BS 2019 2-4 SEPT ROME 16th IBPSA INTERNATIONAL CONFERENCE AND EXHIBITION

INTERNATIONAL BUILDING PERFORMANCE SIMULATION ASSOCIATION

Influence of Physiological Variability on Thermal Comfort:

A Numerical Evaluation

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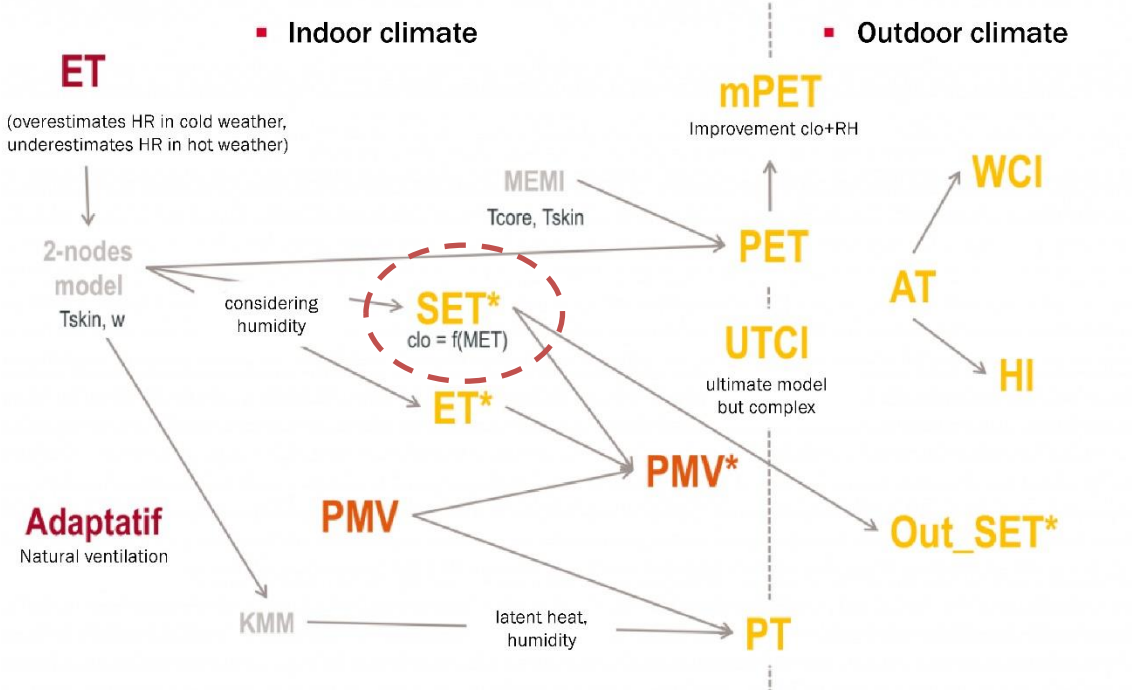
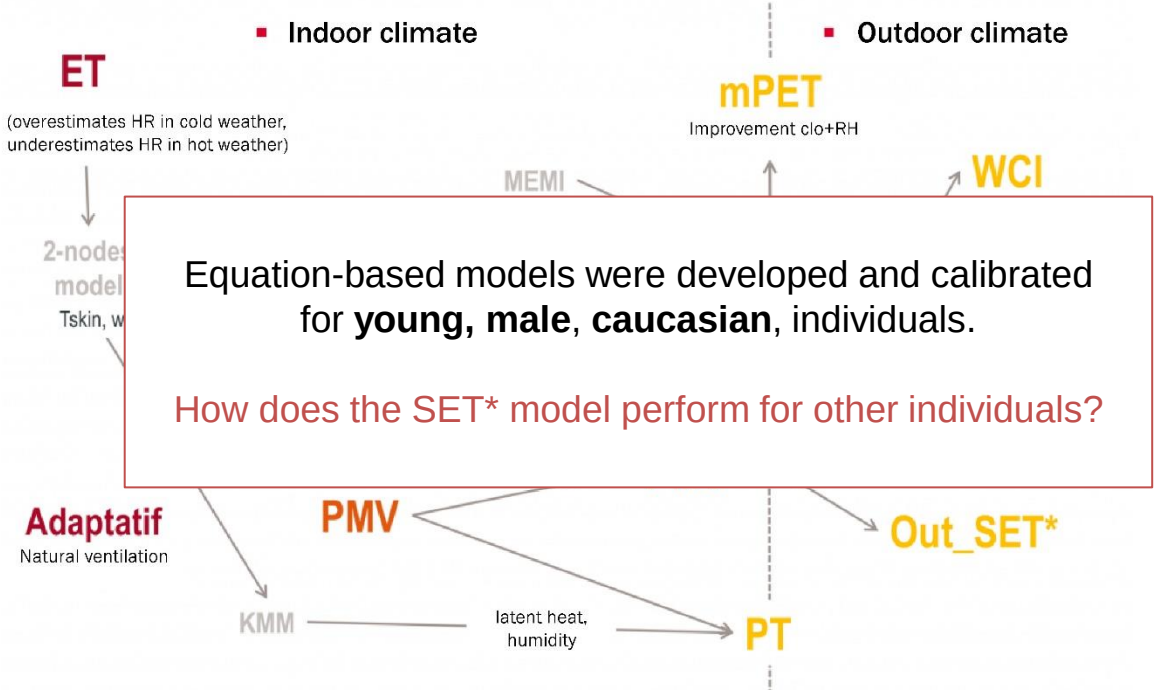
Context – Comfort indexes



Context – Comfort indexes



The two-node model (Gagge 1971)

- A transient, equation-based physiological model

$$\alpha \frac{mc_p}{A}\frac{dT_c}{dt} = M - U_T \times (T_c - T_s) - Q_r \quad \text{(core node)}$$

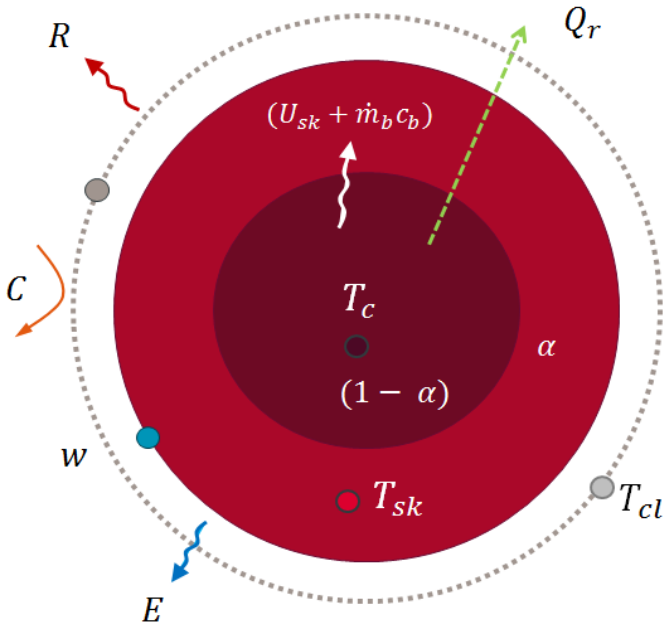
$$(1-\alpha)\frac{mc_p}{A}\frac{dT_s}{dt} = U_T \times (T_c - T_s) - H - E \quad \text{(skin node)}$$

- Thermal control: based on set points deviations
  - Blood flow (dilation, striction)
  - Sweating
  - Shivering

- Computing physiological response to environment (T_{sk}, w)

  → 13 physiological parameters

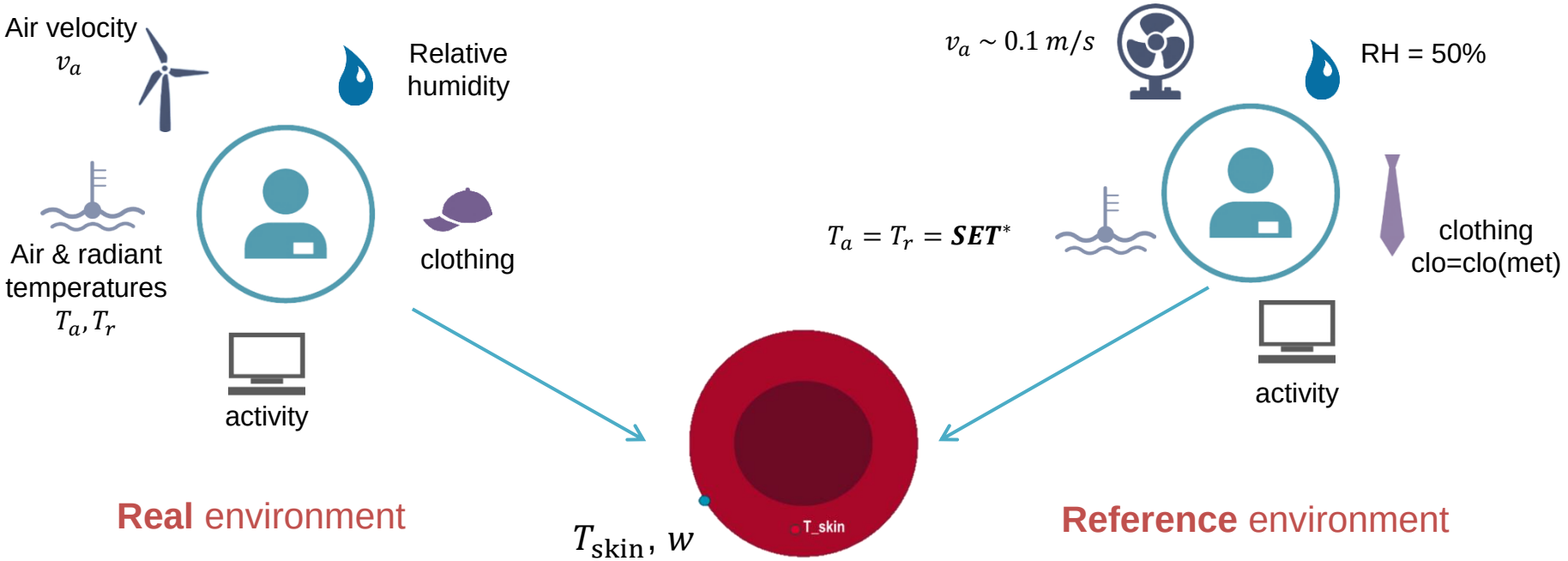
  $age, h, BMI, T_c^{SET}, T_s^{SET}, m, \beta, e_{sk}, U_{c-sk}, C_d, C_{st}, C_{sw}, C_{sh}$



[Cylindrical model of the human being]
https://lhypercube.arep.fr/en/

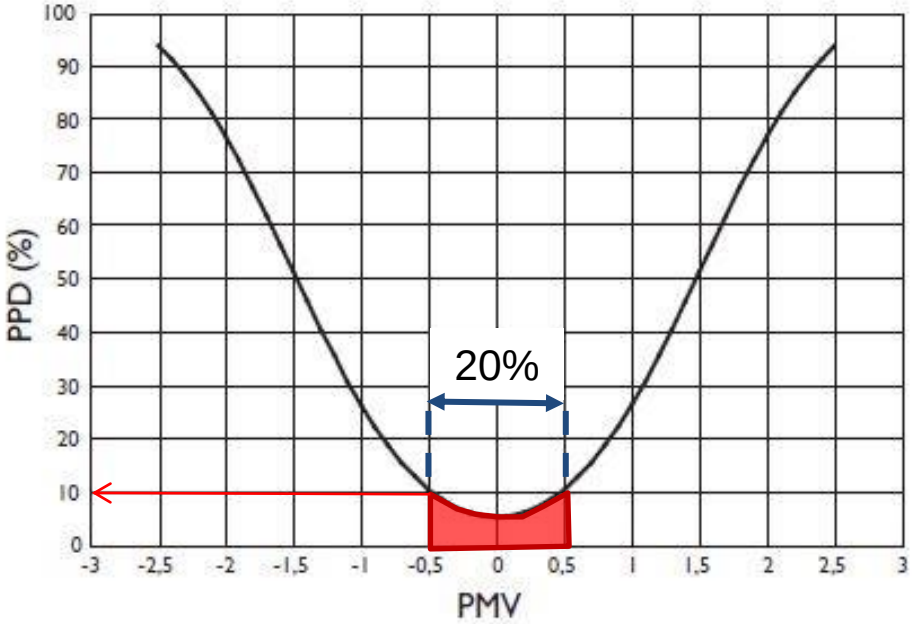
The *Standard Effective Temperature* (SET*)

- From the real to the reference environment (Nishi & Gagge 1977)



SET* comfort range

- A “comfort conversion” from PMV to SET* → 20% acceptability range



$$-0{,}5 < PMV < +0{,}5$$

$$\Leftrightarrow 72°F < T < 78°F \quad @ \sim 50\%RH$$

$$\Leftrightarrow 22.2°C < T < 25.6°C \quad @ \sim 50\%RH$$

(Nishi & Gagge 1977, ASHRAE 55)

Methodology – Physiological variability

- Computing 13 parameters

5 primary parameters from literature (INSEE 2007) …

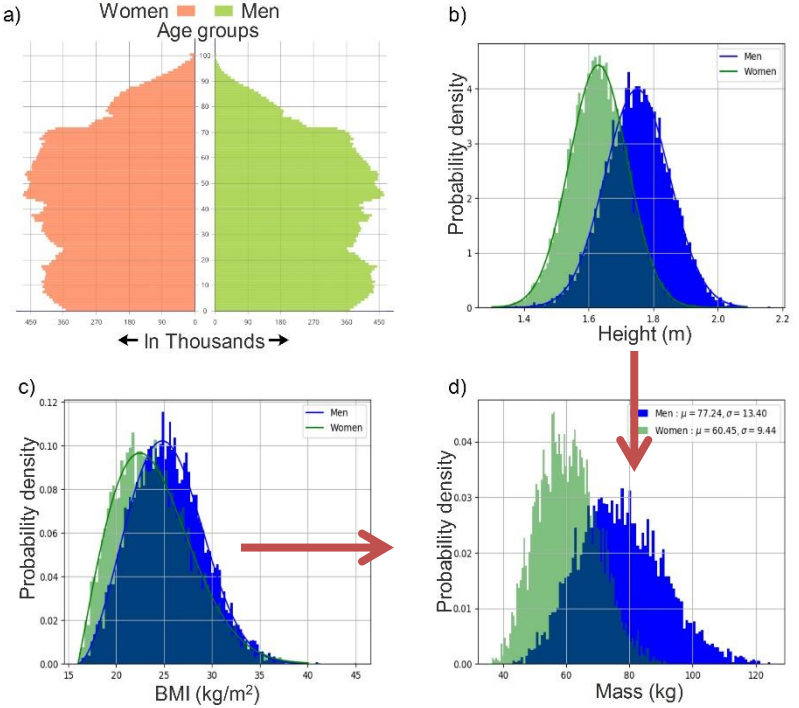
$$age, h, BMI, T_c^{SET}, T_s^{SET}$$

… allow for the computation 8 others (Havenith 2001)

$$m, \beta, e_{sk}, U_{c-sk}, C_d, C_{st}, C_{sw}, C_{sh}$$

- Coherent comparison with available data

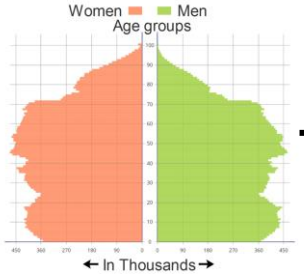
- Mass $m = 77.2\ [kg]$ versus $77\ [kg]$ measured
- Skinfold thickness $e_{sk} \sim 10 - 45\ [mm]$
- Skin conductance $U_{c-sk} \sim 6 - 15\ [W/m^2/K]$
- …



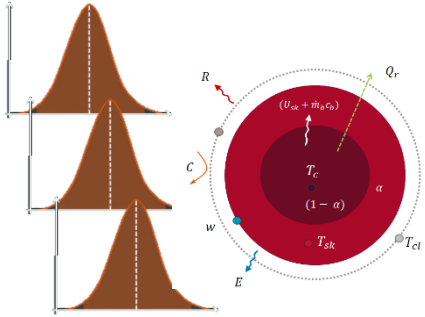
[Age, Height, BMI and Mass of the French population]

Methodology – Physiological variability

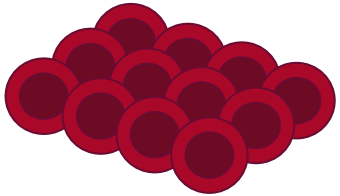
- Graphical summary of this study

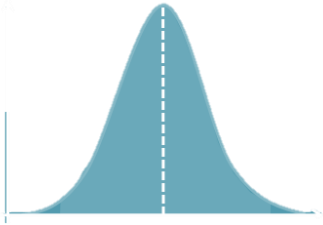


Consider one population
(10 000 sample)

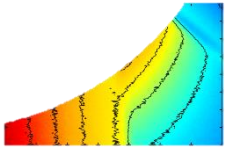


Compute 5+8=13 parameters
for each individual

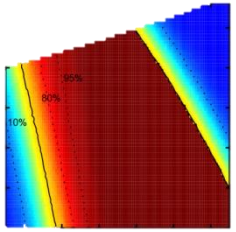




Get the comfort index
distribution



Standard-deviation?



Comparison with
comfort zone?

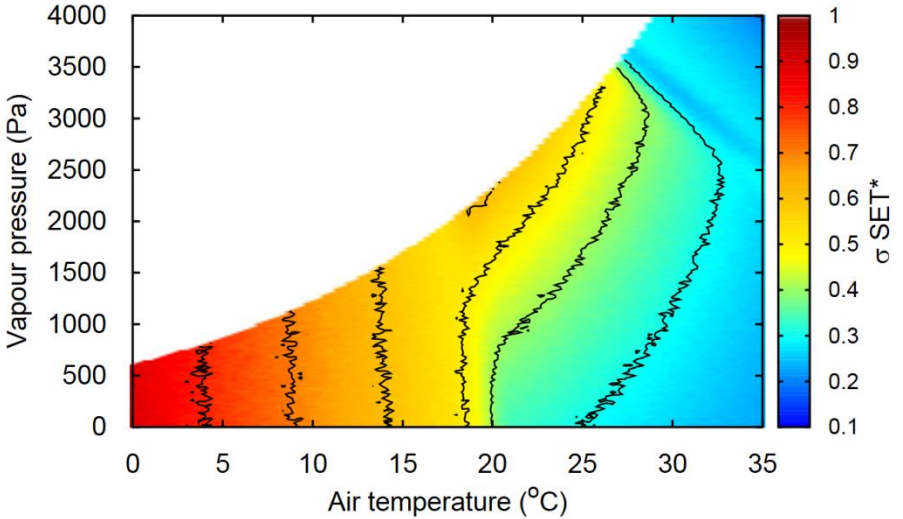
Results - Variability

- Various conditions tested (T, p_v)
  - Operative temperature
  - High MRT
  - Windy conditions
  - Wind + high MRT

For all cases standard deviation remains **below 1 $[K]$** *id est* **± 2 $[K]$ around average**.

Field data up to ~10 [K] (van Hoof 2008)

→ Mathematical models do not capture thermal sensation !
(nor behavioural, psychological aspects)



[Standard deviation of SET^* on the psychrometric chart for « operative » conditions]

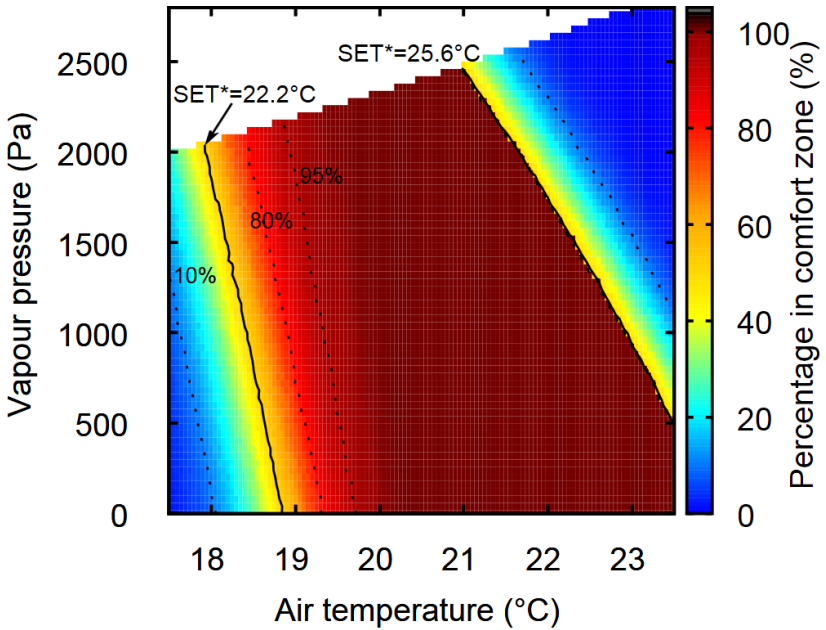
Results – Comfort range

- Population within comfort zone

Warm boundary: same position and tight iso-percentages

→Vasodilation more homogeneous in warm conditions: more consistent perception

→“Shift to the right” expected



[Percentage of sample within comfort zone on the psychrometric chart]

Results – Comfort range

- Population within comfort zone

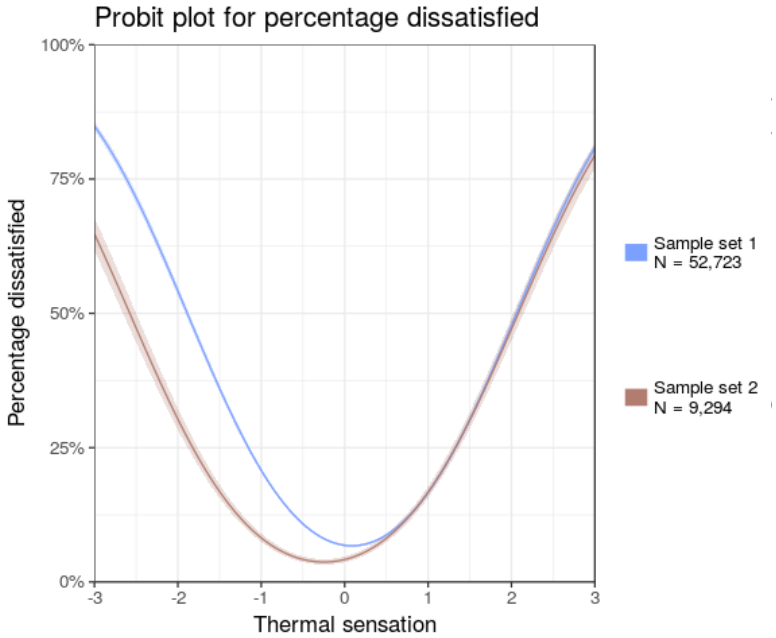
Warm boundary: same position and tight iso-percentages

→Vasodilation more homogeneous in warm conditions: more consistent perception

→“Shift to the right” expected

Cold boundary: +0.5 [K] and spread iso-percentages and assymetry

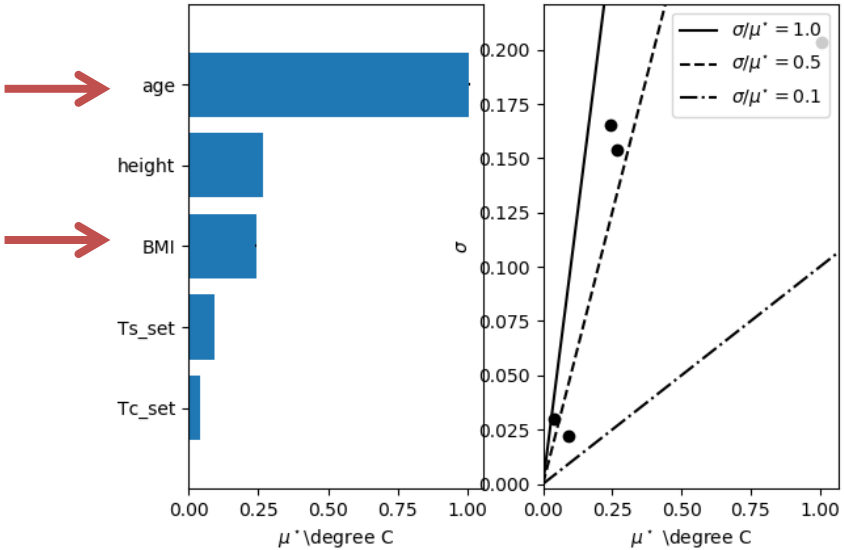
→Similarly to (ASHRAE Database II)



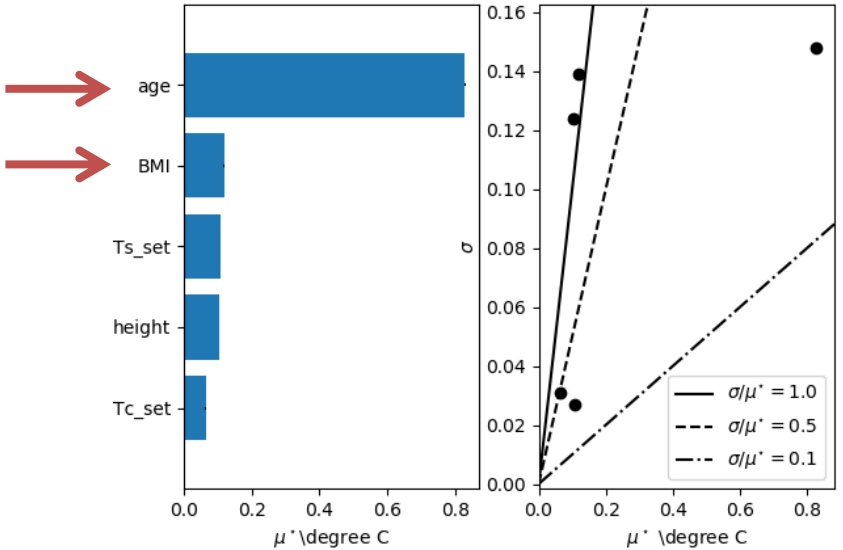
[From https://cbe-berkeley.shinyapps.io/comfortdatabase/]

Results - Sensitivity Analysis after Morris'

- Gender, age, BMI as the most influent parameters (Rupp et. al 2018)



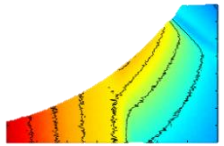
*[Parameter ranking for **female** individuals]*



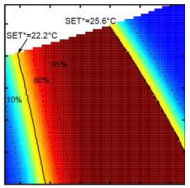
*[Parameter ranking for **male** individuals]*

Conclusions

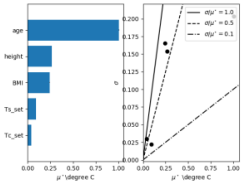
- Low variability of the two-node model compared to field data



- Cold boundary ~0.5 [K] higher for this population.
  Warm boundary unchanged (!)



- Morris' sensitivity analysis rate Gender, age, BMI as most influential parameters: coherent with litterature



→ Unexpectedly, the model seems to reproduce an observed behaviour on the cold side. Further investigations needed!

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Questions and Comments

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Our website sharing theory & open-source code
https://lhypercube.arep.fr/en/