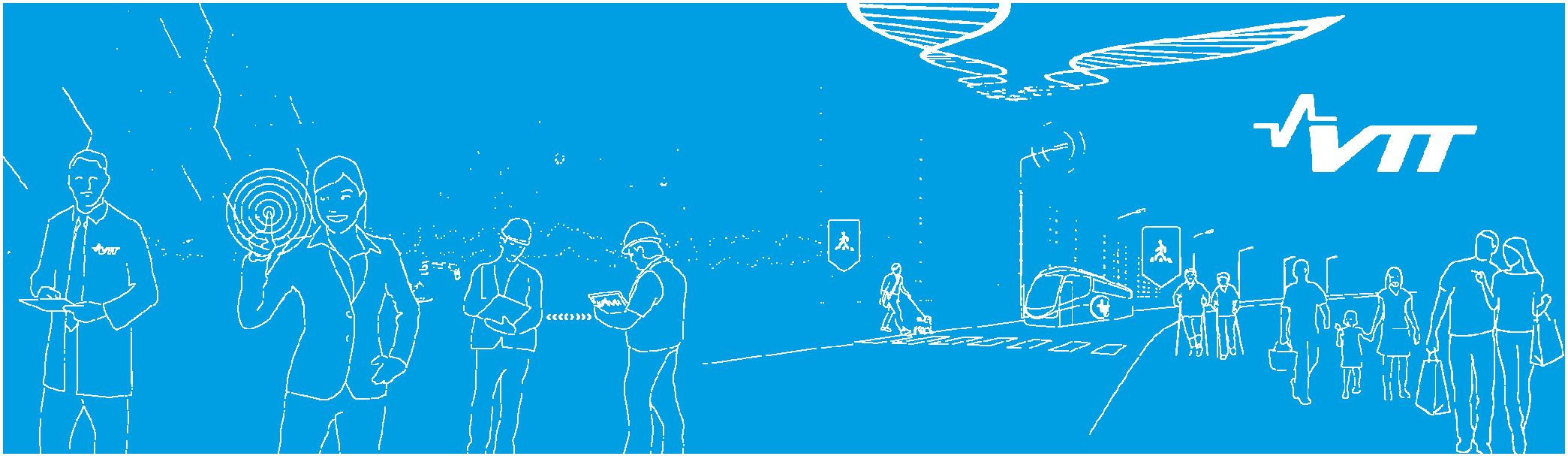


A comprehensive Human Thermal Model (HTM) for evaluating individual thermal sensation

Pekka.Tuomaala@vtt.fi
VTT Technical research centre of Finland

IBPSA-Nordic, September 26th 2014

Human Thermal Sensation Boundary Conditions

- External parameters
  - Operative temperature
    - Air temperature
    - Surface temperatures
  - Air velocity
  - Air humidity
- Internal parameters
  - Metabolic rate
    - Anatomy (tissue distribution)
    - Activity level
  - Clothing

Alternative evaluation methods

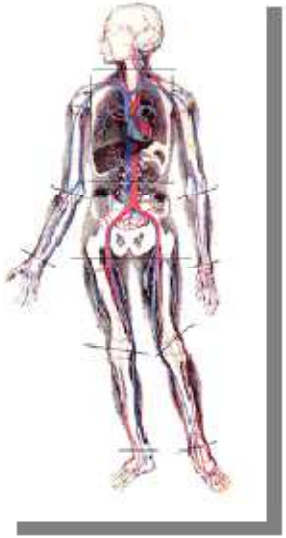
Simplified methods

PMV (PPD)

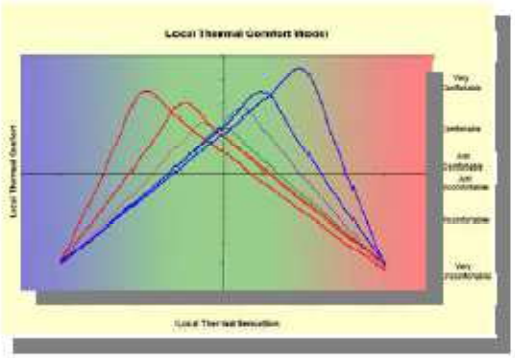
DR
PD

Fanger (1970)

Detailed methods



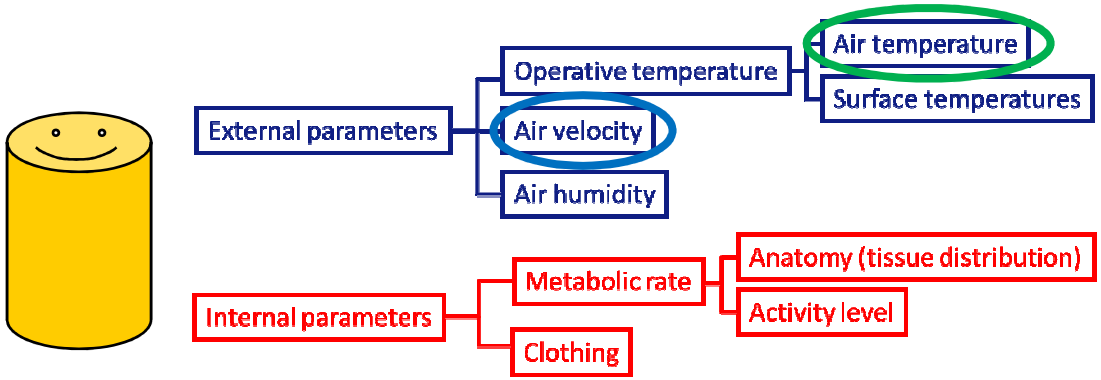
Wissler
Gagge
Gordon
Stolwijk
Smith
Fiala
Zhang
…



Anatomy and physiology modelling

Individual thermal sensation and thermal comfort

DR (Draught Rating) – a simplified method



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The impact of draught related to air velocity, air temperature and workload

Barbara Griefahn[a,*], Christa Künemund[a], Ulrike Gehring[b]

[a]Institute for Occupational Physiology at the University of Dortmund, Ardeystr. 67, D-44139 Dortmund, Germany

[b]GSF - National Research Center for Environment and Health, Institute of Epidemiology, Ingolstädter Landstr. 1, D-85764 Oberschleißheim, Germany

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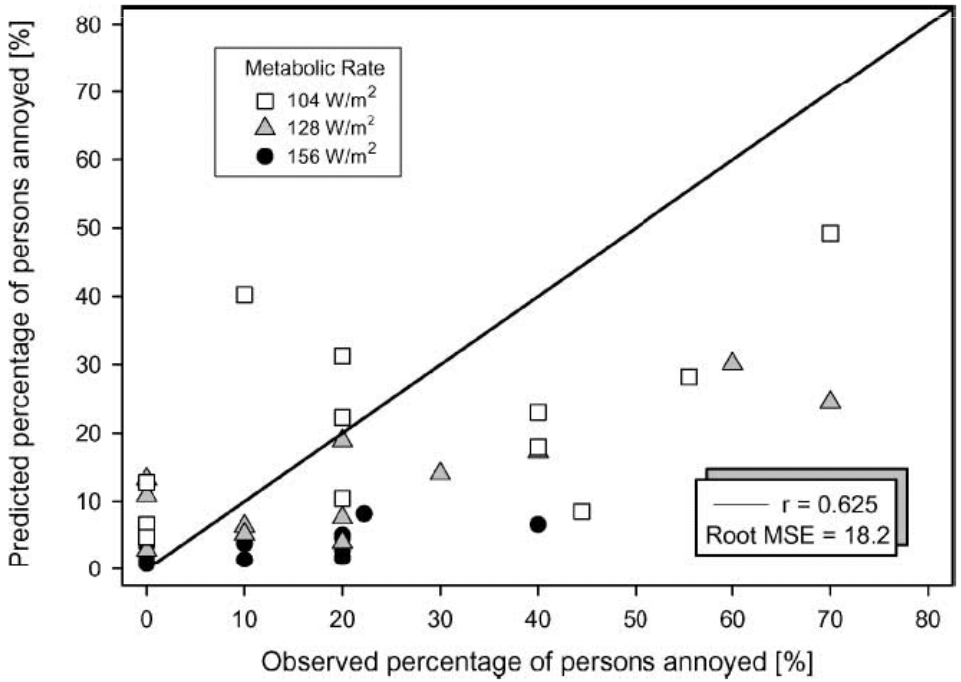
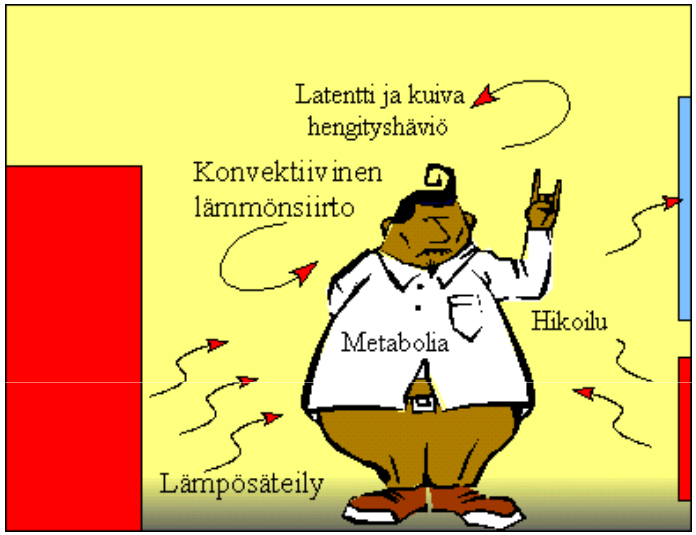
$$DR = (34 - T_a)(v_o - 0.05)^{0.62}(37 \cdot I_o v_o + 3.14)$$

DR	*predicted percentage of dissatisfied*
T_a	*air tempetarure*
v_0	*local velocity*
I_0	*turbulence intencity*

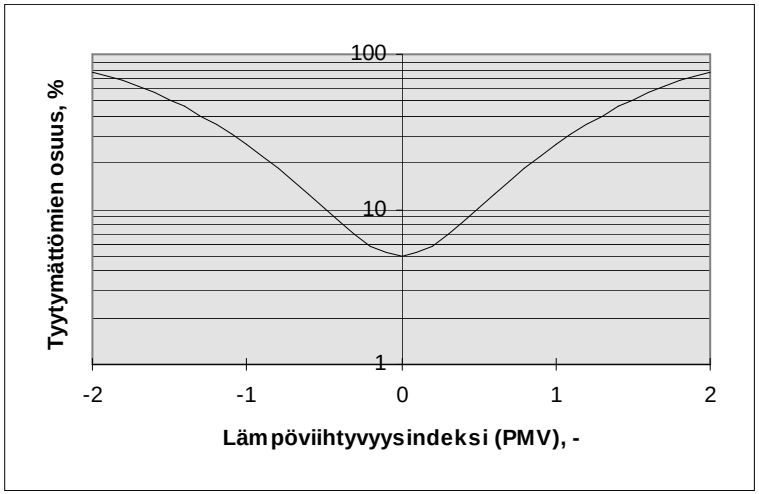


NO transient phenomena
NO spatial features
NO individual aspects (anatomy, clothing, activity)
Unrealiable results reported

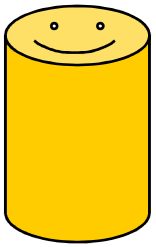
PMV(PPD) Fanger (1970) – a simplified method



$$PPD = 100 - 95 \cdot e^{-\left(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2\right)}$$



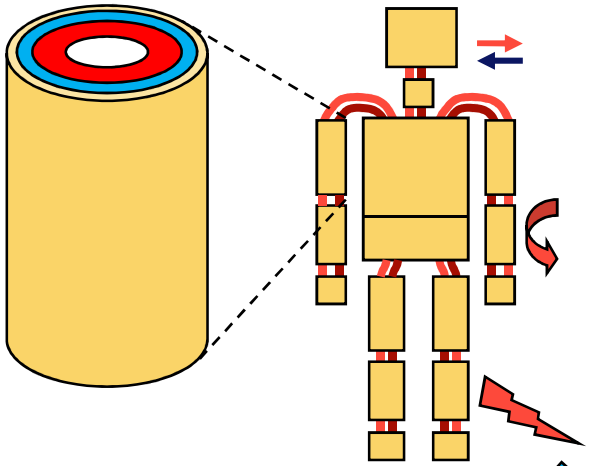
$$PMV = (0{,}303\, e^{-0{,}036\, M} + 0{,}028)$$
$$\{ (M - W) - 3{,}05 \cdot 10^{-3} [5733{,}0 - 6{,}99\,(M - W) - p_a]$$
$$- 0{,}42\,[(M - W) - 58.15]$$
$$- 1{,}7 \cdot 10^{-5}\, M\,(5867{,}0 - p_a)$$
$$- 0{,}0014\, M\,(34{,}0 - T_{ilma})$$
$$- 3{,}96 \cdot 10^{-8}\, f_{vaatteet}\,[(T_{vaatteet} + 273)^4 - (T_{MRT} + 273)^4]$$
$$- f_{vaatteet}\, h_{vaatteet}\,(T_{vaatteet} - T_{ilma}) \}$$



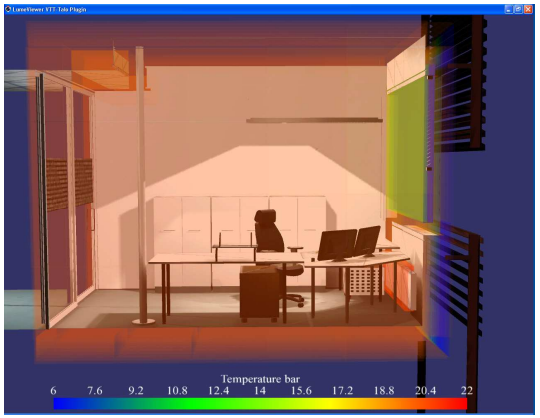
Evaporative heat transfer from skin
Sweating
Evaporative breathing heat excange
Dry breathing heat excange
Thermal radiation
Convective heat transfer

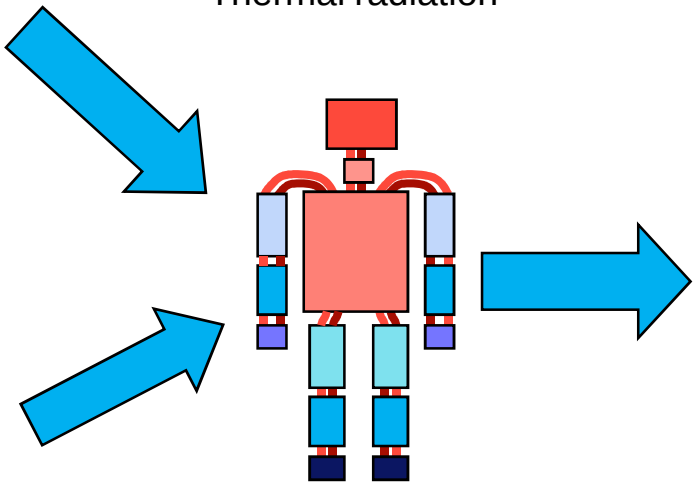
Fanger: Neither spatial nor temporal variations – no individual aspects

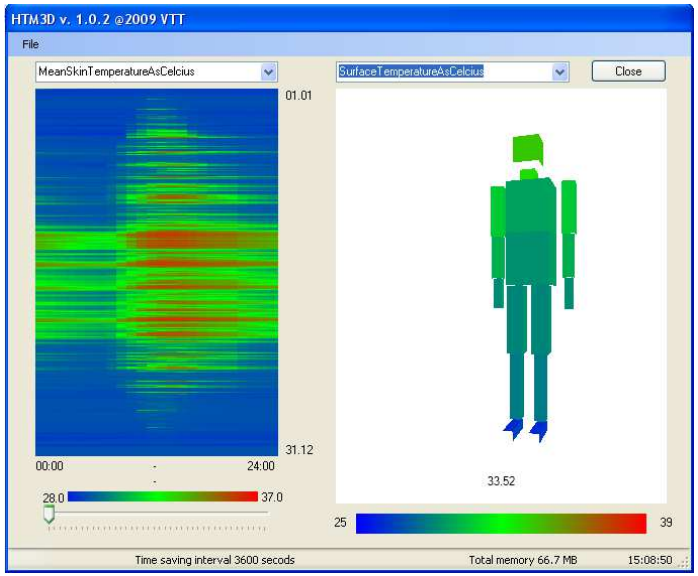
Methods - VTT Human Thermal Model (HTM)



- **Human anatomy (Passive Model)**
  - 16 body parts
  - Typically four tissue layers (bone, muscle, fat, and skin in limbs)
- **Physiology (Control Model)**
  - Metabolic rate depending on activity level
  - Blood circulation (skin blood flow in controlling inner organ temperatures)
  - Sweating and shivering
- **Interaction between human body and surrounding space**
  - Evaporative heat transfer
  - Convective heat transfer
  - Thermal radiation



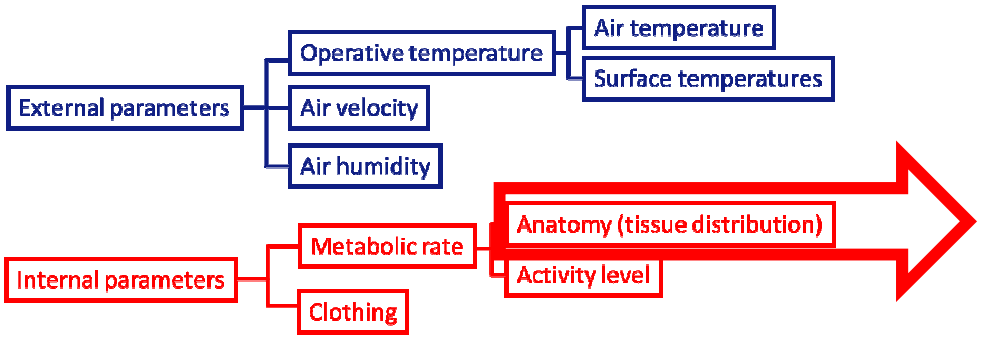




Human Thermal Sensation – Impact of individual body composition

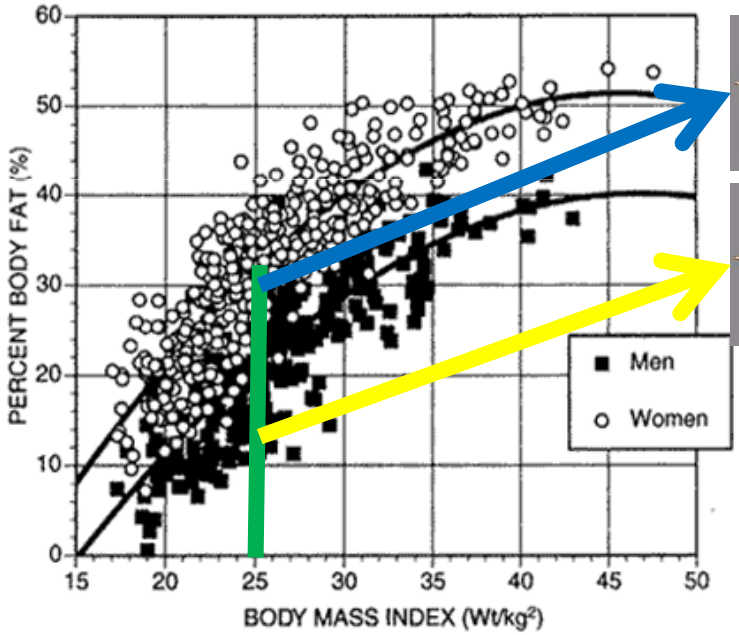
BMI = 25

Average Body Fat$_{females}$ = 30 %
Average Body Fat$_{males}$ = 20 %



1. External and internal parameters influencing human thermal sensation

Thermal comfort *is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standard 55)*

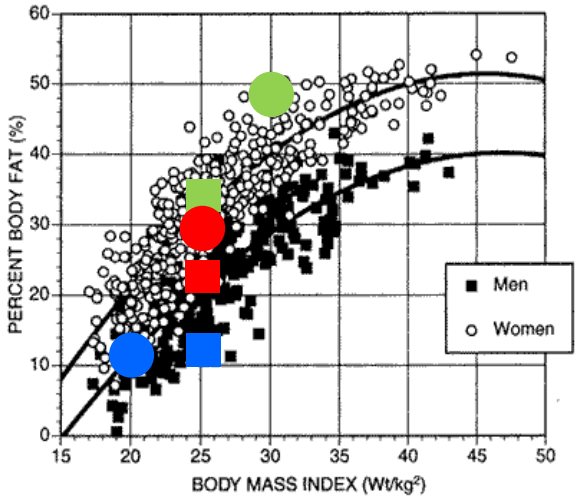


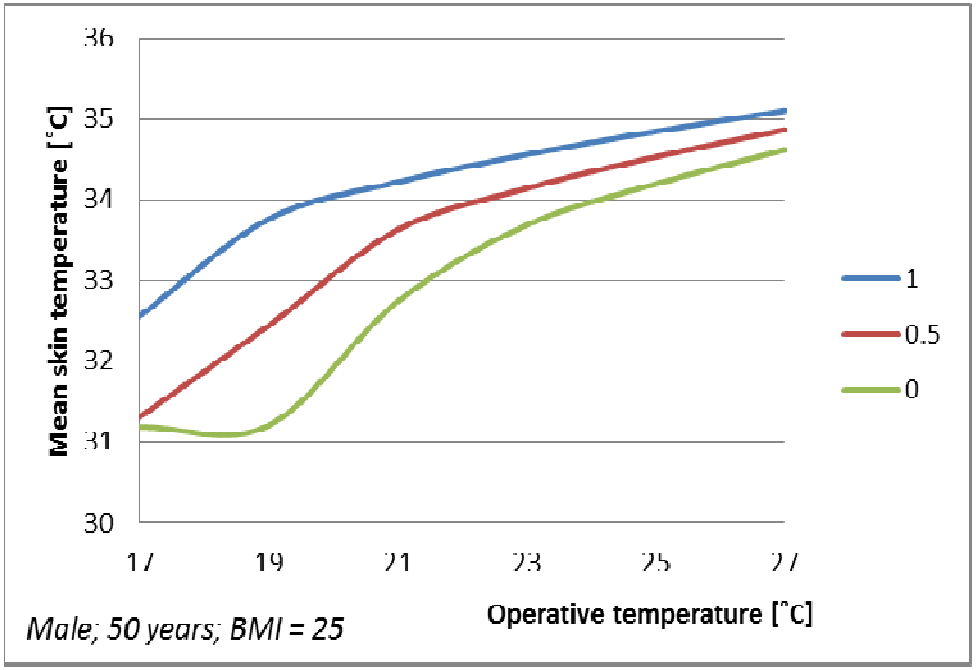
2. Individual proportions of different tissue types depend on age, gender, BMI, and fitness

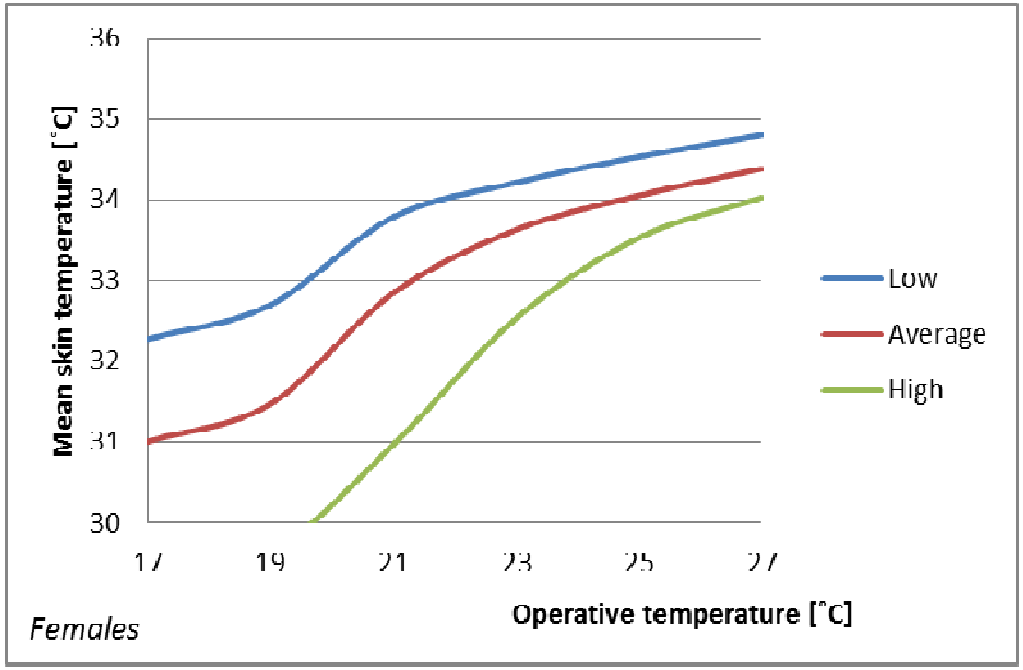
Q_{fat} = 0.004 W/kg
Q_{muscle} = 1.38 W/kg
Q_{skin} = 1.01 W/kg
$Q_{viscera}$ = 3.83 W/kg
Q_{brain} = 12.7 W/kg

Results – mean skin temperature

- Equal activity level 1 MET (58 W/m^2)
- Equal clothing insulation 0.86 clo
- Operative temperature varied (17˚C … 27˚C)
- Three males and three females

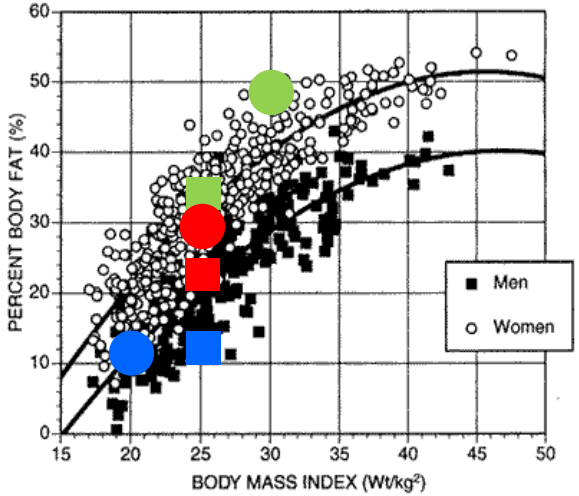




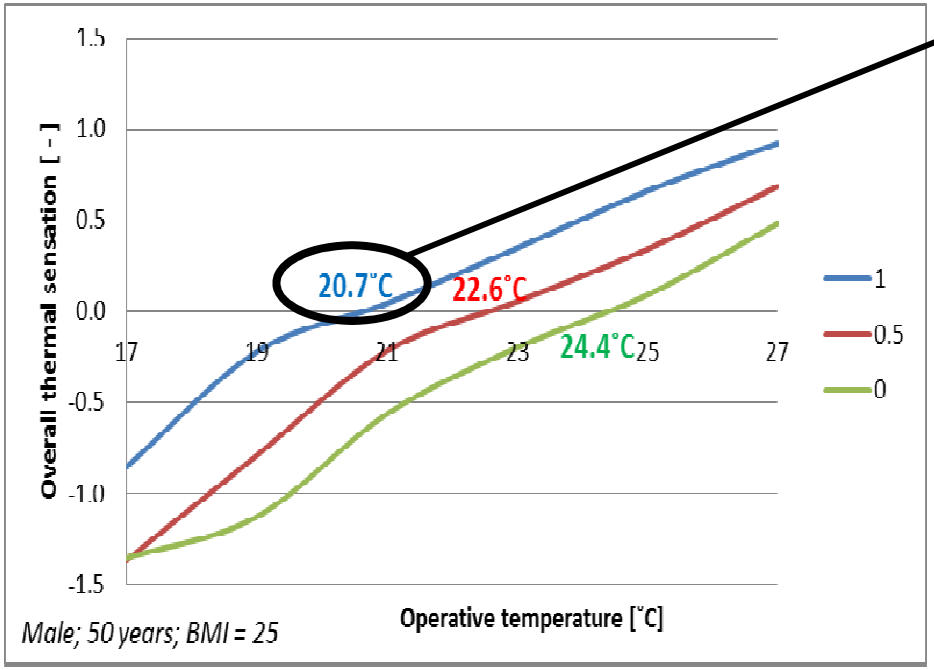


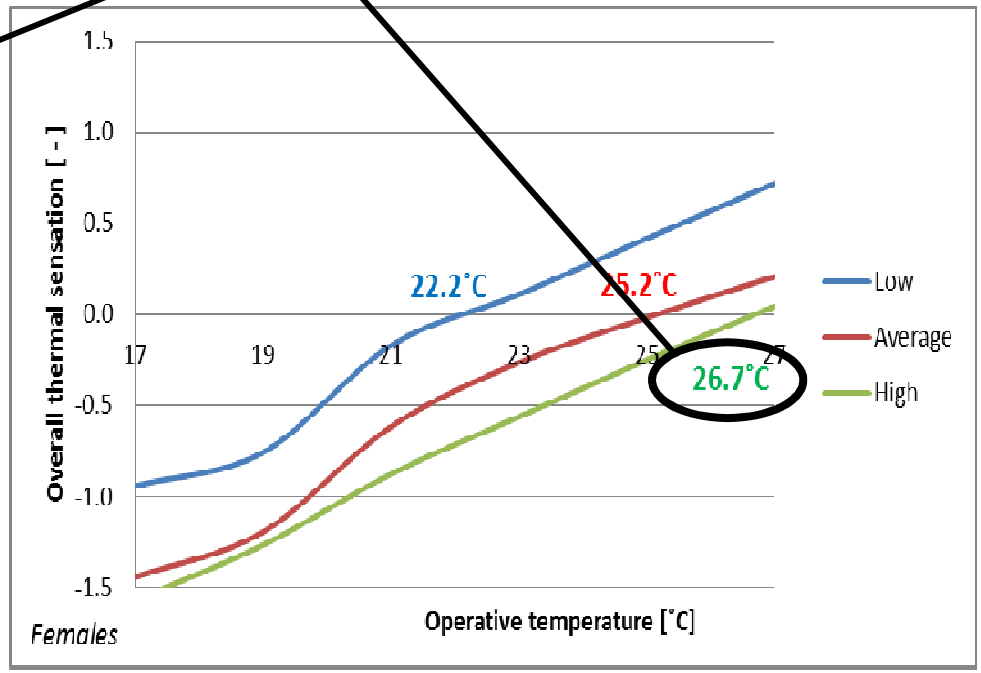
Results – Overall thermal sensation

- Equal activity level 1 MET (58 W/m^2)
- Equal clothing insulation 0.86 clo
- Operative temperature varied (17˚C …27˚C)
- Three males and three females



ΔTNT = 6˚C





TNT is Thermal Neutrality Temperature (overall thermal sensation is zero)

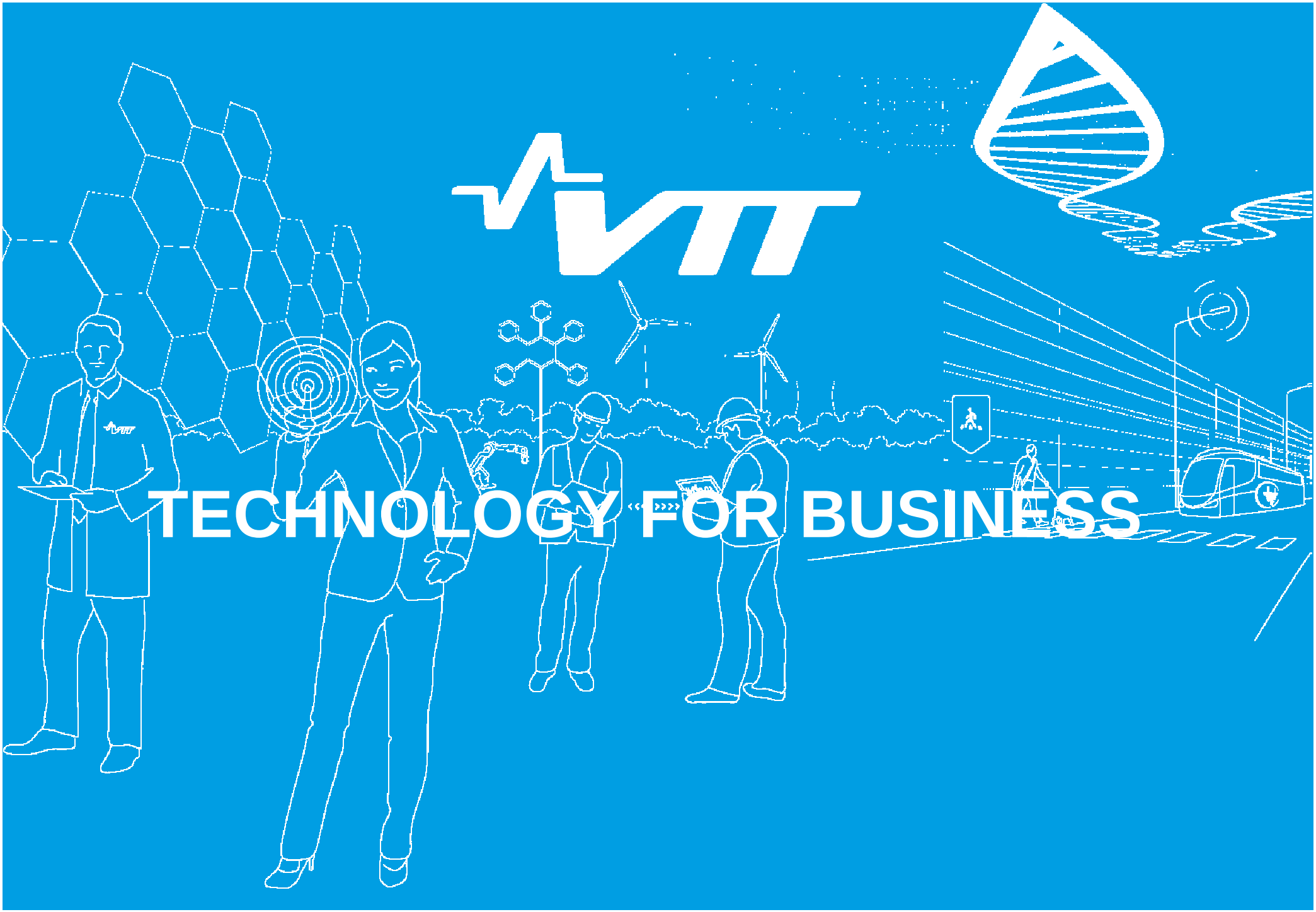
Summary and discussion

- In this study, when estimating individual human thermal sensation,
  - operative temperature levels were varied
  - all other *external* boundary conditions (i.e., air velocity, and humidity) were assumed to be constants
  - activity level and clothing were kept constants (1.0MET; 0.86 clo)

- When evaluating impacts of different operative temperature levels on individual thermal sensation by a newly developed Human Thermal Model (HTM), it could be noticed that
  1. Mean skin temperature depends systematically on both operative temperature and proportion of muscle tissue *(Muscularity Index)*.
  2. There is a similar correlation between overall thermal sensation, operative temperature, and *Muscularity Index* allowing definition of individual thermo-neutral temperature values.

Conclusions

- Based on the result obtained in this study, it is evident that **individual** characteristics have clear impacts on thermal sensation.
- This is most likely due to individual body **fat and muscle tissue ratios**. Especially gender and individual muscularity seem to have strong impacts on different tissue type distributions – and ultimately on thermal sensation.
- **More systematic laboratory and field measurements** with different individual boundary condition parameter combinations **are needed** in order to present final conclusions.
- In the future, impacts of individual characteristics on thermal sensation ought to have influence on **design and dimensioning guideline development** for different types of buildings.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