

Effects of different cooling principles on thermal sensation and physiological responses

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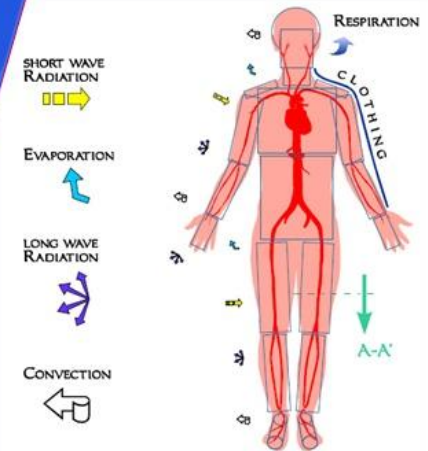
Effects of different cooling principles

on thermal sensation and physiological responses

Lisje Schellen

Windsor 2012

15 April 2012



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Where innovation starts

Introduction

Annex 37: Optimal energy/exergy-use will not always lead to an increased comfort level [*Juussela, 2003*].

Application of low-energy/exergy HVAC systems can result in local discomfort [*Prendergast and Erdtsieck, 2003; Isaksson and Karlsson, 2006; Richter, 2007; Hashigushi et al. 2010*].

The **thermal environments** in buildings with low-energy/exergy systems can be more **complex** due to **non-uniformity**.

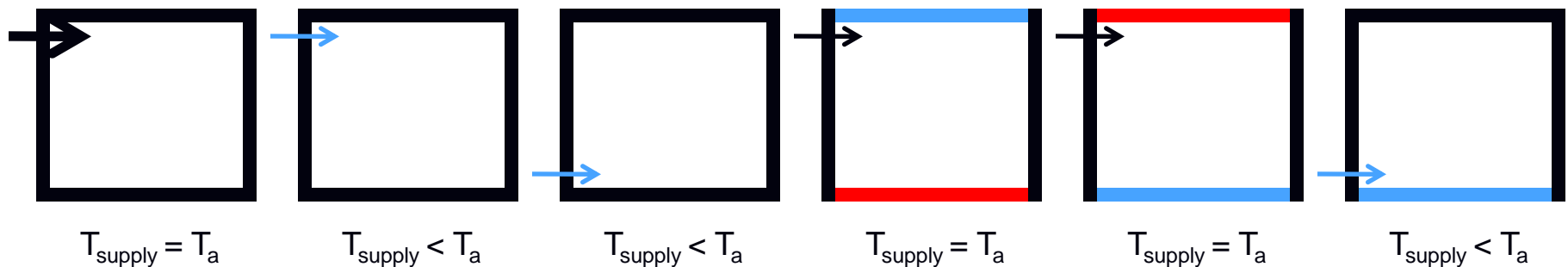
Combined radiant and convective heat transfer play an important role in the **assessment of thermal comfort**.

Thermal comfort is one of the **main requirements** to successfully apply **low-exergy HVAC systems**.

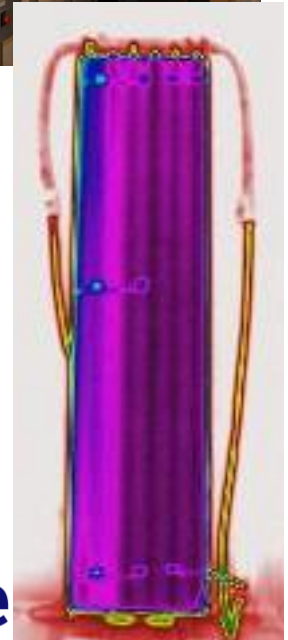
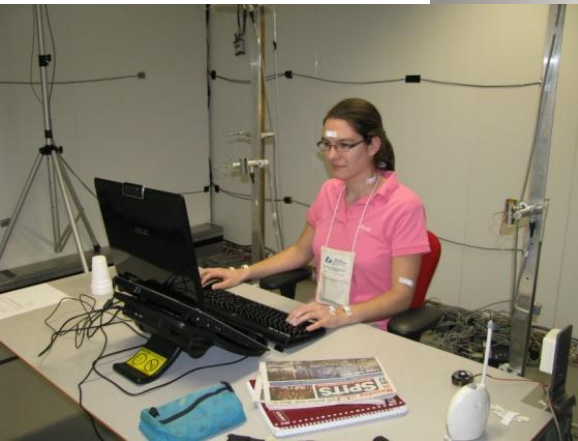
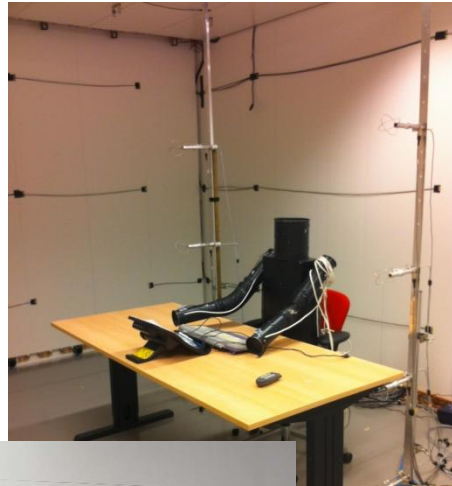
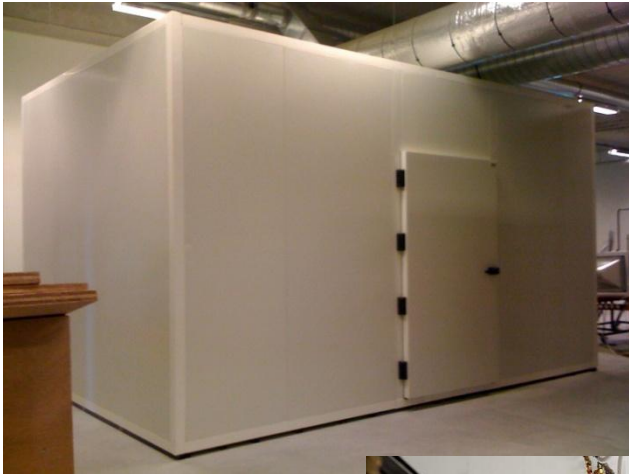
Methods - Cases

Cooling:

1. **Passive** cooling through **mixing** ventilation
2. **Active** cooling through **convection** and **mixing** ventilation
3. **Active** cooling through **convection** and **displacement** ventilation
4. **Active** cooling through **radiation** by the **ceiling** and **mixing** ventilation
5. **Active** cooling through **radiation** by the **floor** and **mixing** ventilation
6. **Active** cooling through **radiation** by the **floor** and **displacement** ventilation



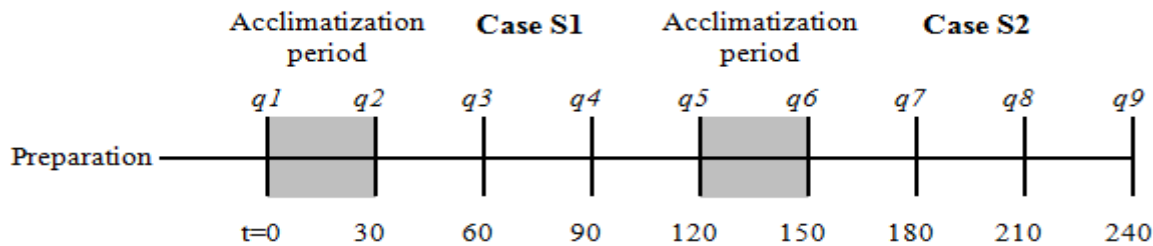
Methods - Thermophysiological test room



TU/e

Methods (2)

Time schedule

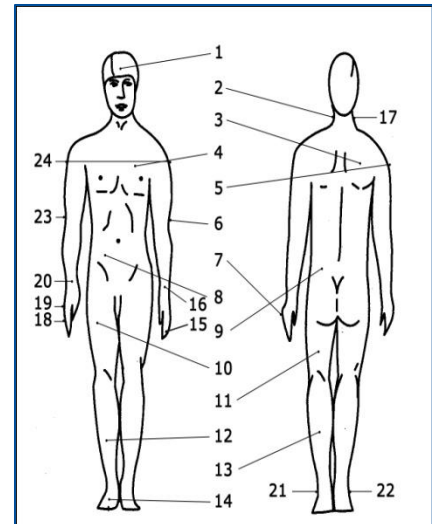


Measurements

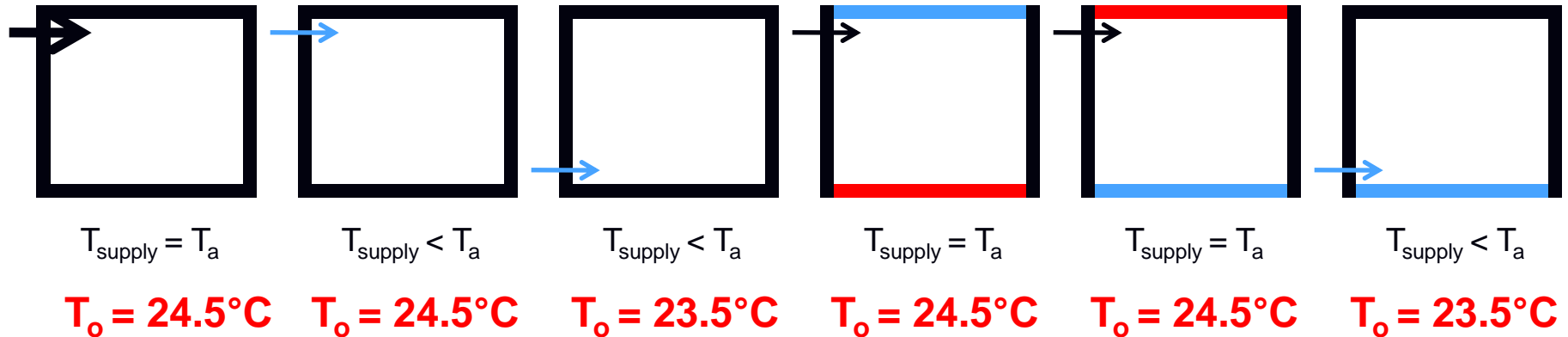
- **Physical** (T_a , RH, v_a , T_r , E_v) and **physiological parameters** (T_{sk} , T_{cr} , vasomotion) **continuously**.

Questionnaires

- **Global and local comfort**
- **Remote Performance Method** [Toftum et al., 2005]



Methods



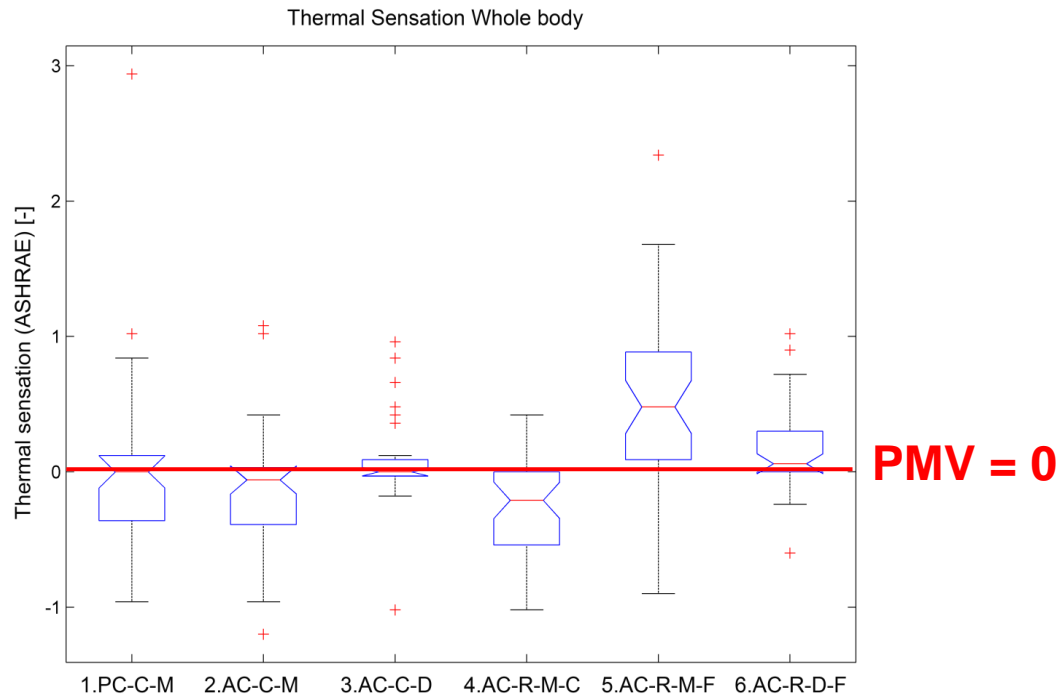
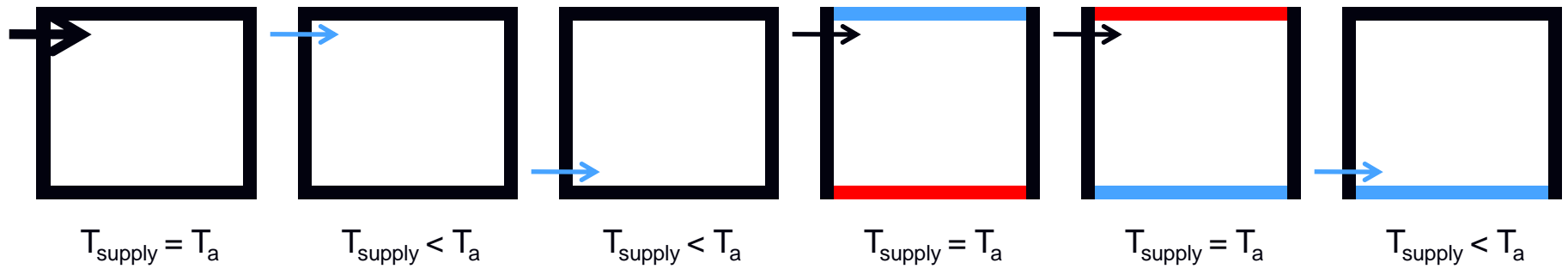
Boundary conditions all cases:

PMV = 0 \Rightarrow $T_a = T_{rm}$ (0.7 clo, 1.2 met)

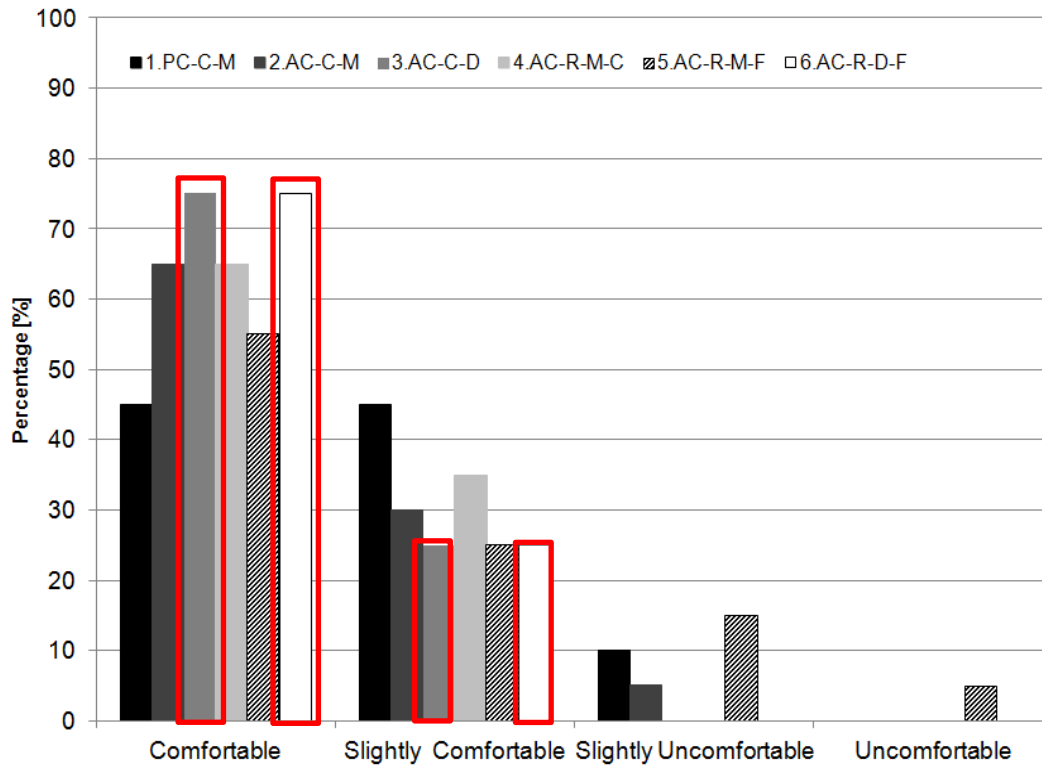
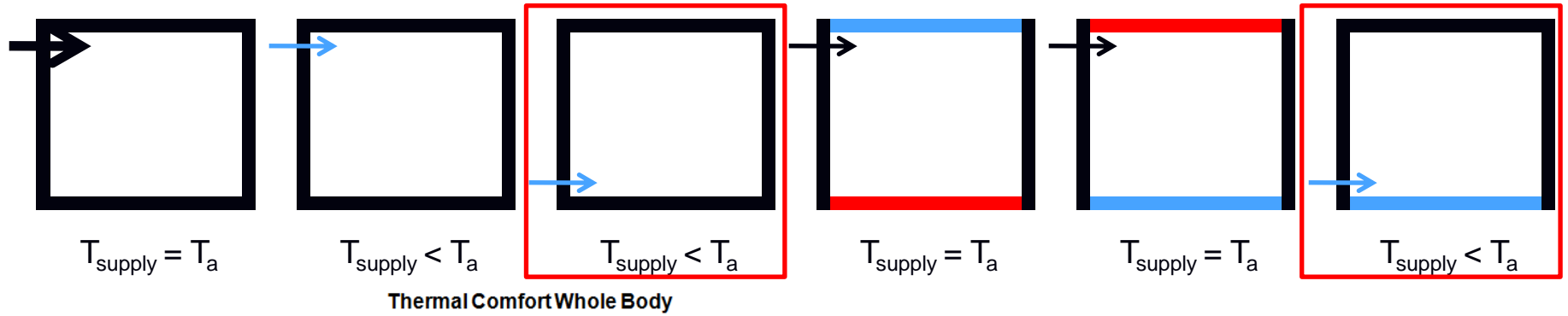
10 healthy male subjects (♂)

10 healthy female subjects ()

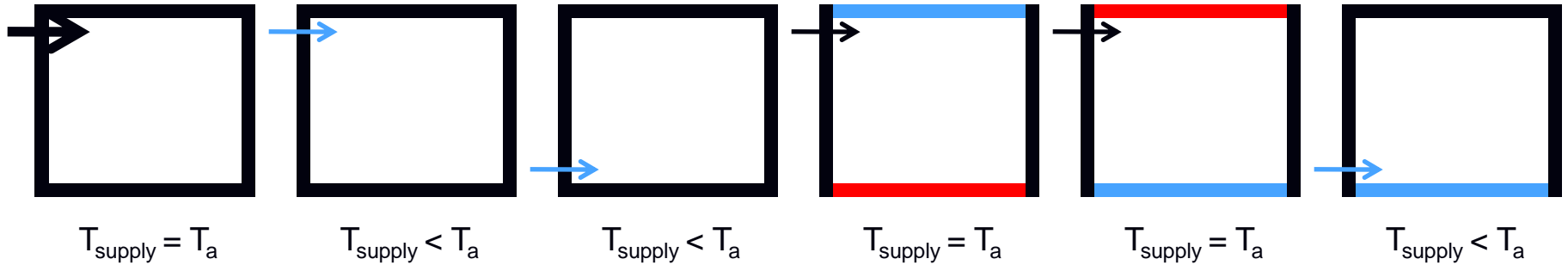
Results - Males



Results - Males

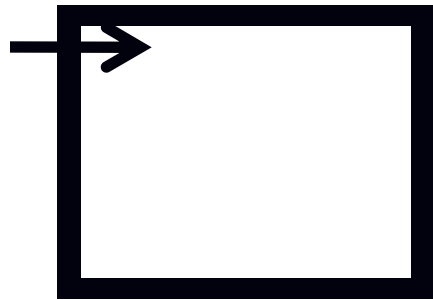


Results - Males



| Variable | Norm | Case 1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 |
|--|------|--------|--------|--------|--------|--------|--------|
| PD Draft (DR) [%] | <20 | Green | Green | Green | Green | Green | Green |
| PD Vertical air temperature difference [%] | <5 | Green | Green | Green | Green | Red | Red |
| PD Warm or Cool floor [%] | <10 | Green | Green | Green | Red | Green | Green |
| PD Warm or Cool Ceiling | <5 | Green | Green | Green | Green | Red | Red |

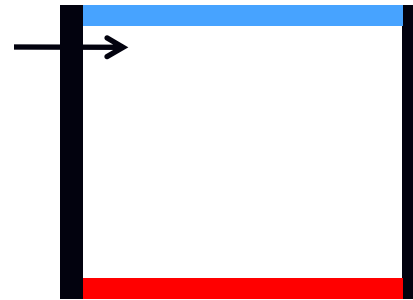
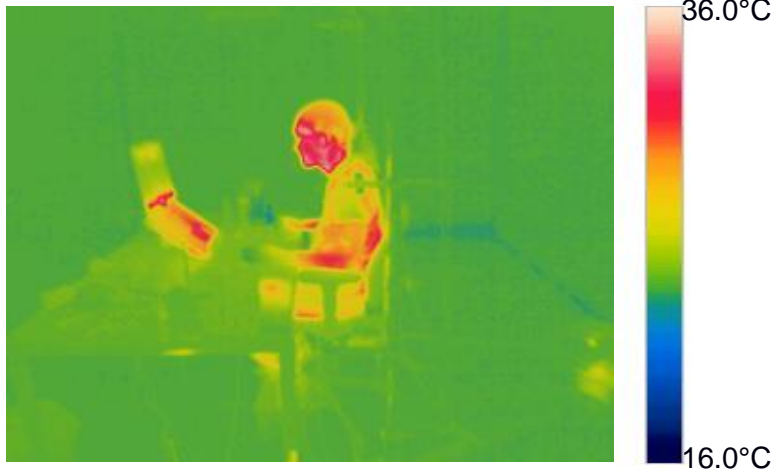
Results – Males vs Females



$T_o = 25.3 \pm 0.17^\circ\text{C}$
 $T_a = 25.5 \pm 0.21^\circ\text{C}$
 $T_{rm} = 25.0 \pm 0.12^\circ\text{C}$
 $v_a = 0.27 \pm 0.02 \text{ m/s}$

$$T_{\text{supply}} = T_a$$

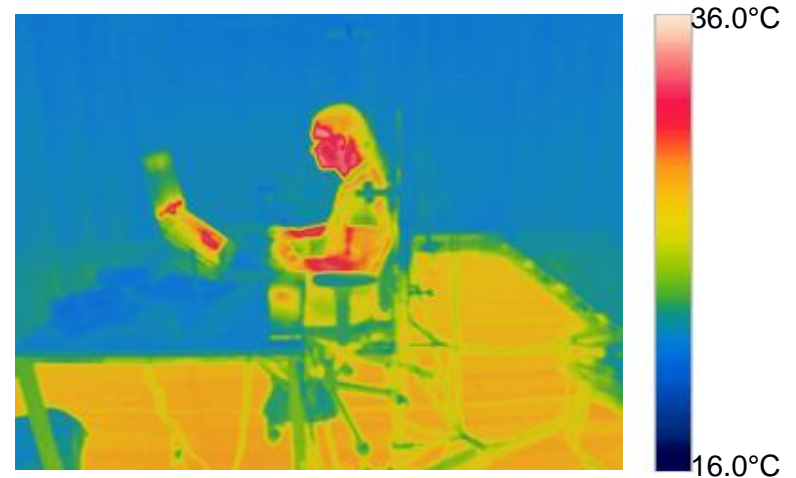
Passive cooling – Uniform (1)



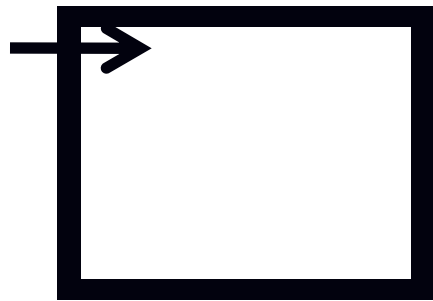
$T_o = 24.4 \pm 0.06^\circ\text{C}$
 $T_a = 24.1 \pm 0.08^\circ\text{C}$
 $T_{rm} = 24.6 \pm 0.04^\circ\text{C}$
 $v_a = 0.14 \pm 0.00 \text{ m/s}$

$$T_{\text{supply}} = T_a$$

Active cooling – Non-uniform (4)

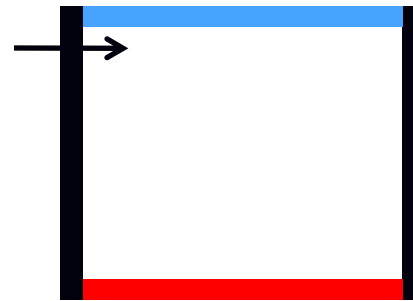


Results – Males vs Females



$T_o = 25.3 \pm 0.17^\circ\text{C}$
 $T_a = 25.5 \pm 0.21^\circ\text{C}$
 $T_{rm} = 25.0 \pm 0.12^\circ\text{C}$
 $v_a = 0.27 \pm 0.02 \text{ m/s}$

$$T_{\text{supply}} = T_a$$



$T_o = 24.4 \pm 0.06^\circ\text{C}$
 $T_a = 24.1 \pm 0.08^\circ\text{C}$
 $T_{rm} = 24.6 \pm 0.04^\circ\text{C}$
 $v_a = 0.14 \pm 0.00 \text{ m/s}$

$$T_{\text{supply}} = T_a$$

Subject votes

| Variable | Males | Females |
|----------|-------------------|----------------------------|
| PMV [-] | 0.3 ± 0.05 | $0.1 \pm 0.07^{\wedge}$ |
| AMV [-] | $-0.3 \pm 0.64^*$ | $-0.4 \pm 0.95^{*,\wedge}$ |

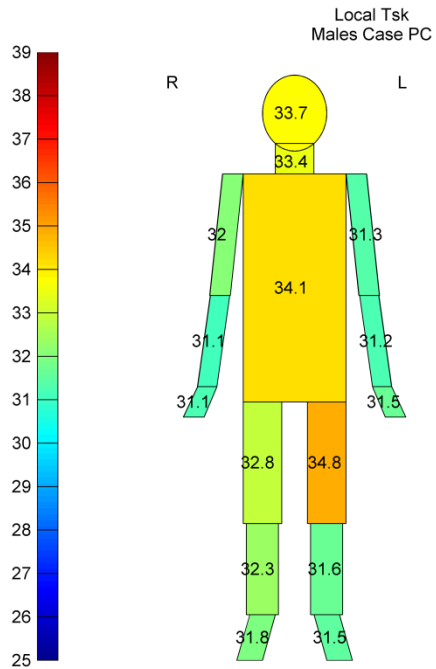
| Variable | Males | Females |
|----------|---------------------|----------------------------|
| PMV [-] | $0.1 \pm 0.02^{\#}$ | $0.0 \pm 0.02^{\wedge,\#}$ |
| AMV [-] | $-0.3 \pm 0.41^*$ | $-0.6 \pm 0.69^{*,\wedge}$ |

* Significant different from PMV ($p < 0.001$)

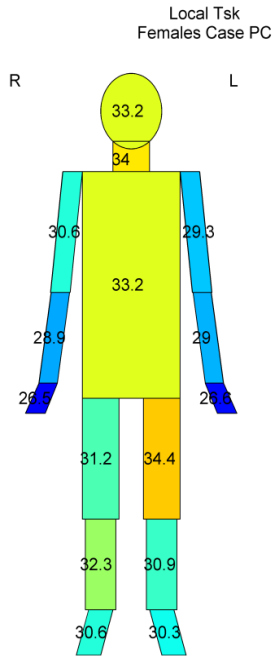
\wedge Significant different from males ($p < 0.05$)

$\#$ Significant different from case PC ($p < 0.001$, within gender)

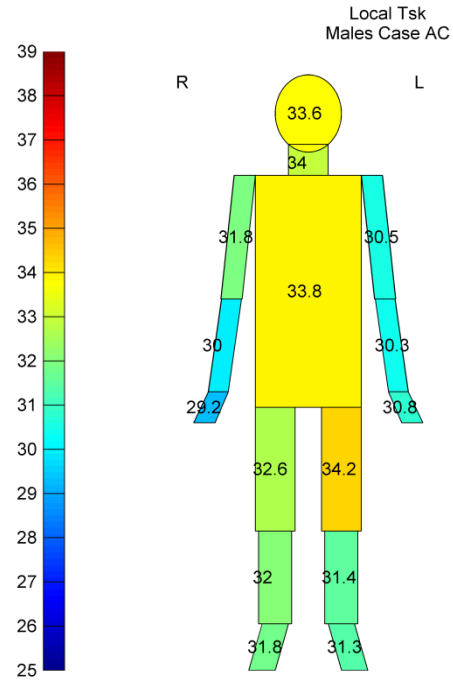
Results – Local skin temperatures



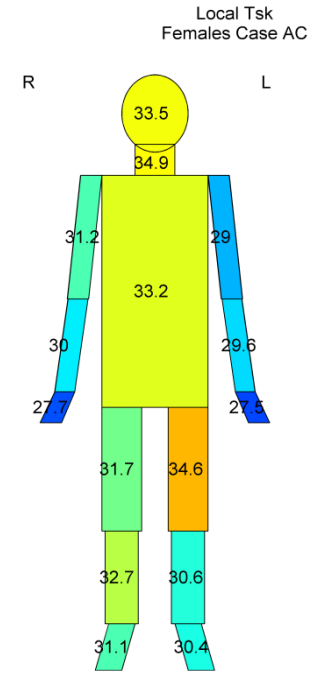
Males



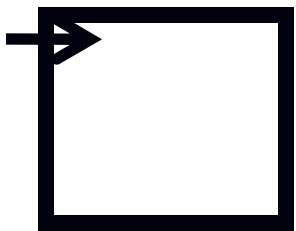
Females



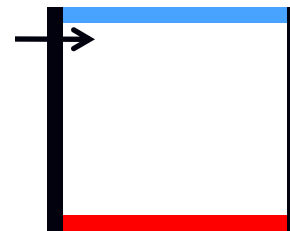
Males



Females

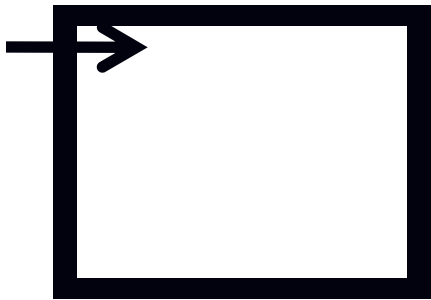


$$T_{\text{supply}} = T_a$$



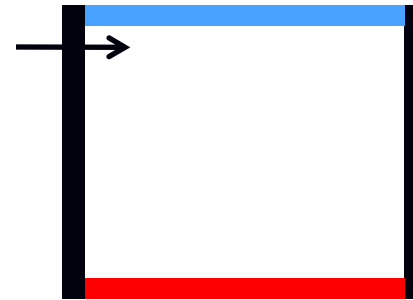
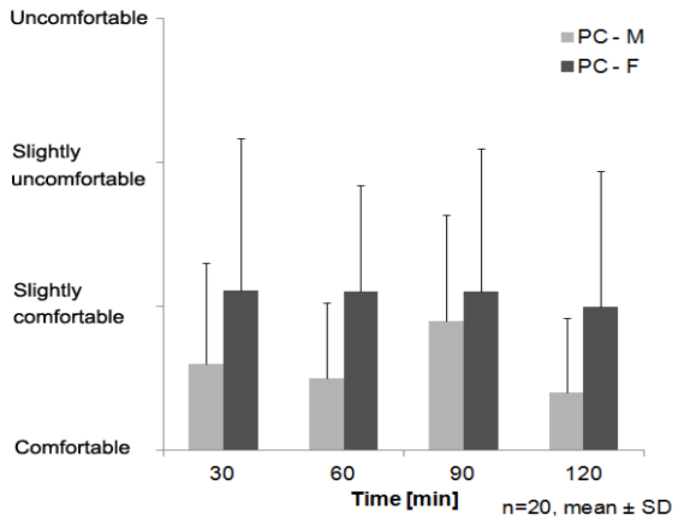
$$T_{\text{supply}} = T_a$$

Results – Subject votes



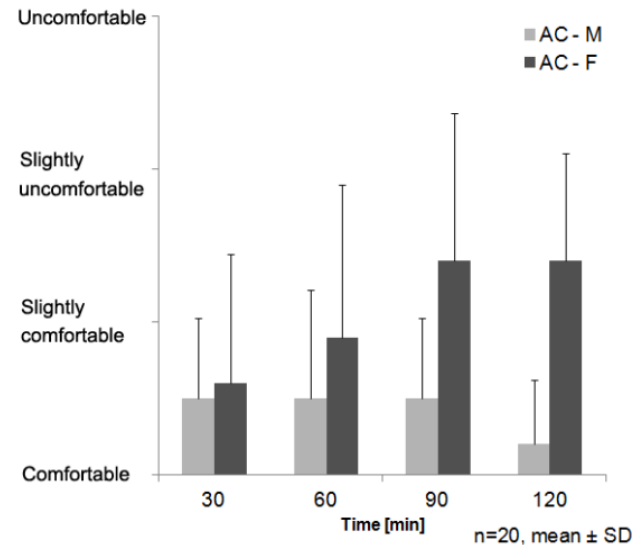
$$T_{\text{supply}} = T_a$$

Passive cooling - Uniform



$$T_{\text{supply}} = T_a$$

Active cooling – Non-uniform



Discussion

- Although cases were designed at $PMV = 0$, subjects thermal sensation votes significantly differed from neutral
- Is PMV (together with complimentary boundary conditions) applicable under non-uniform conditions?
- Uncovered body parts significantly influenced whole body TS
- Should focus be on extremities regarding the prediction of TS and TC?
- TS and TC between males and females were significant different
- Males found active cooling more comfortable; females preferred passive cooling
- Emphasis should be on a more individualized assessment [Schellen et al. 2010]

Conclusion

- **Operative temperature is not sufficient to assess TS and TC under non-uniform conditions**
- **Highly non-uniform environments can achieve a comparable or even a more comfortable assessment compared to uniform environments**
- **Under the studied uniform conditions the thermal sensation can be predicted well by the PMV model**
- **Contrary, non-uniform environments can achieve significantly different thermal sensation votes as predicted in advance**
- **The differences are most probably caused by local effects (local thermal sensations and local skin temperatures) and the presence of combined local discomfort factors.**

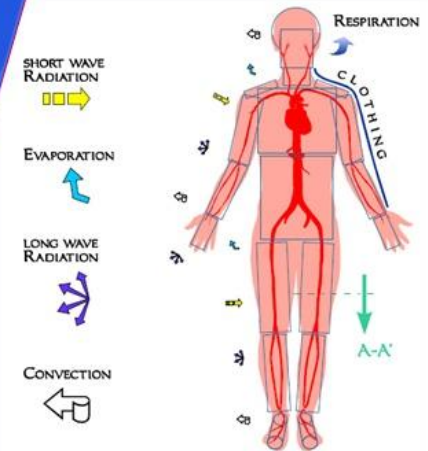
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