Effects of different cooling principles on thermal sensation and physiological responses

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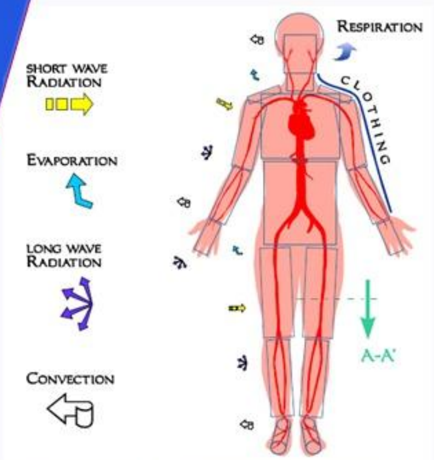

Lisje Schellen

Windsor 2012

15 April 2012

Technische Universiteit **Eindhoven** University of Technology

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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.

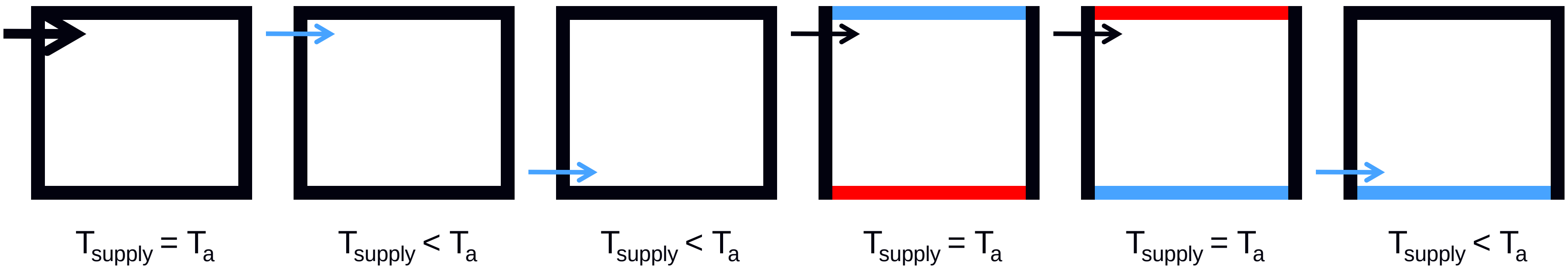
Combined radiant and convective heat transfer play an important role in the assessment of thermal comfort.

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

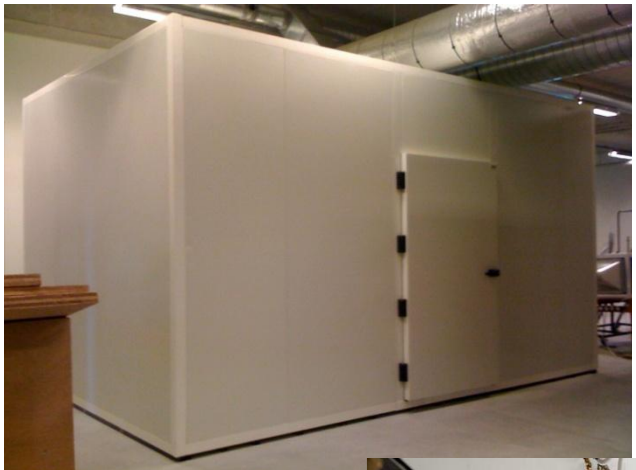
Methods - Cases

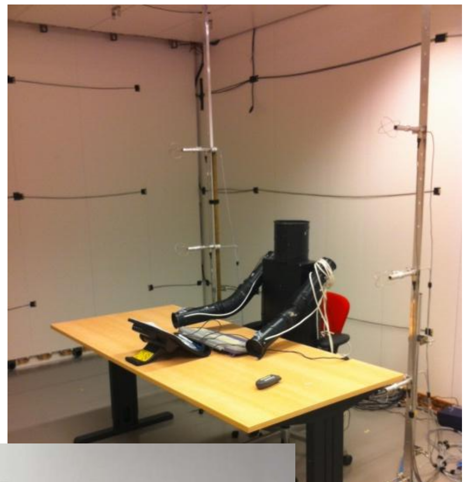
Cooling:

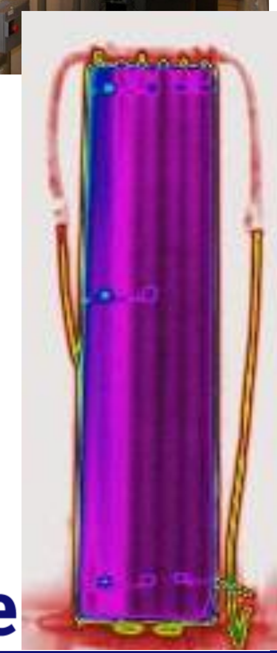
1. **Passive cooling through mixing ventilation**
2. **Active cooling through convection and mixing ventilation**
3. **Active cooling through convection and displacement ventilation**
4. **Active cooling through radiation by the ceiling and mixing ventilation**
5. **Active cooling through radiation by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

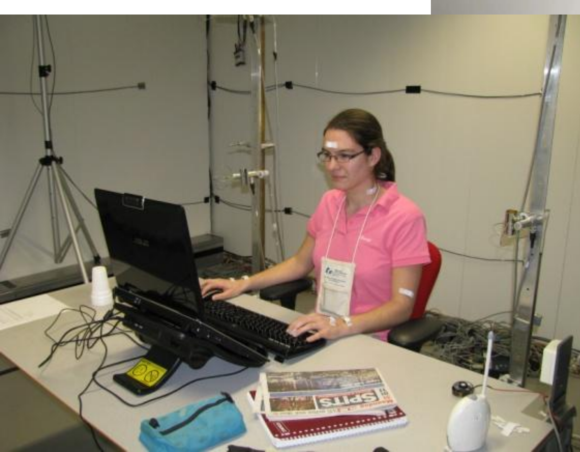


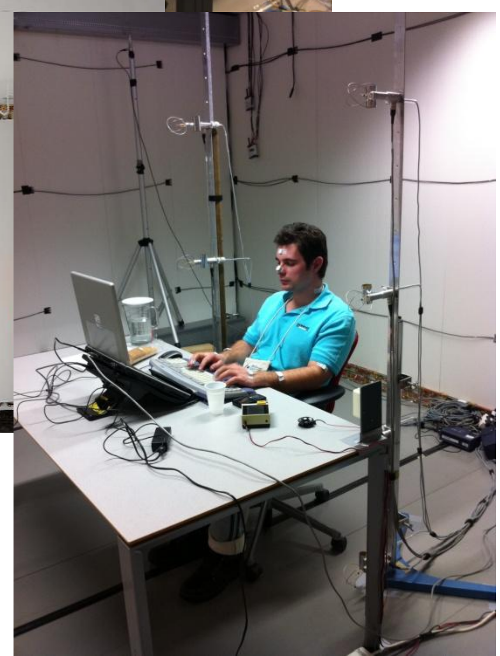
Methods - Thermophysiological test room





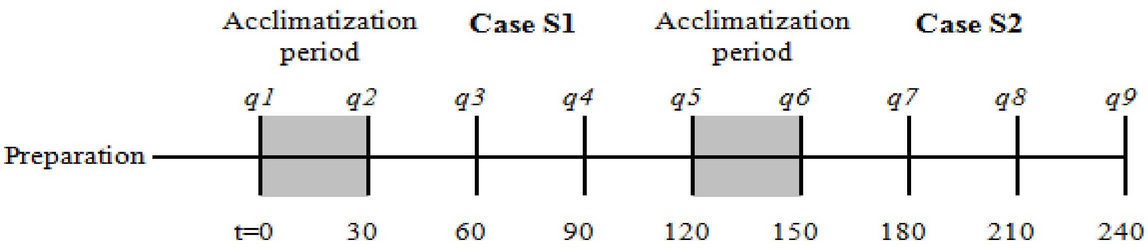






Methods (2)

Time schedule

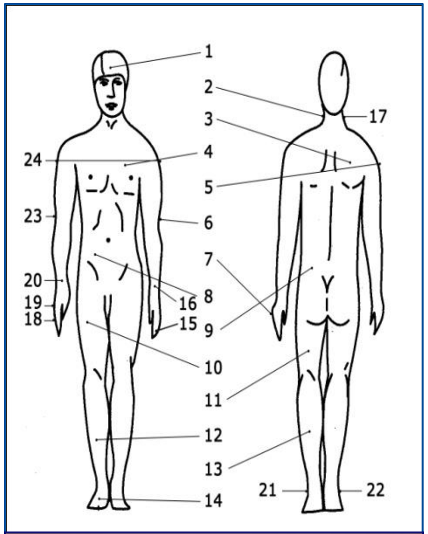


Measurements

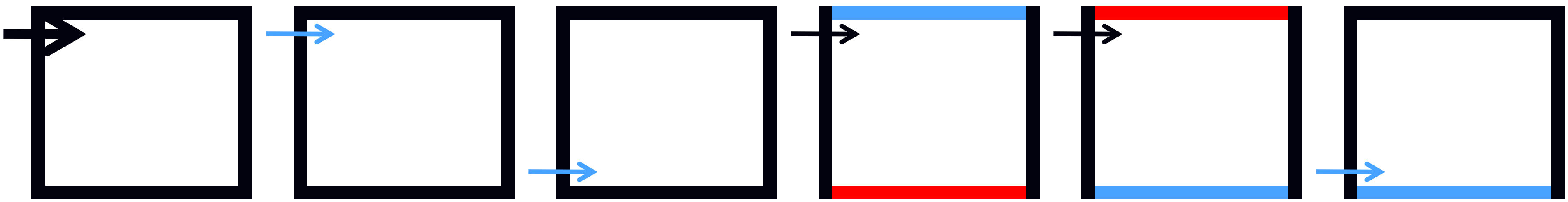
- **Physical** (T_a, RH, v_a, T_r, E_v) **and physiological parameters** (T_{sk}, T_{cr}, vasomotion) **continuously.**

Questionnaires

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



Methods



$T_{supply} = T_a$ | $T_{supply} < T_a$ | $T_{supply} < T_a$ | $T_{supply} = T_a$ | $T_{supply} = T_a$ | $T_{supply} < T_a$

T_o = 24.5°C | **T_o = 24.5°C** | **T_o = 23.5°C** | **T_o = 24.5°C** | **T_o = 24.5°C** | **T_o = 23.5°C**

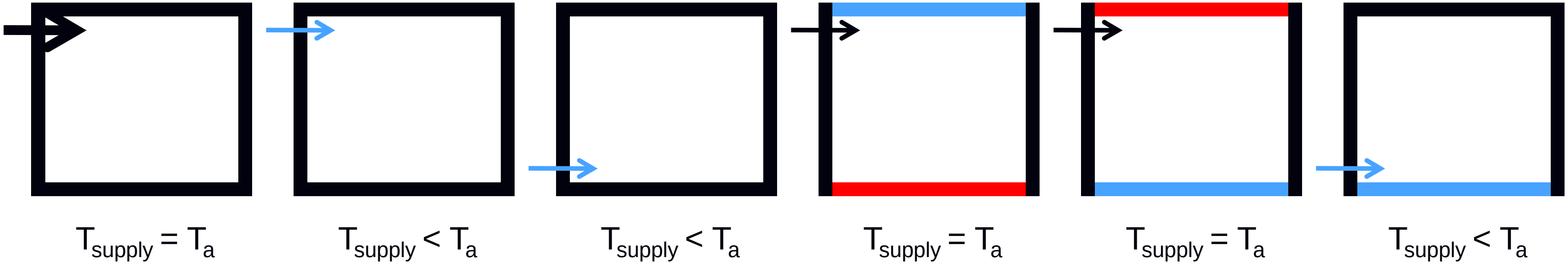
Boundary conditions all cases:

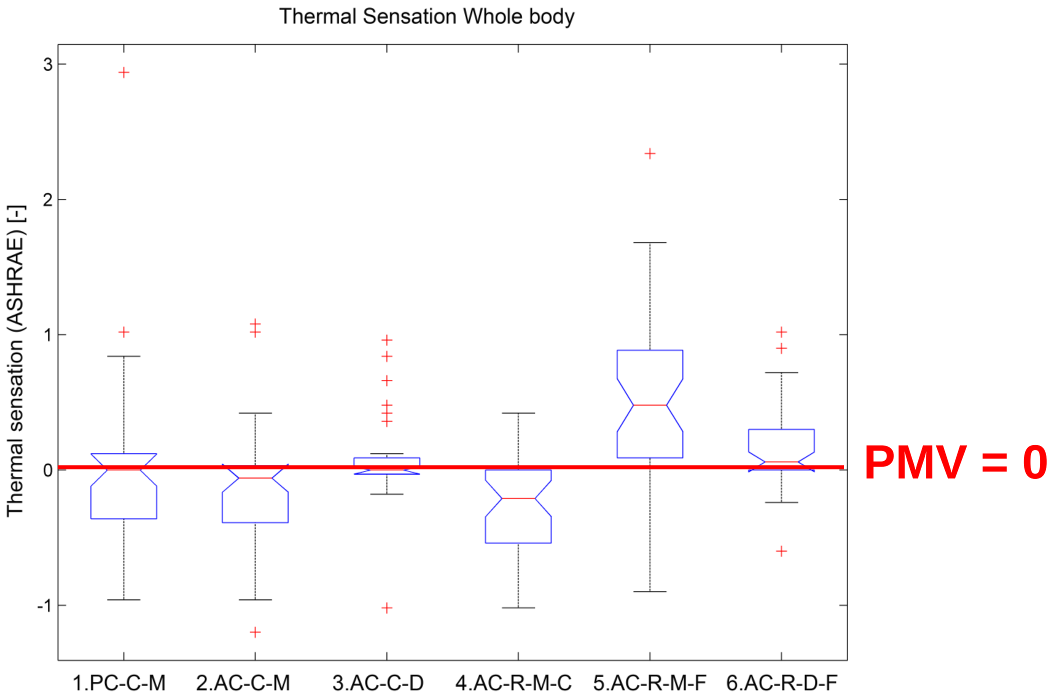
PMV = 0 ⇨ **$T_a = T_{rm}$** (0.7 clo, 1.2 met)

10 healthy male subjects (♂)

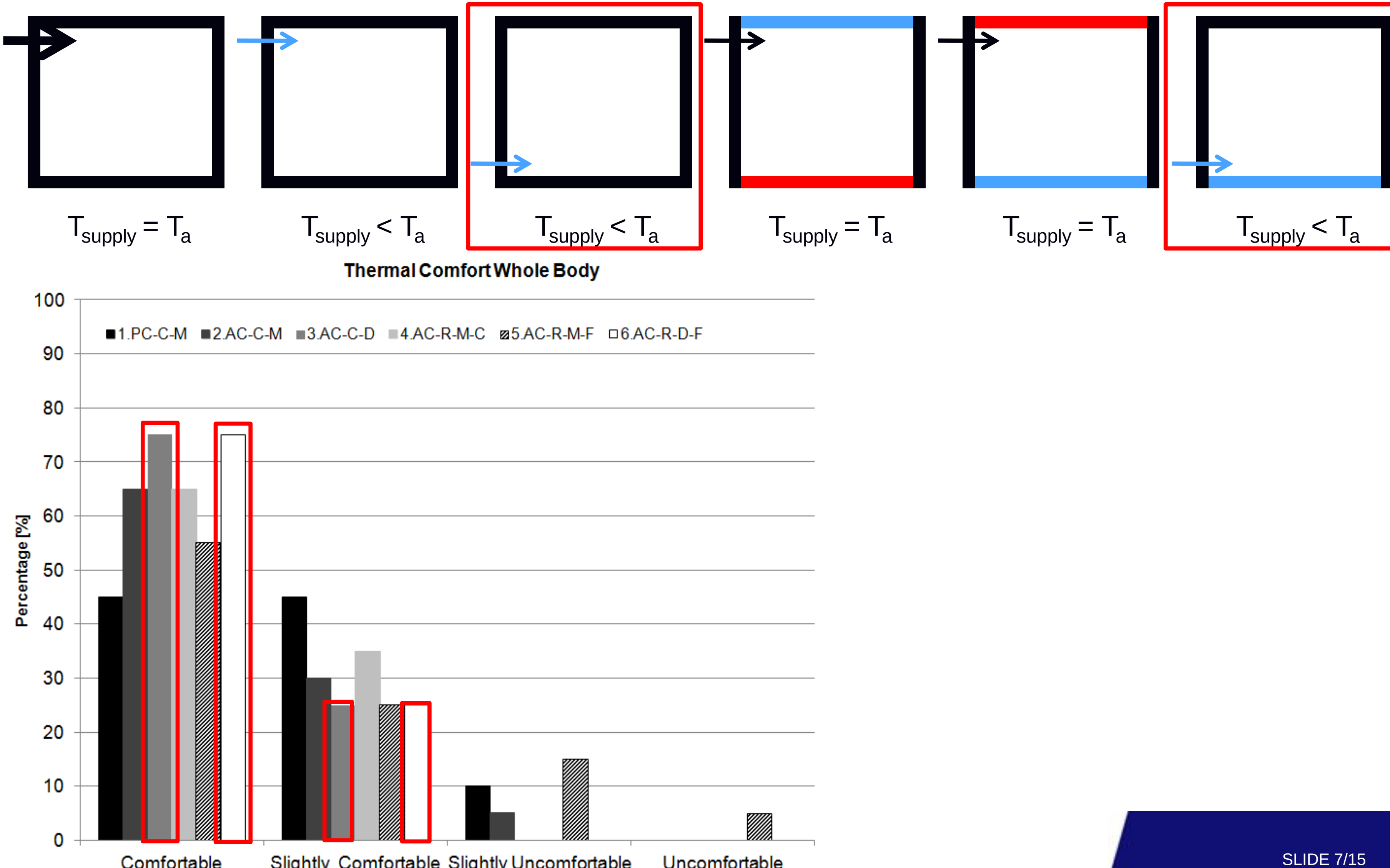
10 healthy female subjects ( )

Results - Males

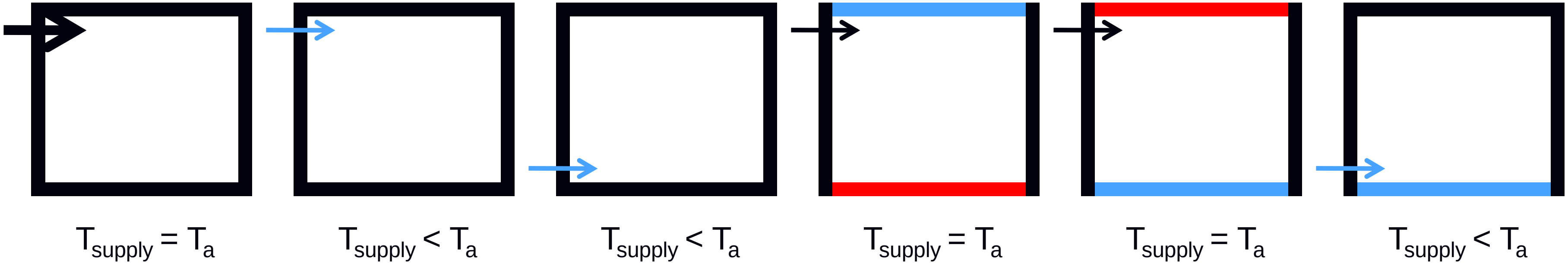




Results - Males

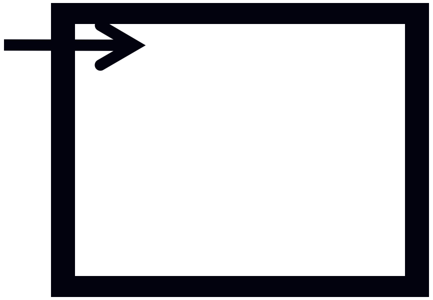


Results - Males

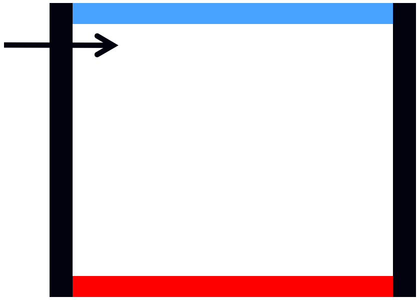


Variable	Norm	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
PD Draft (DR) [%]	<20						
PD Vertical air temperature difference [%]	<5						
PD Warm or Cool floor [%]	<10						
PD Warm or Cool Ceiling	<5						

Results – Males vs Females



T_o = 25.3 ± 0.17°C
T_a = 25.5 ± 0.21°C
T_{rm} = 25.0 ± 0.12°C
v_a = 0.27 ± 0.02 m/s



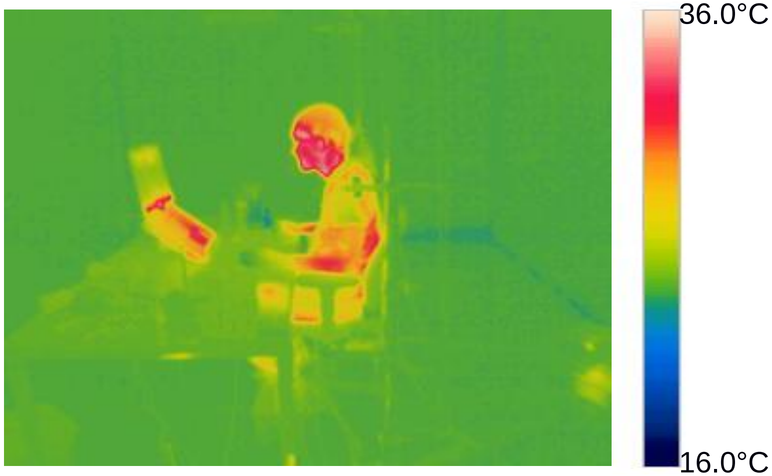
T_o = 24.4 ± 0.06°C
T_a = 24.1 ± 0.08°C
T_{rm} = 24.6 ± 0.04°C
v_a = 0.14 ± 0.00 m/s

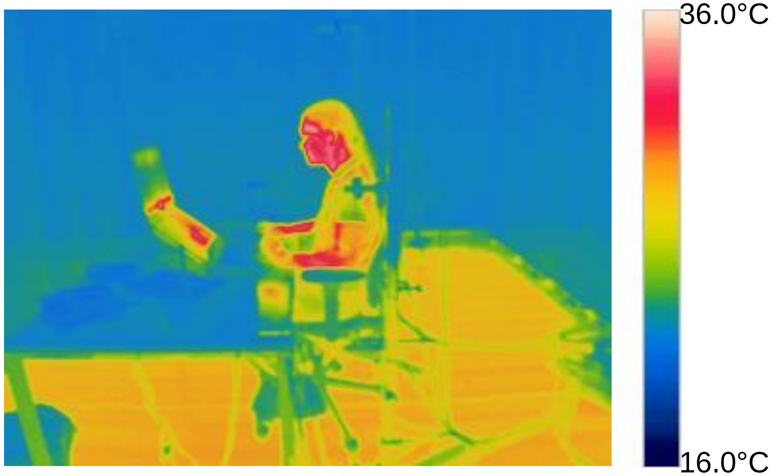
$T_{supply} = T_a$

$T_{supply} = T_a$

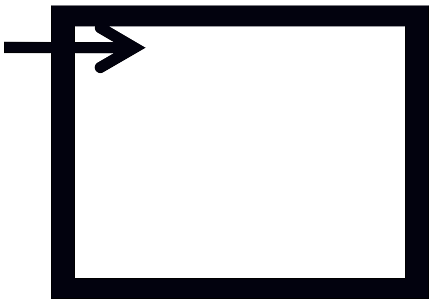
Passive cooling – Uniform (1)

Active cooling – Non-uniform (4)





Results – Males vs Females



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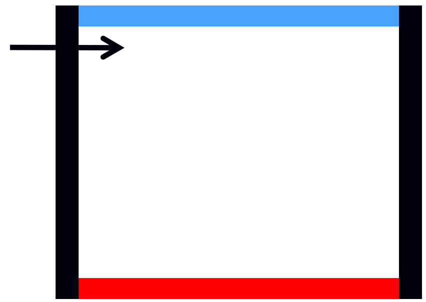


T_o = 24.4 ± 0.06°C
T_a = 24.1 ± 0.08°C
T_{rm} = 24.6 ± 0.04°C
v_a = 0.14 ± 0.00 m/s

$T_{supply} = T_a$

Subject votes

Variable	Males	Females
PMV [-]	0.3 ± 0.05	0.1 ± 0.07^
AMV [-]	-0.3 ± 0.64*	-0.4 ± 0.95*,^

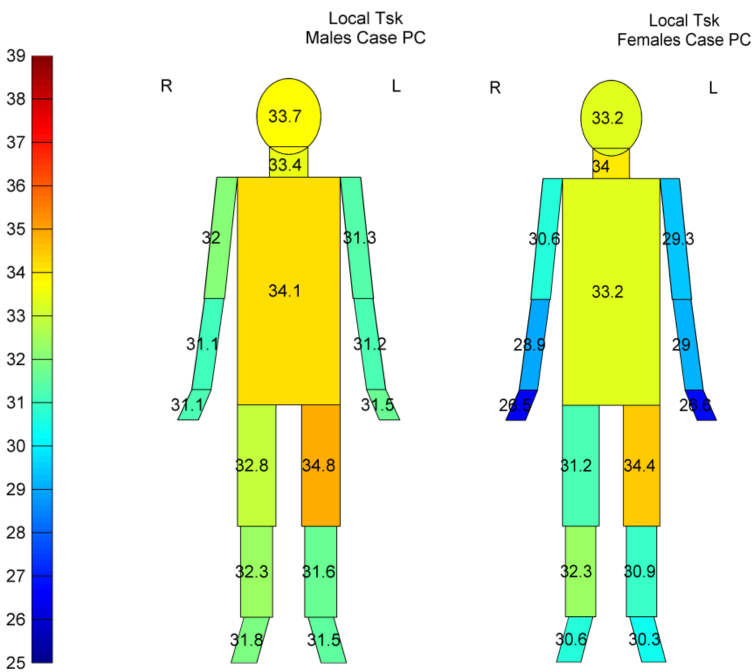
Variable	Males	Females
PMV [-]	0.1 ± 0.02#	0.0 ± 0.02^,#
AMV [-]	-0.3 ± 0.41*	-0.6 ± 0.69*,^

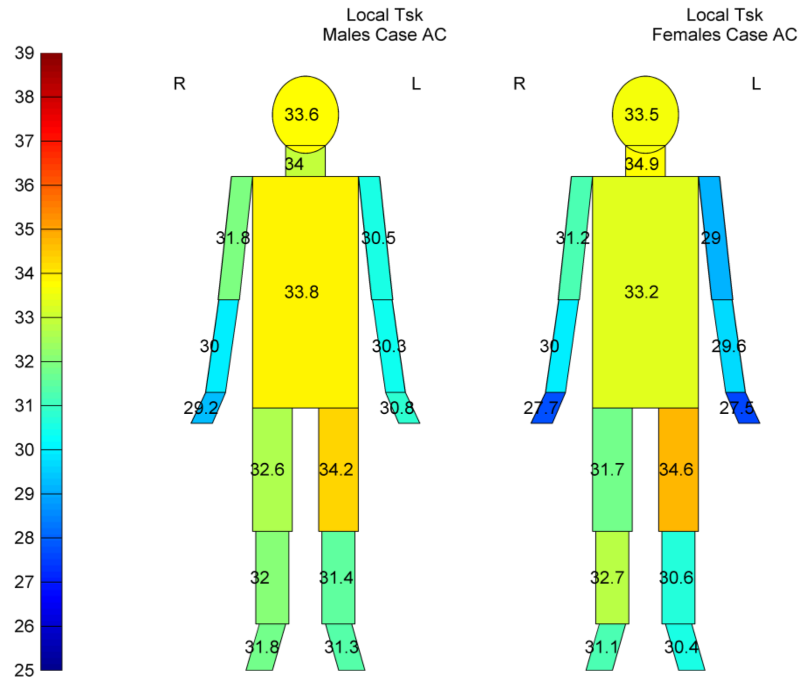
* Significant different from PMV ($p<0.001$)

^ Significant different from males ($p<0.05$)

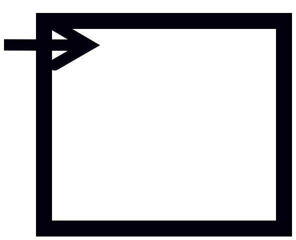
Significant different from case PC ($p<0.001$, within gender)

Results – Local skin temperatures

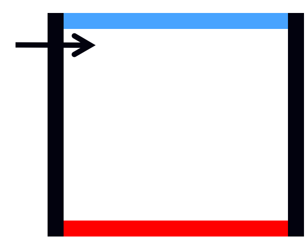




Males **Females** **Males** **Females**

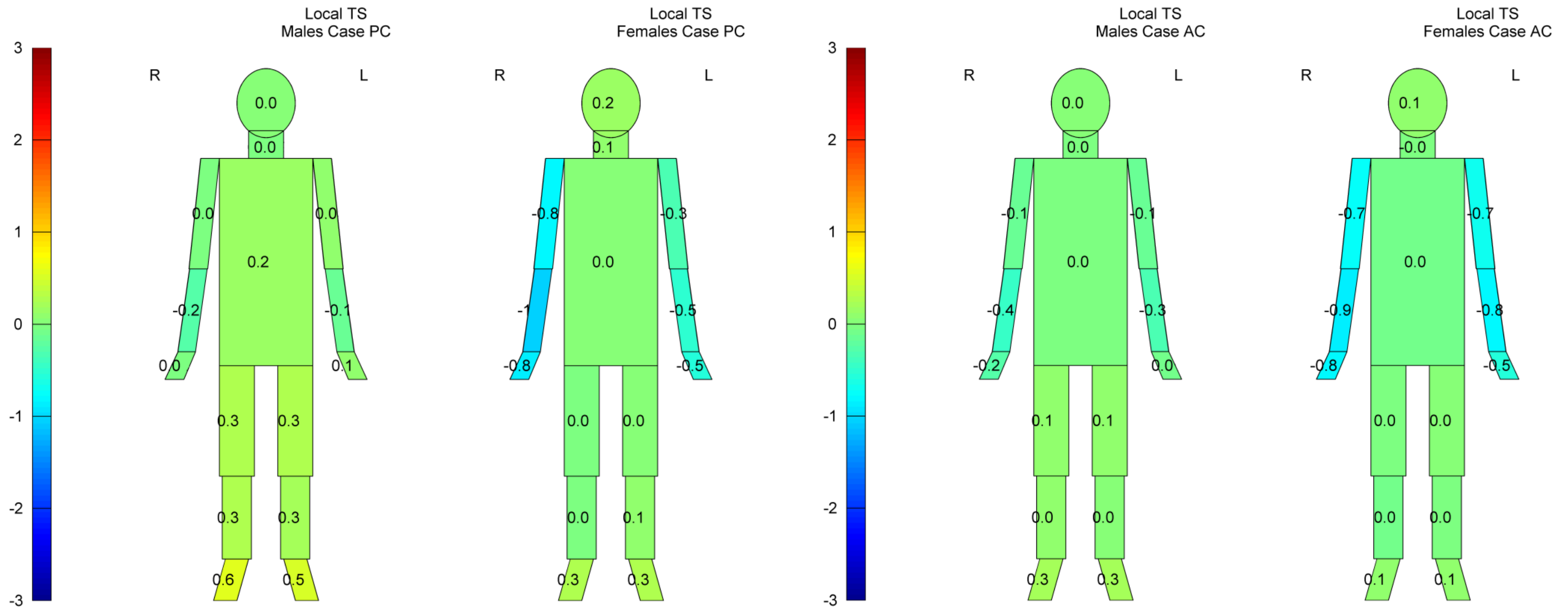


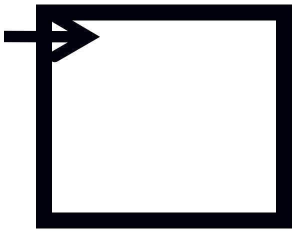
$T_{supply} = T_a$



$T_{supply} = T_a$

Results – Local thermal sensation

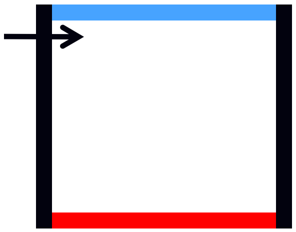




$T_{supply} = T_a$

$AMV_{;WB;males} = -0.3 \pm 0.64$

$AMV_{;WB;females} = -0.4 \pm 0.95$

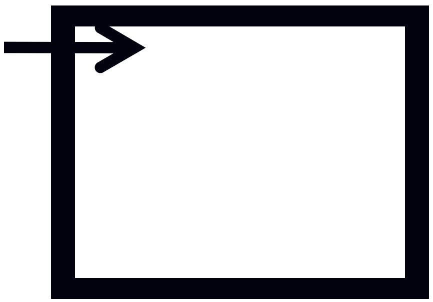


$T_{supply} = T_a$

$AMV_{;WB;males} = -0.3 \pm 0.41$

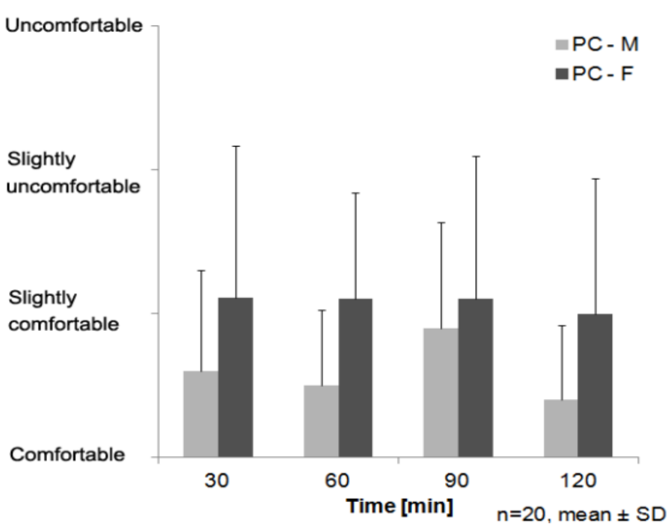
$AMV_{;WB;females} = -0.6 \pm 0.69$

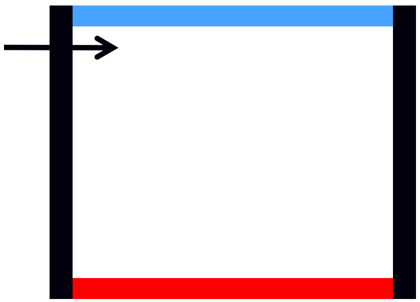
Results – Subject votes



$T_{supply} = T_a$

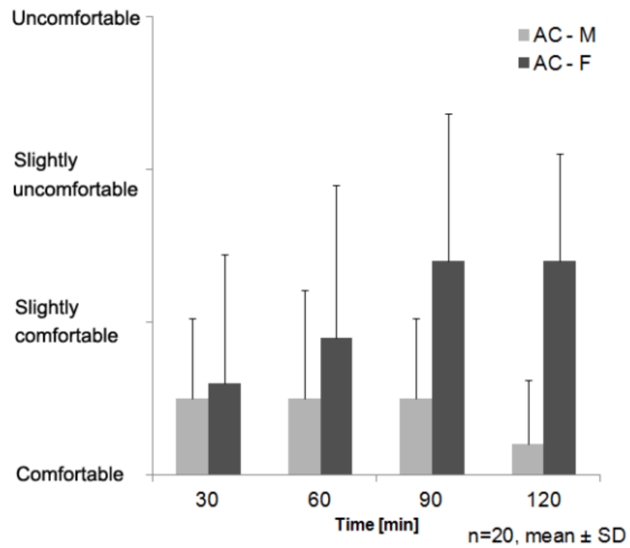
Passive cooling - Uniform





$T_{supply} = T_a$

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**

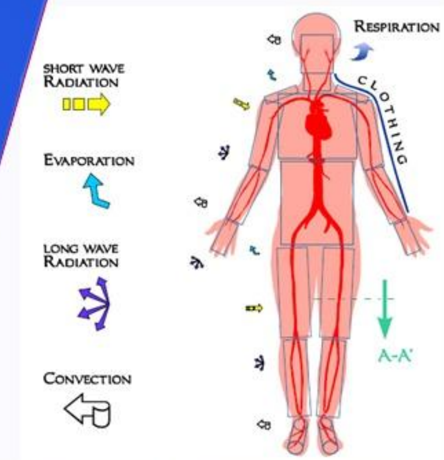
→ **Emphasis should be on a more individualized assessment** *[Schellen et al. 2010]*

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.**

Effects of different cooling principles

on thermal sensation and physiological responses



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