       0.0
+       0.0      0.0     0.0     0.0     0.0             0.0
$
MANFDBG 1        LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE....NSEC.........L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1        1       HEAD    SPHERE  1               0.0     0.0
+       1.0      1.0     1.0     1.0     1.0     1.0     1.0
+       0.0      0.0     400.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....PHI.....VF_SED..VF_STND.E_SF
MANFSEC 1        1       ALL     3       360.0   0.0     0.0     0.0
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.
MANFLAYR1        1       LAY1    9       0.04    0.49    1080.0  3850.0  0.0     0.0
+                        LAY2    9       0.075   0.49    1080.0  3850.0  0.0     0.0
+                        LAY3    9       0.103   0.49    1080.0  3850.0  0.0     0.0
$
$
$ transient simulation
SOL                      1.0     57600
$
TINITFE ALL              37
$
POSTFRQ 1800
$---------------------- End of Theseus input file ---------------------
```

Zeile 1, Spalte 1

The comment line above the keyword MANIKIN will be stored in the result file (hdf) and is used as a name/description.
This is useful when more than one manikin is simulated (e.g. „driver“ and „passenger“).
Furthermore the keyword TITLE can be used to add a general description to the model.

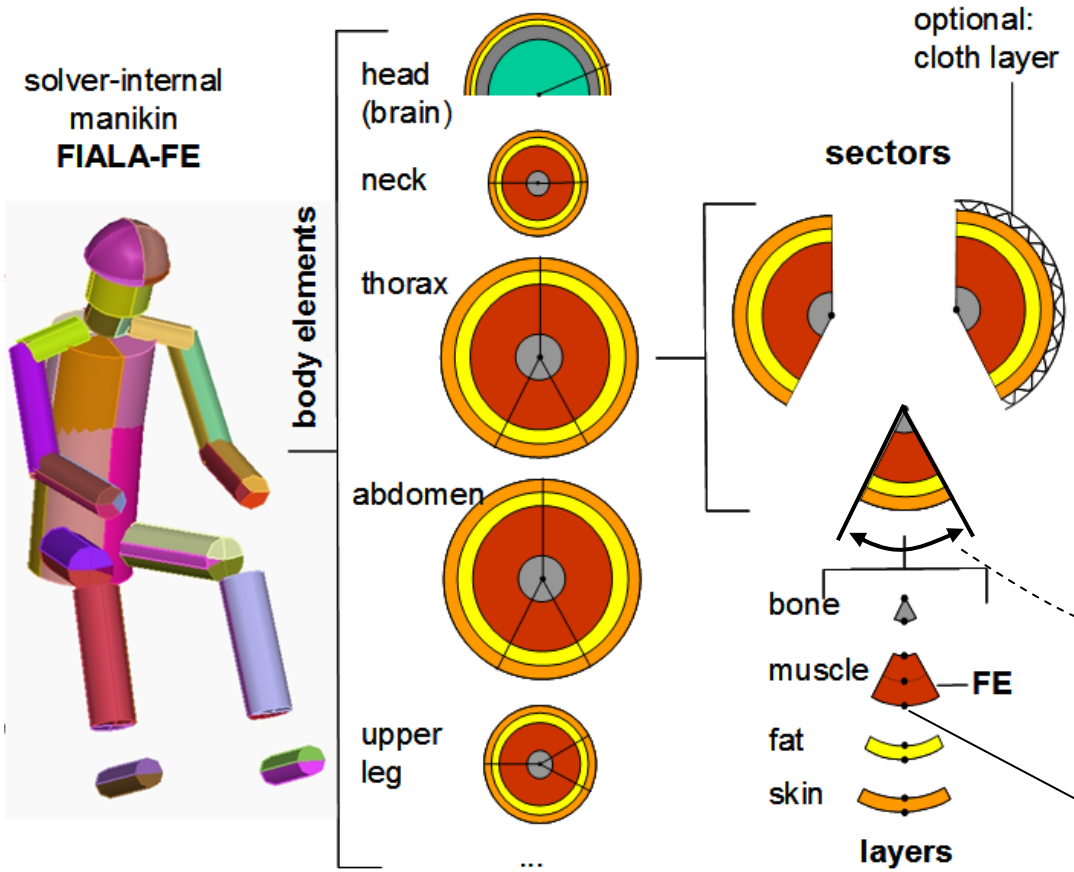
Spherical body element

- A tfe-file can define any number of manikins. Every manikin has an ID (=MANID).
- Body parts are defined using MANFBEL. Every body part has an ID (=BE_ID).
- The layered structure of the body parts is defined with MANFLAYR.
- The body parts are subdivided into sectors using MANFSEC.
- SEC_ID is determined implicitly from the order of definition in MANFSEC (↓).
- The keyword MANFSCL is optional and is necessary to define clothing.
- Local boundary conditions can be defined using MANFSBC.




```
$ Man with single spherical body element
MANIKIN 1       FIALA   UNCPLD  PASSIVE STND    1       0.0
+       0.0     0.0     0.0     0.0     0.0             0.0
$
MANFDBG 1       LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE....NSEC............L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       1       HEAD    SPHERE  1               0.0     0.0
+       1.0     1.0     1.0     1.0     1.0     1.0     1.0
+       0.0     0.0     400.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....PHI.....VF_SED..VF_STND.E_SF
MANFSEC 1       1       ALL     3       360.0   0.0     0.0     0.0
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C......
MANFLAYR1       1       LAY1    9       0.04    0.49    1080.0  3850.0
+                       LAY2    9       0.075   0.49    1080.0  3850.0
+                       LAY3    9       0.103   0.49    1080.0  3850.0
$
```

Spherical body element



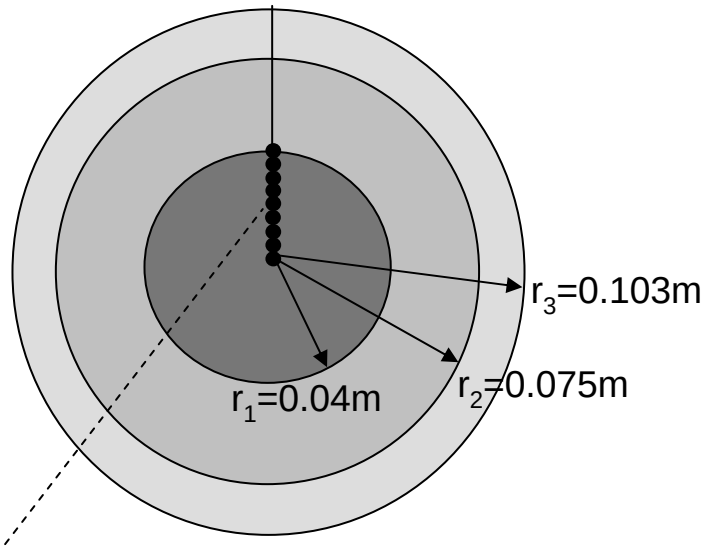

```
$ Man with single spherical body element
MANIKIN 1       FIALA   UNCPLD  PASSIVE STND
+       0.0     0.0     0.0     0.0     0.0
$
MANFDBG 1       LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE....NSEC...
$.......A_SK....A_SW....A_DL....A_CS....A_SH...
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       1       HEAD    SPHERE  1
+       1.0     1.0     1.0     1.0     1.0
+       0.0     0.0     400.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....PHI...
MANFSEC 1       1       ALL     3       360.0
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R......
MANFLAYR1       1       LAY1    9       0.04
+                       LAY2    9       0.075
+                       LAY3    9       0.103
$
```

DISC... number of the
temperature degrees of freedom per layer (2-9)

Notes:

- In the picture above hands are missing.
- In the tfe-file (right) there is just one sector with opening angle 360°.

Model *sphere.tfe* :
Calculation of the convective cooling of the dead brain (starting from 37°C).



DISC=9
(9 degree of freedom per layer)

sphere.tfe - Editor

```
$        2        3        4        5        6        7        8        9       10
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
$
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ Man with single spherical body element
MANIKIN 1        FIALA   UNCPLD  PASSIVE STND    1        0.0
+       0.0      0.0     0.0     0.0     0.0              0.0
$
MANFDBG 1        LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE....NSEC............L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1        1       HEAD    SPHERE  1                0.0      0.0
+       1.0      1.0     1.0     1.0     1.0      1.0     1.0
+       0.0      0.0     400.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....PHI.....VF_SED..VF_STND.E_SF
MANFSEC 1        1       ALL     3       360.0    0.0     0.0     0.0
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.
MANFLAYR1        1       LAY1    9       0.04     0.49    1080.0  3850.0  0.0     0.0
+                        LAY2    9       0.075    0.49    1080.0  3850.0  0.0     0.0
+                        LAY3    9       0.103    0.49    1080.0  3850.0  0.0     0.0
$
$
$ transient simulation
SOL                      1.0     57600
$
TINITFE ALL              37
$
POSTFRQ 1800
$----------------------- End of Theseus input file ---------------------
```

Zeile 1, Spalte 1

Brain:

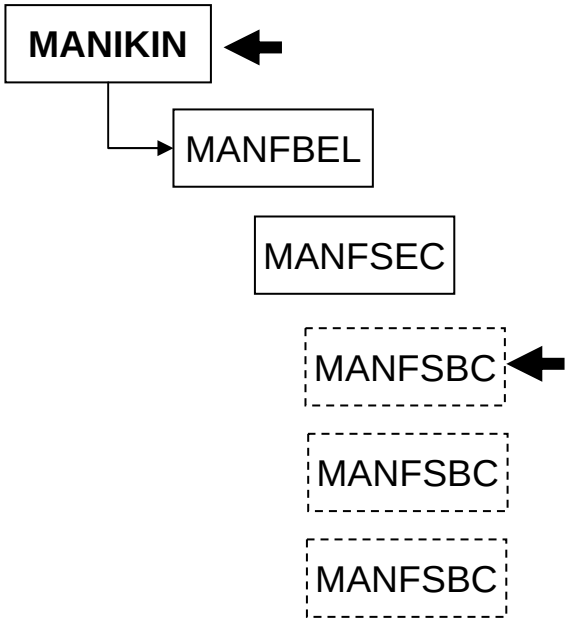
conductivity:	k = 0.49 W/mK
density:	ρ = 1080 kg/m^3
specific heat:	c = 3850 J/kgK

Global boundary conditions are stored in the keyword MANIKIN

1	2	3	4	5	6	7	8
MANIKIN	MANID	**FIALA-FE**	MODE	SYSTEM	POSI	BE	ACT
+	T_W	E_W	T_A	V_A	RH	T_BLA	LEWIS

and can be overwritten locally per sector with MANFSBC.
(MANFSBC stands for Manikin-Fiala-Sector-Boundary-Conditions)

1	2	3	4	5	6	7	8	9	10
MANFSBC	MANID	BE_ID	SEC_ID	T_W	T_A	V_A	RH		Q_SF



ACT ... Activity level (resting: ACT=0.8 stands for 87.1W)

T_W ... Radiation background wall: temperature in °C

E_W ... Radiation background wall: emissivity (e.g. 0.9)

T_A ... Air temperature in °C

V_A ... Air speed in m/s

RH ... Air humidity in %

Q_SF ... Additional heat flux (local) in W/m^2

Convection:

Heat flux: $$q_{conv} = h_{c,mix} \cdot (T_a - T_{sf})$$

Coefficient: $$h_{c,mix} = \sqrt{a_{nat}\sqrt{|T_a - T_{sf}|} + a_{frc} v_{a,eff} + a_{mix}}$$

Here: $a_{nat} = 0,\ a_{frc} = 0,\ a_{mix} = 400$

$$h_{c,mix} = \sqrt{400} = 20\,W/m^2K$$

T_a ... Air temperature in °C, T_{sf} ... Surface temperature

sphere.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$        2        3        4        5        6        7        8        9
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$23456
$
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ Man with single spherical body element
MANIKIN 1        FIALA   UNCPLD  PASSIVE STND    1       0.0
+       0.0      0.0     0.0     0.0     0.0             0.0
$
MANFDBG 1        LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE....NSEC............L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1        1       HEAD    SPHERE  1               0.0     0.0
+       1.0      1.0     1.0     1.0     1.0     1.0     1.0
+       0.0      0.0     400.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....PHI.....VF_SED..VF_STND.F_SF
MANFSEC 1        1       ALL     3       360.0   0.0     0.0     0.0
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.....
MANFLAYR1        1       LAY1    9       0.04    0.49    1080.0  3850.0
+                        LAY2    9       0.075   0.49    1080.0  3850.0
+                        LAY3    9       0.103   0.49    1080.0  3850.0
$
$
$ transient simulation
SOL                      1.0     57600
$
TINITFE ALL              37
$
POSTFRQ 1800
$----------------------- End of Theseus input file -------------------
```

Zeile 1,

Radiation:

$$q_{rad} = h_r (T_w - T_{sf})$$
$$h_r = \sigma \varepsilon_{sf} \varepsilon_w \psi_{sf-w} \left(\overline{T}_{sf}^{\,2} + \overline{T}_w^{\,2}\right)\left(\overline{T}_{sf} + \overline{T}_w\right)$$

ε_{sf} , ε_w ... Emission of manikin and wall

ψ_{sf-w} ... View factor to the radiant wall T_w (VF_SED: sedentary; VF_STND: standing)

$\overline{T} = T + 273.15K$

Here : $\varepsilon = 0 \Rightarrow h_r = 0$ no radiation!

More Keywords:

MANFDBG ... generates extensive results in the hdf-file (the calculation runs faster without this keyword, but there will be fewer output results)

SOL ... Define the start step size (dt_0=1s) and the end time (57600 s) of the simulation.
Additionally there are a lot of settings for the solver, which are ordinarily not necessary.
Most of them have sensible default values (e.g. mx_dt=60s).

TINITFE ... Define the global start temperature (37°C)

POSTFRQ ... Define the interval (z.B. dt_{post}=1800s) between two results, which will be written in the hdf-file.

Starting the Solver:

theseus job=sphere

sphere.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$        2        3        4        5
$2345678$2345678$2345678$2345678$2345
$
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTE
$.......T_W.....E_W.....T_A.....V_A..
$ Man with single spherical body elem
MANIKIN 1        FIALA    UNCPLD   PASSI
+        0.0      0.0      0.0      0.0
$
MANFDBG 1        LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE.
$.......A_SK....A_SW....A_DL....A_CS.
$.......A_NAT...A_FR....A_MIX
MANFBEL 1        1        HEAD     SPHER
+        1.0      1.0      1.0      1.0
+        0.0      0.0      400.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY.
MANFSEC 1        1        ALL      3
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC.
MANFLAYR1        1        LAY1     9
+                         LAY2     9
+                         LAY3     9
$
$
$ transient simulation
SOL                       1.0      57600
$
TINITFE ALL               37
$
POSTFRQ 1800
$----------------------- End of These
```

Results are stored in the hdf file.

The binary file can be opened with HDFView.

Content:

Information about the used solver version.

User defined job description

All results for Manikin 1:

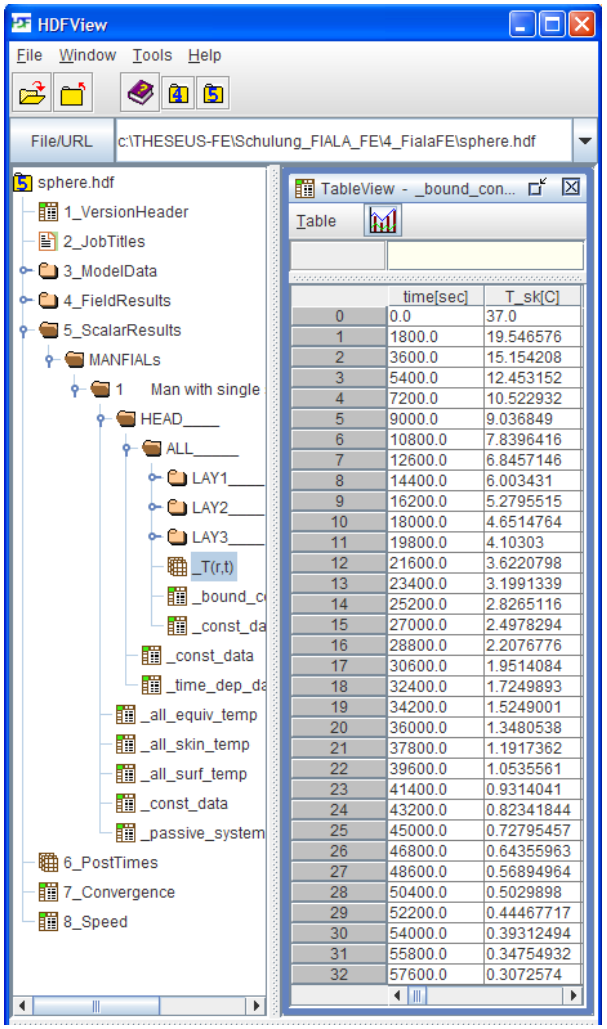
- all essential physical quantities of the calculation described in the Theory Manual will be displayed (e.g. all types of heat convection at all sectors)
- The nomenclature of the physical quantities is largely consistent with the Theory Manual.

  e.g. T_sk = T_{sk} , h_c_mix = $h_{c,mix}$
- result transfer to MS-Excel with copy/paste
- Without the keyword MANFDBG far less data is produced.

Post-Times: all times t_{post} which produce results

Information about numerical solution: e.g. time step and convergence behaviour

General information about the simulation...



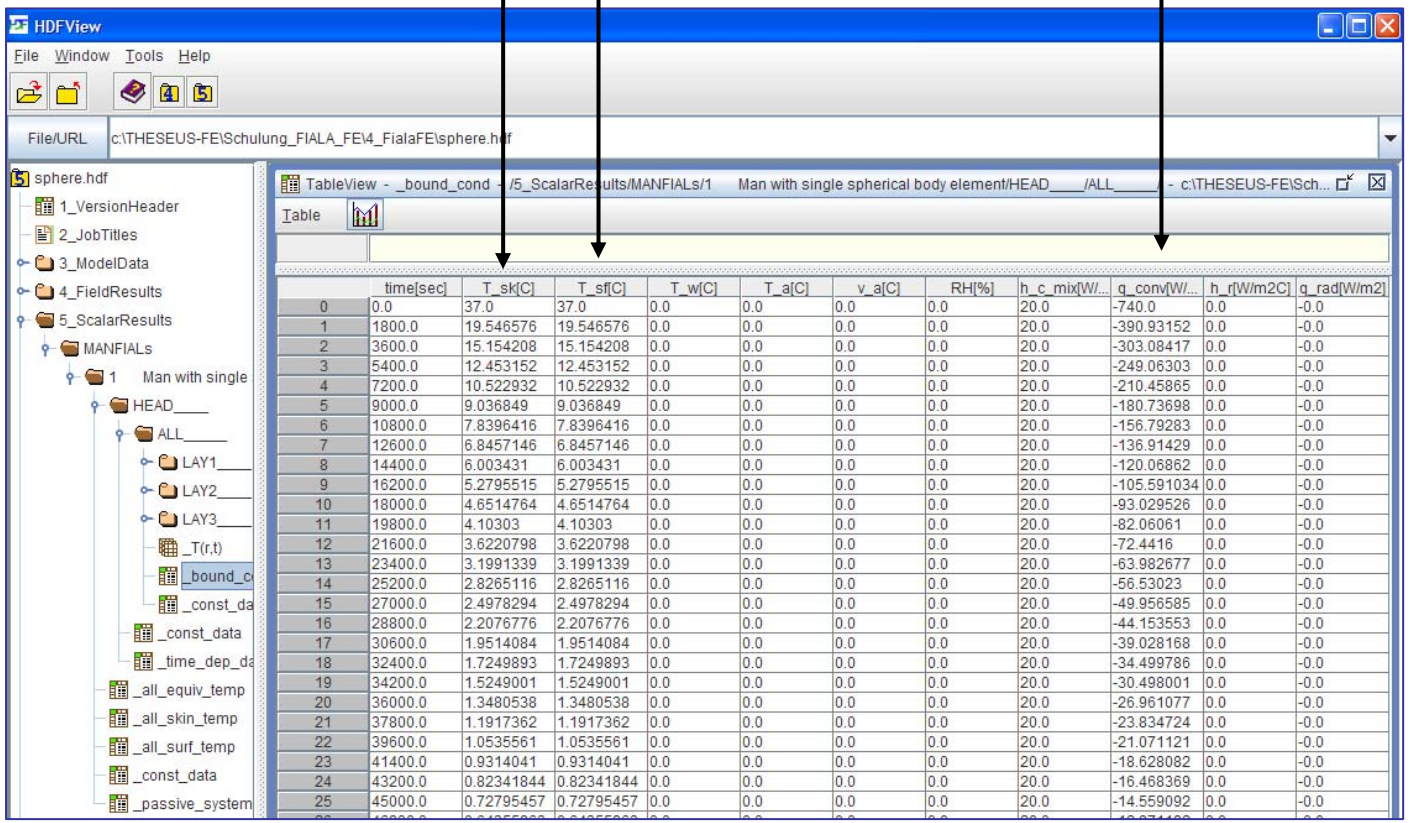
Notes:
nonsensical results are produced by the equivalent temperatures (_all_eqiv_temp)

Spherical body element

The outer temperature nodes of a sector represent the surface of the skin: T_{sk}
If the keyword MANFSCL exists, it will represent the clothing: T_{sf}
If no clothing exists $\Rightarrow$ $T_{sk} = T_{sf}$.

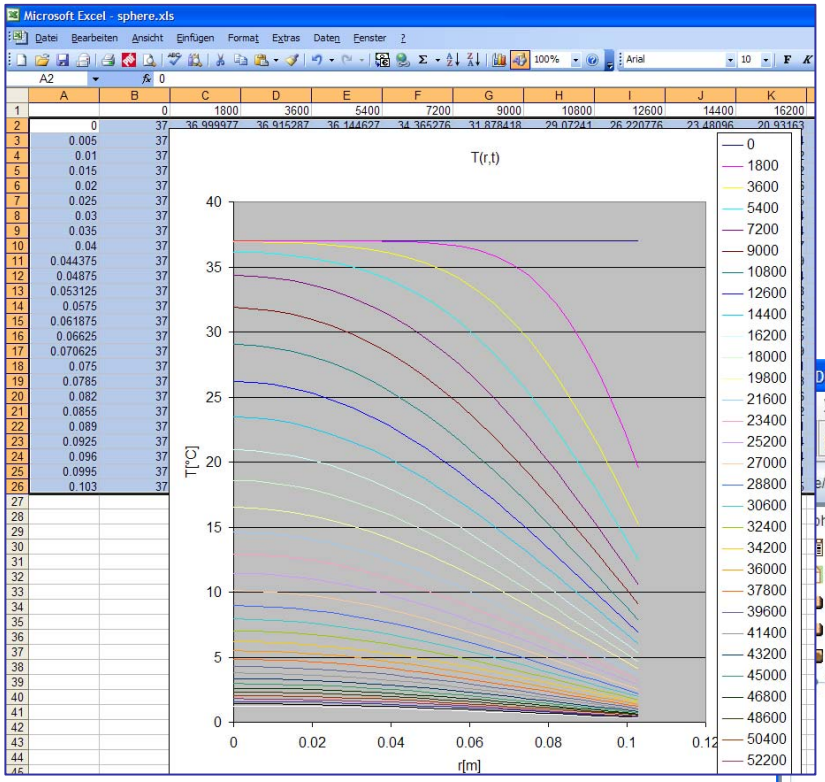
$$q_{conv} = h_{c,mix} \cdot (T_a - T_{sf})$$

(convective)



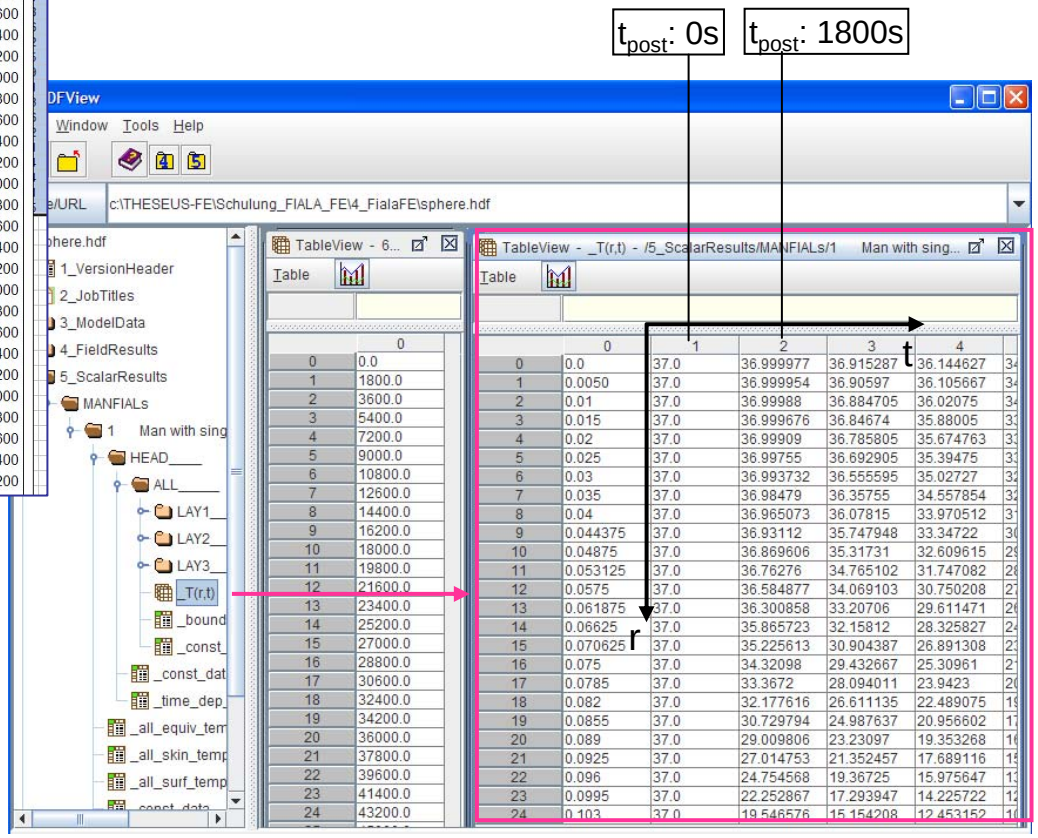
	time[sec]	T_sk[C]	T_sf[C]	T_w[C]	T_a[C]	v_a[C]	RH[%]	h_c_mix[W/...	q_conv[W/...	h_r[W/m2C]	q_rad[W/m2]
0	0.0	37.0	37.0	0.0	0.0	0.0	0.0	20.0	-740.0	0.0	-0.0
1	1800.0	19.546576	19.546576	0.0	0.0	0.0	0.0	20.0	-390.93152	0.0	-0.0
2	3600.0	15.154208	15.154208	0.0	0.0	0.0	0.0	20.0	-303.08417	0.0	-0.0
3	5400.0	12.453152	12.453152	0.0	0.0	0.0	0.0	20.0	-249.06303	0.0	-0.0
4	7200.0	10.522932	10.522932	0.0	0.0	0.0	0.0	20.0	-210.45865	0.0	-0.0
5	9000.0	9.036849	9.036849	0.0	0.0	0.0	0.0	20.0	-180.73698	0.0	-0.0
6	10800.0	7.8396416	7.8396416	0.0	0.0	0.0	0.0	20.0	-156.79283	0.0	-0.0
7	12600.0	6.8457146	6.8457146	0.0	0.0	0.0	0.0	20.0	-136.91429	0.0	-0.0
8	14400.0	6.003431	6.003431	0.0	0.0	0.0	0.0	20.0	-120.06862	0.0	-0.0
9	16200.0	5.2795515	5.2795515	0.0	0.0	0.0	0.0	20.0	-105.591034	0.0	-0.0
10	18000.0	4.6514764	4.6514764	0.0	0.0	0.0	0.0	20.0	-93.029526	0.0	-0.0
11	19800.0	4.10303	4.10303	0.0	0.0	0.0	0.0	20.0	-82.06061	0.0	-0.0
12	21600.0	3.6220798	3.6220798	0.0	0.0	0.0	0.0	20.0	-72.4416	0.0	-0.0
13	23400.0	3.1991339	3.1991339	0.0	0.0	0.0	0.0	20.0	-63.982677	0.0	-0.0
14	25200.0	2.8265116	2.8265116	0.0	0.0	0.0	0.0	20.0	-56.53023	0.0	-0.0
15	27000.0	2.4978294	2.4978294	0.0	0.0	0.0	0.0	20.0	-49.956585	0.0	-0.0
16	28800.0	2.2076776	2.2076776	0.0	0.0	0.0	0.0	20.0	-44.153553	0.0	-0.0
17	30600.0	1.9514084	1.9514084	0.0	0.0	0.0	0.0	20.0	-39.028168	0.0	-0.0
18	32400.0	1.7249893	1.7249893	0.0	0.0	0.0	0.0	20.0	-34.499786	0.0	-0.0
19	34200.0	1.5249001	1.5249001	0.0	0.0	0.0	0.0	20.0	-30.498001	0.0	-0.0
20	36000.0	1.3480538	1.3480538	0.0	0.0	0.0	0.0	20.0	-26.961077	0.0	-0.0
21	37800.0	1.1917362	1.1917362	0.0	0.0	0.0	0.0	20.0	-23.834724	0.0	-0.0
22	39600.0	1.0535561	1.0535561	0.0	0.0	0.0	0.0	20.0	-21.071121	0.0	-0.0
23	41400.0	0.9314041	0.9314041	0.0	0.0	0.0	0.0	20.0	-18.628082	0.0	-0.0
24	43200.0	0.82341844	0.82341844	0.0	0.0	0.0	0.0	20.0	-16.468369	0.0	-0.0
25	45000.0	0.72795457	0.72795457	0.0	0.0	0.0	0.0	20.0	-14.559092	0.0	-0.0

Excel File: *sphere.xls*

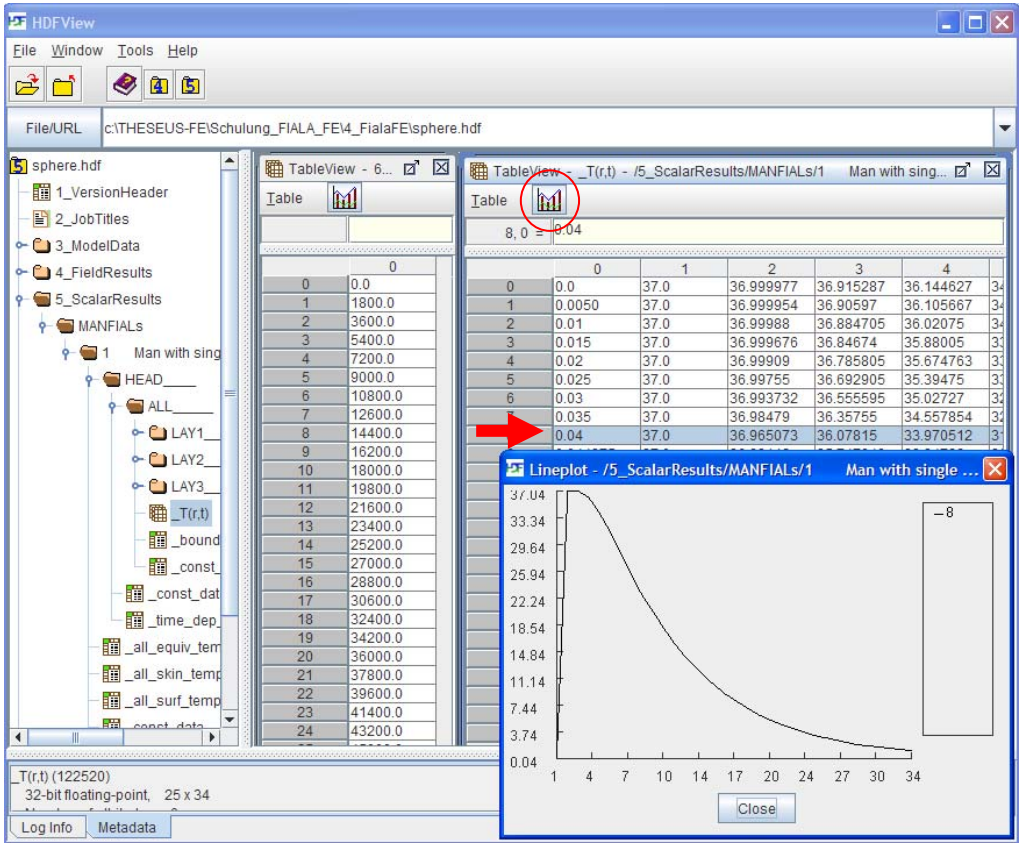


The content of the dataset „_T(r,t)“ was inserted by copy/paste.

In each line in the dataset „_T(r,t)“ the first entry is the radius r of the temperature node. Following entries are the calculated temperatures at the „Post-Times“ t_{post}: 0s, 1800s, 3600s, ...



If you want to plot e.g. the cooling curve at r = 0.04m, copy the corresponding line to Excel.
The corresponding Post-Times are stored in the dataset „6_PostTimes“.



Simple 2D-Plot functions are also available in the HDFViewer:

Validation:
(Validation Man., Kap.4.1.1)

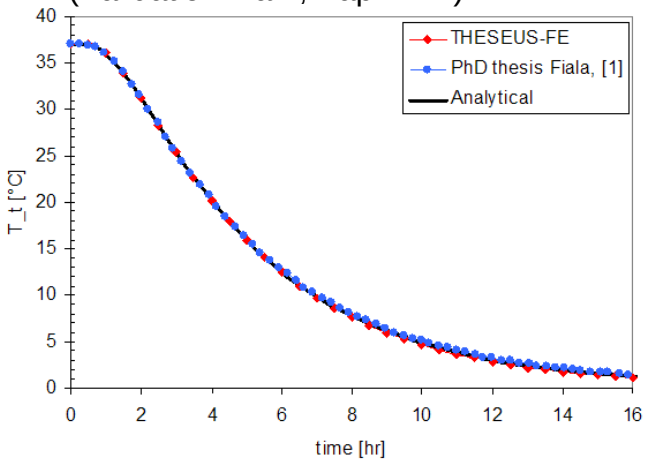


Fig. 4-1: Tissue temperature, radius 4.0 cm

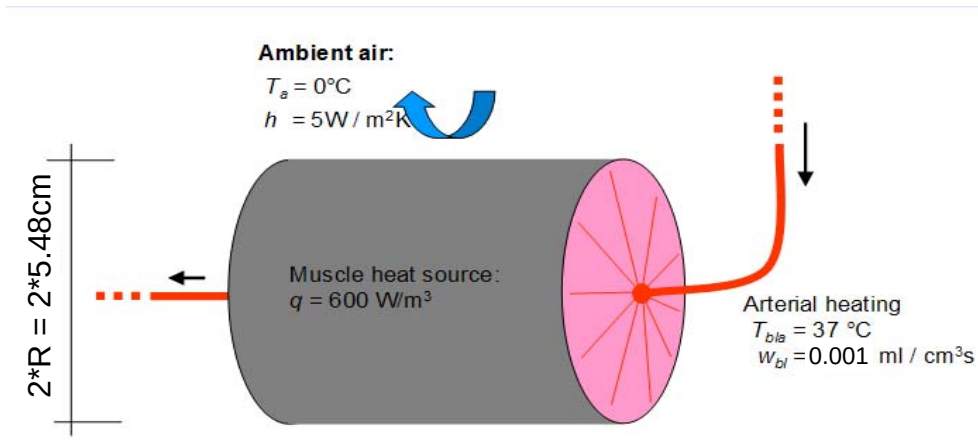
Cylindrical body element with metabolism and blood perfusion

Model: *cylinder.tfe*
A cold leg (starting by 0°C) will be warmed up by metabolism (600W/m³) and arterial blood perfusion.

ODE:

$$\underbrace{k\left(\frac{\partial^2 T}{\partial r^2}+\frac{\omega}{r}\frac{1}{\partial r}\right)}_{\text{conduction}}+\underbrace{q_m}_{\text{metabol.}}+\underbrace{\rho_{bl}w_{bl}c_{bl}\left(T_{bl,a}-T\right)}_{\text{arterial blood heating}}=\rho c\frac{\partial T}{\partial t}$$

ω = 1 for cylindrical body elm.



cylinder.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$        2        3        4        5        6        7        8        9        10
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ Man with single cylindrical body element with metabolism and blood perfusion
MANIKIN 1        FIALA   UNCPLD  PASSIVE STND    1       0.8
+       0.0      0.0     0.0     0.0     0.0     37.0    0.0
$
MANFDBG 1        LAYER
$
$body element definitions
$.......MANID...BE_ID...NAME....TYPE....NSEC............L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1        1       LEG     CYLINDR 1       3       1.0     0.0
+       1.0      1.0     1.0     1.0     1.0     1.0     1.0
+       0.0      0.0     25.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....PHI.....VF_SED..VF_STND.E_SF_1
MANFSEC 1        1       ALL     3       360.0   0.0     0.0     0.0
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M..
MANFLAYR1        1       LAY1    9       0.022   0.42    1085.0  3768.0  0.001   600.0
+                        LAY2    9       0.0493  0.42    1085.0  3768.0  0.001   600.0
+                        LAY3    9       0.0548  0.42    1085.0  3768.0  0.001   600.0
$
$
$ transient simulation
SOL                      1.0     6000
$
TINITFE ALL              0.0
$
POSTFRQ 300
$---------------------- End of Theseus input file ---------------------
```

To apply a constant metabolic heat flux density of 600W/m³

1. the active system must be disabled (SYSTEM=PASSIVE)
2. the activity level must be ACT=0.8

see next slide…

see slide 21

Calculation of the metabolic heat flux density :

Terms controlled by the active system omitted here due to SYSTEM=PASSIVE.

$$q_m = q_{m,bas,0} + \Delta q_m$$

$$q_m = q_{m,bas,0} + \cancel{q_{m,bas,0}\left[2^{(T-T_0)/10} - 1\right]} + \cancel{q_{m,sh}} + q_{m,w}$$

$$q_m = q_{m,bas,0} + \underbrace{q_{m,bas,0}\left[2^{(T-T_0)/10} - 1\right]}_{\text{Q10–Effekt}} + \underbrace{a_{sh,i}\frac{Sh}{V_{mus,i}}}_{\text{shivering}} + \underbrace{a_{m,w,i}\frac{H}{V_{mus,i}}}_{\text{mechanical work}}$$

here:

$$q_m = q_{m,bas,0} = 600\,W/m^3$$

both parts will be applied on the muscle volume V_{mus}.

Total amount of shivering in [W]:

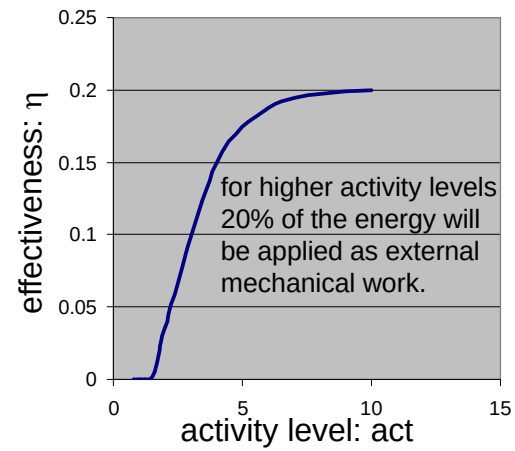
$$Sh = 10 \cdot \left[\tanh\left(0.51 \cdot \Delta T_{sk,m} + 4.19\right) - 1\right] \cdot \Delta T_{sk,m} - 27.5 \cdot \Delta T_{hy} - 28.2 + \underbrace{1.9 \cdot \Delta T_{sk,m} \frac{\partial T_{sk,m}}{\partial t}}_{=0 \text{ if } \partial T_{sk,m}/\partial t > 0 \text{ or } \Delta T_{sk,m} > 0}$$

$\Delta T_{sk,m} = T_{sk,m} - T_{sk,m,0}$ is the deviation of the current average skin temperature from neutrality. Analogously for the hypothalamus T_{hy}.

Additional thermal power through mechanical work:

$$H = act\frac{M_{bas,0}}{act_{bas}}(1-\eta) - M_{bas,0}$$

$$H = 0.8\frac{87.1W}{0.8} - 87.1W = 0$$



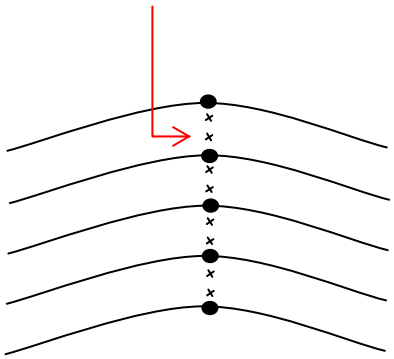
The parameters $a_{sh,i}$ and $a_{m,w,i}$ are stored in the keyword MANFBEL. They specify how much of the globally available heat can be delivered. The total sum over all $a_{sh,i}$ and $a_{m,w,i}$ should be 1.

Cylindr. body element with metabolism and blood perfusion

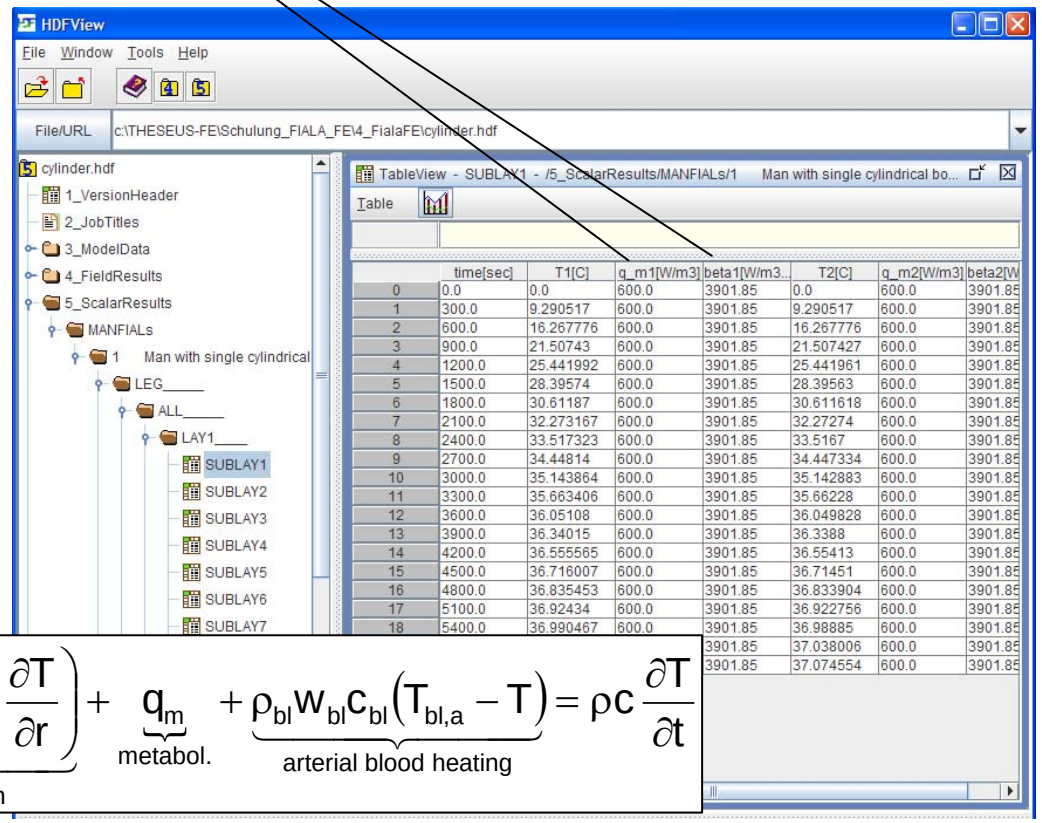
DISC=9
generate 8=9-1 sub-layers (finite elements)
with 2 integration points per layer

$$q_m = q_{m,bas,0} = 600\,W/m^3$$

$$\beta = \rho_{bl} \cdot c_{bl} \cdot w_{bl} = 1069\,kg/m^3 \cdot 3650\,J/kgK \cdot 0.001ml/cm^3s = 3901.85\,\frac{W}{m^3K}$$



Generally q_m and β are functions of the temperature in the ODE. This is the reason why they have been evaluated at each integration point.



	time[sec]	T1[C]	q_m1[W/m3]	beta1[W/m3...	T2[C]	q_m2[W/m3]	beta2[W
0	0.0	0.0	600.0	3901.85	0.0	600.0	3901.85
1	300.0	9.290517	600.0	3901.85	9.290517	600.0	3901.85
2	600.0	16.267776	600.0	3901.85	16.267776	600.0	3901.85
3	900.0	21.50743	600.0	3901.85	21.507427	600.0	3901.85
4	1200.0	25.441992	600.0	3901.85	25.441961	600.0	3901.85
5	1500.0	28.39574	600.0	3901.85	28.39563	600.0	3901.85
6	1800.0	30.61187	600.0	3901.85	30.611618	600.0	3901.85
7	2100.0	32.273167	600.0	3901.85	32.27274	600.0	3901.85
8	2400.0	33.517323	600.0	3901.85	33.5167	600.0	3901.85
9	2700.0	34.44814	600.0	3901.85	34.447334	600.0	3901.85
10	3000.0	35.143864	600.0	3901.85	35.142883	600.0	3901.85
11	3300.0	35.663406	600.0	3901.85	35.66228	600.0	3901.85
12	3600.0	36.05108	600.0	3901.85	36.049828	600.0	3901.85
13	3900.0	36.34015	600.0	3901.85	36.3388	600.0	3901.85
14	4200.0	36.555565	600.0	3901.85	36.55413	600.0	3901.85
15	4500.0	36.716007	600.0	3901.85	36.71451	600.0	3901.85
16	4800.0	36.835453	600.0	3901.85	36.833904	600.0	3901.85
17	5100.0	36.92434	600.0	3901.85	36.922756	600.0	3901.85
18	5400.0	36.990467	600.0	3901.85	36.98885	600.0	3901.85
				3901.85	37.038006	600.0	3901.85
				3901.85	37.074554	600.0	3901.85

ODE:

$$\underbrace{k\left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r}\right)}_{\text{conduction}} + \underbrace{q_m}_{\text{metabol.}} + \underbrace{\rho_{bl} w_{bl} c_{bl}\left(T_{bl,a} - T\right)}_{\text{arterial blood heating}} = \rho c \frac{\partial T}{\partial t}$$

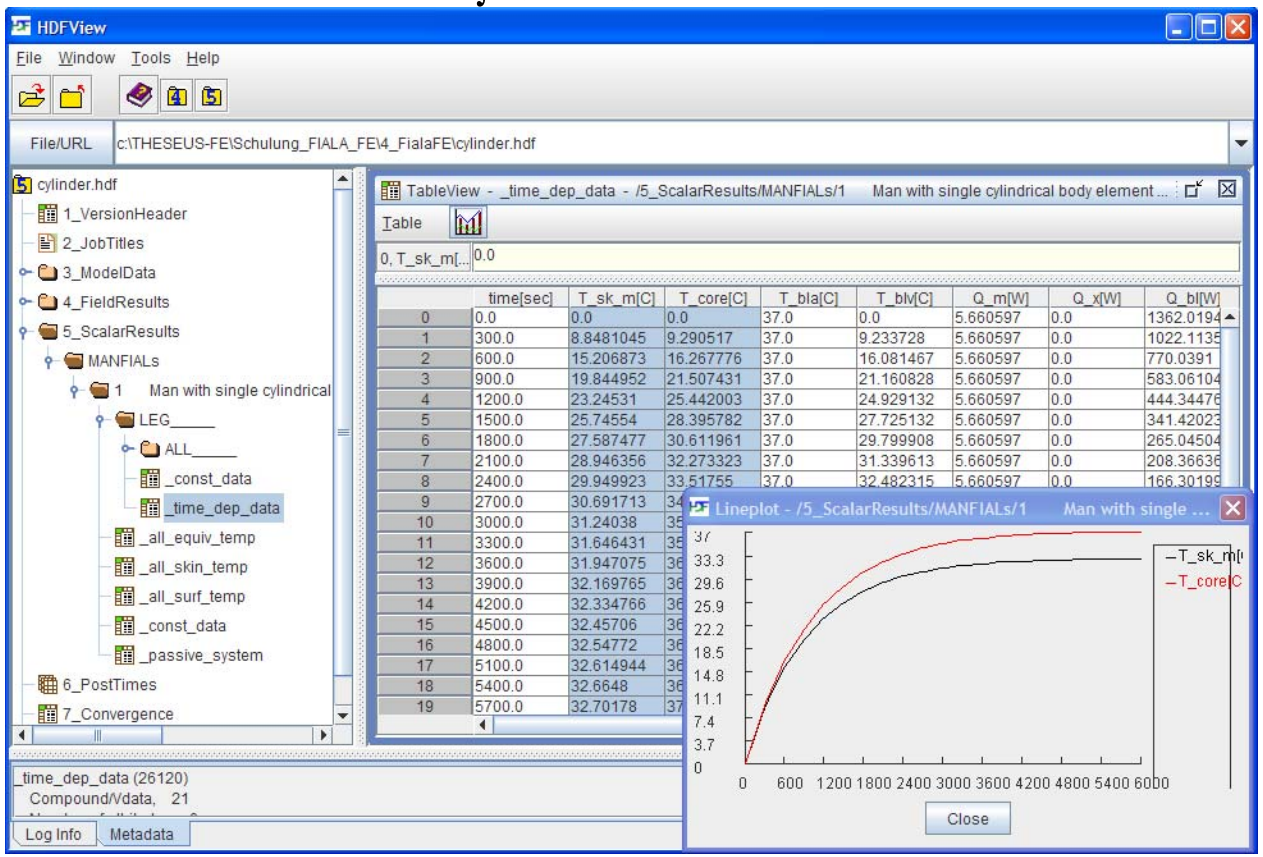
Cylindr. body element with metabolism and blood perfusion

Time-dependent results in the body element „LEG“

$T_{sk,m}$ ... average skin temperature , T_{core} ... core temperature
$T_{bl,a}$ ... temperature of the arteries (given) , $T_{bl,v}$ ... temperature of the veins
Q_m ... metabolic heat flow, Q_x ... heat flow between arteries and veins
Q_{bl} ... arterial heating $Q_{bl} = \int \beta (T_{bl,a} - T) dV$

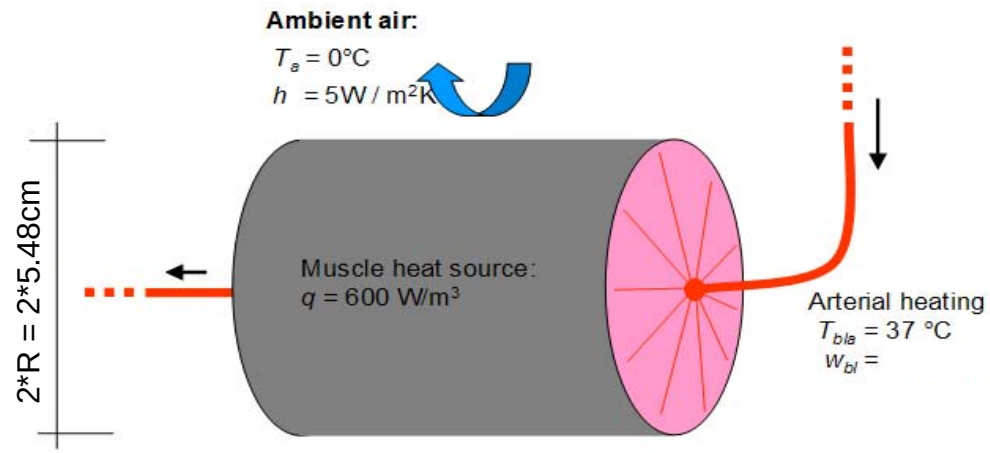
$$T_{bl,v} = \frac{\int w_{bl} T dV}{\int w_{bl} dV}$$

$$Q_x = \int h_x (T_{bl,a} - T_{bl,v}) dV$$



Cylindr. body element with metabolism and blood perfusion

Validation:
(Validation Manual, Section 4.1.2/3)



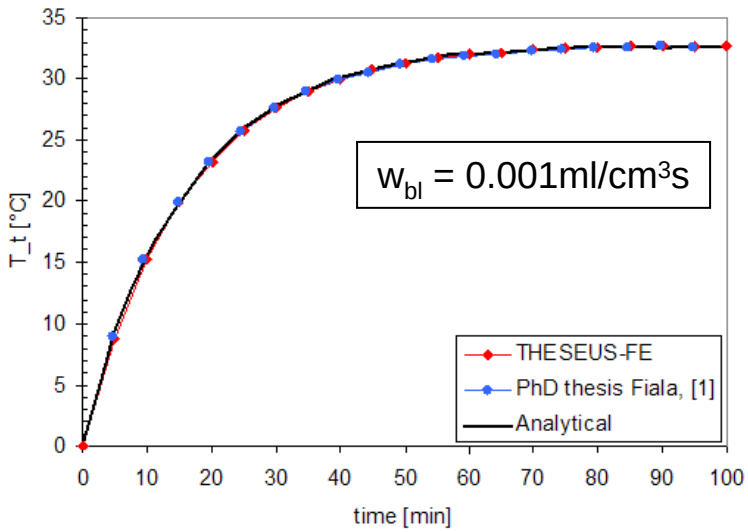


Fig. 4-6: Tissue temperature, radius 5.48 cm

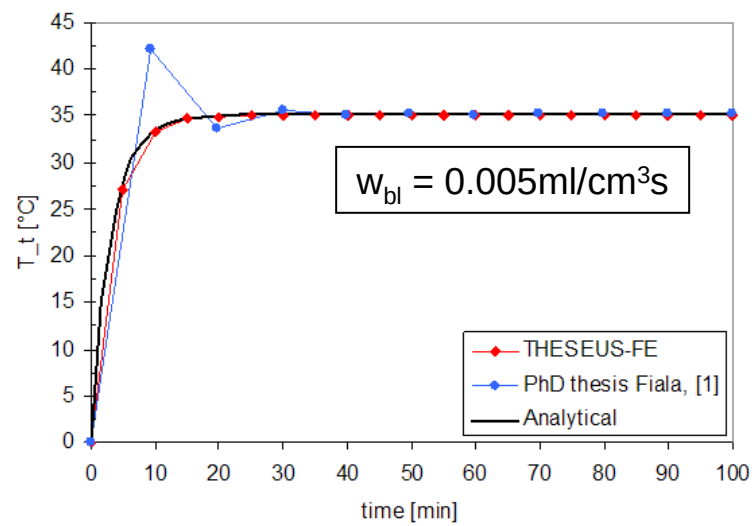
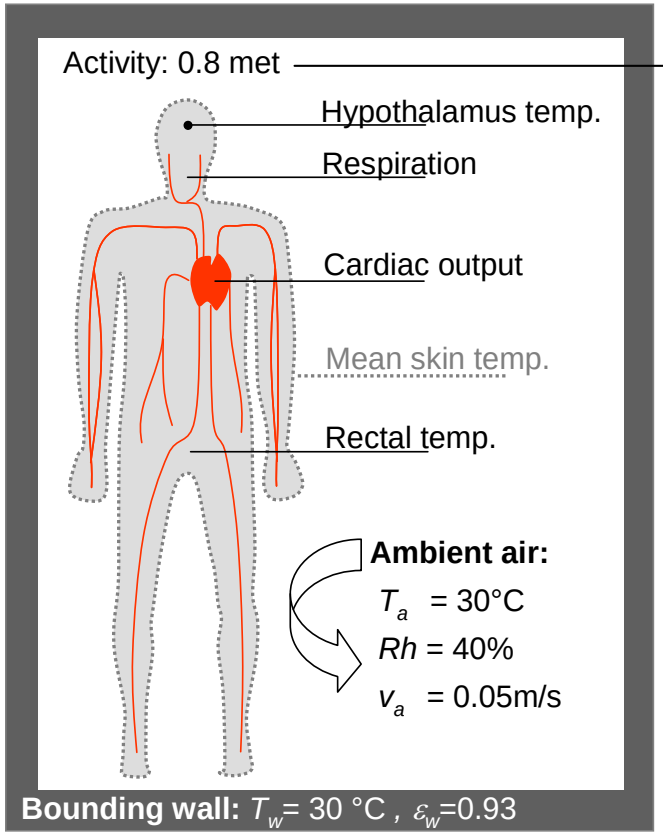


Fig. 4-7: Tissue temperature, radius 5.48 cm

Model: *neutral_naked.tfe*



	Activity [met]		Activity [met]
Resting:		**Office Activities:**	
Sleeping	0.7	Reading, writing (seated)	1.0
Reclining	0.8	Typing	1.1
Seat, quiet	1.0	Lifting, packing	2.1
Standing, relaxed	1.2	**Driving:**	
Walking:		Car	1.2
3.2 km/h	2	Aircraft, routine	1.2
6.4 km/h	3.8	Aircraft, landing	1.8
Miscellaneous:		Heavy vehicle	3.2
Dancing	2.4		
Heavy work	4		
Extrem sports	7.5		

Thermal neutrality
is the energetic equilibrium state, where the inner metabolic heat sources and the boundary heat flows are equal.
At the same time all control mechanisms of the active system are inactive: no shivering, no sweating and no vasoconstriction or vasodilatation.
⇒ This state is considered to be comfortable!

Paper: D. Fiala, K. J. Lomas and M. Stohrer:
"A computer model of human thermoregulation for a wide range of environmental conditions: **the passive system"**

Table 2. *Passive-system parameters*

Body Elements	L, cm	h_k, W/K	$h_{c,mix}$ a_{nat}	$h_{c,mix}$ a_{frc}	$h_{c,mix}$ a_{mix}	a_{sk}	$a_{m,w}$ Sed	$a_{m,w}$ Stnd	Sector	φ, °	$\psi_{sf\text{-}sr}$ Sed	$\psi_{sf\text{-}sr}$ Stnd	ϵ_{sf}	Material	N	r, cm	k, W·m⁻¹·K⁻¹	ρ, kg/m²	c, J·kg⁻¹·K⁻¹	$w_{bl,0}$, l·s⁻¹·m⁻³	$q_{m,0}$, W/m³
														Brain	5	8.60	0.49	1,080	3,850	10.1320	13,400
Head (sphere)		0.00	3.0	113	−5.7	0.0835	0.00	0.00	Forehead	10	1.00	1.00	0.99	Bone	2	10.05	1.16	1,500	1,591	0.0000	0
									Head	170	0.90	0.90	0.80	Fat	2	10.20	0.16	850	2,300	0.0036	58
														Skin	4	10.40	0.47	1,085	3,680	5.4800	368
														Muscle	1	2.68	0.42	1,085	3,768	0.5380	684
														Bone	1	5.42	1.16	1,500	1,591	0.0000	0
Face (cylinder)	9.84	0.00	3.0	113	−5.7	0.0418	0.00	0.00		210	0.90	0.90	0.99	Muscle	1	6.80	0.42	1,085	3,768	0.5380	684
														Fat	2	7.60	0.16	850	2,300	0.0036	58
														Skin	2	7.80	0.47	1,085	3,680	11.1700	368
														Bone	1	1.90	0.75	1,357	1,700	0.0000	0
Neck (cylinder)	8.42	0.00	1.6	130	−6.5	0.0417	0.03	0.01	Anterior	180	0.70	0.70	0.99	Muscle	4	5.46	0.42	1,085	3,768	0.5380	684
									Posterior	180	0.75	0.75	0.99	Fat	2	5.56	0.16	850	2,300	0.0036	58
														Skin	4	5.67	0.47	1,085	3,680	6.8000	368
														Bone	1	3.70	0.75	1,357	1,700	0.0000	0
Shoulders (cylinder)	32.00	0.80	5.9	216	−10.8	0.0300	0.05	0.02		130	0.90	0.90	0.99	Muscle	2	3.90	0.42	1,085	3,768	0.5380	684
														Fat	2	4.40	0.16	850	2,300	0.0036	58
														Skin	2	4.60	0.47	1,085	3,680	1.0100	368
														Lung	1	7.73	0.28	550	3,718	CO	600
									Anterior	150	0.80	0.90	0.99	Bone	3	8.91	0.75	1,357	1,700	0.0000	0
Thorax (cylinder)	30.60	0.00	0.5	180	−7.4	0.3060	0.12	0.07	Posterior	150	0.95	0.95	0.99	Muscle	3	12.34	0.42	1,085	3,768	0.5380	684
									Inferior	60	0.05	0.10	0.99	Fat	6	12.68	0.16	850	2,300	0.0036	58
														Skin	6	12.90	0.47	1,085	3,680	1.5800	368
														Viscera	1	7.85	0.53	1,000	3,697	4.3100	4,100
									Anterior	150	0.80	0.90	0.99	Bon							
Abdomen (cylinder)	55.20	0.00	1.2	180	−9.0	0.1210	0.46	0.20	Posterior	150	0.95	0.95	0.99	Mus							
									Inferior	60	0.20	0.30	0.99	Fat							
														Ski							
														Bon							
Arms (cylinder)	127.40	4.13	8.3	216	−10.8	0.1800	0.19	0.08	Anterior	135	0.75	0.85	0.99	Mus							
									Posterior	135	0.80	0.90	0.99	Fat							
									Inferior	90	0.10	0.20	0.99	Ski							
														Bone	1	0.70	0.75	1,357	1,700	0.0000	0
Hands (cylinder)	62.00	0.57	8.3	216	−10.8	0.0900	0.02	0.01	Handback	180	0.80	0.80	0.99	Muscle	2	1.74	0.42	1,085	3,768	0.5380	684
									Palm	180	0.10	0.20	0.99	Fat	2	2.04	0.16	850	2,300	0.0036	58
														Skin	4	2.26	0.47	1,085	3,680	4.5400	368
														Bone	1	2.20	0.75	1,357	1,700	0.0000	0
Legs (cylinder)	139.00	6.90	5.3	220	−11.0	0.2080	0.11	0.60	Anterior	150	0.85	0.90	0.99	Muscle	6	4.80	0.42	1,085	3,768	0.5380	684
									Posterior	150	0.95	0.90	0.99	Fat	6	5.33	0.16	850	2,300	0.0036	58
									Inferior	60	0.10	0.65	0.99	Skin	6	5.53	0.47	1,085	3,680	1.0500	368
														Bone	1	2.00	0.75	1,357	1,700	0.0000	0
Feet (cylinder)	48.00	3.40	6.8	210	−10.5	0.0750	0.02	0.01	Instep	180	0.90	0.90	0.99	Muscle	2	2.50	0.42	1,085	3,768	0.5380	684
									Sole	180	1.00	1.00	0.99	Fat	4	3.26	0.16	850	2,300	0.0036	58
														Skin	4	3.50	0.47	1,085	3,680	1.5000	368
Blood																		1,069	3,650		

Sector=Inferior
typically has a small view factor ψ, because other human body elements (e.g. arms) cover it
$\Rightarrow$ lower influence of heat radiation to/from the wall

The **symmetric manikin** consists of 10 body elements. The symmetric body elements (shoulder, arms, hands, legs, feet) are defined only once, but with double length: e.g. legs 139 cm.

Boundary conditions:

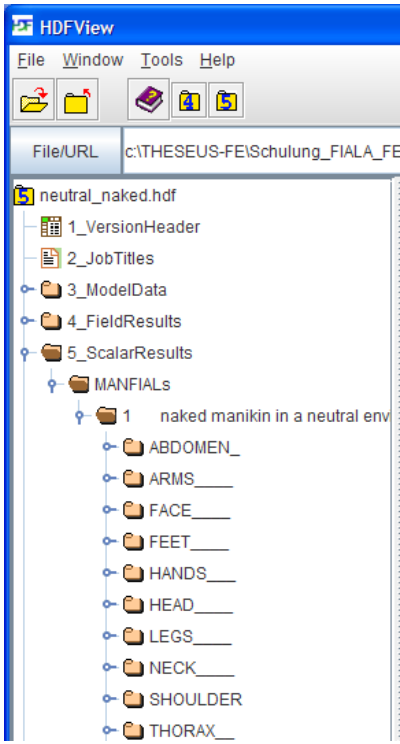
- unclothed
- System: passive
- Position: standing
- Activity: 0.8*87.1W
- Air temperature: 30°C
- Air speed: 0.05m/s
- Humidity: 40%
- Wall temperature: 30°C
- Emissivity of the wall 0.93

neutral_naked.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ naked manikin in a neutral environment
MANIKIN 1       FIALA   UNCPLD  PASSIVE STND    10      0.8
+       30.0    0.93    30.0    0.05    40.0
$
$
MANFDBG 1
$
$---------------------
$ H E A D
$---------------------
$
$body element definitions:
$.......MANID...BE_ID...NAME....TYPE....NSEC....    ....L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       1       HEAD    SPHERE  2               0.0     0.0
+       0.0835  0.0950  0.0550  0.0300  0.0000  0.0     0.0
+       3.0     113.0   -5.7
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
MANFSEC 1       1       FOREHEAD7       10.0    1.0     1.0     0.99
+                       HEAD    7       170.0   0.9     0.9     0.8
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.....A_RSP
MANFLAYR1       1       BRAIN1  3       0.03    0.49    1080.0  3850.0  10.132-313400.0 0.0
+                       BRAIN2  3       0.076   0.49    1080.0  3850.0  10.132-313400.0 0.0
+                       BRAIN3  3       0.086   0.49    1080.0  3850.0  10.132-313400.0 0.0
+                       BONE    3       0.1005  1.16    1500.0  1591.0  0.0     0.0     0.0
+                       FAT     3       0.102   0.160   850.0   2300.0  3.6-6   58.0    0.0
+                       SKIN    3       0.103   0.47    1085.0  3680.0  10.96-3 736.0   0.0
+                       XSKIN   3       0.104   0.47    1085.0  3680.0  0.0     0.0     0.0
$
$
$---------------------
$ F A C E
$---------------------
$
$body element definitions:
$.......MANID...BE_ID...NAME....TYPE....NSEC....    ....L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       2       FACE    CYLINDR 1               0.0984  0.0
+       0.0418  0.0540  0.0460  0.0330  0.0020  0.0     0.0
+       3.0     113.0   -5.7
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
MANFSEC 1       2       FACE    6       210.0   0.9     0.9     0.99
```

Results in the layers are not written out here anymore. (ordinarily not necessary)



Calculating the stable condition of thermal neutrality is the aim of the simulation.
For this task the THESEUS-FE steady-state-solver will used:

```
$        2        3        4        5        6        7        8        9        10
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678
SOL      STEADY
$
TINITFE ALL              34
$
POSTFRQ END
$------------------------ End of Theseus input file ---------------------
```

Results are written out to the hdf-file at the end of the simulation.*

* In THESEUS-FE the initial state at t=0 will always be written.
The final state in a steady-state simulation has time t=1.
See next slide.

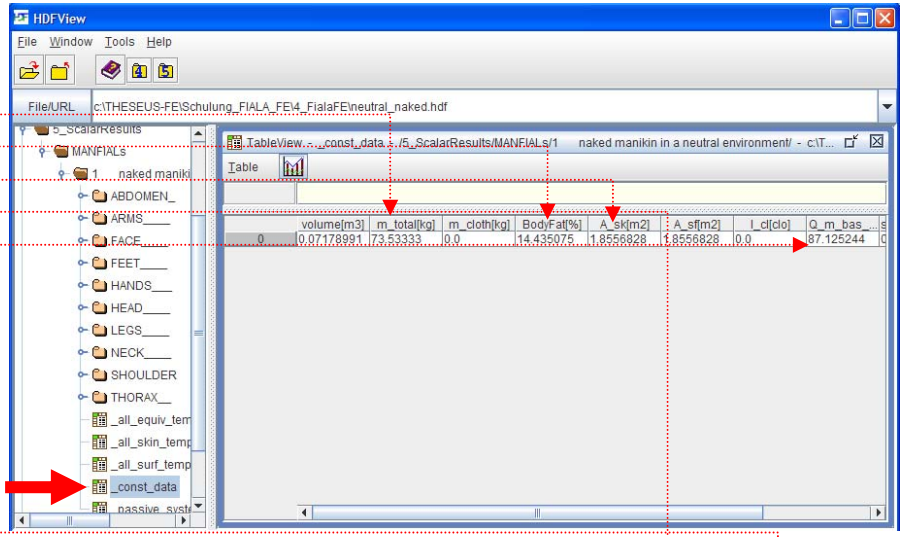
Symmetric Manikin - Thermal neutrality

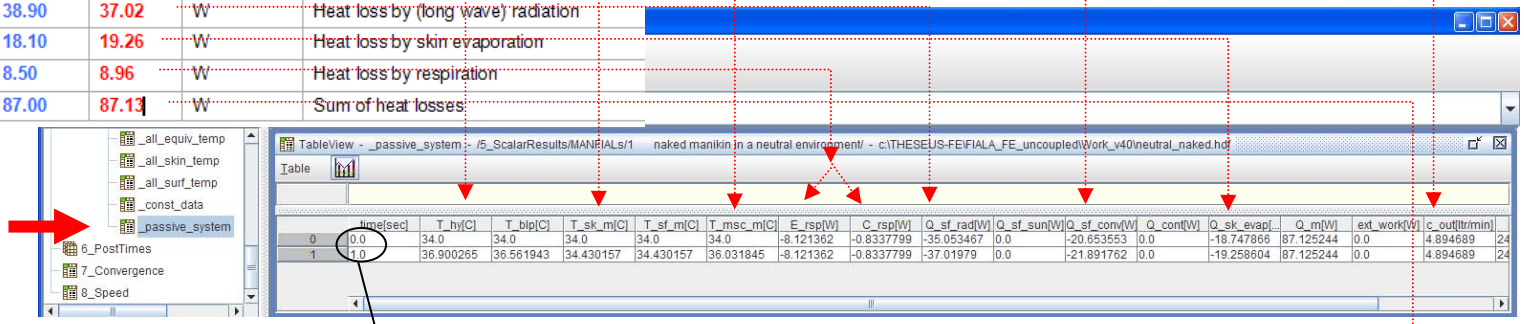
Results

PhD thesis Fiala, [1] THESEUS-FE

Quantity	Value	Value	Unit	Description
Wght	73.50	73.53	kg	Body weight
Body Fat	14.00	14.44	%	Fat/body-mass ratio
A_{sk}	1.90	1.86	m²	Skin surface area
CardOut	4.90	4.89	ltr / min	Cardiac output
$M_{bas,0}$	87.10	87.13	W	Basal metabolism

Quantity	Value	Value	Unit	Description
$T_{sk,m}$	34.40	34.43	°C	Mean skin temperature
$T_{msc,m}$	36.20	36.03	°C	Mean muscle temperature
T_{hy}	37.00	36.90	°C	Head core (hypothalamus) temperature
T_{re}	36.88	36.80	°C	Abdomen core (rectal) temperature
$h_{c,m}$	2.70	2.66	W / m² *K	Mean convective heat transfer coefficient
$h_{r,m}$	5.00	4.50	W / m² *K	Mean radiative heat transfer coeeficient
Q_{sk}	78.50	78.17	W	Skin heat loss
$Q_{sk,c}$	21.50	21.89	W	Heat loss by convection
$Q_{sk,r}$	38.90	37.02	W	Heat loss by (long wave) radiation
$Q_{sk,e}$	18.10	19.26	W	Heat loss by skin evaporation
Q_{rsp}	8.50	8.96	W	Heat loss by respiration
Q_{sum}	87.00	87.13	W	Sum of heat losses



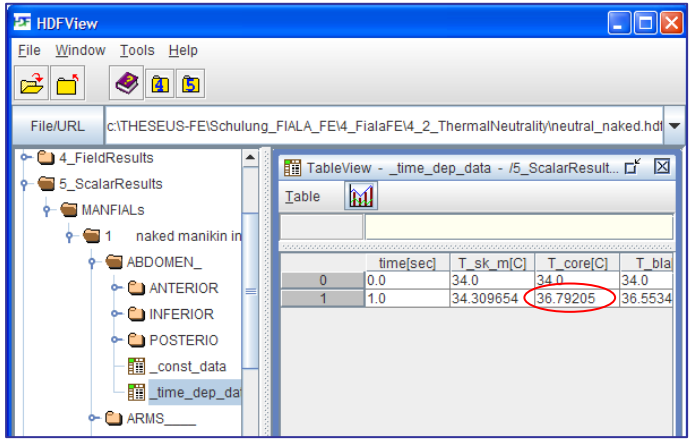


- t=0 : initial values at
- t=1: final results of the steady state simulation

$$Q_{sk} = Q_{sk,c} + Q_{sk,r} + Q_{sk,e} = 78.17W$$
$$21.89 + 37.02 + 19.26$$

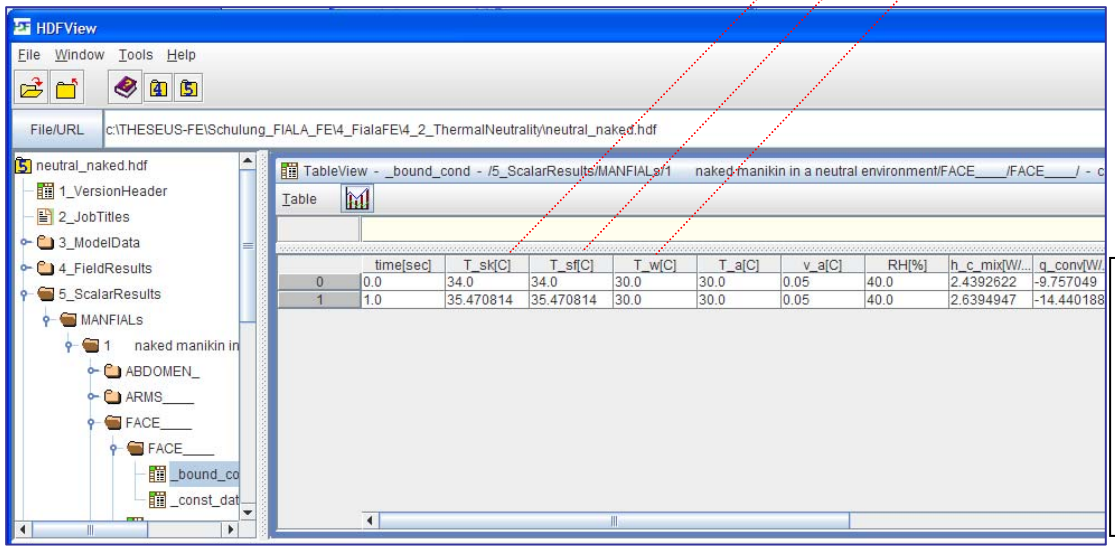
$$Q_{sum} = Q_{sk} + Q_{rsp} = 87.13\ W = M_{bas,0}$$
$$78.17 + 8.96$$

Rectal Temperature = Abdomen Core Temperature



Local parameters stored per sector:

- T_{sk} skin temperature
- T_{sf} surface temperature (at skin or clothing)
- T_w radiated background temperature
- T_a air temperature
- v_a air speed [m/s]
- RH humidity [%]
- $h_{c,mix}$ convective heat transfer coeff.
- q_{conv} convective heat flux
- h_r radiation heat transfer coefficient
- q_{rad} radiation heat flux
- q_{sun} solar heat flux*
- q_{cont} contact heat flux**
- q_e heat flux from evaporation



Parameter used by the calculation of evaporation:
$U_{e,cl}$, dm, p_a, $p_{sk,sat}$, p_{sk}, dm_{sw}, dm_{ac}, m_{ac}
(see Theory Manual, Section 4.1.4.4)

*q_{sun} : is created only in coupled manikin mode

**q_{cont} : here in decoupled mode, the locally applied heat flows (Q_SF) are written.

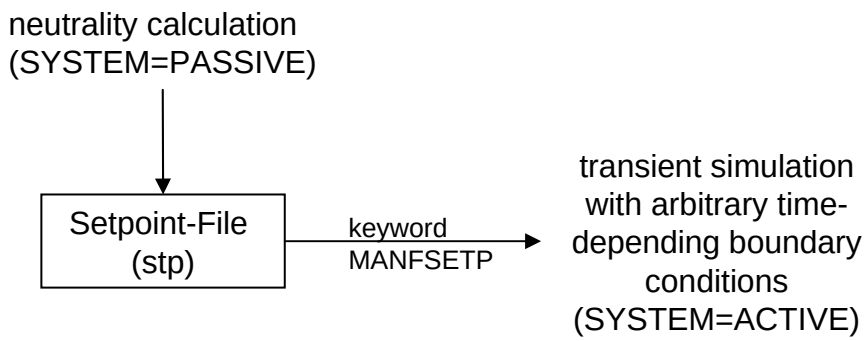
Symmetric Manikin - Thermal neutrality

MANIKIN	MANID	FIALA-FE	MODE	SYSTEM	POSI	BE	ACT	LINK	
+	T_W	E_W	T_A	V_A	RH	T_BLA	LEWIS	ACT_BAS	

SYSTEM=PASSIVE:
Typically used for a steady-state calculation of thermal neutrality that creates a setpoint-file (*neutral_naked.stp)* containing the neutrality temperatures at each temperature degree of freedom.

SYSTEM=ACTIVE:
Typically used for a transient simulation with arbitrary time-dependent boundary conditions. Requires a pre-calculated setpoint file for determining the difference between the actual temperatures and setpoints ($T-T_0$).
These control active system functions e.g. sweating, shivering, Q-10 effect.
The body temperatures stored in the setpoint-file are also used to initialize the active system simulation.

For active system simulations of a clothed human the setpoint file must contain clothing temperatures. This is the reason why *neutral_naked.stp* can only be used for a naked human.



$\Delta T_{sk,m} = T_{sk,m} - T_{sk,m,0}$ is the main input quantity for the active system. It is the deviation of the current average skin temperature from neutrality. Analogously for the hypothalamus temperature. $\Delta T_{hy} = T_{hy} - T_{hy,0}$.

The model: *neutral_naked.tfe*
will be now copied and renamed to *neutral_shorts.tfe*

Afterwards, a clothing layer (at the abdomen) will added using vanishingly small isolation (0.0001), to avoid changing the results of the thermal neutrality calculation.

neutral_shorts.tfe - Editor

```
$
$---------------------
$ A B D O M E N
$---------------------
$
$body element definitions:
$.......MANID...BE_ID...NAME....TYPE....NSEC....    ....L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       6       ABDOMEN CYLINDR 3               0.552   0.0
+       0.1210  0.1810  0.1610  0.0205  0.2400  0.46    0.2
+       1.2     180.0   -9.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
MANFSEC 1       6       ANTERIOR7       150.0   0.8     0.9     0.99
+                       POSTERIO7       150.0   0.95    0.95    0.99
+                       INFERIOR7       60.0    0.20    0.30    0.99
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.....A_RSP
MANFLAYR1       6       CORE    3       0.0785  0.53    1000.0  3697.0  4.31-3  4100.0  0.0
+                       BONE    3       0.0834  0.75    1357.0  1700.0  0.0     0.0     0.0
+                       MUSCLE  3       0.1090  0.42    1085.0  3768.0  0.538-3 684.0   0.0
+                       FAT     3       0.1244  0.160   850.0   2300.0  3.6-6   58.0    0.0
+                       SKIN    3       0.1252  0.47    1085.0  3680.0  2.88-3  736.0   0.0
+                       XSKIN   3       0.1260  0.47    1085.0  3680.0  0.0     0.0     0.0
$
$
$       MANID   BE_ID   SEC_ID  DISC    THICKN  SICL    SIICL   NSM     C
MANFSCL 1       6       1       3       0.0001  0.0001  0.0001  0.0001  0.0001
MANFSCL 1       6       2       3       0.0001  0.0001  0.0001  0.0001  0.0001
MANFSCL 1       6       3       3       0.0001  0.0001  0.0001  0.0001  0.0001
$
```

Zeile 1, Spalte 1

Increase the number of layers from 6 to 7!

Dummy-clothing layers create additional degree of freedoms in the stp-file.

Running the job should deliver almost the same results as on slide 28. The produced stp-file can now be used for an active-mode simulation (clothed with underwear).

The model: *neutral_shorts.tfe* will now be copied and renamed as *cool_shorts.tfe*

Afterwards clothing layers with realistic values will be inserted at the abdomen (BE_ID=6) ...

piece of clothing		fabric	d	R_{cl}	R_{ecl}
N°	description	description	thickness of fabric (mm)	intrinsic fabric insulation (m^2K/W)	evaporative resistance of fabric (m^2Pa/W)
	shirts				
1	long-sleeve, shirt collar	broadcloth, plain weave, 65% polyester, 35% cotton	0.533	0.025	2.4
2	long-sleeve, shirt collar	flannel, napped, plain weave, 80% cotton, 20% polyester	1.422	0.047	5.2
3	long-sleeve, rugby, heavy	single knit, 100% cotton	1.575	0.036	5.2
4	short-sleeve, shirt collar	broadcloth, plain weave, 65% polyester, 35% cotton	0.533	0.025	2.4
5	short-sleeve, sport shirt	double knit, 65% polyester, 35% cotton	1.118	0.039	3.9
	sweaters				
6	long-sleeve, round neck	napped plain weave, 100% wool	2.464	0.061	7.9
	suit jackets and vests				
7	single-breasted suit jacket	denim, 100% cotton	1.778	0.037	6.6
8	single-breasted suit jacket	tweed plain weave, 50% wool, 50% polyester / lining, plain weave, 100% polyester	1.727 / 0.102	0.049 / 0.008	5.5 / 1.8
9	vest	denim, 100% cotton	1.778	0.037	6.6
10	vest	tweed plain weave, 50% wool, 50% polyester / lining, plain weave, 100% polyester	1.727 / 0.102	0.049 / 0.008	5.5 / 1.8
	trousers				
11	straight, long, fitted	denim, 100% cotton	1.778	0.037	6.6
12	straight, long, fitted	tweed plain weave, 50% wool, 50% polyester / lining, plain weave, 100% polyester	1.727 / 0.102	0.049 / 0.008	5.5 / 1.8
13	straight, long, loose	denim, 100% cotton	1.778	0.037	6.6
14	straight, long, loose	tweed plain weave, 50% wool, 50% polyester / lining, plain weave, 100% polyester	1.727 / 0.102	0.049 / 0.008	5.5 / 1.8
15	straight, long, fitted	pinwheel corduroy, 75% cotton, 25% polyester	1.880	0.041	6.5
16	straight, long, fitted	poplin, 60% cotton, 40% polyester	0.787	0.026	4.1
17	walking shorts	denim, 100% cotton	1.778	0.037	6.6
18	shorts	plain weave, 100% cotton	0.965	0.025	4.4
	underwear				
19	briefs	jersey single knit, 100% cotton	1.270	0.036	4.0

Note:
The (local) clothing parameters (d, R_c) in the table do not consider the air trapped between clothing and skin. These parameters should be higher to model this air-trapping effect! For this reason these values are only sensible when using tight fitting underwear.

d = 0.00127 m
R_{cl} = 0.036m^2 K/W
R_{ecl} = 4.0m^2 Pa/W

Clothing data for the shorts:

$d = 0.00127$ m , $R_{cl} = 0.036\ m^2K/W$, $R_{ecl} = 4.0\ m^2Pa/W$, $M = 0.065$ kg , $c = 1100$ J/kgK

Values from the literature (McCullough):

Conversion to the dimensionless parameters I_{cl} and I_{cl}/i_{cl} which are required in MANFSCL:

$$1clo = 0.155\frac{m^2K}{W}\ ,\ L_a = 0.0165\frac{K}{Pa}$$

$$\sum I_{cl} = I_{cl} = \frac{R_{cl}}{1clo} = R_{cl}\cdot 6.45\frac{W}{m^2K} = 0.23\ [clo]$$

$$\sum \frac{I_{cl}}{i_{cl}} = \frac{I_{cl}}{i_{cl}} = \frac{R_{ecl}L_a}{1clo} = R_{ecl}\cdot 0.106\frac{W}{m^2Pa} = 0.43\ [clo]$$

Calculating the mass per area:
(NSM stands for „non-structural-mass“)

$$A = 2\pi RL = 2\pi\cdot 0.126\cdot 0.552 = 0.44m^2$$

$$NSM = M/A = 0.15\frac{kg}{m^2}$$

d

```
$
$       MANID   BE_ID   SEC_ID  DISC    THICKN  SICL    SIICL   NSM     C
MANFSCL 1       6       1       3       0.00127 0.23    0.43    0.15    1100
MANFSCL 1       6       2       3       0.00127 0.23    0.43    0.15    1100
MANFSCL 1       6       3       3       0.00127 0.23    0.43    0.15    1100
$
```

Formulary:

Clothing resistance : $R_{cl} = I_{cl}*0.155\ m^2K/W$

Conductivity: : $k = d/R_{cl}$ in W/mK

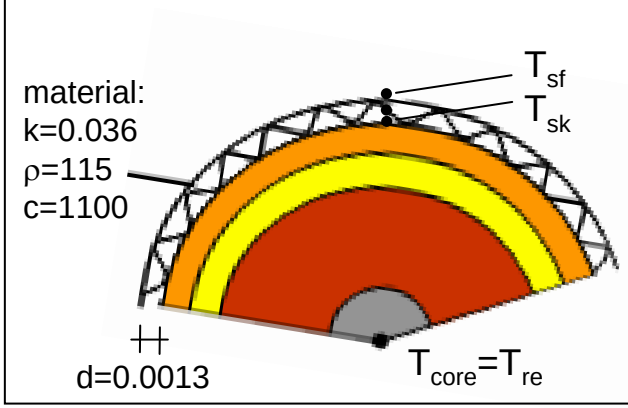
Density: : $\rho = NSM/d$ in kg/m³

moisture permeability index $i_{cl} = \frac{R_{cl}}{R_{ecl}L_a} \doteq \frac{I_{cl}\cdot 0.155\,m^2K/W}{R_{ecl}L_a}$

Evaporative resistance : $\Rightarrow R_{ecl} = \frac{I_{cl}}{i_{cl}}\cdot 0.155\,m^2K/W\cdot\frac{1}{L_a}$ in $\left[\frac{m^2Pa}{W}\right]$

Lewis constant : $L_a = 0.0165\ K/Pa$

The clothing layer at the abdomen has DISC=3 degree of freedoms.



```
$
$       MANID   BE_ID   SEC_ID  DISC    THICKN  SICL    SIICL   NSM     C
MANFSCL 1       6       1       3       0.00127 0.23    0.43    0.15    1100
MANFSCL 1       6       2       3       0.00127 0.23    0.43    0.15    1100
MANFSCL 1       6       3       3       0.00127 0.23    0.43    0.15    1100
$
```

Notes to the sensitivity of the clothing data:

- SICl contains the thermal resistance and has the biggest influence to the simulation results.
- SIICl contains the evaporation resistance and has lower influence.
  (in a cold environment: Q_{evapo}/Q_{conv} = 1:10 … but the influence rises in a warmer environment)
- THICKN, NSM and C control the heat capacity of the clothes. The effective heat capacity is ordinarily low and only important in case of rapidly changing boundary conditions. For slowly changing boundary conditions very small dummy values are possible, e.g. THICKN=NSM=C=0.0001. The influence of the effective heat capacity will then be negligible.

Summary:

You should pay attention to correct local clothing parameter SICL.

The quantities THICKN, NSM and C can be replaced by dummy values if necessary .

You should keep in mind that the thickness of the clothing layer (d=THICKN) also increases the heat flow from radiation and convection. See next slide.

Notes for the f_{cl}-value:

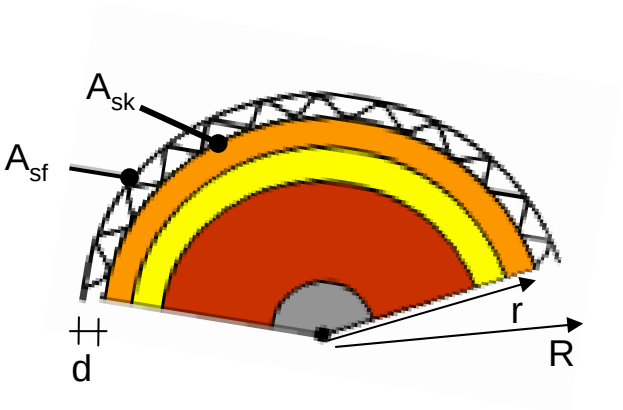
This value is often stated in literature. It represents the ratio of surface areas of a clothed human to an unclothed human:

$$f_{cl} = \frac{A_{sf}}{A_{sk}} \approx 1.1..1.2$$

This means:
10-20% more outer surface leads to 10-20% rise of heat flow from convection/radiation .

This value is not explicitly used in THESEUS-FE. However, for cylindrical body elements there is a relation between thickness of the clothing and the f_{cl}-value:

$$f_{cl} = \frac{A_{sf}}{A_{sk}} = \frac{2\pi RL}{2\pi rL} = \frac{R}{r} = \frac{r+d}{r} = 1 + d/r$$



If the f_{cl}-value is known, the thickness of the clothing can be calculated..

$$d = r(f_{cl} - 1)$$

Notes to the local/global clothing data:

Fiala (and also THESEUS-FE) uses local clothing parameters in his PhD-thesis.
He marks this situation with an asterisk: R_{cl}^* , I_{cl}^* , ...

Clothing parameters from literature are typically global quantities denoting the thermal resistance relative to the completely body.

global: $$R_{cl} = \frac{T_{sf,m} - T_{sk,m}}{(Q_{conv} + Q_{rad})/A_{sk}} = \frac{27.59 - 28.07}{(-157.55 - 126.49)/1.86} = \frac{-0.48}{-152.7} = 0.0031 \quad \Rightarrow I_{cl} = 6.45 \cdot R_{cl} = 0.020 \text{ [clo]}$$

($T_{sk,m}$ and $T_{sf,m}$ are mean skin- and surface temperatures of the whole body)

local: (Abdomen) $$R_{cl}^* = \frac{T_{sf} - T_{sk}}{q_{conv} + q_{rad}} = \frac{23.98 - 28.03}{-50.16 - 62.94} = \frac{-4.05}{-113.1} = 0.036 \quad \Rightarrow I_{cl}^* = 6.45 \cdot R_{cl}^* = 0.23 \text{ [clo]}$$

The local isolation is therefore always higher than the global: $I_{cl}^* > I_{cl}$

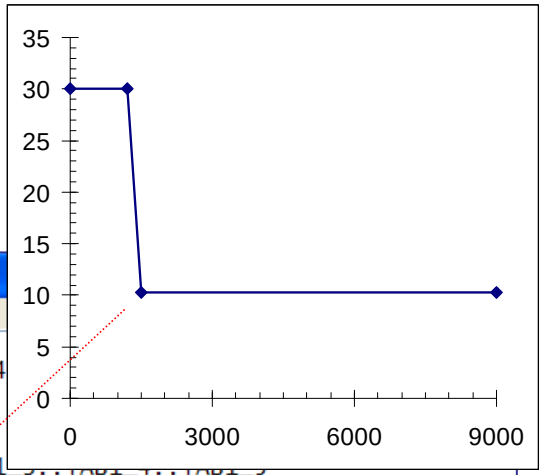
The temperatures and heat flows used here are taken from from *cool_shorts.hdf* at the time t=3600s.

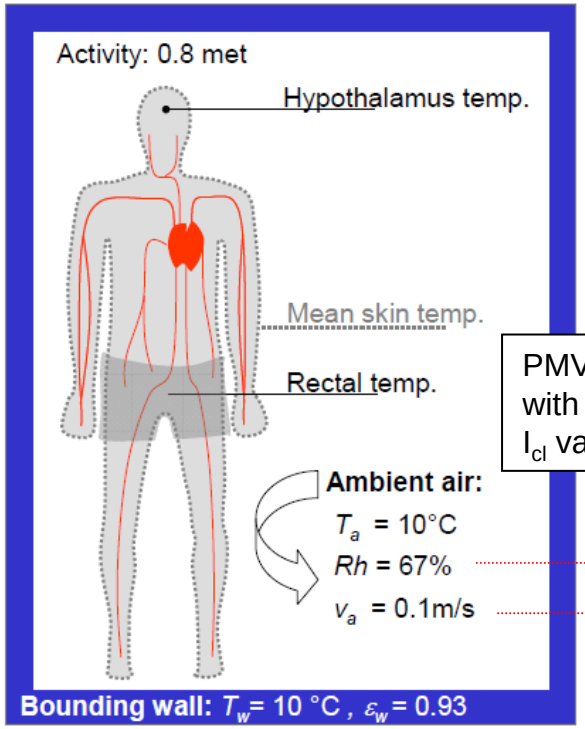
The conversion from global clothing parameters (from literature) to local ones is rather involved ...
You initialize a simulation with an approximate value of the local clothing resistance and derive the global resistance from the resulting heat fluxes. Afterwards you modify the local clothing resistance and repeat the process until the global resistance fits with the given value.

Modell: *cool_shorts.tfe*
The manikin in underwear will be abruptly cooled down from the ambient air temperature 30°C to 10.3°C.

The time dependent curves of T_a and T_w are stored in a table (ID=1). Function values are stored in column-ID 2. Instead of a constant value the temperature will now be a reference to „TAB1_2“.

ambient air temperature T_a:





PMV calculation with global I_{cl} value = 0.02*

cool_shorts.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$        2         3         4
$2345678$2345678$2345678$234
345678
$
$
$.......TAB1_1..TAB1_2..TAB1
$.......time....TA
TABTIME 1
+       0         30
+       1200      30
+       1500      10.3
+       9000      10.3
$
$
$manikin definitions new
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ manikin clothed with shorts in a cool environment
MANIKIN 1       FIALA    UNCPLD  ACTIVE  STND    10      0.8
+       TAB1_2  0.93     TAB1_2  0.1     67
$
MANFPMV 1       0.02
MANFDBG 1
$
$--------------------
$ H E A D
$--------------------
```

* see slide before

```
$        2        3        4        5        6        7
$2345678$2345678$2345678$2345678$2345678$2345678$234567
SOL      TRANS1                    3600.0           100
$
MANFSETP
+        neutral_shorts.stp
$
POSTFRQ 300
$----------------------- End of Theseus input file ----
```

More Keywords:

SOL-TRANS1 ... Implicit transient solver (1.order) with the end time 3600s. Additionally the maximum time step size is limited to 100s. The initial time step size starts with the default value 0.1s.

MANSETP ... The setpoint-file will be used for the active system when calculating the difference between the current temperatures and the setpoints ($T-T_0$) during the simulation.

POSTFRQ ... Defines the time intervals (dt_{post}=300s) to use for writing post-processing results into the hdf-file.

Human initial temperatures will not be set by the keyword TINITFE in the active system. Temperatures at t=0 will be read from the setpoint-file (*neutral_shorts.stp).* Alternatively, temperatures at t=0 can be read from a restart file (with the keyword RESTREAD) created by a previous transient simulation*.

Starting the Solver: *theseus job=cool_shorts*

* see slide 41

Validation:
(Validation Man., Chap.4.3.11)
(simulated time: t=0..9000s)

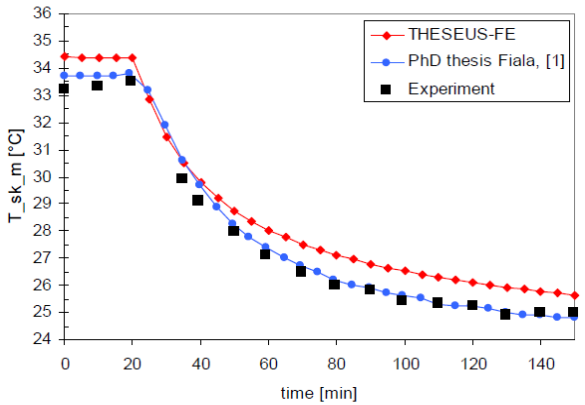


Fig. 4-54: Mean skin temperature

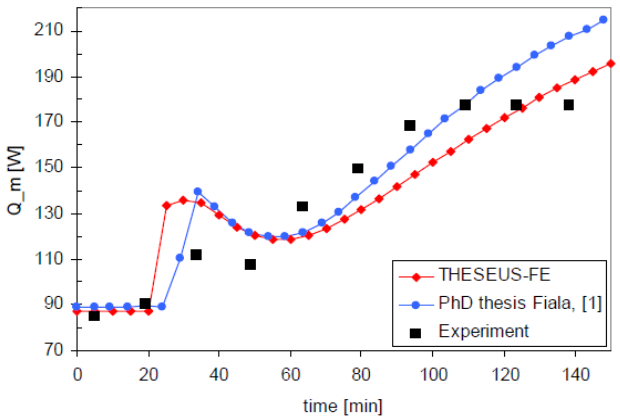


Fig. 4-55: Metabolism

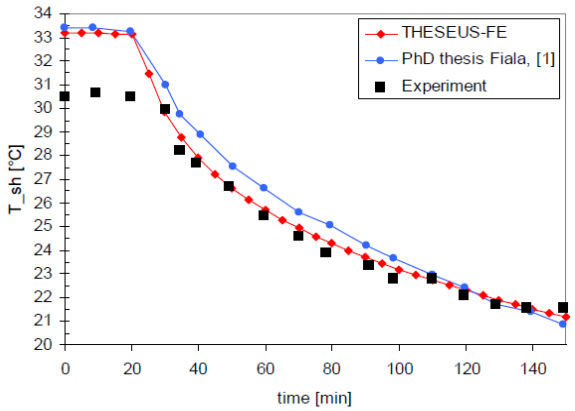


Fig. 4-56: Shoulder temperature

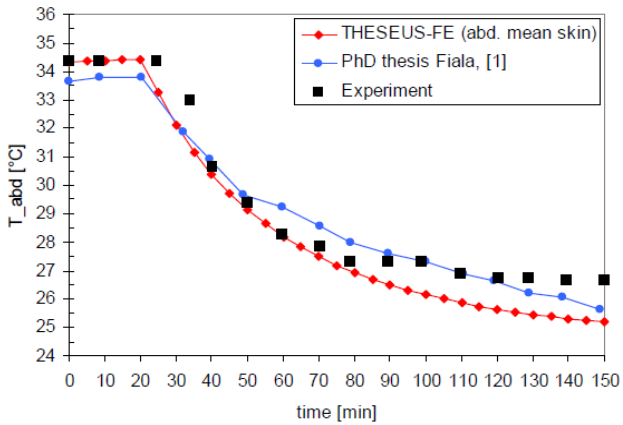
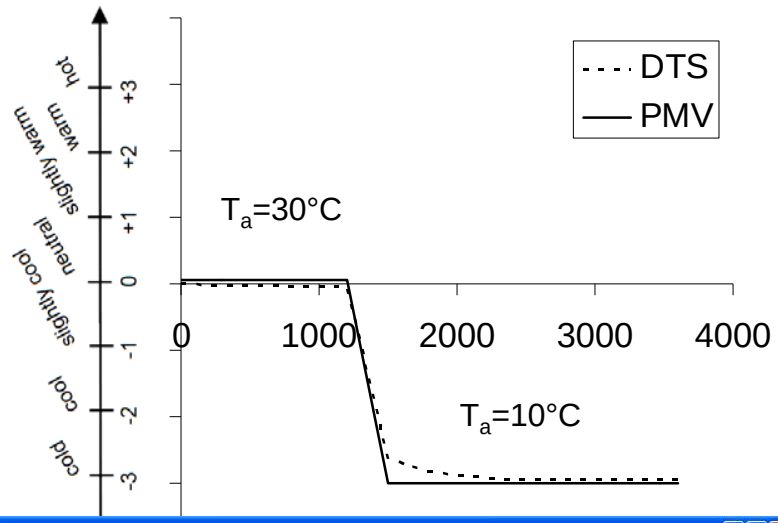


Fig. 4-58: Abdomen temperature

Tasks:

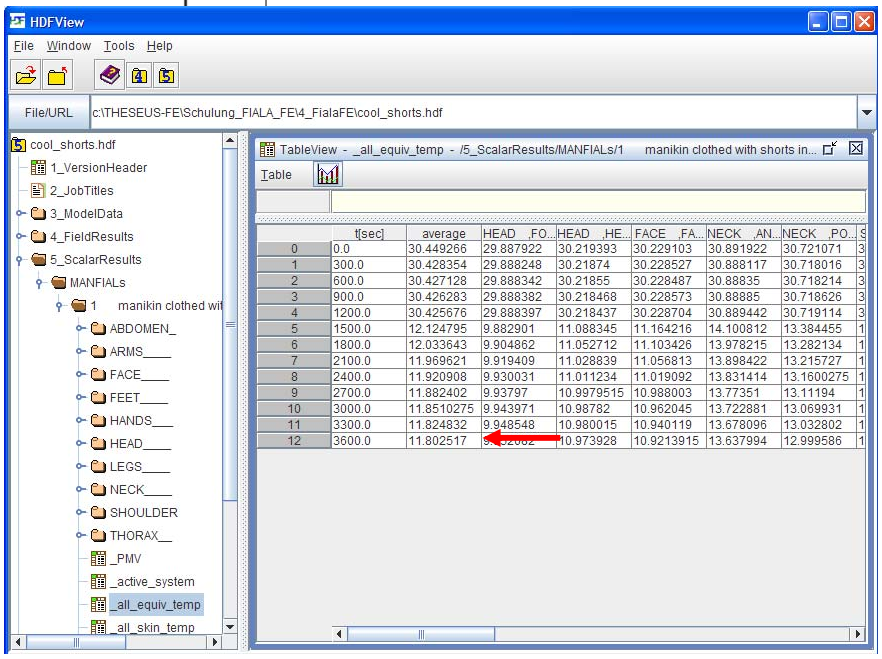
- Compare the global comfort index: PMV with DTS (from hdf-dataset „_PMV“ and „_comfort“).
- Check if the results from the hdf-file after 1h=60min are the same as the results from the previous slide.
- Determine the influence of air speed/radiation on the average equivalent temperature after t=1h.



Baseline: $v = 0.1 m/s \Rightarrow T_{eq} = 11.8°C$, at t = 1h

$v = 1.0 m/s \Rightarrow T_{eq} = -0.5°C$, at t = 1h

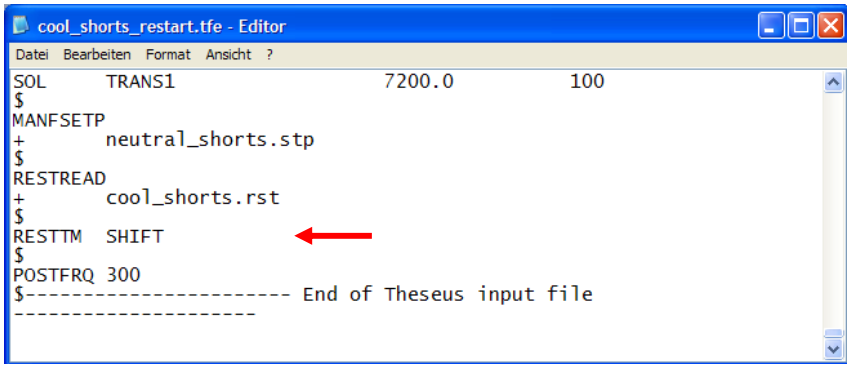
$\varepsilon = 0 \Rightarrow T_{eq} = 20.1°C$, at t = 1h



	t[sec]	average	HEAD ,FO...	HEAD ,HE...	FACE ,FA...	NECK ,AN...	NECK ,PO...
0	0.0	30.449266	29.887922	30.219393	30.229103	30.891922	30.721071
1	300.0	30.428354	29.888248	30.21874	30.228527	30.888117	30.718016
2	600.0	30.427128	29.888342	30.21855	30.228487	30.88835	30.718214
3	900.0	30.426283	29.888382	30.218468	30.228573	30.88885	30.718626
4	1200.0	30.425676	29.888397	30.218437	30.228704	30.889442	30.719114
5	1500.0	12.124795	9.882901	11.088345	11.164216	14.100812	13.384455
6	1800.0	12.033643	9.904862	11.052712	11.103426	13.978215	13.282134
7	2100.0	11.969621	9.919409	11.028839	11.056813	13.898422	13.215727
8	2400.0	11.920908	9.930031	11.011234	11.019092	13.831414	13.1600275
9	2700.0	11.882402	9.93797	10.9979515	10.988003	13.77351	13.11194
10	3000.0	11.8510275	9.943971	10.98782	10.962045	13.722881	13.069931
11	3300.0	11.824832	9.948548	10.980015	10.940119	13.678096	13.032802
12	3600.0	11.802517	[illegible]	10.973928	10.9213915	13.637994	12.999586

Now we continue the simulated at 60 minutes with a restart.

Copy the file *cool_shorts.tfe*
to *cool_shorts_restart.tfe*

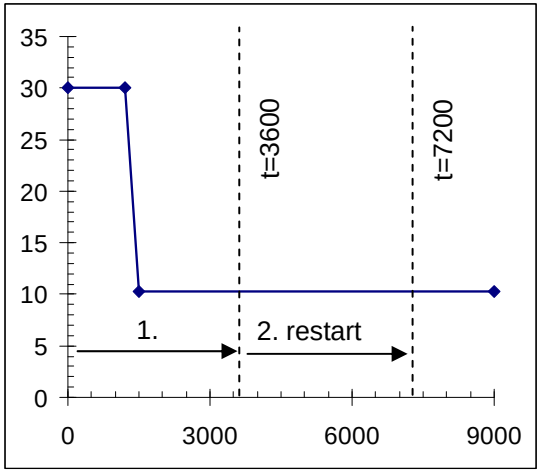


More Keywords:

RESTREAD* ... the final temperatures from the previous simulation (*cool_shorts*) will be used now as start temperatures of the new simulation (*cool_shorts_restart*)

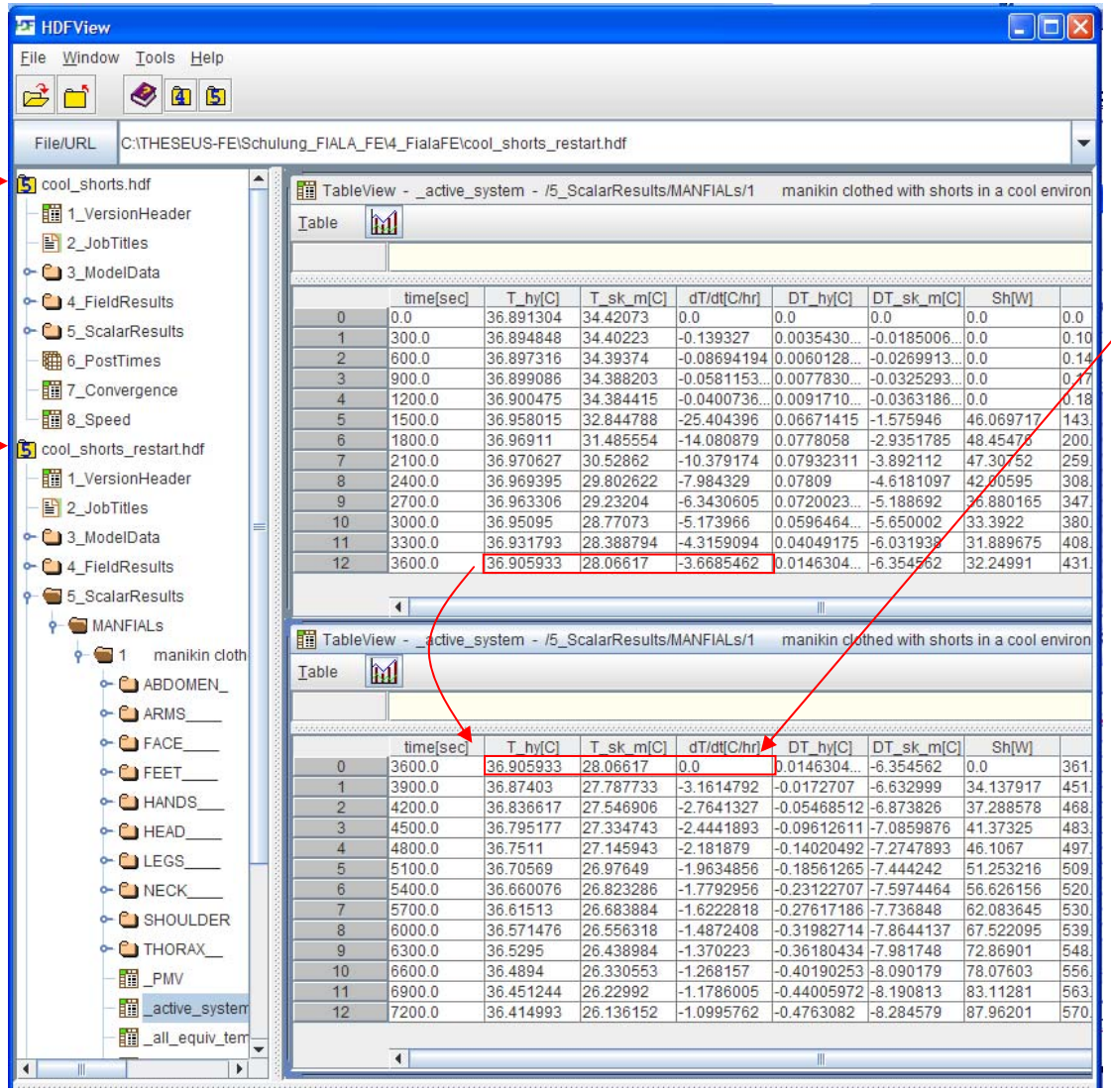
RESTTM-SHIFT ... the analysis-time will not start with t=0 but with the end time stored in the rst-file (t=3600s). This guarantees the correct choice of function values $T_a(t)$ and $T_w(t)$, see figure on the right. Without this keyword, the restart will start at t=0.

Ambient Air Temperature:



Starting the Solver: *theseus job=cool_shorts_restart*

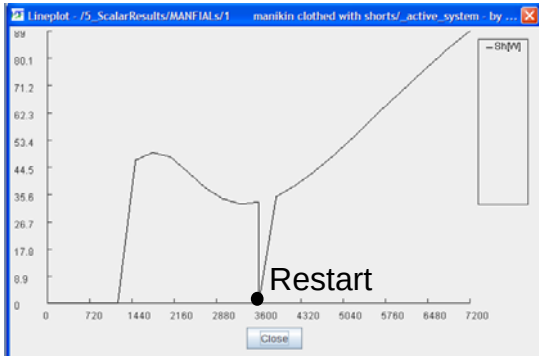
*Each simulation with the active system produces a binary rst-file that stores the current temperatures after each converged time step. At the end of the calculation the final temperatures are stored in the file. Each simulation with the passive system produces a stp-file with the same content. This file will be used as setpoint-file for the active system. Restart files can only be used if the number of degree-of-freedoms remains unchanged!



	time[sec]	T_hy[C]	T_sk_m[C]	dT/dt[C/hr]	DT_hy[C]	DT_sk_m[C]	Sh[W]	
0	0.0	36.891304	34.42073	0.0	0.0	0.0	0.0	0.0
1	300.0	36.894848	34.40223	-0.139327	0.0035430...	-0.0185006...	0.0	0.10
2	600.0	36.897316	34.39374	-0.08694194	0.0060128...	-0.0269913...	0.0	0.14
3	900.0	36.899086	34.388203	-0.0581153...	0.0077830...	-0.0325293...	0.0	0.17
4	1200.0	36.900475	34.384415	-0.0400736...	0.0091710...	-0.0363186...	0.0	0.18
5	1500.0	36.958015	32.844788	-25.404396	0.06671415	-1.575946	46.069717	143.
6	1800.0	36.96911	31.485554	-14.080879	0.0778058	-2.9351785	48.45476	200.
7	2100.0	36.970627	30.52862	-10.379174	0.07932311	-3.892112	47.30752	259.
8	2400.0	36.969395	29.802622	-7.984329	0.07809	-4.6181097	42.00595	308.
9	2700.0	36.963306	29.23204	-6.3430605	0.0720023...	-5.188692	36.880165	347.
10	3000.0	36.95095	28.77073	-5.173966	0.0596464...	-5.650002	33.3922	380.
11	3300.0	36.931793	28.388794	-4.3159094	0.04049175	-6.031938	31.889675	408.
12	3600.0	36.905933	28.06617	-3.6685462	0.0146304...	-6.354562	32.24991	431.

	time[sec]	T_hy[C]	T_sk_m[C]	dT/dt[C/hr]	DT_hy[C]	DT_sk_m[C]	Sh[W]	
0	3600.0	36.905933	28.06617	0.0	0.0146304...	-6.354562	0.0	361.
1	3900.0	36.87403	27.787733	-3.1614792	-0.0172707	-6.632999	34.137917	451.
2	4200.0	36.836617	27.546906	-2.7641327	-0.05468512	-6.873826	37.288578	468.
3	4500.0	36.795177	27.334743	-2.4441893	-0.09612611	-7.0859876	41.37325	483.
4	4800.0	36.7511	27.145943	-2.181879	-0.14020492	-7.2747893	46.1067	497.
5	5100.0	36.70569	26.97649	-1.9634856	-0.18561265	-7.444242	51.253216	509.
6	5400.0	36.660076	26.823286	-1.7792956	-0.23122707	-7.5974464	56.626156	520.
7	5700.0	36.61513	26.683884	-1.6222818	-0.27617186	-7.736848	62.083645	530.
8	6000.0	36.571476	26.556318	-1.4872408	-0.31982714	-7.8644137	67.522095	539.
9	6300.0	36.5295	26.438984	-1.370223	-0.36180434	-7.981748	72.86901	548.
10	6600.0	36.4894	26.330553	-1.268157	-0.40190253	-8.090179	78.07603	556.
11	6900.0	36.451244	26.22992	-1.1786005	-0.44005972	-8.190813	83.11281	563.
12	7200.0	36.414993	26.136152	-1.0995762	-0.4763082	-8.284579	87.96201	570.

Because the time derivative of the mean skin temperature is not available at the beginning of the restart, there are some small errors in the functions, which use dT_{sk_m}/dt: e.g. *DTS*-Index or shivering *Sh*.



cool_shorts_restart.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
SOL      TRANS1                    7200.0          100
$
MANFSETP
+        neutral_shorts.stp
$
RESTREADYES
+        cool_shorts.rst
+        cool_shorts.hdf
$
RESTTM   SHIFT
$
POSTFRQ 300
$----------------------- End of Theseus input file
---------------------
```

RESTREAD

Restart analysis, reading initial temperatures from a restart file (suffix .rst).

Syntax:

1	2	3	4	5	6	7	8	9	10
RESTREAD	APHDF								
+	FNAME								
+	HDFNAME								

Field:	**Contents:**
[APHDF]	switch to enable appending to an existing HDF result file; possible values are: "NO" (default) and "YES"
FNAME	name of restart file
[HDFNAME]	optional: name of existing THESEUS-FE result file for APHDF=YES (default: job name + ".hdf")

Related Keywords:

RESTTM, RESTWR

The option APHDF=YES can be activated with the keyword RESTREAD. This will redirect the results to the old hdf-file (*cool_shorts.hdf*).

Then the time t=3600s will appear two times in the hdf-file (see figure on the right side).

HDFView

File Window Tools Help

File/URL c:\THESEUS-FE\Schulung_FIALA_FE\4_FialaFE\cool_shorts.hdf

cool_shorts.hdf
- 1_VersionHeader
- 2_JobTitles
- 3_ModelData
- 4_FieldResults
- 5_ScalarResults
  - MANFIALs
    - 1 manikin cloth
      - ABDOMEN_
      - ARMS____
      - FACE____
      - FEET____
      - HANDS___
      - HEAD____
      - LEGS____
      - NECK____
      - SHOULDER
      - THORAX__
      - _PMV
      - _active_system
      - _all_equiv_tem
      - _all_skin_temp
      - _all_surf_temp

TableView - _active_system - /5_ScalarResults/MANFIALs/1 manikin clothed with shorts in a c...

Table

	time[sec]	T_hy[C]	T_sk_m[C]	dT/dt[C/hr]	DT_hy[C]	DT_sk_m[C]	Sh[W]	
0	0.0	36.891304	34.42073	0.0	0.0	0.0	0.0	0.0
1	300.0	36.894848	34.40223	-0.139327	0.0035430...	-0.0185006...	0.0	0.10
2	600.0	36.897316	34.39374	-0.08694194	0.0060128...	-0.0269913...	0.0	0.14
3	900.0	36.899086	34.388203	-0.0581153...	0.0077830...	-0.0325293...	0.0	0.17
4	1200.0	36.900475	34.384415	-0.0400736...	0.0091710...	-0.0363186...	0.0	0.18
5	1500.0	36.958015	32.844788	-25.404396	0.06671415	-1.575946	46.069717	143.
6	1800.0	36.96911	31.485554	-14.080879	0.0778058	-2.9351785	48.45476	200.
7	2100.0	36.970627	30.52862	-10.379174	0.07932311	-3.892112	47.30752	259.
8	2400.0	36.969395	29.802622	-7.984329	0.07809	-4.6181097	42.00595	308.
9	2700.0	36.963306	29.23204	-6.3430605	0.0720023...	-5.188692	36.880165	347.
10	3000.0	36.95095	28.77073	-5.173966	0.0596464...	-5.650002	33.3922	380.
11	3300.0	36.931793	28.388794	-4.3159094	0.04049175	-6.031938	31.889675	408.
12	3600.0	36.905933	28.06617	-3.6685462	0.0146304...	-6.354562	32.24991	431.
13	3600.0	36.905933	28.06617	0.0	0.0146304...	-6.354562	0.0	361.
14	3900.0	36.87403	27.787733	-3.161479	-0.0172705...	-6.632999	34.137905	451.
15	4200.0	36.836617	27.546906	-2.7641325	-0.0546849...	-6.873826	37.28857	468.
16	4500.0	36.795177	27.334743	-2.4441893	-0.096126	-7.0859876	41.373245	483.
17	4800.0	36.7511	27.145943	-2.181879	-0.14020483	-7.2747893	46.106697	497.
18	5100.0	36.705692	26.97649	-1.9634856	-0.1856125	-7.444242	51.25321	509.
19	5400.0	36.660076	26.823286	-1.7792956	-0.23122695	-7.5974464	56.626152	520.
20	5700.0	36.61513	26.683884	-1.6222818	-0.27617174	-7.736848	62.08364	530.
21	6000.0	36.571476	26.556318	-1.4872408	-0.31982702	-7.8644133	67.522095	539.
22	6300.0	36.5295	26.438984	-1.370223	-0.36180425	-7.981748	72.86901	548.
23	6600.0	36.4894	26.330553	-1.268157	-0.40190244	-8.090179	78.07603	556.
24	6900.0	36.451244	26.22992	-1.1786005	-0.44005963	-8.190813	83.1128	563.
25	7200.0	36.414993	26.136152	-1.0995762	-0.4763081	-8.284579	87.96201	570.

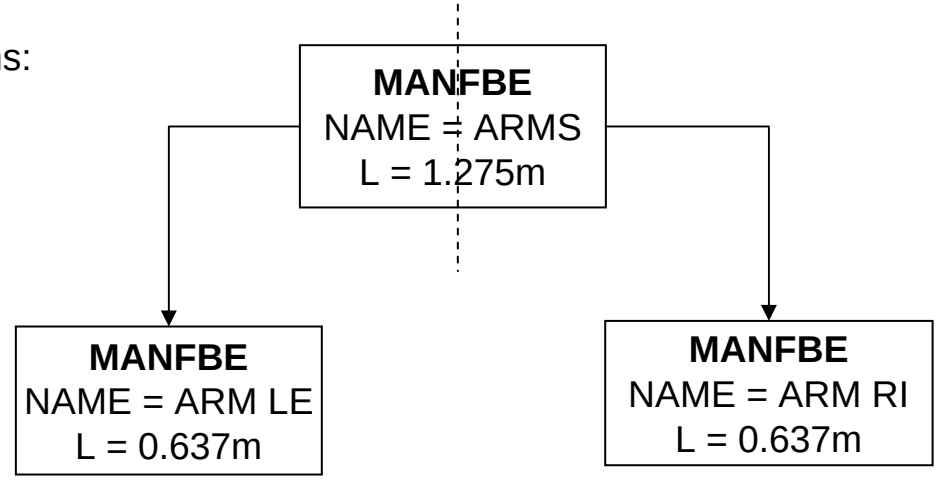
Remark:
Restarts are often used to update boundary conditions in coupled simulations, e.g. manikin FIALA-FE with a CFD-solver. The option APHDF=YES makes sense in this context, since all results are stored in a single hdf-file.

An asymmetric manikin model will be constructed starting from the symmetric model.
First, the thermal neutrality (and the stp-file) have to be re-calculated.
The new model can be validated with results from the (old) symmetric model.

Copy the file *neutral_shorts.tfe*
to *neutral_shorts_unsymmetric_arm.tfe*

The **asymmetric manikin** consists of 15=10+5 body elements. The symmetric body elements (shoulder, arms, hands, legs, feet) will be split and the length will be halved, e.g. arms left/right L=127.5cm/2 = 63.7cm.

We start with the split for the arms:



Asymmetric Manikin: Thermal neutrality

Basically the splitting of the body elements concerns the keyword MANFBEL and is documented in the Theory Manual (right picture).

KeywordManual_4_0_secured.pdf (GESCHÜTZT) - Adobe Reader

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THESEUS-FE 4.0 Keyword Manual

MANFBEL

Body element definitions for manikin FIALA-FE.

References: Theory Manual Chapter 4

Syntax:

1	2	3	4	5	6	7	8	9	10
MANFBEL	MANID	BE_ID	NAME	TYPE	NSEC		L	H_X	
+	A_SK	A_SW	A_DL	A_CS	A_SH	A_M_W1	A_M_W2		
+	A_NAT	A_FR	A_MIX						

Field:	Contents:
MANID	manikin id. (integer > 0)
BE_ID	body element id. (integer > 0)
NAME	body element name (char*8)
TYPE	= SPHERE or CYLINDR
NSEC	number of sectors (integer > 0)
L	length in [m] of body element (real > 0)
H_X	CCX coefficient in [W/K] (real ≥ 0)
A_SK	distribution coefficient for mean skin temperature (0 ≤ real ≤ 1)
A_SW	distribution coefficient for sweating (0 ≤ real ≤ 1)
A_DL	distribution coefficient for vasodilatation (0 ≤ real ≤ 1)
A_CS	distribution coefficient for vasoconstriction (0 ≤ real ≤ 1)
A_SH	distribution coefficient for shivering (0 ≤ real ≤ 1)
A_M_W1	workload distribution coefficient, sedentary (0 ≤ real ≤ 1)
A_M_W2	workload distribution coefficient, standing (0 ≤ real ≤ 1)
A_NAT	Regression coeff., natural convection (real ≥ 0)
A_FRC	Regression coeff., forced convection (real ≥ 0)
A_MIX	Regression coeff., mixed convection (real)

TheoryManual_4_0_secured.pdf (GESCHÜTZT) - Adobe Reader

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THESEUS-FE 4.0 Theory Manual

	j	a_sk	a_sw	a_dl	a_cs	a_sh	a_m_w_sed	a_m_w_stnd	h_x
head	1	0.0835	0.0950	0.0550	0.0300	0.0000	0.0000	0.0000	0.0000
face	2	0.0418	0.0540	0.0460	0.0330	0.0020	0.0000	0.0000	0.0000
neck	3	0.0417	0.0420	0.0310	0.0250	0.0020	0.0300	0.0100	0.0000
left shoulder	4	0.0150	0.0185	0.0100	0.0100	0.0001	0.0250	0.0100	0.4000
right shoulder	5	0.0150	0.0185	0.0100	0.0100	0.0001	0.0250	0.0100	0.4000
thorax	6	0.1290	0.1010	0.1410	0.0005	0.6305	0.1200	0.0700	0.0000
abdomen	7	0.1210	0.1810	0.1610	0.0205	0.2400	0.4600	0.2000	0.0000
left arm	8	0.0900	0.0665	0.0475	0.1945	0.0200	0.0950	0.0400	2.0650
right arm	9	0.0900	0.0665	0.0475	0.1945	0.0200	0.0950	0.0400	2.0650
left hand	10	0.0450	0.0245	0.0605	0.1100	0.0010	0.0100	0.0050	0.2850
right hand	11	0.0450	0.0245	0.0605	0.1100	0.0010	0.0100	0.0050	0.2850
left leg	12	0.1040	0.1305	0.1150	0.2000	0.0407	0.0550	0.3000	3.4500
right leg	13	0.1040	0.1305	0.1150	0.2000	0.0407	0.0550	0.3000	3.4500
left foot	14	0.0375	0.0235	0.0500	0.3765	0.0010	0.0100	0.0050	1.7000
right foot	15	0.0375	0.0235	0.0500	0.3765	0.0010	0.0100	0.0050	1.7000
sum		1.0000	1.0000	1.0000	1.8910	1.0000	1.0000	1.0000	

Figure 4-9: Distribution coefficients and h_x values for the split manikin FIALA-FE

A_CS is not changed!

The following parameters will be halved in the keyword MANFBEL:
L, H_X, A_SK, A_SW, A_DL, A_SH, A_M_W1, A_M_W2

Asymmetric Manikin: Thermal neutrality

We start with splitting the arms:

Compare contents

c:\THESEUS-FE\FIALA_FE_uncoupled\Work_v40\neutral_shorts.tfe

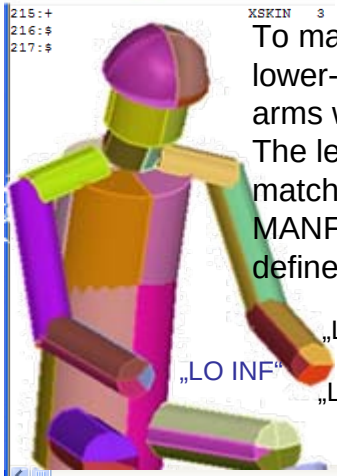
```
192:$ A R M S
193:$---------------------
194:$
195:$body element definitions:
196:$.......MANID...BE_ID...NAME....TYPE....NSEC....     ....L.......H_X
197:$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
198:$.......A_NAT...A_FR....A_MIX
199:MANFBEL 1       7       ARMS    CYLINDR 3               1.274   4.13
200:+       0.1800  0.1330  0.0950  0.1945  0.0400  0.19    0.08
201:+       8.3     216.0   -10.8
202:$
203:$sector definitions
204:$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
205:MANFSEC 1       7       ANTERIOR5       135.0   0.75    0.85    0.99
206:+                       POSTERIO5       135.0   0.80    0.90    0.99
207:+                       INFERIOR5       90.0    0.10    0.20    0.99
208:$
209:$layer definitions
210:$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.....A_RSP
211:MANFLAYR1       7       BONE    3       0.0153  0.75    1357.0  1700.0  0.0     0.0     0.0
212:+                       MUSCLE  3       0.0343  0.42            3768.0  0.538-3 684.0   0.0
213:+                       FAT     3       0.0401  0.160           2300.0  3.6-6   58.0    0.0
214:+                       SKIN    3       0.04095 0.47            3680.0  2.2-3   736.0   0.0
215:+                       XSKIN   3       0.0418  0.47            3680.0  0.0     0.0     0.0
216:$
217:$
```

c:\THESEUS-FE\FIALA_FE_uncoupled\Work_v40\neutral_shorts_unsym_arms.tfe

```
192:$ A R M S
193:$---------------------
194:$
195:$body element definitions:
196:$.......MANID...BE_ID...NAME....TYPE....NSEC....     ....L.......H_X
197:$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
198:$.......A_NAT...A_FR....A_MIX
199:MANFBEL 1       7       ARM LE  CYLINDR 6               0.637   2.065
200:+       0.0900  0.0665  0.0475  0.1945  0.0200  0.095   0.04
201:+       8.3     216.0   -10.8
202:$
203:$sector definitions
204:$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF....L
205:MANFSEC 1       7       UP ANT  5       135.0   0.75    0.85    0.99    0.3185
206:+                       UP POS  5       135.0   0.80    0.90    0.99    0.3185
207:+                       UP INF  5       90.0    0.10    0.20    0.99    0.3185
208:+                       LO ANT  5       135.0   0.75    0.85    0.99    0.3185
209:+                       LO POS  5       135.0   0.80    0.90    0.99    0.3185
210:+                       LO INF  5       90.0    0.10    0.20    0.99    0.3185
211:$
212:$layer definitions
213:$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.....A_RSP
214:MANFLAYR1       7       BONE    3       0.0153  0.75    1357.0  1700.0  0.0     0.0     0.0
215:+                       MUSCLE  3       0.0343  0.42    1085.0  3768.0  0.538-3 684.0   0.0
216:+                       FAT     3       0.0401  0.160   850.0   2300.0  3.6-6   58.0    0.0
217:+                       SKIN    3       0.04095 0.47    1085.0  3680.0  2.2-3   736.0   0.0
218:+                       XSKIN   3       0.0418  0.47    1085.0  3680.0  0.0     0.0     0.0
219:$
220:$
221:$body element definitions:
222:$.......MANID...BE_ID...NAME....TYPE....NSEC....     ....L.......H_X
223:$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
224:$.......A_NAT...A_FR....A_MIX
225:MANFBEL 1       8       ARM RI  CYLINDR 6               0.637   2.065
226:+       0.0900  0.0665  0.0475  0.1945  0.0200  0.095   0.04
227:+       8.3     216.0   -10.8
228:$
229:$sector definitions
230:$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF....L
231:MANFSEC 1       8       UP ANT  5       135.0   0.75    0.85    0.99    0.3185
232:+                       UP POS  5       135.0   0.80    0.90    0.99    0.3185
233:+                       UP INF  5       90.0    0.10    0.20    0.99    0.3185
234:+                       LO ANT  5       135.0   0.75    0.85    0.99    0.3185
235:+                       LO POS  5       135.0   0.80    0.90    0.99    0.3185
236:+                       LO INF  5       90.0    0.10    0.20    0.99    0.3185
237:$
238:$layer definitions
239:$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q_M.....A_RSP
240:MANFLAYR1       8       BONE    3       0.0153  0.75    1357.0  1700.0  0.0     0.0     0.0
241:+                       MUSCLE  3       0.0343  0.42    1085.0  3768.0  0.538-3 684.0   0.0
242:+                       FAT     3       0.0401  0.160   850.0   2300.0  3.6-6   58.0    0.0
243:+                       SKIN    3       0.04095 0.47    1085.0  3680.0  2.2-3   736.0   0.0
244:+                       XSKIN   3       0.0418  0.47    1085.0  3680.0  0.0     0.0     0.0
245:$
```

L/2

copy/paste



To make temperatures available at the lower- and upper arm, the left and right arms will be divided into 6 sectors each. The length of the sectors (L/2) will not match the length L in the keyword MANFBEL anymore and needs to be defined separately.

It might be useful to increase the view factor VF_SED at the sector „LO INF“ (e.g. to 0.8) for the sitting manikin .

The new body element „ARM RI“ will be produced by copy/paste. The NAME and BE_ID (7⇒8) will be adjusted. Afterwards, all following body element IDs (for HANDS, LEGS, FEET) in the model must be raised by 1.

Finally, the total number of body elements in the keyword MANIKIN have to be increased to 10+1=11:

neutral_shorts_unsym_arms.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$        2        3        4        5        6        7        8        9        1
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$
$
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ split arm manikin clothed with dummy shorts in a neutral environment
MANIKIN 1        FIALA    UNCPLD   PASSIVE STND     11       0.8
+       30.0     0.93     30.0     0.05     40.0
$
```

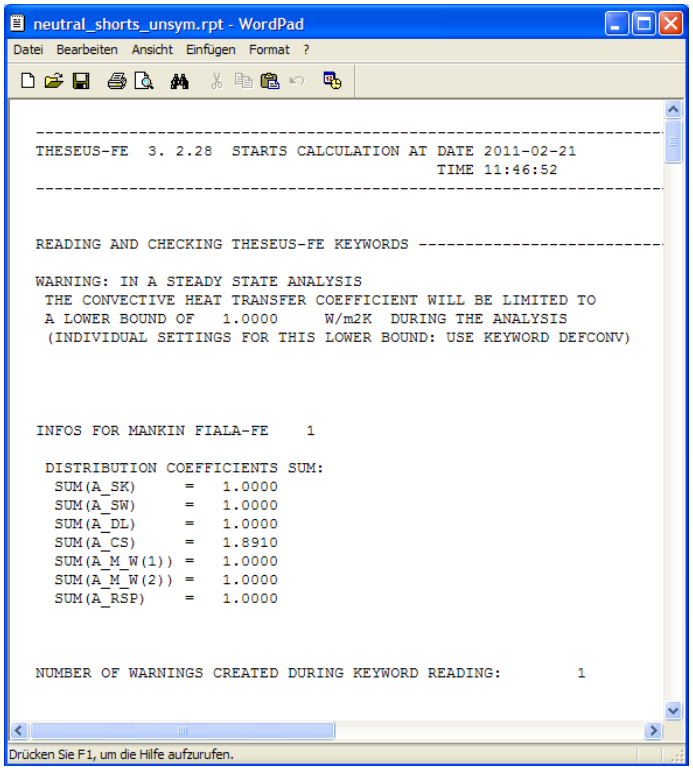
Starting the Solver: *theseus job=neutral_shorts_unsymmetric_arm*

Starting the job should reproduce the same results for the thermal neutrality as shown on slide 28.

Task:
Now shoulders, hands, legs, and feet need to be split.
An increase of the sector count from 3 to 6 (as for the arms) will be done for the legs.
An increase of the sector count from 3 to 4 (see next slide) will be done for the thorax and abdomen.

Copy the file *neutral_shorts_unsymmetric_arm.tfe*
to *neutral_shorts_unsymmetric.tfe*

In the case where the Keyword MANFDBG exists:
The rpt-file will contain the sums over the distribution coefficients.
They should match with the values in Fig.4-9 (Theory Man.).
All should have the sum to 1 except Σa_{cs} !

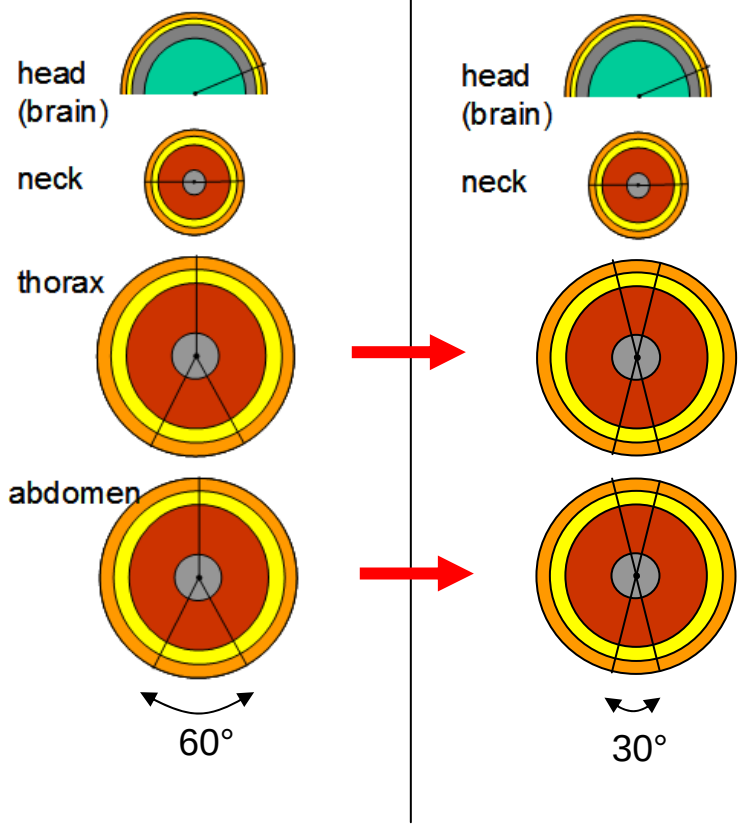

neutral_shorts_unsym.rpt - WordPad

```
THESEUS-FE  3. 2.28  STARTS CALCULATION AT DATE 2011-02-21
                                             TIME 11:46:52

READING AND CHECKING THESEUS-FE KEYWORDS ---------------------------

WARNING: IN A STEADY STATE ANALYSIS
 THE CONVECTIVE HEAT TRANSFER COEFFICIENT WILL BE LIMITED TO
 A LOWER BOUND OF   1.0000     W/m2K  DURING THE ANALYSIS
 (INDIVIDUAL SETTINGS FOR THIS LOWER BOUND: USE KEYWORD DEFCONV)

INFOS FOR MANKIN FIALA-FE    1

 DISTRIBUTION COEFFICIENTS SUM:
  SUM(A_SK)      =   1.0000
  SUM(A_SW)      =   1.0000
  SUM(A_DL)      =   1.0000
  SUM(A_CS)      =   1.8910
  SUM(A_M_W(1)) =   1.0000
  SUM(A_M_W(2)) =   1.0000
  SUM(A_RSP)     =   1.0000

NUMBER OF WARNINGS CREATED DURING KEYWORD READING:        1
```

An increase of the sector count from 3 to 4 will be done for the thorax and the abdomen.

Original model by Fiala: (symmetric)

Split model: (asymmetric)



„INFERIOR“: Extension of the sector number from 3 to 4

neutral_shorts_unsym.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$---------------------
$ A B D O M E N
$---------------------
$
$body element definitions:
$.......MANID...BE_ID...NAME....TYPE....NSEC....    ....L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       7       ABDOMEN CYLINDR 4                  0.552   0.0
+       0.1210  0.1810  0.1610  0.0205  0.2400  0.46    0.2
+       1.2     180.0   -9.0
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
MANFSEC 1       7       ANTERIOR7       150.0   0.8     0.9     0.99
+                       POSTERIO7       150.0   0.95    0.95    0.99
+                       INF LE  7       30.0    0.20    0.30    0.99
+                       INF RI  7       30.0    0.20    0.30    0.99
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....
MANFLAY 1       7       CORE    3       0.0785  0.53    1000.0  3697.0  4.31-3
+                       BONE    3       0.0834  0.75    1357.0  1700.0  0.0
+                       MUSCLE  3       0.1090  0.42    1085.0  3768.0  0.538-3
+                       FAT     3       0.1244  0.160   850.0   2300.0  3.6-6
+                       SKIN    3       0.1252  0.47    1085.0  3680.0  2.88-3
+                       XSKIN   3       0.1260  0.47    1085.0  3680.0  0.0
$
$
$       MANID   BE_ID   SEC_ID  DISC    THICKN  SICL    SIICL   NSM     C
MANFSCL 1       7       1       3       0.0001  0.0001  0.0001  0.0001  0.0001
MANFSCL 1       7       2       3       0.0001  0.0001  0.0001  0.0001  0.0001
MANFSCL 1       7       3       3       0.0001  0.0001  0.0001  0.0001  0.0001
MANFSCL 1       7       3       4       0.0001  0.0001  0.0001  0.0001  0.0001
```

- The new sector „INF LE“ is covered by the left arm. This is the reason for the low view factor (VF).
- The new sector: „INF RI“ is covered by the right arm ...

The results of the neutrality calculation can be compared again with those on slide 28.

Additionally, the local skin temperatures in the hdf-dataset „_all_skin_temp“ can be compared…

TableView - _all_skin_temp - /5_ScalarResults/MANFIALs/1 manikin clothed with shorts in a neutral environment/ - c:\THESEUS-FE\FIALA_FE_uncoupled\Work_v40\neutral_shorts.hdf

	t[sec]	HEAD -FO...	HEAD -HE...	FACE -FA...	NECK -AN...	NECK -P...	SHOULDE...	THORAX -A...	THORAX -P...	THORAX -I...	ABDOMEN -...	ABDOMEN -...	ABDOMEN -...	ARMS -AN...	ARMS -PO...	ARMS -IN...	HANDS -H...	HANI
0	0.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0
1	1.0	35.642242	35.78279	35.47799	35.07846	35.049324	33.193645	35.08048	35.038486	35.864525	34.21498	34.162598	34.965416	33.720177	33.681057	34.31551	35.05396	35.4

TableView - _all_skin_temp - /5_ScalarResults/MANFIALs/1 split manikin clothed with dummy shorts in a neutral environment/ - C:\THESEUS-FE\FIALA_FE_uncoupled\Work_v40\neutral_shorts_unsym.hdf

	t[sec]	HEAD -FO...	HEAD -HE...	FACE -FA...	NECK -AN...	NECK -P...	SHLD LE -S...	SHLD RI -S...	THORAX -A...	THORAX -P...	THORAX -I...	THORAX -I...	ABDOMEN -...	ABDOMEN -...	ABDOMEN -...	ABDOMEN -...	ARM LE -U...	ARM
0	0.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0
1	1.0	35.642242	35.78279	35.47799	35.07846	35.049324	33.193645	33.193645	35.08048	35.038486	35.864525	35.864525	34.21498	34.162598	34.965416	34.965416	33.720177	33.6

Whether the distribution coefficients have been chosen correctly will only be noticeable in simulations with the active system. The sum checks on slide 48 should be enough for now.

Asymmetric Manikin: Thermal neutrality

The model: *neutral_shorts_unsymmetric.tfe*
will be copied and renamed: *neutral_summer_unsymmetric.tfe*

Afterwards we will add clothing layers for summer clothing with infinitesimal isolation (0.00001) that insure that the neutrality results are not affected by clothing.

Clothing layers will be inserted at the following body elements/sectors:

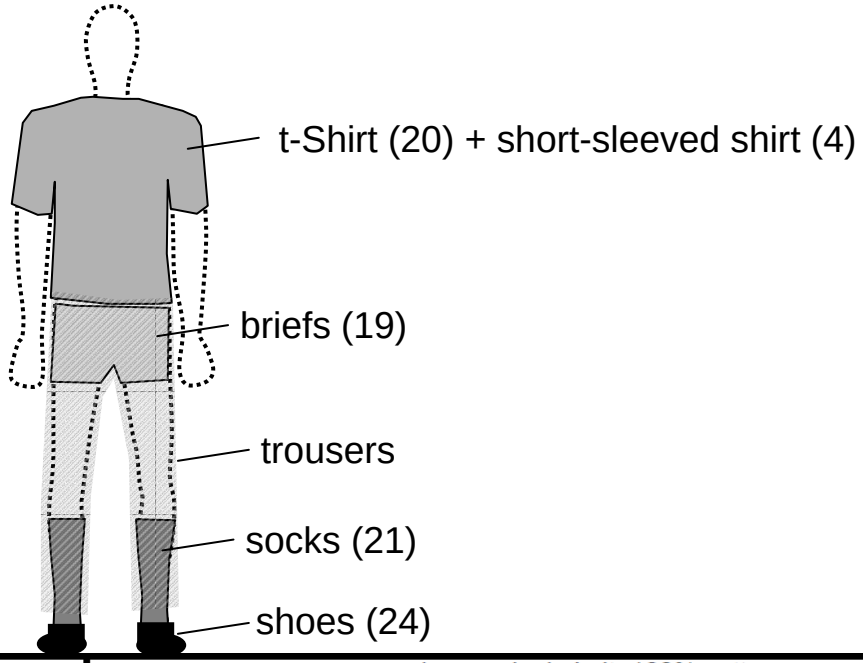
- Shoulders
- Thorax
- Abdomen
- Upper Arms
- Upper & Lower Legs
- Feet

Repeat procedure as shown on slide 31.

The results of the neutrality calculation can be compared again with slide 28.

The model: *neutral_summer_unsymmetric.tfe*
will be copied and renamed: *cool_summer_unsymmetric.tfe*

Afterwards realistic values for the summer clothing insulation will be inserted...



B	Men´s Summer Casual	19	briefs	jersey single knit, 100% cotton
		20	t-shirt	jersey single knit, 100% cotton
		21	calf length dress socks	rib knit, 75% hi-bulk orlon acrylic, 25% stretch nylon
		4	short-sleeve, shirt collar	broadcloth, plain weave, 65% polyester, 35% cotton
		16	straight, long, fitted	poplin, 60% cotton, 40% polyester
		24	hard-soled street shoes	vinyl

Source: Theory Manual - Appendix A: Database of Clothing Resistances of Ensembles

Source: Theory Manual - Appendix A: Database of Clothing Resistances of Ensembles

	head			face			neck			shoulders			thorax			abdomen		
N°	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl
A	0.00	0.00	1.00	0.00	0.00	1.00	0.16	2.40	1.01	1.62	27.00	1.13	2.21	38.80	1.10	2.42	45.30	1.14
B	**0.00**	**0.00**	**1.00**	**0.00**	**0.00**	**1.00**	**0.00**	**0.00**	**1.00**	**0.16**	**2.40**	**1.01**	**0.38**	**4.50**	**1.01**	**0.60**	**9.80**	**1.00**
C	0.00	0.00	1.00	0.00	0.00	1.00	0.23	5.10	1.03	0.23	5.00	1.03	0.45	7.20	1.02	0.73	14.20	1.04
D	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00	1.00	0.25	3.80	1.02	0.25	3.90	1.01	0.51	8.20	1.01
E	**0.00**	**0.00**	**1.00**	**0.00**	**0.00**	**1.00**	**1.22**	**16.10**	**1.46**	**2.20**	**34.00**	**1.52**	**2.77**	**40.80**	**1.19**	**2.94**	**43.90**	**1.19**

summer

winter (E)

upper arms			lower arms			hands			upper legs			lower legs			feet		
Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl	Icl (clo)	Recl (m²Pa/W)	fcl
1.32	24.90	1.41	1.30	24.50	1.44	0.00	0.00	1.00	0.97	19.30	1.20	1.21	26.10	1.43	1.51	22.40	1.22
0.69	**17.30**	**1.94**	**0.00**	**0.00**	**1.00**	**0.00**	**0.00**	**1.00**	**0.90**	**17.30**	**1.19**	**1.14**	**24.50**	**1.41**	**1.51**	**22.40**	**1.22**
0.84	20.30	1.62	0.86	19.80	1.53	0.00	0.00	1.00	0.95	19.40	1.20	1.14	25.90	1.43	1.41	19.40	1.24
0.70	9.20	1.10	0.00	0.00	1.00	0.00	0.00	1.00	0.89	17.60	1.19	0.21	3.60	1.03	1.41	19.40	1.24
1.70	**23.00**	**1.58**	**1.70**	**23.00**	**1.58**	**0.00**	**0.00**	**1.00**	**0.97**	**19.30**	**1.20**	**1.21**	**26.10**	**1.43**	**1.51**	**22.40**	**1.22**

$$\frac{I_{cl}}{i_{cl}} = R_{ecl} \cdot 0.106$$

$$d = r(f_{cl} - 1)$$

$$U = 2(r + d)\pi$$

$$A = UnL$$

$$M = nsm \cdot A$$

Microsoft Excel - Summer_clothing.xls

Datei Bearbeiten Ansicht Einfügen Format Extras Daten Fenster ?

K9

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1		Icl [clo]	Recl [m2Pa/W]	Icl/icl [clo]	fcl	r[m]	n	L[m]	Phi[deg]	d[m]	NSM[kg/m2]	c[J/kgK]	U[m]	A[m2]	M[kg]
2	shoulders	0.159	2.4	0.254	1.012	0.0460	2	0.1600	130	0.00055	0.1349	1100	0.1056	0.0338	0.0046
3	thorax	0.381	4.5	0.477	1.012	0.1290	1	0.3060	360	0.00155	0.1349	1100	0.8201	0.2510	0.0338
4	abdomen	0.596	9.8	1.039	1.003	0.1260	1	0.5520	360	0.00038	0.6075	1100	0.7939	0.4382	0.2662
5	upper arms	0.691	17.3	1.834	1.943	0.0418	2	0.3185	360	0.03942	0.1349	1100	0.5102	0.3250	0.0438
6	upper legs	0.896	17.3	1.834	1.185	0.0553	2	0.3475	360	0.01023	0.3239	1100	0.4117	0.2861	0.0927
7	lower legs	1.140	24.5	2.597	1.407	0.0553	2	0.3475	360	0.02251	0.3239	1100	0.4888	0.3397	0.1100
8	feet	1.511	22.4	2.374	1.220	0.0350	2	0.2400	360	0.00770	5.0000	1490	0.2682	0.1288	0.6438
9														1.8025	1.1949

The boundary conditions for the file *cool_summer_unsymmetric.tfe* will be taken from *cool_shorts.tfe* (see slide 37).

neutral_summer_unsym.stp will be used as setpoint file.

```
$.......TAB1_1..TAB1_2..TAB1_3..TAB1_4..TAB1_5
$.......time....TA
TABTIME 1
+       0       30
+       1200    30
+       1500    10.3
+       3600    10.3
+       3900    25
+       4800    25
$
$manikin definitions
$.......MANID...TYPE....MODE....SYSTEM..POSI....BE......ACT
$.......T_W.....E_W.....T_A.....V_A.....RH......T_BLA...LEWIS
$ split manikin clothed with summer clothes in a cool environ
MANIKIN 1       FIALA   UNCPLD  ACTIVE  STND    15      1.2
+       TAB1_2  0.93    TAB1_2  0.1     67.0
$
$
MANFPMV 1       0.4
MANFDBG 1               300
MANFISO 1       SUMMER
MANFZLC 1
$
```

added

see slide 56 (grey box)

- local comfort model by ISO 14505-2
- local comfort model by Zhang

	Activity [met]		Activity [met]
Resting:		**Office Activities:**	
Sleeping	0.7	Reading, writing (seated)	1.0
Reclining	0.8	Typing	1.1
Seat, quiet	1.0	Lifting, packing	2.1
Standing, relaxed	1.2	**Driving:**	
Walking:		Car	1.2
3.2 km/h	2	Aircraft, routine	1.2
6.4 km/h	3.8	Aircraft, landing	1.8
Miscellaneous:		Heavy vehicle	3.2
Dancing	2.4		
Heavy work	4		
Extrem sports	7.5		

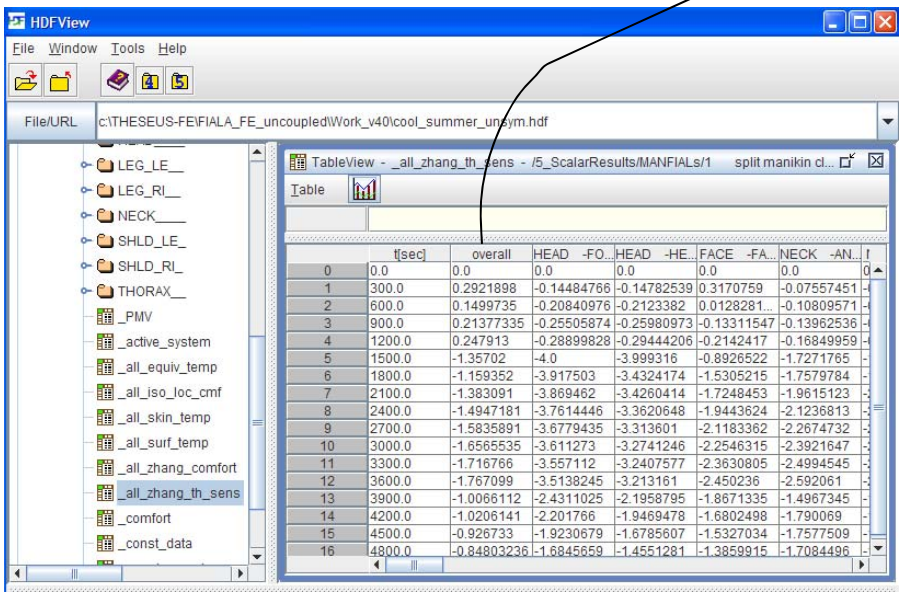
```
$       MANID   BE_ID   SEC_ID  DISC    THICKN  SICL    SIICL   NSM     C
MANFSCL 1       15      1       3       0.0077  1.511   2.374   9.9946  1490
MANFSCL 1       15      2       3       0.0077  1.511   2.374   9.9946  1490
$
$
$
$
$
$
$       2       3       4       5       6       7       8       9       10
$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$2345678$234
SOL     TRANS1                  4800.0          100
$
MANFSETP
+       neutral_summer_unsym.stp
$
POSTFRQ 300
$------------------------ End of Theseus input file ---------------------
```

Starting the Solver: *theseus job=cool_summer_unsymmetric*

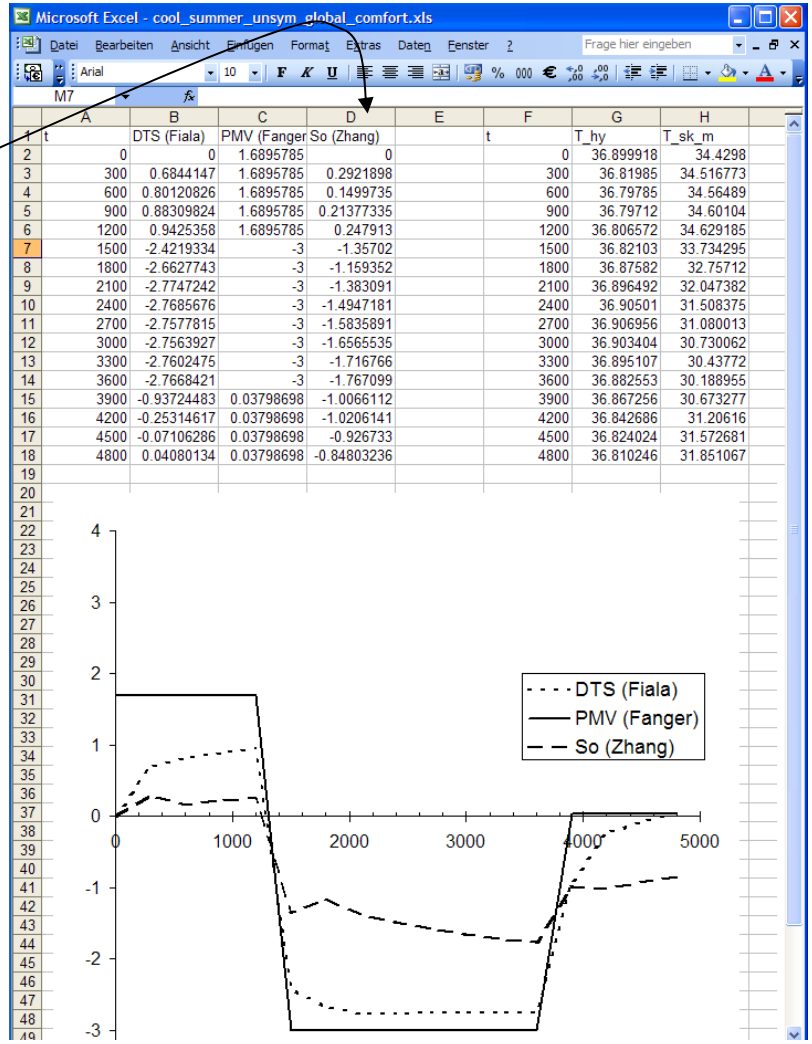
Asymmetric Manikin: Active system simulation – comfort prediction

Results from the file
cool_summer_unsymmetric.hdf
will be copied to the excel-file
cool_summer_unsym_global_comfort.xls.

copy/paste

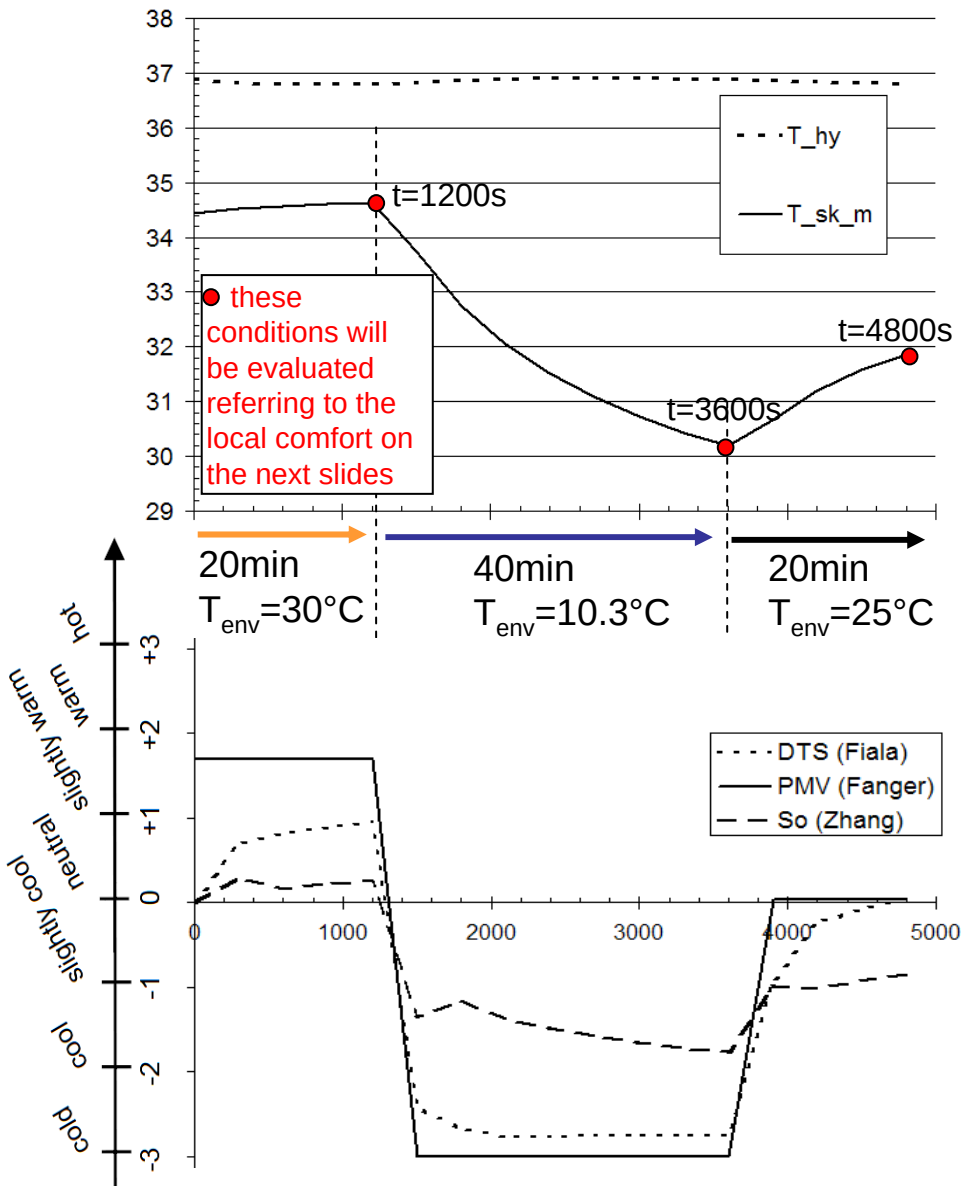


	t[sec]	overall	HEAD -FO...	HEAD -HE...	FACE -FA...	NECK -AN...
0	0.0	0.0	0.0	0.0	0.0	0.0
1	300.0	0.2921898	-0.14484766	-0.14782539	0.3170759	-0.07557451
2	600.0	0.1499735	-0.20840976	-0.2123382	0.0128281...	-0.10809571
3	900.0	0.21377335	-0.25505874	-0.25980973	-0.13311547	-0.13962536
4	1200.0	0.247913	-0.28899828	-0.29444206	-0.2142417	-0.16849959
5	1500.0	-1.35702	-4.0	-3.999316	-0.8926522	-1.7271765
6	1800.0	-1.159352	-3.917503	-3.4324174	-1.5305215	-1.7579784
7	2100.0	-1.383091	-3.869462	-3.4260414	-1.7248453	-1.9615123
8	2400.0	-1.4947181	-3.7614446	-3.3620648	-1.9443624	-2.1236813
9	2700.0	-1.5835891	-3.6779435	-3.313601	-2.1183362	-2.2674732
10	3000.0	-1.6565535	-3.611273	-3.2741246	-2.2546315	-2.3921647
11	3300.0	-1.716766	-3.557112	-3.2407577	-2.3630805	-2.4994545
12	3600.0	-1.767099	-3.5138245	-3.213161	-2.450236	-2.592061
13	3900.0	-1.0066112	-2.4311025	-2.1958795	-1.8671335	-1.4967345
14	4200.0	-1.0206141	-2.201766	-1.9469478	-1.6802498	-1.790069
15	4500.0	-0.926733	-1.9230679	-1.6785607	-1.5327034	-1.7577509
16	4800.0	-0.84803236	-1.6845659	-1.4551281	-1.3859915	-1.7084496



	A	B	C	D	E	F	G	H
1	t	DTS (Fiala)	PMV (Fanger	So (Zhang)		t	T_hy	T_sk_m
2	0	0	1.6895785	0		0	36.899918	34.4298
3	300	0.6844147	1.6895785	0.2921898		300	36.81985	34.516773
4	600	0.80120826	1.6895785	0.1499735		600	36.79785	34.56489
5	900	0.88309824	1.6895785	0.21377335		900	36.79712	34.60104
6	1200	0.9425358	1.6895785	0.247913		1200	36.806572	34.629185
7	1500	-2.4219334	-3	-1.35702		1500	36.82103	33.734295
8	1800	-2.6627743	-3	-1.159352		1800	36.87582	32.75712
9	2100	-2.7747242	-3	-1.383091		2100	36.896492	32.047382
10	2400	-2.7685676	-3	-1.4947181		2400	36.90501	31.508375
11	2700	-2.7577815	-3	-1.5835891		2700	36.906956	31.080013
12	3000	-2.7563927	-3	-1.6565535		3000	36.903404	30.730062
13	3300	-2.7602475	-3	-1.716766		3300	36.895107	30.43772
14	3600	-2.7668421	-3	-1.767099		3600	36.882553	30.188955
15	3900	-0.93724483	0.03798698	-1.0066112		3900	36.867256	30.673277
16	4200	-0.25314617	0.03798698	-1.0206141		4200	36.842686	31.20616
17	4500	-0.07106286	0.03798698	-0.926733		4500	36.824024	31.572681
18	4800	0.04080134	0.03798698	-0.84803236		4800	36.810246	31.851067
19								
20								

Zhang:
So ... overall sensation index
Sl_i ... local sensation indices
(for each body elm. sector)



$$DTS = F\left(\Delta T_{sk,m}, \Delta T_{hy}, \frac{\partial T_{sk,m}}{\partial t}\right)$$

$$\Delta T_{sk,m} = T_{sk,m} - T_{sk,m,0}$$

$$\Delta T_{hy} = T_{hy} - T_{hy,0}$$

To create the original DTS index as introduced by Fiala* the time derivative of the mean skin temperature is only updated every 300 seconds:

$$\frac{\partial T_{sk,m}(t)}{\partial t} = \frac{T_{sk,m}(t) - T_{sk,m}(t - 300s)}{300s}$$

For this purpose the keyword MANFDBG is used in the model:

MANFDBG 1 300

* Fiala used a solver with fixed time steps dt=300s, whereas THESEUS-FE works with adaptive time steps.

Local evaluation of the equivalent temperature T_{eq} and the comfort zones by DIN EN ISO 14505-2

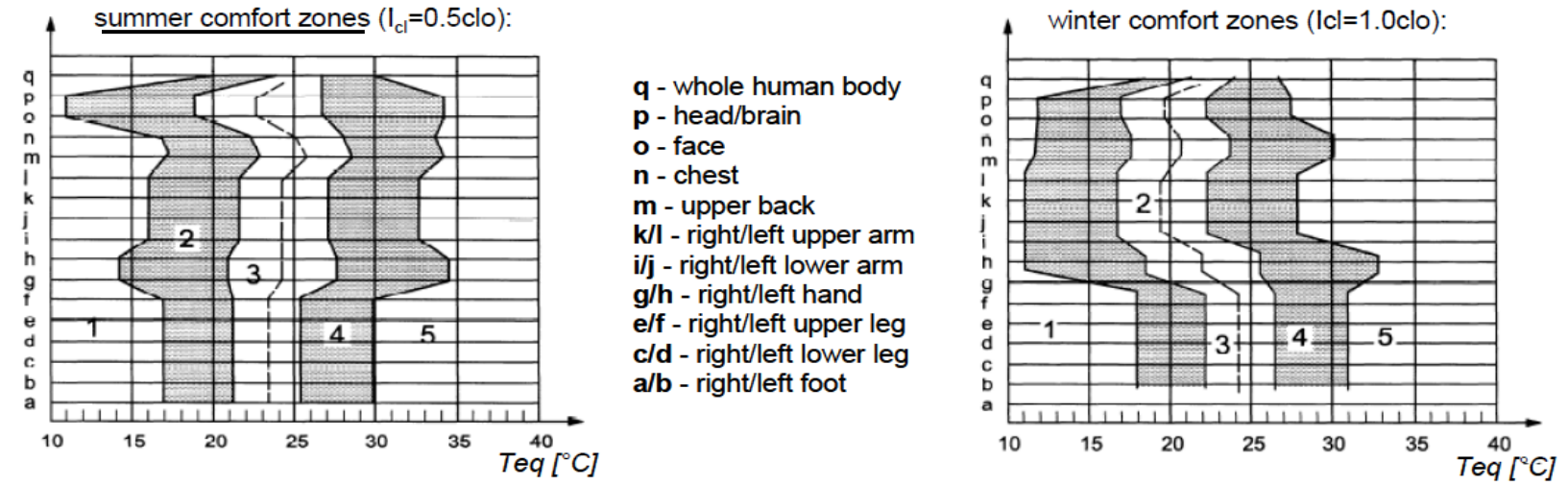
Valid for
- quasi-stationary thermal loading conditions
- activity level 1.2

DIN EN ISO 14505-2 DIN

ICS 13.180

Ergonomie der thermischen Umgebung –
Beurteilung der thermischen Umgebung in Fahrzeugen –
Teil 2: Bestimmung der Äquivalenttemperatur (ISO 14505-2:2006);
Deutsche Fassung EN ISO 14505-2:2006

THESEUS-FE Theory Manual:

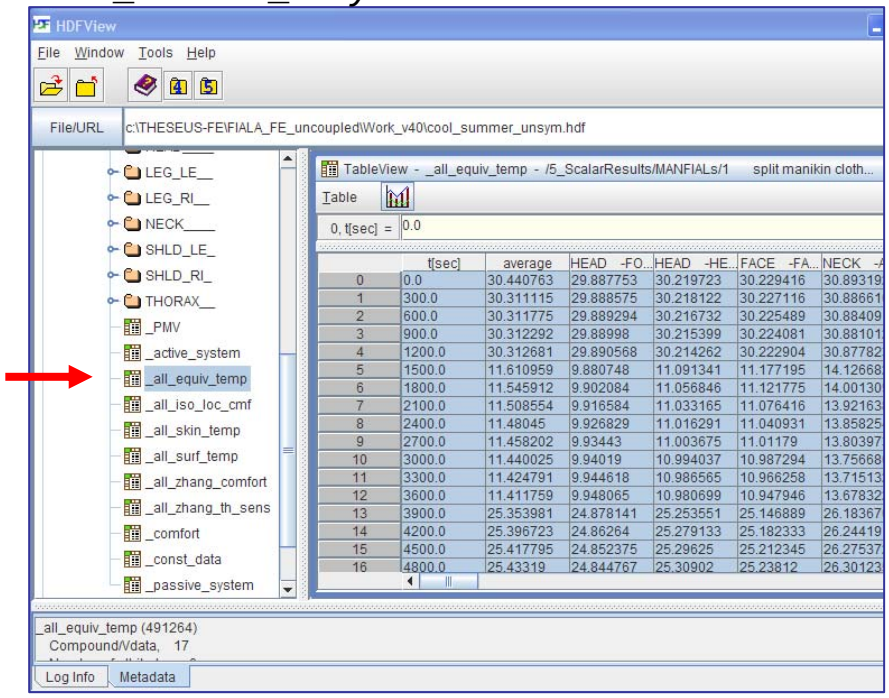


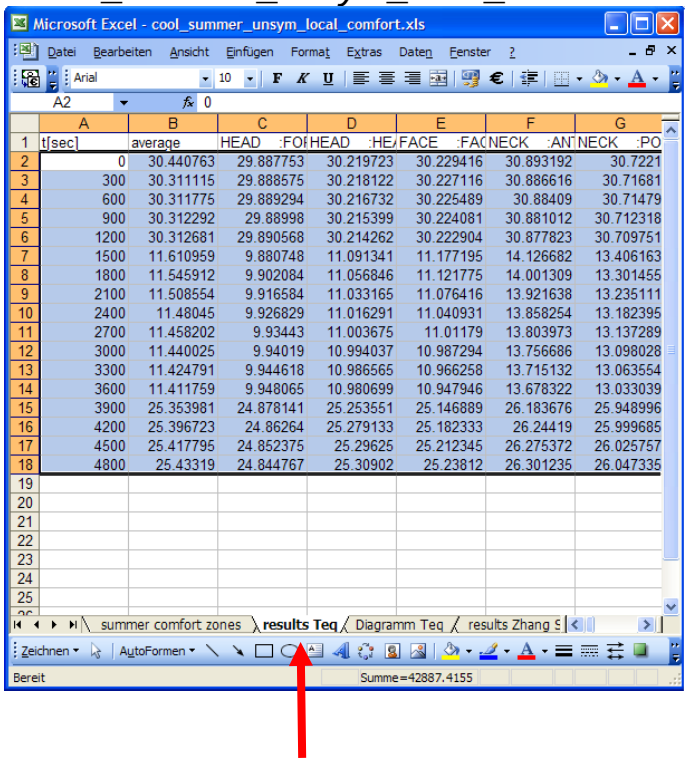
1 - to cold (uncomfortable), **2** - cold, but comfortable, **3** - neutral, **4** - warm, but comfortable, **5** - to warm (uncomfortable)

Figure 4-15: Local thermal comfort zones (ISO 14505-2)

Equivalent temperature T_{eq} will be copied from the hdf-file to a prepared xls-file.

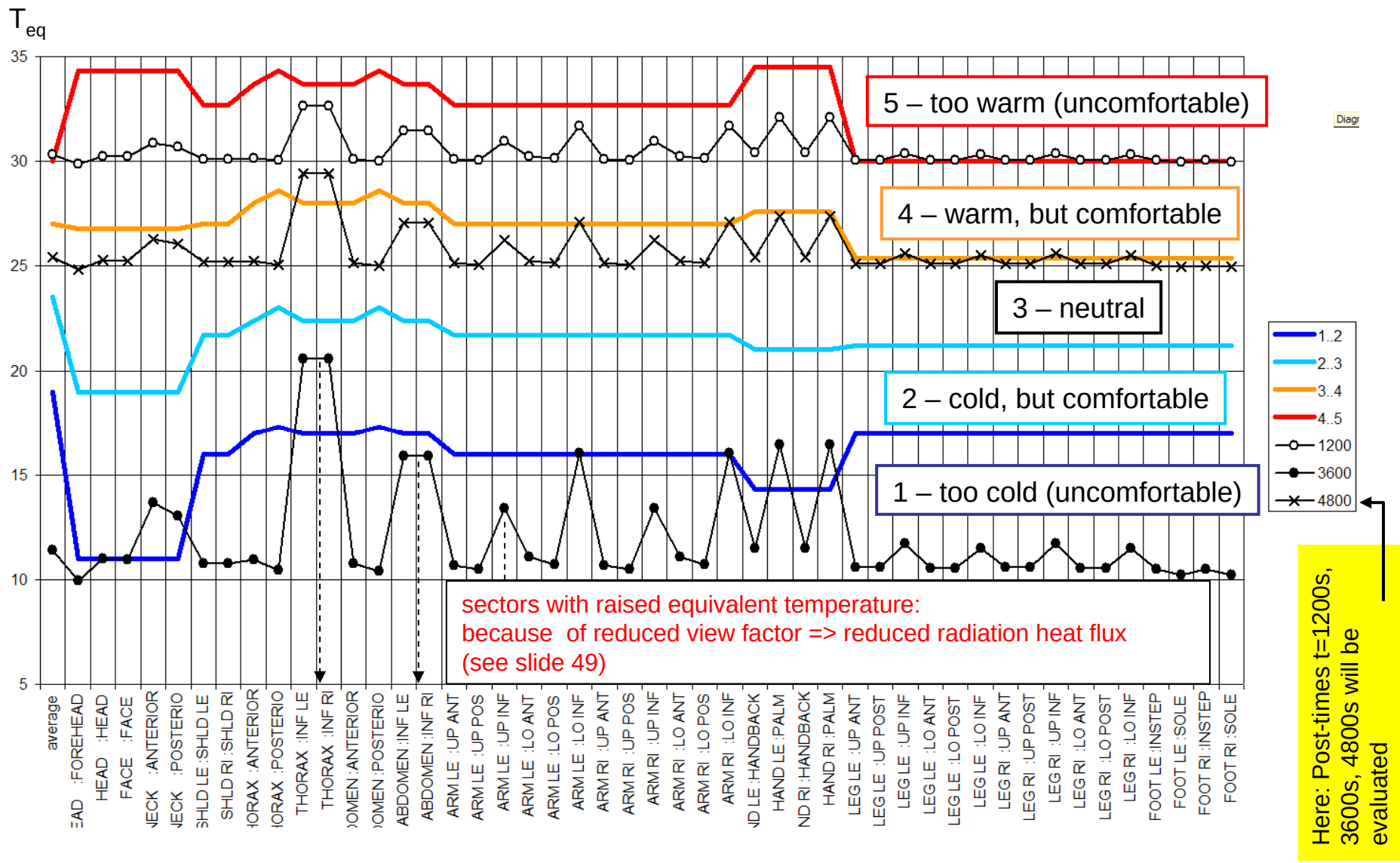
cool_summer_unsymmetric.hdf => *cool_summer_unsym_local_comfort.xls*





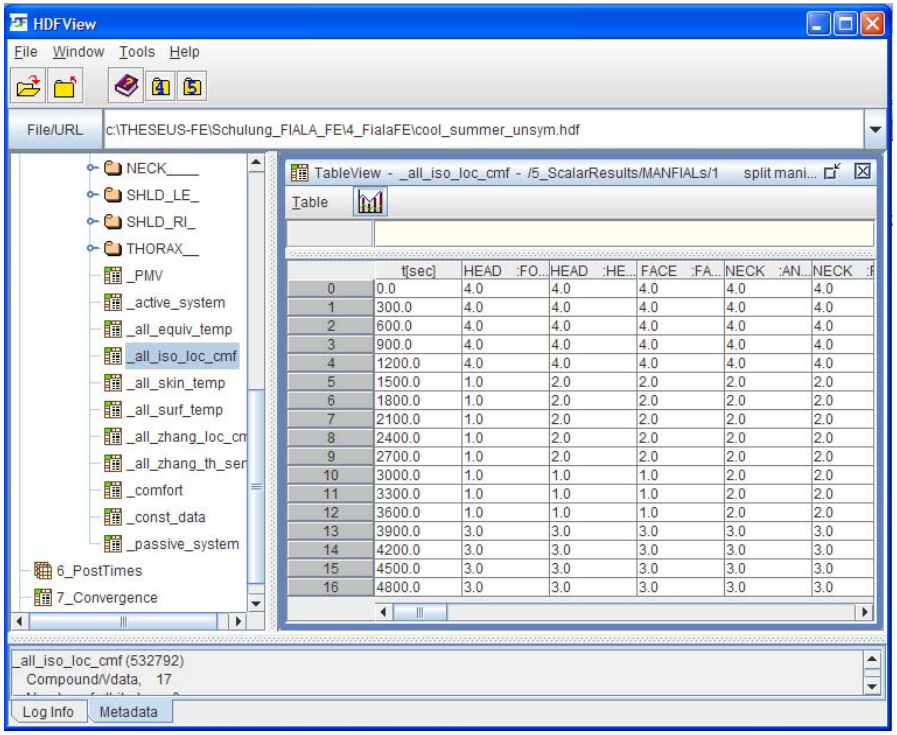
	A	B	C	D	E	F	G
1	t[sec]	average	HEAD :FO	HEAD :HE	FACE :FA	NECK :AN	NECK :PO
2	0	30.440763	29.887753	30.219723	30.229416	30.893192	30.7221
3	300	30.311115	29.888575	30.218122	30.227116	30.886616	30.71681
4	600	30.311775	29.889294	30.216732	30.225489	30.88409	30.71479
5	900	30.312292	29.88998	30.215399	30.224081	30.881012	30.712318
6	1200	30.312681	29.890568	30.214262	30.222904	30.877823	30.709751
7	1500	11.610959	9.880748	11.091341	11.177195	14.126682	13.406163
8	1800	11.545912	9.902084	11.056846	11.121775	14.001309	13.301455
9	2100	11.508554	9.916584	11.033165	11.076416	13.921638	13.235111
10	2400	11.48045	9.926829	11.016291	11.040931	13.858254	13.182395
11	2700	11.458202	9.93443	11.003675	11.01179	13.803973	13.137289
12	3000	11.440025	9.94019	10.994037	10.987294	13.756686	13.098028
13	3300	11.424791	9.944618	10.986565	10.966258	13.715132	13.063554
14	3600	11.411759	9.948065	10.980699	10.947946	13.678322	13.033039
15	3900	25.353981	24.878141	25.253551	25.146889	26.183676	25.948996
16	4200	25.396723	24.86264	25.279133	25.182333	26.24419	25.999685
17	4500	25.417795	24.852375	25.29625	25.212345	26.275372	26.025757
18	4800	25.43319	24.844767	25.30902	25.23812	26.301235	26.047335

Asymmetric Manikin: Active system simulation – comfort prediction



Here: Post-times t=1200s, 3600s, 4800s will be evaluated

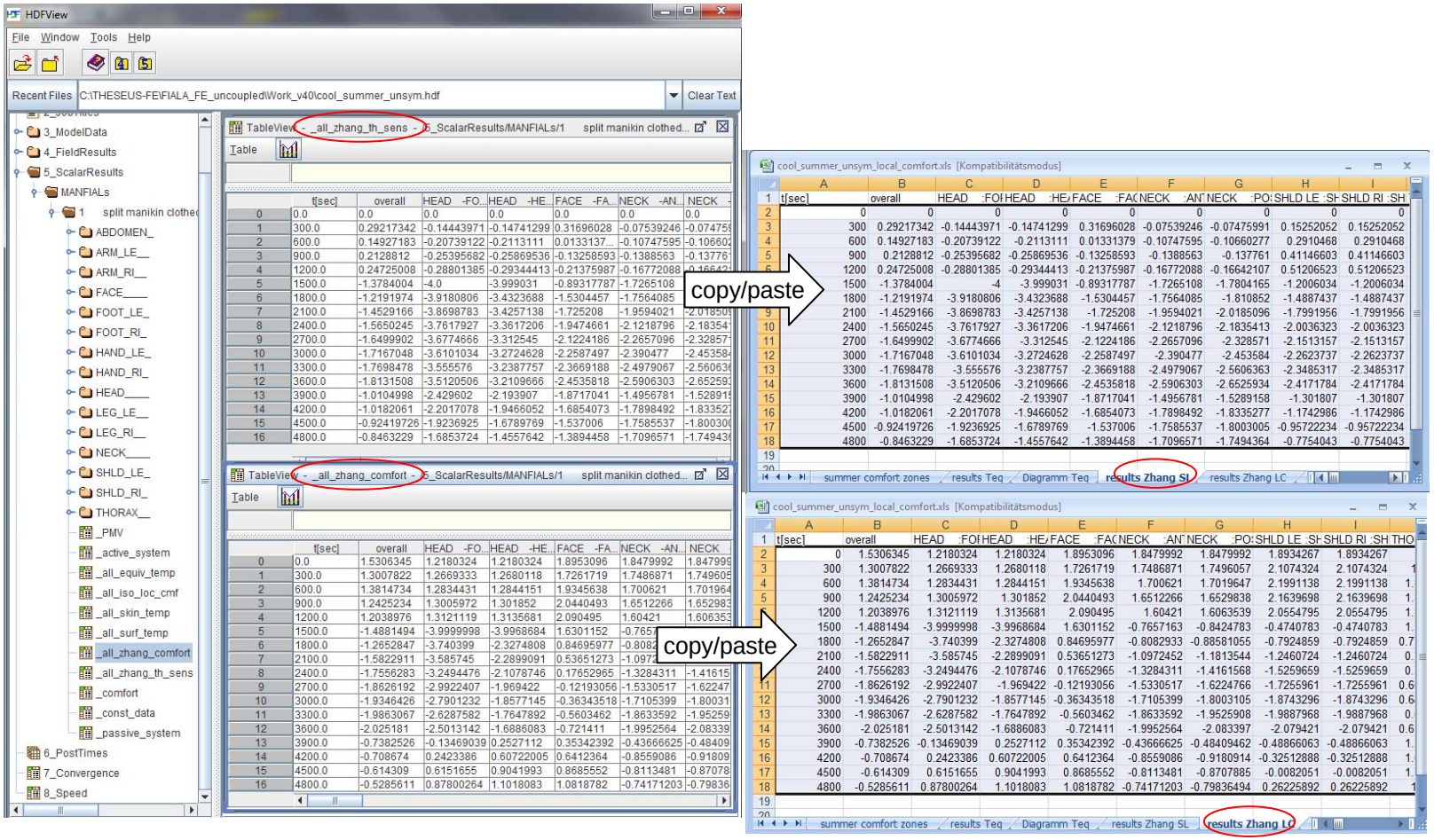
The evaluation of comfort zones (1-5) will be stored in the hdf-dataset „_all_iso_loc_comf“.



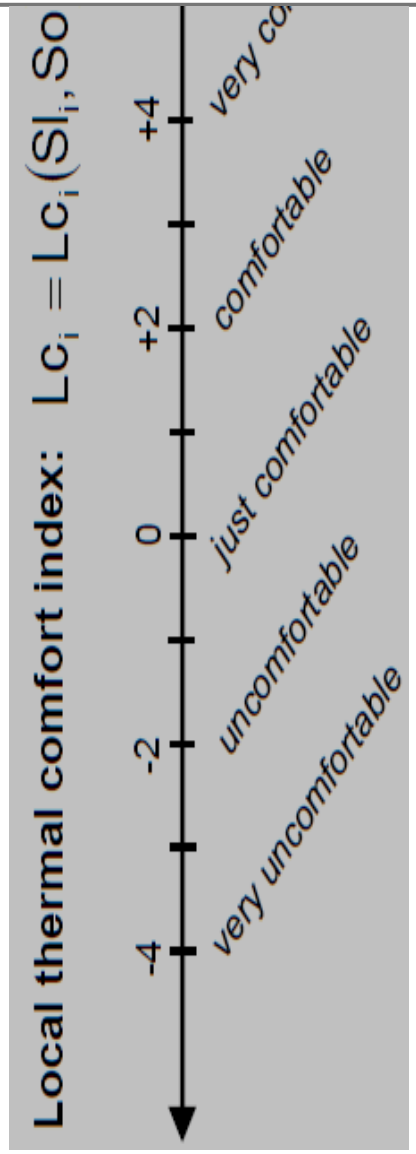
	t[sec]	HEAD :FO...	HEAD :HE...	FACE :FA...	NECK :AN...	NECK :f
0	0.0	4.0	4.0	4.0	4.0	4.0
1	300.0	4.0	4.0	4.0	4.0	4.0
2	600.0	4.0	4.0	4.0	4.0	4.0
3	900.0	4.0	4.0	4.0	4.0	4.0
4	1200.0	4.0	4.0	4.0	4.0	4.0
5	1500.0	1.0	2.0	2.0	2.0	2.0
6	1800.0	1.0	2.0	2.0	2.0	2.0
7	2100.0	1.0	2.0	2.0	2.0	2.0
8	2400.0	1.0	2.0	2.0	2.0	2.0
9	2700.0	1.0	2.0	2.0	2.0	2.0
10	3000.0	1.0	1.0	1.0	2.0	2.0
11	3300.0	1.0	1.0	1.0	2.0	2.0
12	3600.0	1.0	1.0	1.0	2.0	2.0
13	3900.0	3.0	3.0	3.0	3.0	3.0
14	4200.0	3.0	3.0	3.0	3.0	3.0
15	4500.0	3.0	3.0	3.0	3.0	3.0
16	4800.0	3.0	3.0	3.0	3.0	3.0

Zhang indices Sl and Lc will now be copied from the hdf-file in a prepared xls-file ...

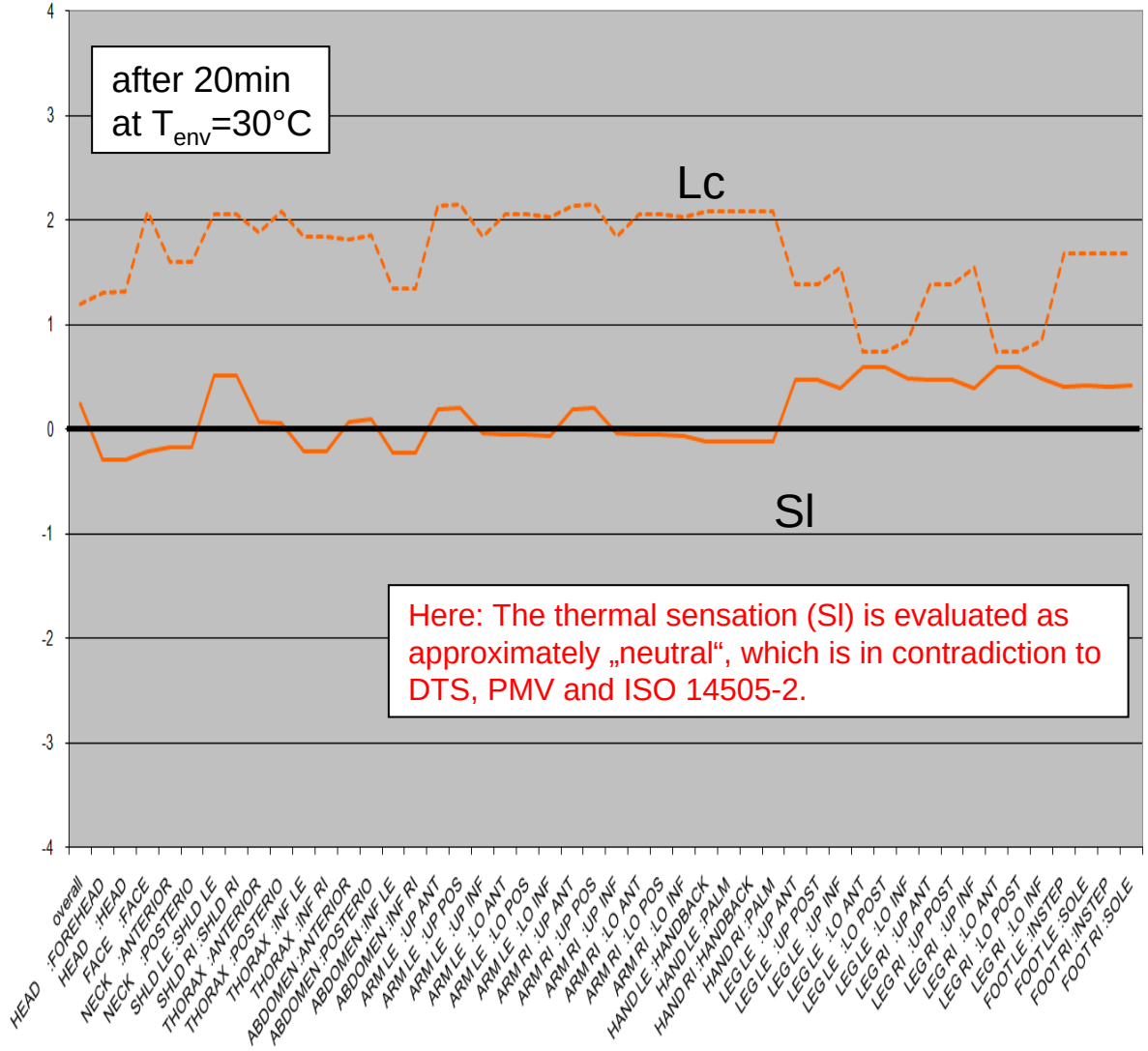
cool_summer_unsymmetric.hdf => *cool_summer_unsym_local_comfort.xls*

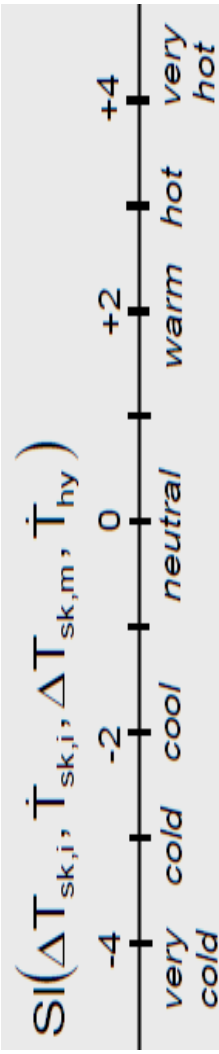


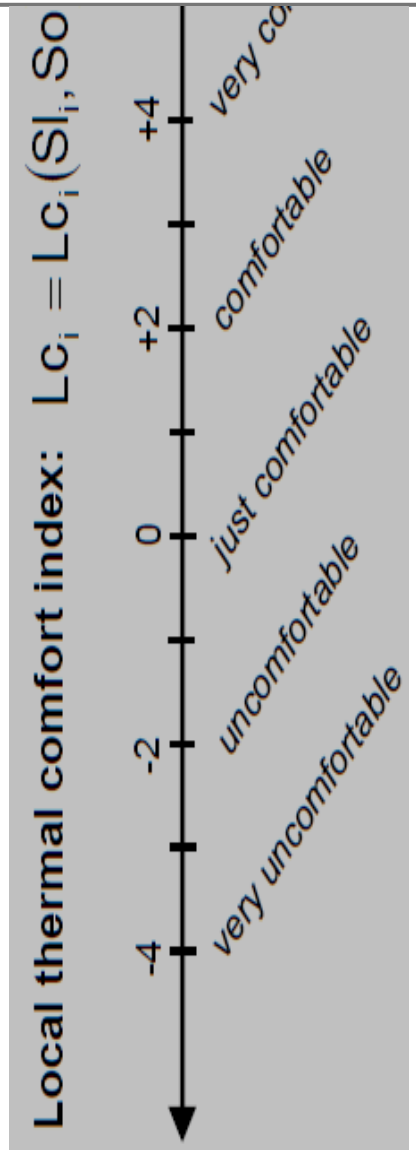
Asymmetric Manikin: Active system simulation – comfort prediction



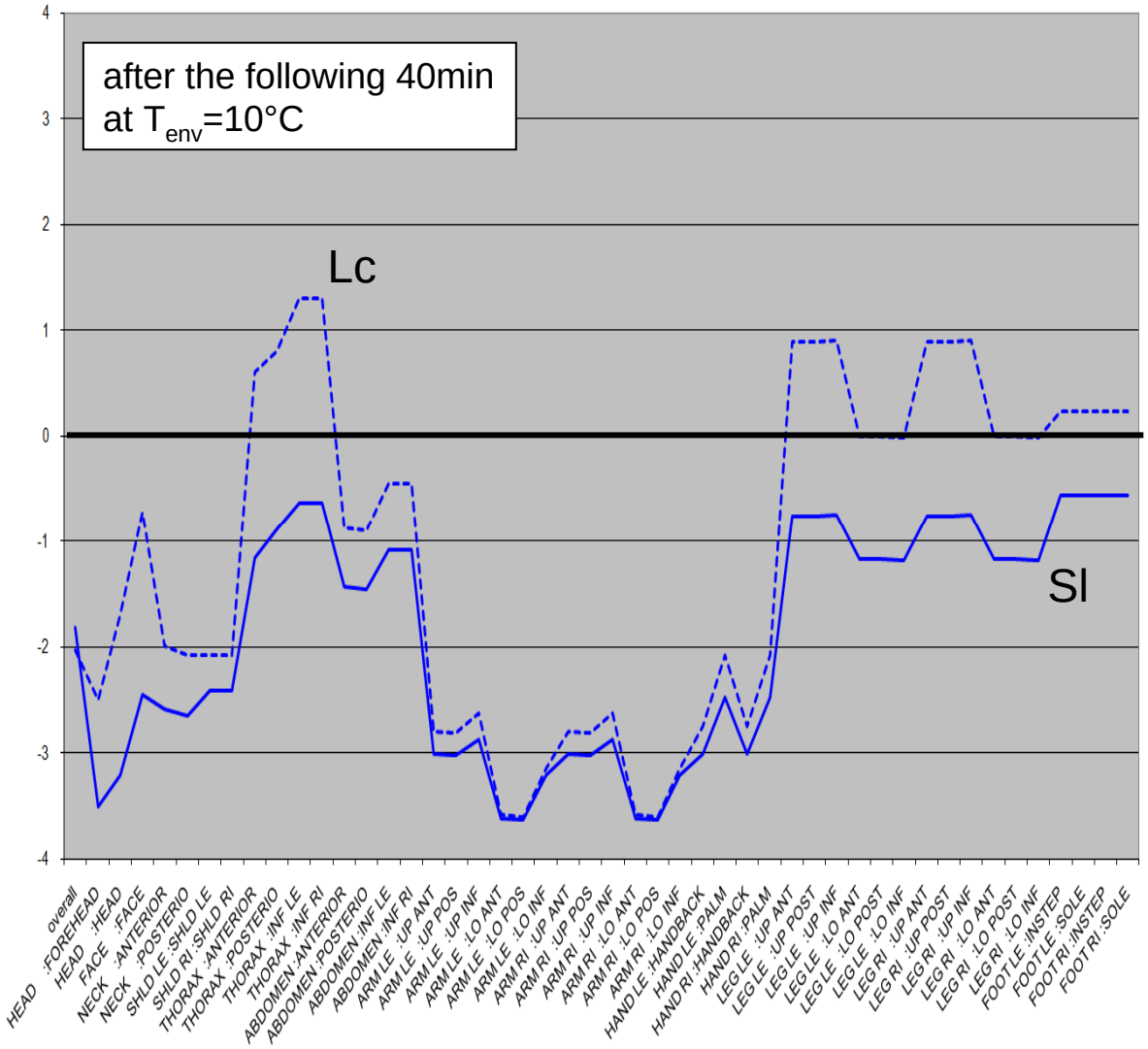
cool_summer_unsym_local_comfort.xls - Diag. Zhang 1200s

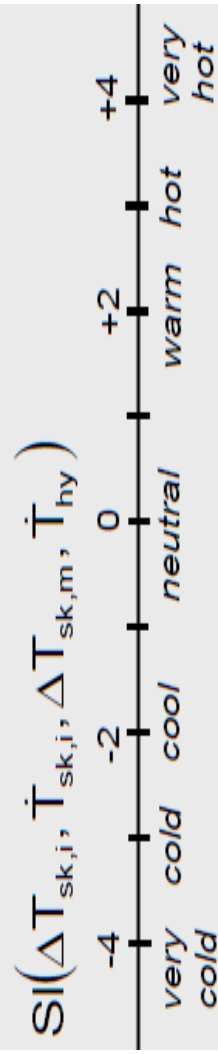


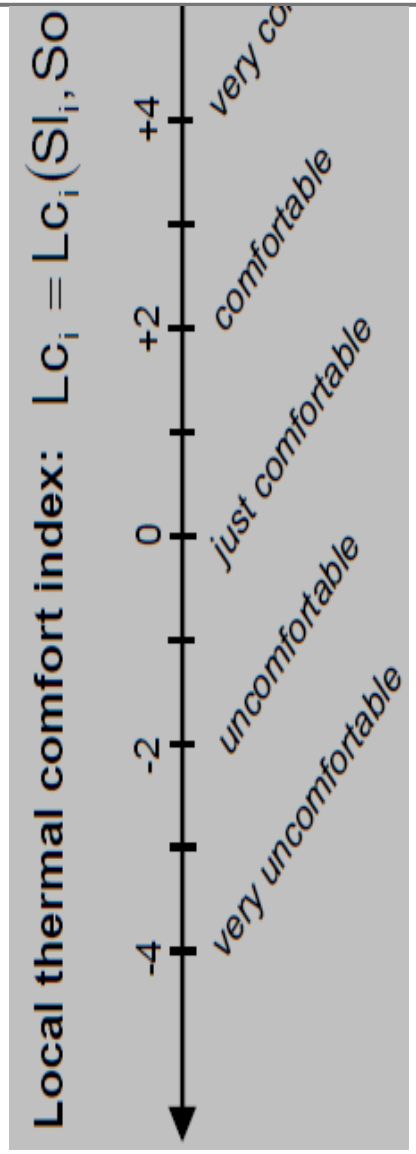




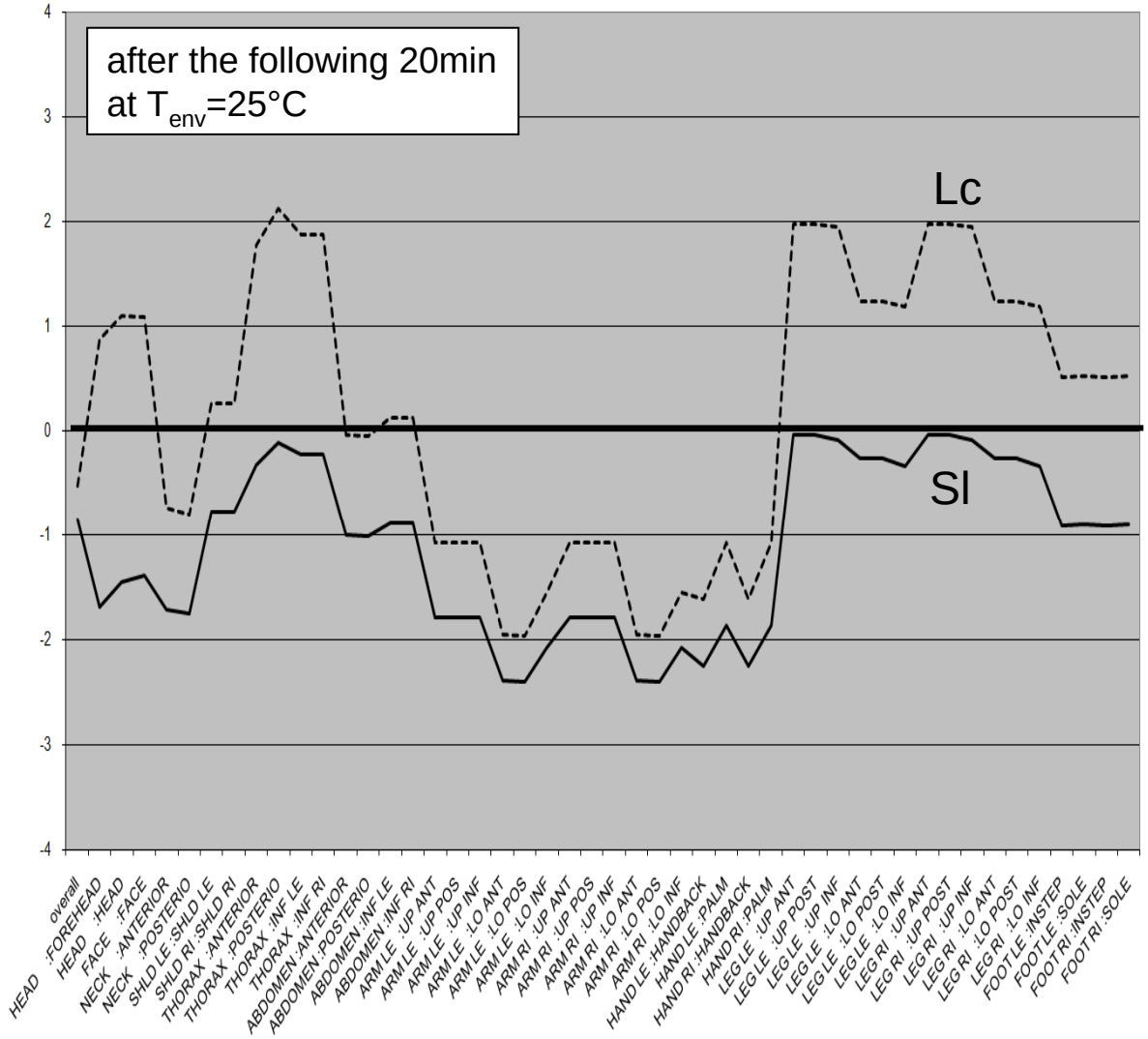
cool_summer_unsym_local_comfort.xls - Diag. Zhang 3600s

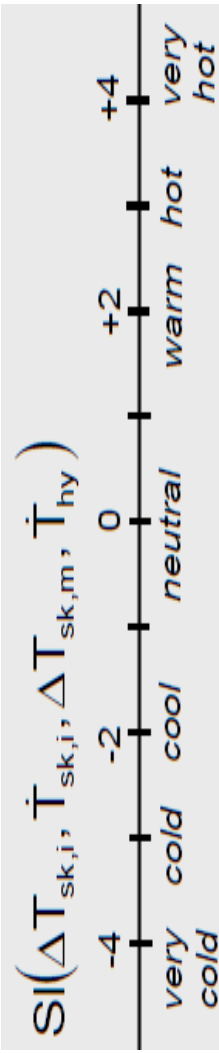




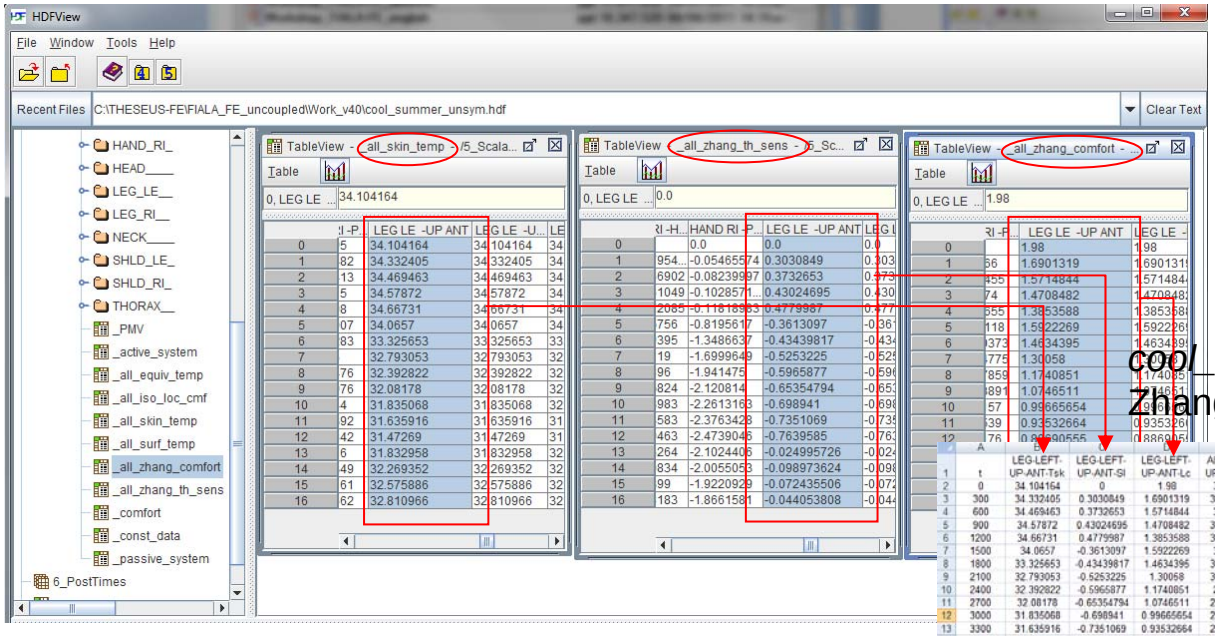


cool_summer_unsym_local_comfort.xls - Diag. Zhang 4800s



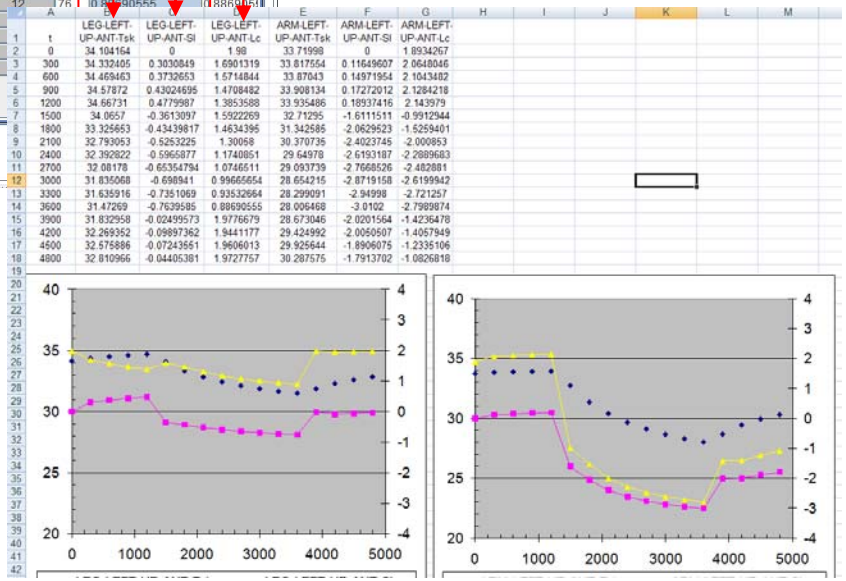


cool_summer_unsymmetric.hdf



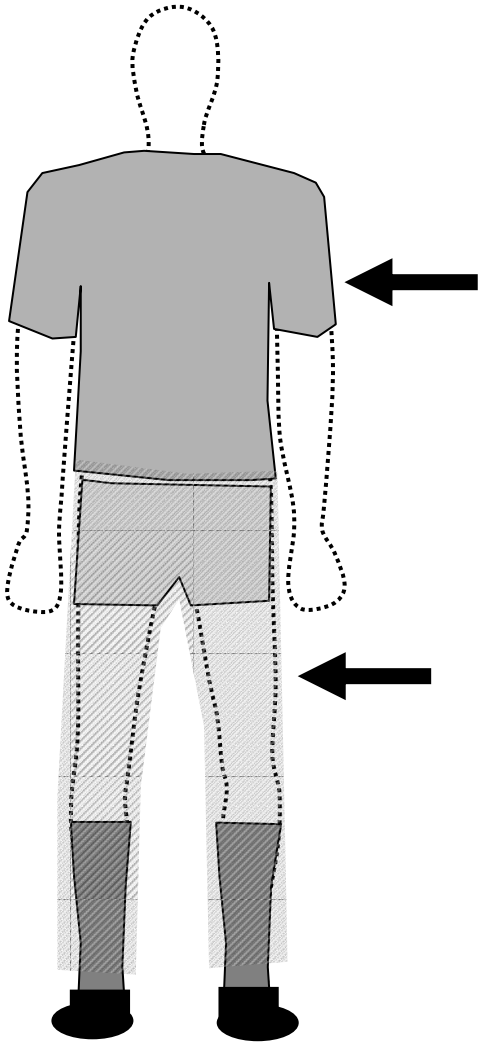
cool_summer_unsym_local_comfort.xls

Zhang Arm Leg:

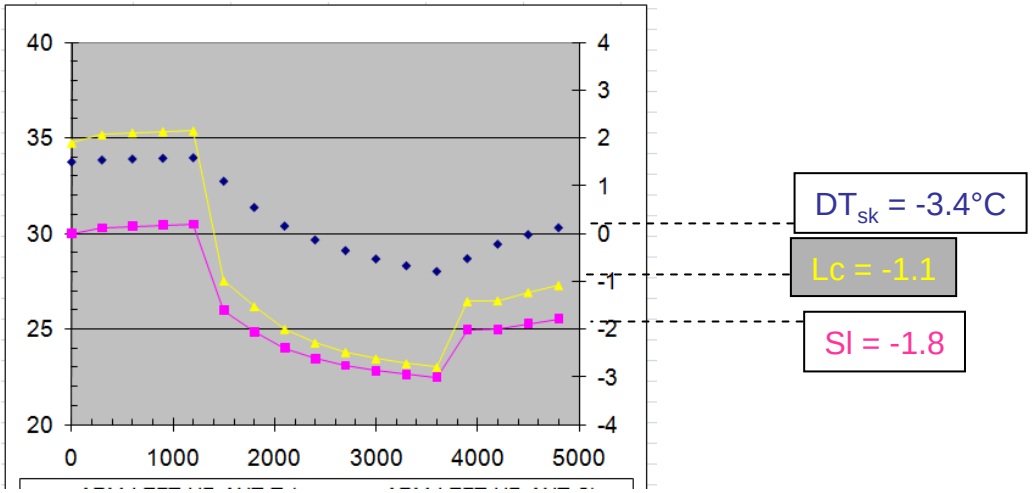


With 2 sectors („LEG LE – UP ANT“ and „ARM LE UP ANT“) it will be demonstrated here how the local skin temperature T_{sk} influences the Zhang indices SI and Lc.
Copy the corresponding columns from the hdf-datasets into the xls-file.

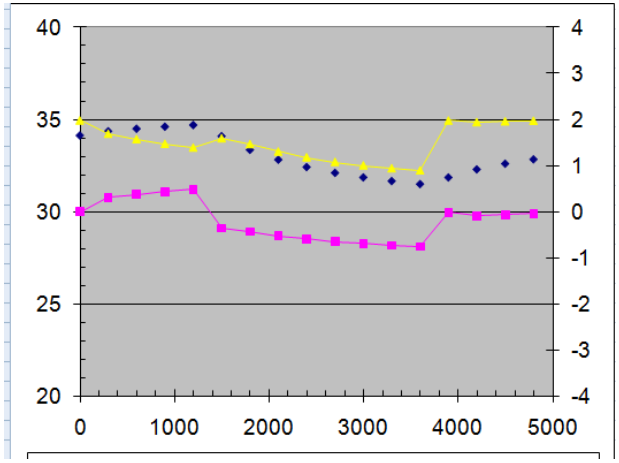
Asymmetric Manikin: Active system simulation – comfort prediction



Upper arm: local clothing: Icl=0.691clo



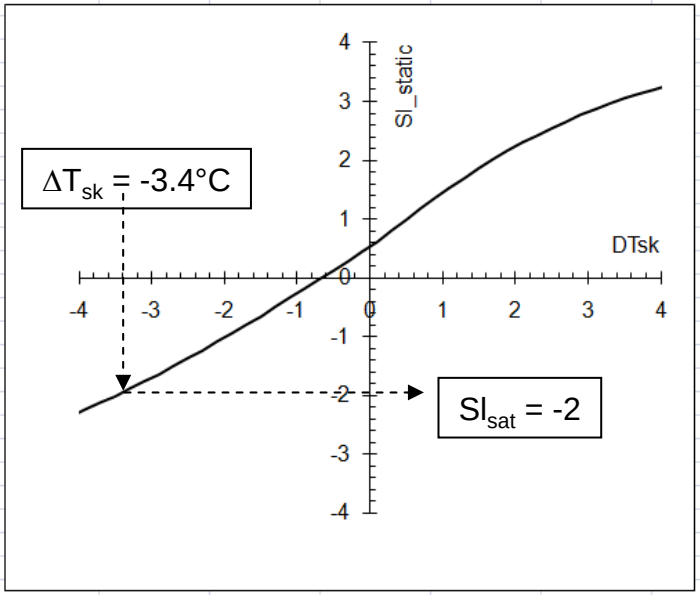
Upper leg: local clothing: Icl=0.896clo



THESEUS-FE Theory Manual:

Body Parts	static local sens. $\Delta T_{sk}<0 \Rightarrow C_1=$	$\Delta T_{sk}\geq 0 \Rightarrow C_1=$	K_1	dynamic local sens. $\dot{T}_{sk}<0 \Rightarrow C_2=$	$\dot{T}_{sk}\geq 0 \Rightarrow C_2=$	C_3
Head	0.38	1.32	0.18	543	90	0
Face	0.15	0.7	0.1	37	105	-2289
Neck	0.4	1.25	0.15	173	217	0
Chest	0.35	0.6	0.1	39	136	-2135
Back	0.3	0.7	0.1	88	192	-4054
Pelvis	0.2	0.4	0.15	75	137	-5053
Up.arm	0.29	0.4	0.1	156	167	0
Lo.arm	0.3	0.7	0.1	144	125	0
Hand	0.2	0.45	0.15	19	46	0
Thigh	0.2	0.29	0.11	151	263	0
Lo.leg	0.29	0.4	0.1	206	212	0
Foot	0.25	0.26	0.15	109	162	0

	UP ARM	
	T_sk0 =	33.7000
	T_sk_m0 =	34.4300
	T_sk_m =	31.8500
dT_sk>0:	C12 =	0.40
dT_sk<0:	C11 =	0.29
	K1 =	0.10
dT_sk_m =		-2.5800



$$Sl_{stat} = 4\left[\frac{2}{1+\exp\left(-C_1\Delta T_{sk} - K_1\left(\Delta T_{sk} - \Delta T_{sk,m}\right)\right)} - 1\right]$$

$$Sl_{dyn} = C_2\dot{T}_{sk} + C_3\dot{T}_{hy}$$

$t = 4800s$

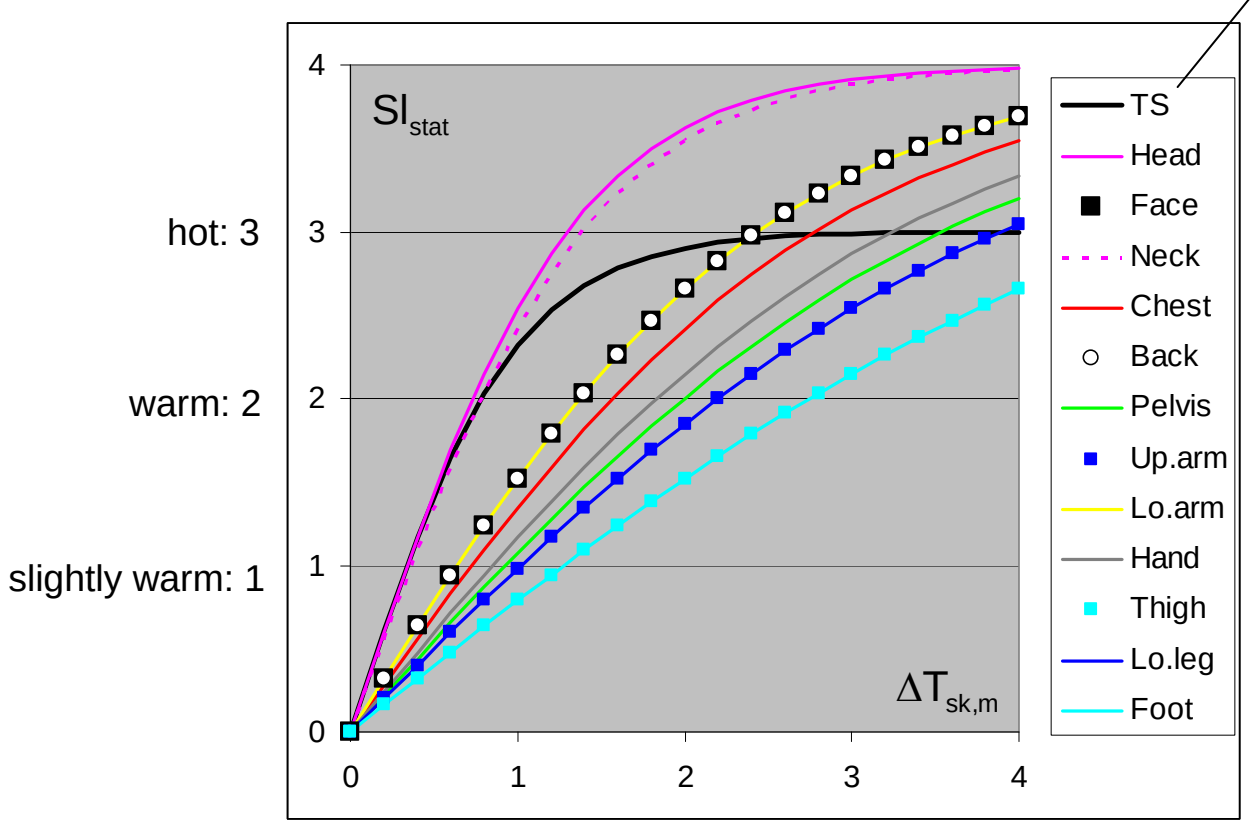
$$\Delta T_{sk} = -3.4°C;\ \Delta T_{sk,m} = -2.5°C;\ \dot{T}_{sk} = 0.0012°C/s$$

$$\Rightarrow Sl = Sl_{stat} + Sl_{dyn} = -2 + 0.0012 \cdot 167 = -2 + 0.2 = -1.8 \ \surd$$

Problem:

Zhang's Sl_{stat}-values for the quasi-static thermal sensitivity in a warm environment ($\Delta T_{sk}>0$) are much too low ... at least in comparison with DTS, PMV and ISO 14505-2.

$$DTS_{stat} = TS = 3 \cdot \tanh(1.026 \cdot \Delta T_{sk,m})$$



Zhang's curves for „Head" and „Neck" are the only ones with gradients comparable to those of Fiala's TS-index.
All other curves are significantly flatter.

E.g. for the upper arm: $\Delta T_{sk,m}$=1°C leads to Sl_{stat}=1 and Fiala's TS-index goes up to 2.3

local comfort...

Body Parts	C_{31}	C_{32}	C_6	C_{71}	C_{72}	C_8	N
Head	0	1.39	1.27	0.28	0.4	0.5	2
Face	-0.11	0.11	2.02	0	0.4	0.41	1.5
Neck	0	0	1.96	0	0	-0.19	1
Chest	-1.15	0	1.88	0.92	0	0	1.5
Back	-0.5	0.59	2.22	0.74	0	0	1
Pelvis	-1	0.38	2.7	0.83	-0.64	-0.75	1
Up.arm	-0.43	0	2. 2	0	0	-0.33	1
Lo.arm	-1.64	0.34	2.38	1.18	0.28	-0. 41	1
Hand	-0.8	0.8	1.99	0.48	0.48	0	1
Thigh	0	0	1.98	0	0	0	1
Lo.leg	-1	1.5	1.27	0.4	1.22	0.36	1.5
Foot	-2.31	0.21	1.62	0.5	0.3	-0.25	2

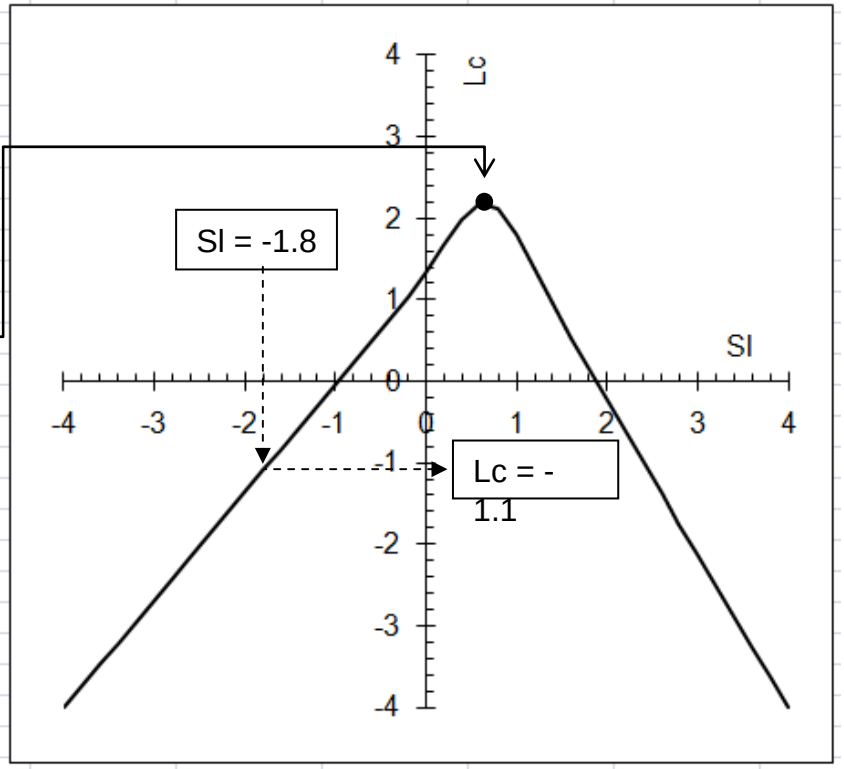
So = -0.85

UP ARM

C31 = -0.43
C32 = 0.00
C6 = 2.20
C71 = 0.00
C72 = 0.00
C8 = -0.33
n = 1.00

offset = -0.70
LCmax = 2.20

le_slope = 1.32
ri_slope = -1.88



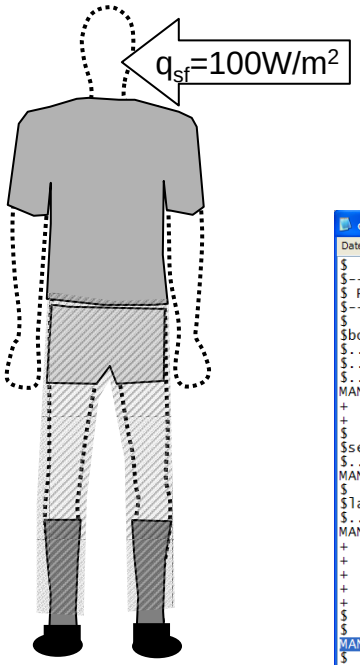
$t = 4800s$

$So = -0.85\ ,\ \ Sl = -1.8$

$\Rightarrow Lc = -1.1$ √

The model: *cool_summer_unsymmetric.tfe*
will be copied and renamed to:
cool_summer_unsymmetric_MANFSBC_1.tfe

Afterwards an additionally heat flow will be applied with the keyword MANFSBC at the face.



e.g. in consequence of an additionally radiation source (sun)

cool_summer_unsym_MANFSBC__1.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$
$---------------------
$ F A C E
$---------------------
$
$body element definitions:
$.......MANID...BE_ID...NAME....TYPE....NSEC....     ....L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       2       FACE    CYLINDR 1               0.0984  0.0
+       0.0418  0.0540  0.0460  0.0330  0.0020  0.0     0.0
+       3.0     113.0   -5.7
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
MANFSEC 1       2       FACE    6       210.0   0.9     0.9     0.99
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q
MANFLAYR1       2       MUSCLE1 3       0.0268  0.42    1085.0  3768.0  0.538-3 6
+                       BONE    3       0.0542  1.16    1500.0  1591.0  0.0     0
+                       MUSCLE2 3       0.068   0.42    1085.0  3768.0  0.538-3 6
+                       FAT     3       0.076   0.160   850.0   2300.0  3.6-6   5
+                       SKIN    3       0.077   0.47    1085.0  3680.0  22.34-3 7
+                       XSKIN   3       0.078   0.47    1085.0  3680.0  0.0     0
$
$       MANID   BE_ID   SEC_ID  T_W     T_A     V_A     RH              Q_SF
MANFSBC 1       2       1                                               100
$
```

Zeile 82, Spalte 1

THESEUS-FE 4.0 Keyword Manual

MANFSBC

Individual boundary conditions for sectors of uncoupled manikin FIALA-FE.

References: Theory Manual Chapter 4.1.4

Syntax:

1	2	3	4	5	6	7	8	9	10
MANFSBC	MANID	BE_ID	SEC_ID	T_W	T_A	V_A	RH		Q_SF

Field:	Contents:
MANID	manikin ID (integer > 0)
BE_ID	body element id (integer > 0)
SEC_ID	sector id (integer > 0)
T_W	individual surrounding wall temperature in [°C] • as a value (real) • or a reference to a time table (TABTIME) T_W=OFF neglects radiation heat exchange on this sector. The radiative heat transfer coefficient h_r=0.
T_A	individual environment temperature in [°C] • as a value (real) • or a reference to a time table (TABTIME) T_A=OFF neglects convective and evaporative heat exchange on this sector. The convective heat transfer coefficient $h_{c,mix}$=0. The air velocity V_A will be ignored.
V_A	individual environment air velocity in [m/s] • as a value (real > 0) • or a reference to a time table (TABTIME)
RH	individual environment air relative humidity in [%] • as a value (0 ≤ real ≤ 100 %) • or a reference to a time table (TABTIME)
[Q_SF]	individually applied heat flux density in [W/m²] on the outer surface[12]

Related Keywords:

MANIKIN – FIALA-FE, MANFSEC

Remarks:

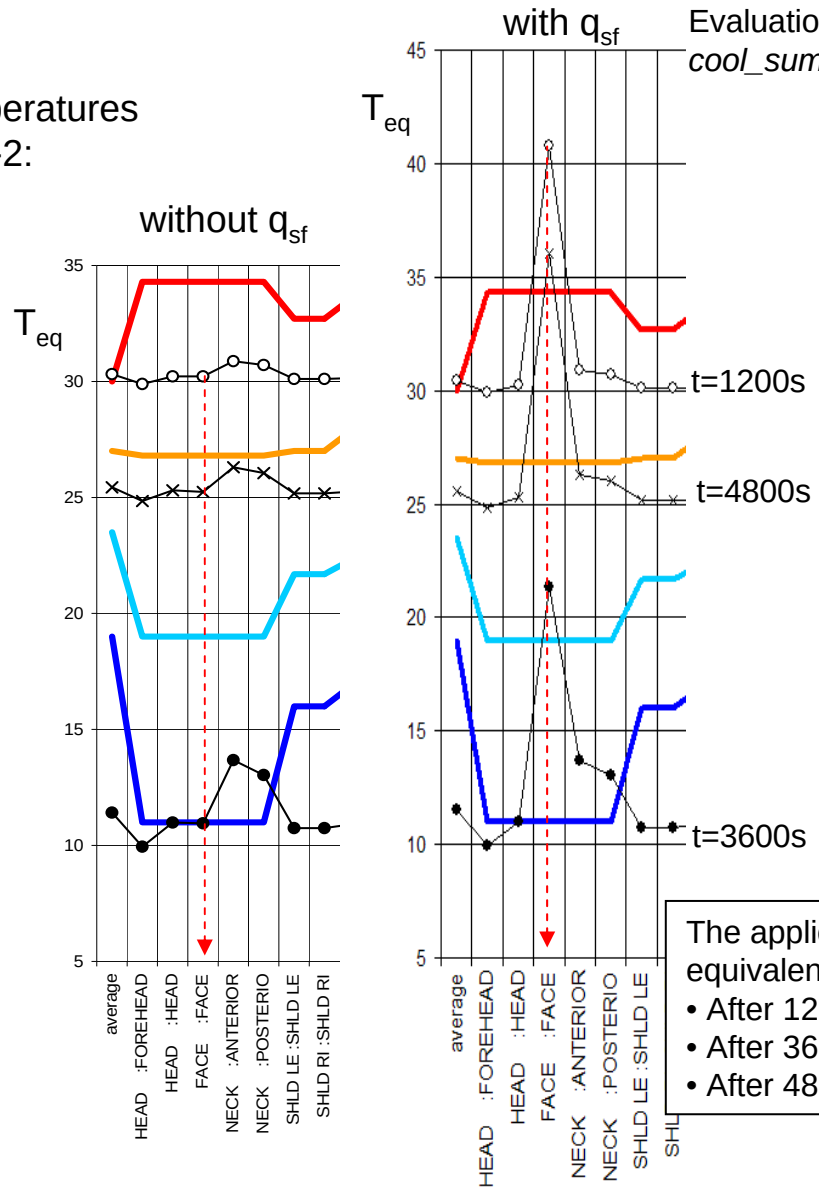
- Q_SF appears as a contact heat fluxes in the result file (suffix .hdf).
- The usage of Q_SF automatically switches the PMV/PPD calculation off.

[12] The outer surface might be cloth or skin (for un-clothed sectors like face).

Remarks:
A PMV-calculation is not possible if local heat flows are applied because the Fanger-formulas do not support additional heat flows.

Evaluation with equivalent temperatures and ISO 14505-2:

Evaluation in the file:
cool_summer_unsym_MANFSBC_1_local_comfort.xls



5 – too warm (uncomfortable)

4 – warm, but comfortable

3 – neutral

2 – cold, but comfortable

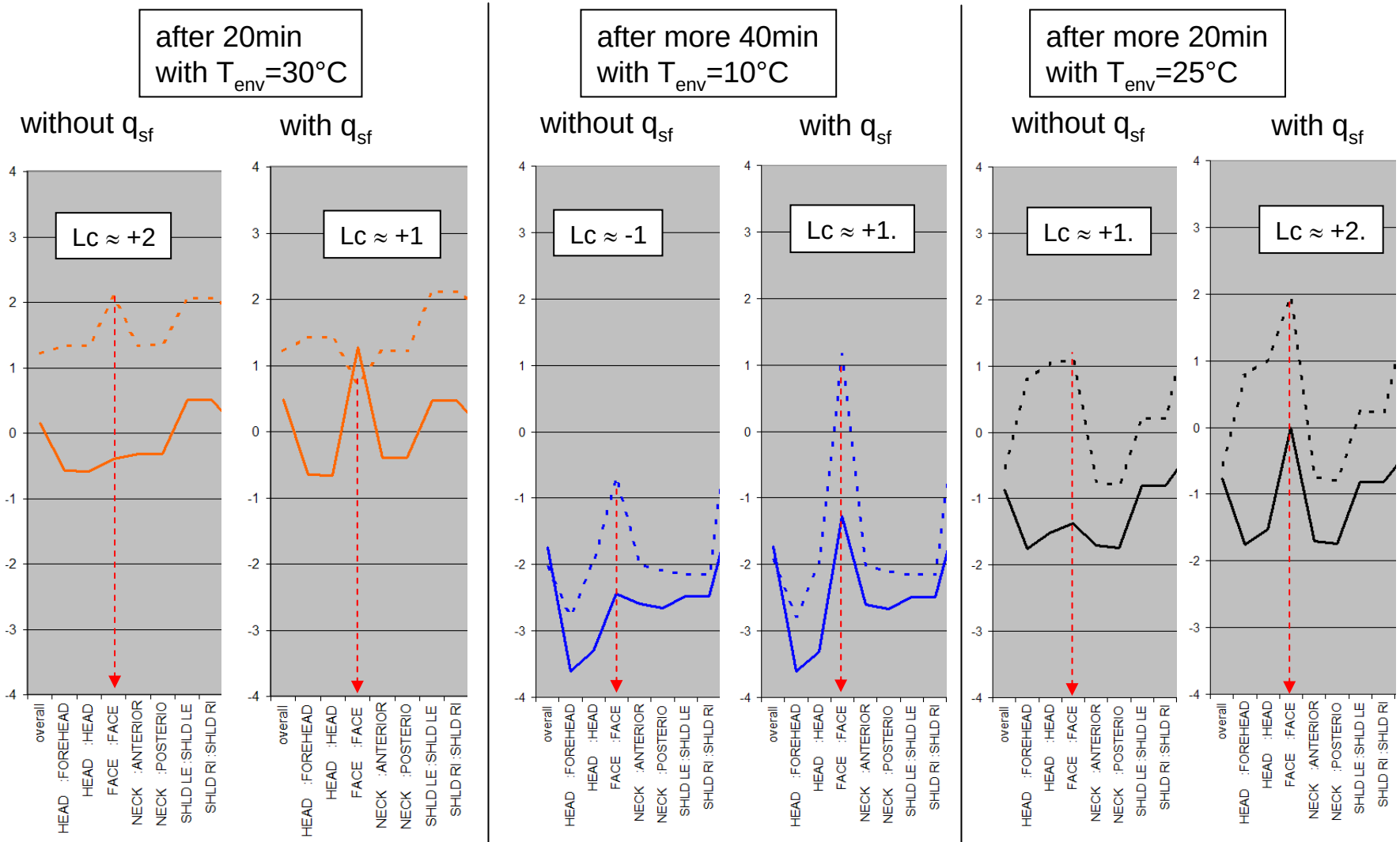
1 – too cold (uncomfortable)

The applied heat flow in the face causes an increase of the equivalent temperature of about $\Delta T_{eq} \approx +10°C$.

- After 1200s the ISO-Index increase from 4 to 5: “worse”
- After 3600s the ISO-Index increase from 1 to 3: “better”
- After 4800s the ISO-Index increase from 3 to 5: “worse”

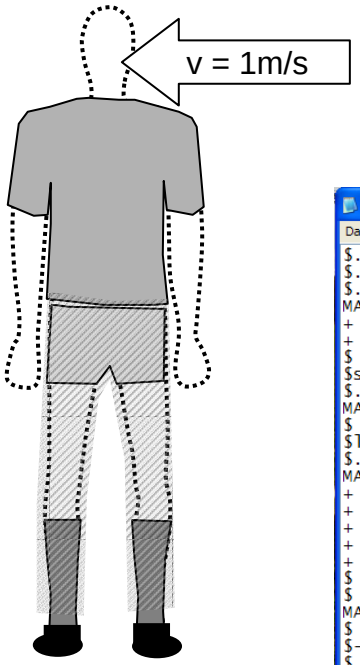
Asymmetric Manikin: Active system simulation – comfort prediction

Evaluation in the file: *cool_summer_unsym_MANFSBC_1_local_comfort.xls*



The model: *cool_summer_unsymmetric_MANFSBC_1.tfe*
will be copied and renamed now to:
cool_summer_unsymmetric_MANFSBC_2.tfe

Afterwards, the air speed will be increased from 0.1 to 1.0m/s
with the keyword MANFSBC at the face.



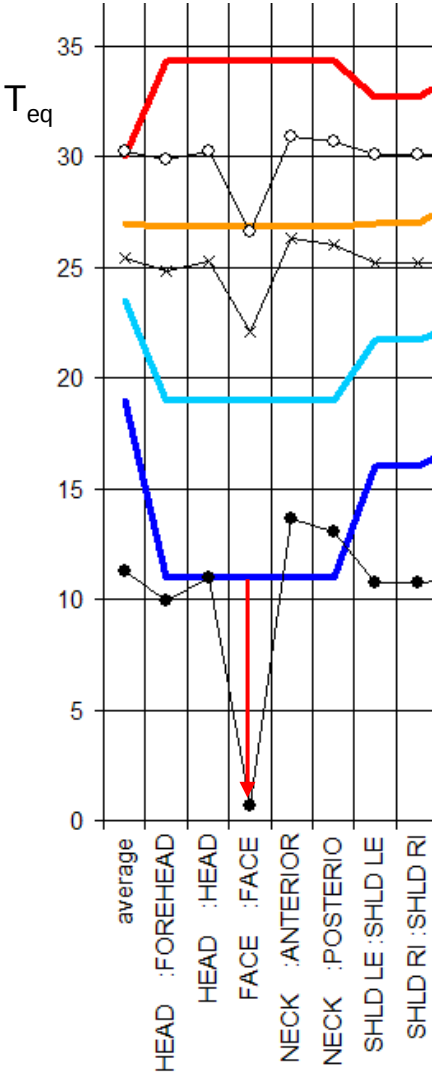
e.g. in consequence of a fan
(„air draft“)

cool_summer_unsym_MANFSBC_2.tfe - Editor

Datei Bearbeiten Format Ansicht ?

```
$.......MANID...BE_ID...NAME....TYPE....NSEC....     ....L.......H_X
$.......A_SK....A_SW....A_DL....A_CS....A_SH....A_M_W1..A_M_W2
$.......A_NAT...A_FR....A_MIX
MANFBEL 1       2       FACE    CYLINDR 1               0.0984  0.0
+       0.0418  0.0540  0.0460  0.0330  0.0020  0.0     0.0
+       3.0     113.0   -5.7
$
$sector definitions
$.......MANID...BE_ID...NAME....NLAY....ANGLE...VF_SED..VF_STND.E_SF
MANFSEC 1       2       FACE    6       210.0   0.9     0.9     0.99
$
$layer definitions
$.......MANID...BE_ID...NAME....DISC....R.......K.......RHO.....C.......W_BL....Q
MANFLAYR1       2       MUSCLE1 3       0.0268  0.42    1085.0  3768.0  0.538-3 6
+                       BONE    3       0.0542  1.16    1500.0  1591.0  0.0     0
+                       MUSCLE2 3       0.068   0.42    1085.0  3768.0  0.538-3 6
+                       FAT     3       0.076   0.160   850.0   2300.0  3.6-6   5
+                       SKIN    3       0.077   0.47    1085.0  3680.0  22.34-3 7
+                       XSKIN   3       0.078   0.47    1085.0  3680.0  0.0     0
$
$       MANID   BE_ID   SEC_ID  T_W     T_A     V_A     RH              Q_SF
MANFSBC 1       2       1                       1
$
$---------------------
$ N E C K
$---------------------
$
$body element definitions:
$.......MANID...BE_ID...NAME....TYPE....NSEC....     ....L.......H_X
```

Zeile 74, Spalte 59



THESEUS-FE 4.0 Keyword Manual

MANFSBC

Individual boundary conditions for sectors of uncoupled manikin FIALA-FE.

References: Theory Manual Chapter 4.1.4

Syntax:

1	2	3	4	5	6	7	8	9	10
MANFSBC	MANID	BE_ID	SEC_ID	T_W	T_A	V_A	RH		Q_SF

Field:	Contents:
MANID	manikin ID (integer > 0)
BE_ID	body element id (integer > 0)
SEC_ID	sector id (integer > 0)
T_W	individual surrounding wall temperature in [°C] • as a value (real) • or a reference to a time table (TABTIME) T_W=OFF neglects radiation heat exchange on this sector. The radiative heat transfer coefficient h_r=0.
T_A	individual environment temperature in [°C] • as a value (real) • or a reference to a time table (TABTIME) T_A=OFF neglects convective and evaporative heat exchange on this sector. The convective heat transfer coefficient $h_{c,mix}$=0. The air velocity V_A will be ignored.
V_A	individual environment air velocity in [m/s] • as a value (real > 0) • or a reference to a time table (TABTIME)
RH	individual environment air relative humidity in [%] • as a value (0 ≤ real ≤ 100 %) • or a reference to a time table (TABTIME)
[Q_SF]	individually applied heat flux density in [W/m²] on the outer surface[12]

Related Keywords:

MANIKIN – FIALA-FE, MANFSEC

Remarks:

- Q_SF appears as a contact heat fluxes in the result file (suffix .hdf).
- The usage of Q_SF automatically switches the PMV/PPD calculation off.

[12] The outer surface might be cloth or skin (for un-clothed sectors like face).

The keyword MANFSBC is useful for coupled simulations:

- You have the possibility to calculate (e.g. for each local sector) the local air temperature T_a and the local air speed v_a in a CFD-solver and apply it using the keyword MANFSBC.
- If you want to specify the heat transfer coefficient instead of the air speed, you can adapt the parameter a_{nat}, a_{fr}, a_{mix} in the keyword MANFBE:

$$a_{nat} = 0,\ a_{fr} = 1,\ a_{mix} = 0$$

$$h_{c,mix} = \sqrt{a_{frc} v_{a,eff}} = \sqrt{v_{a,eff}}$$

(the squares are used!)

- You can also specify for each sector the local radiation background temperature T_w or the local humidity Rh.
- You can also specify the convection heat flow Q_{sf} directly and switch off the internal calculation with T_A=OFF. This also deactivates the evaporation.
- The thermal radiation can be specified as Q_{sf} and the internal calculation can be switched off with T_W=OFF.
- Additional heat flows from solar radiation can be specified for each sector as Q_{sf} (see slide 70).

etc.

Remarks:
Even if all (local) boundary conditions for all body elements are specified with the keyword MANFSBC, the (global) settings in the keyword MANIKIN are still necessary ...

MANIKIN	MANID	**FIALA-FE**	MODE	SYSTEM	POSI	BE	ACT	LINK	
+	T_W	E_W	T_A	V_A	RH	T_BLA	LEWIS		

Rh will always be used for
- PMV-calculation (if requested with the keyword MANFPMV)
- the heat loss from breathing – „respiration“

v_a will always be used for
- PMV-calculation (if requested with the keyword MANFPMV)

T_a will always be used for
- PMV-calculation (if requested with the keyword MANFPMV)
- the heat loss from breathing – „respiration“

T_w will always be used for
- PMV-calculation (if requested with the keyword MANFPMV)

Final remark

You will find a thermal manikin model clothed with a typical winter ensemble in the *Work* folder:

• *cool_winter_unsym.tfe* (Setpoint file: *neutral_winter_unsym.stp*)

For a detailed description of the winter ensemble, see Theory Manual, Appendix A.