TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Effects of different cooling principles on thermal sensation and physiological responses

Citation for published version (APA):
Schellen, L., Wit, de, M. H., Loomans, M. G. L. C., & Marken Lichtenbelt, van, W. D. (2012). Effects of different cooling principles on thermal sensation and physiological responses. In *Proceedings of Windsor 2012 Conference : The changing context of comfort in an unpredictable world, 12-15 April 2012, Windsor, United Kingdom*

Document status and date:
Published: 01/01/2012

Document Version:
Accepted manuscript including changes made at the peer-review stage

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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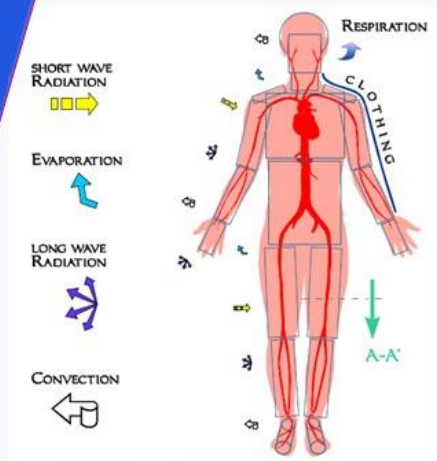
Effects of different cooling principles

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.

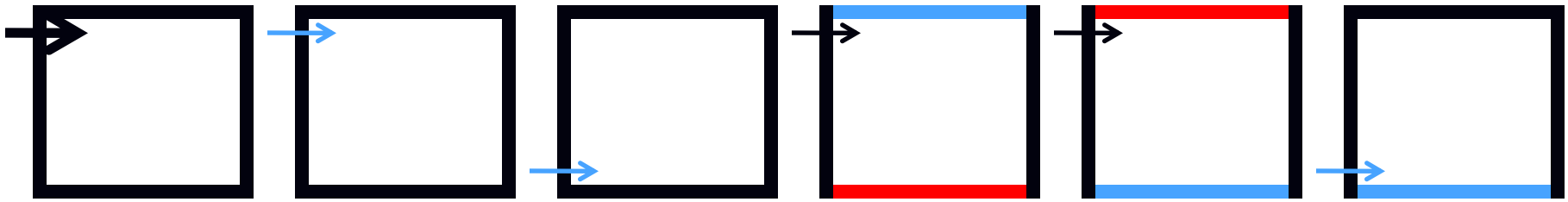
Combined radiant and convective heat transfer play an important role in the assessment of thermal comfort.

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

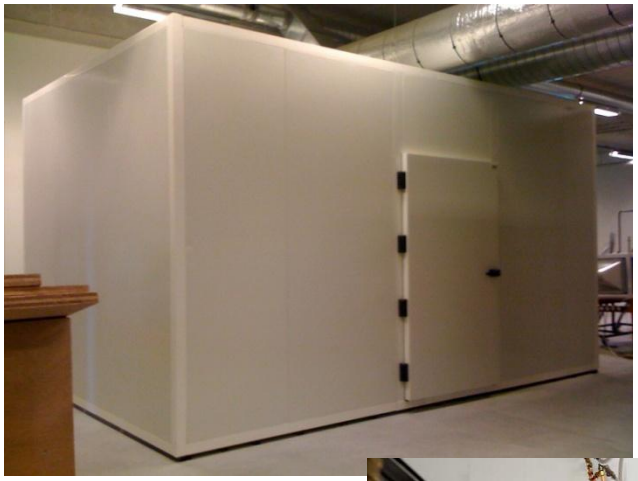
Methods - Cases

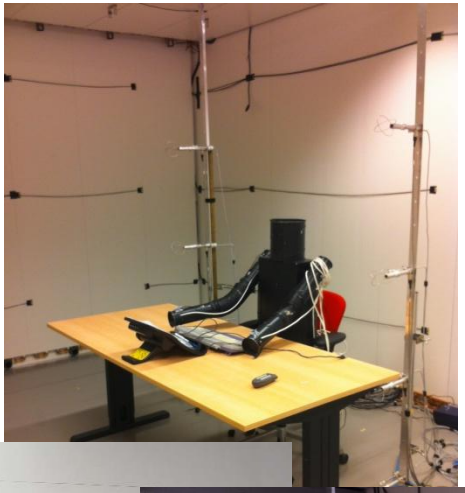
Cooling:

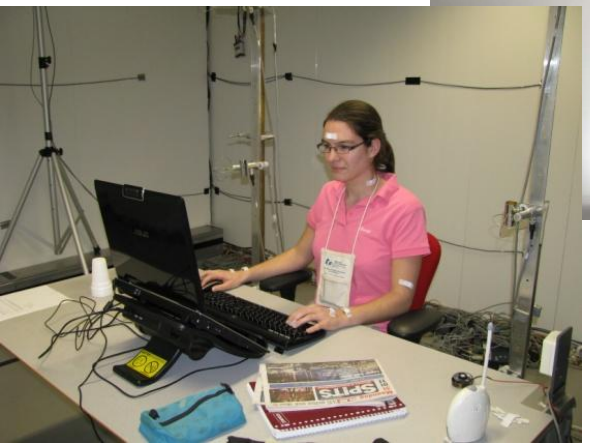
1. **Passive cooling through mixing ventilation**
2. **Active cooling through convection and mixing ventilation**
3. **Active cooling through convection and displacement ventilation**
4. **Active cooling through radiation by the ceiling and mixing ventilation**
5. **Active cooling through radiation by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

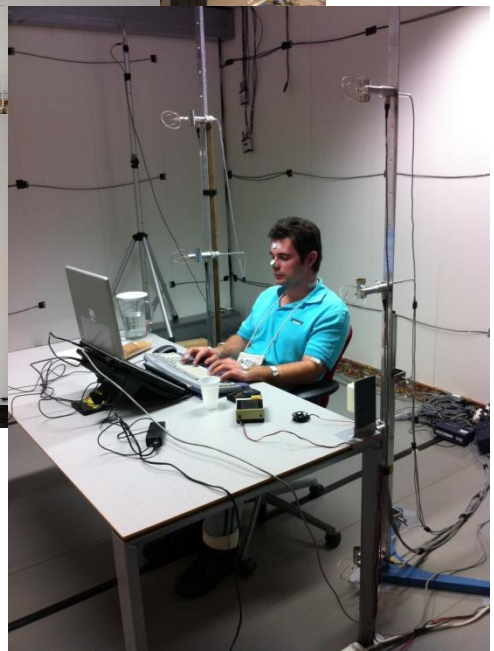


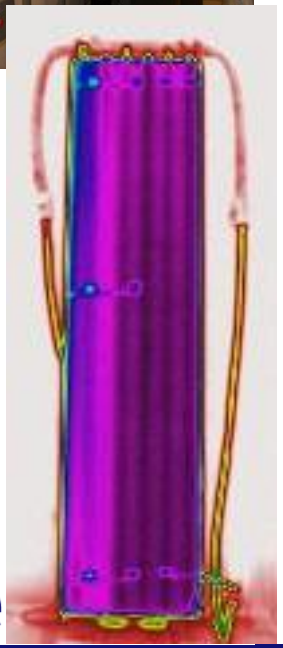
Methods - Thermophysiological test room







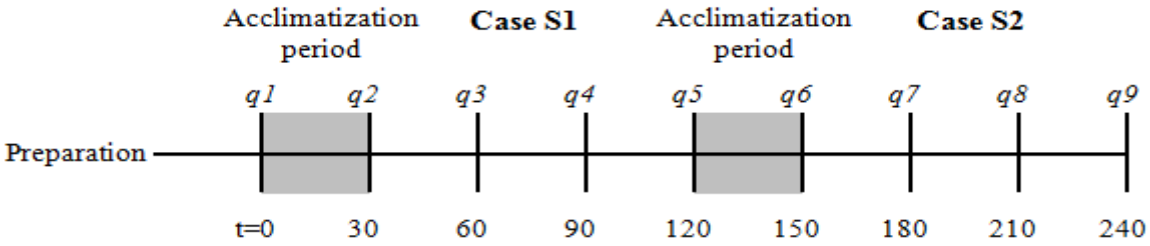




TU/e

Methods (2)

Time schedule

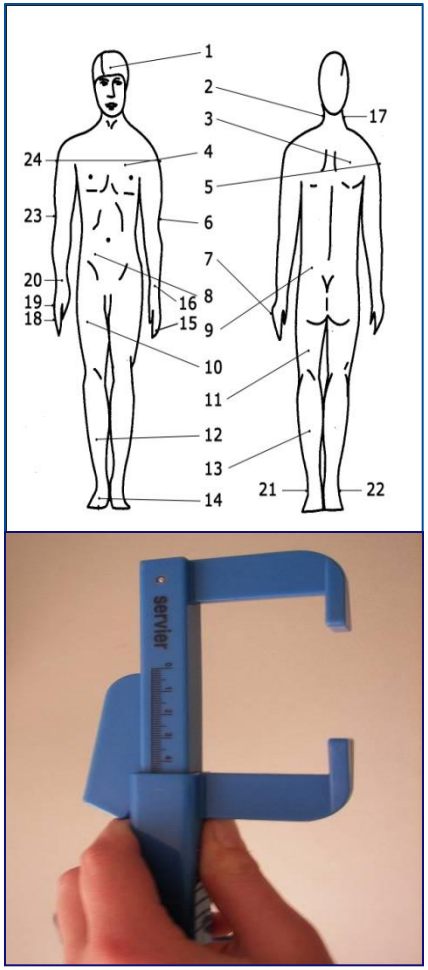


Measurements

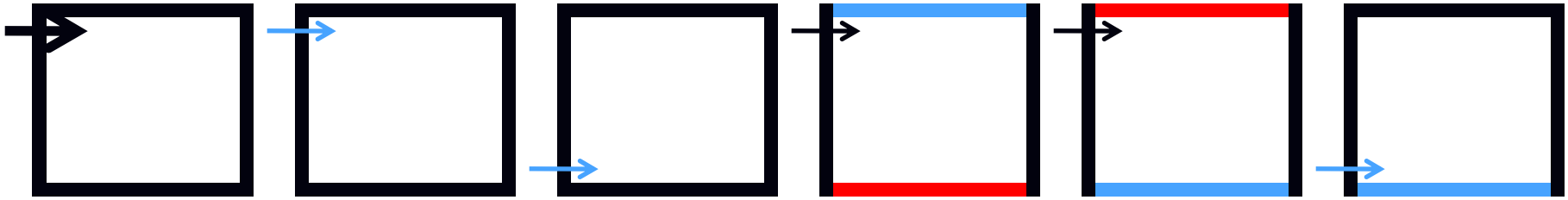
- **Physical** (T_a, RH, v_a, T_r, E_v) **and physiological parameters** (T_{sk}, T_{cr}, vasomotion) **continuously.**

Questionnaires

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



Methods



$T_{supply} = T_a$	$T_{supply} < T_a$	$T_{supply} < T_a$	$T_{supply} = T_a$	$T_{supply} = T_a$	$T_{supply} < T_a$
$T_o = 24.5°C$	$T_o = 24.5°C$	$T_o = 23.5°C$	$T_o = 24.5°C$	$T_o = 24.5°C$	$T_o = 23.5°C$

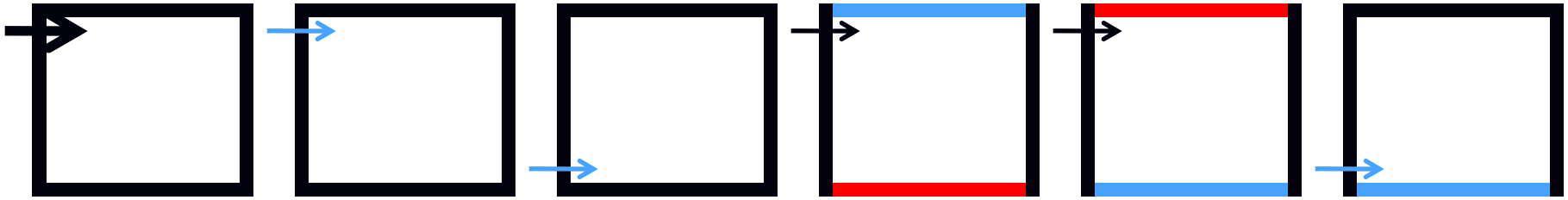
Boundary conditions all cases:

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

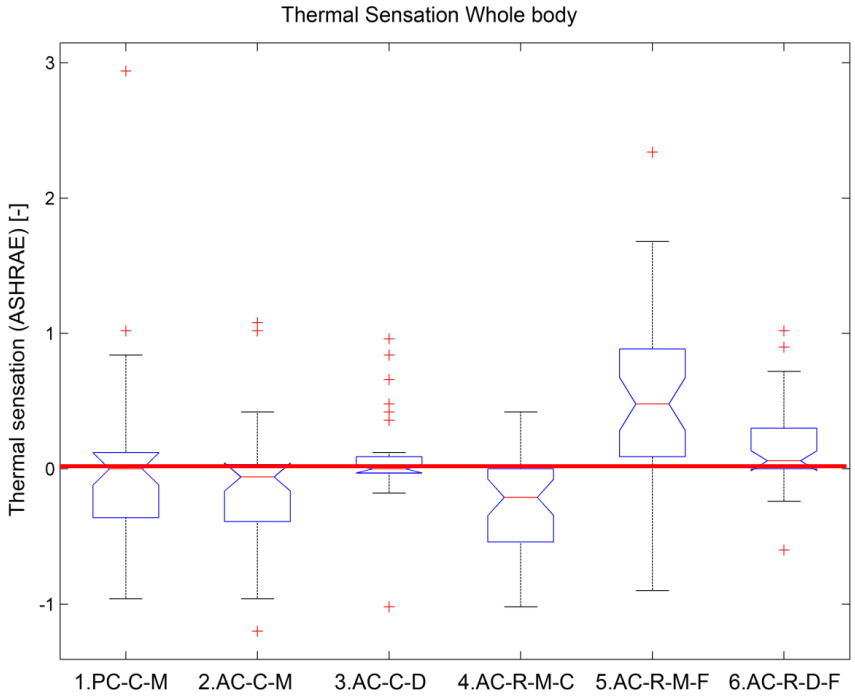
10 healthy male subjects (♂)

10 healthy female subjects ( )

Results - Males

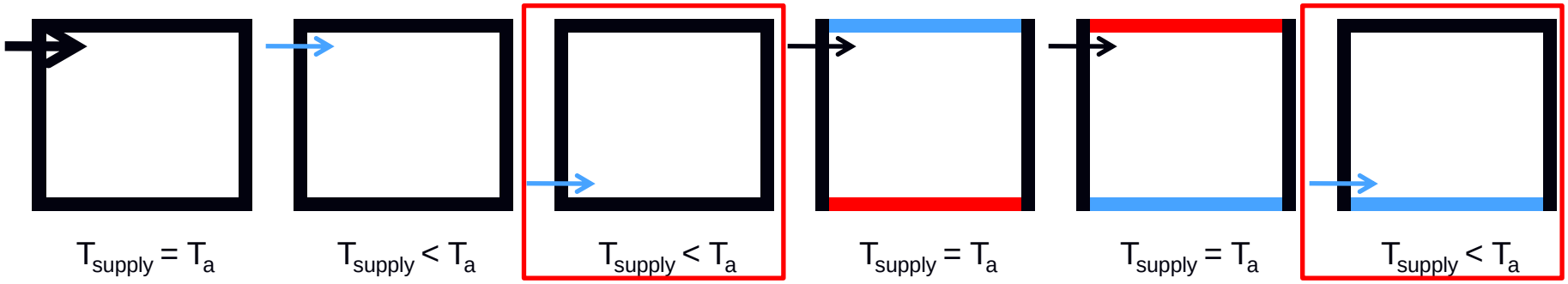


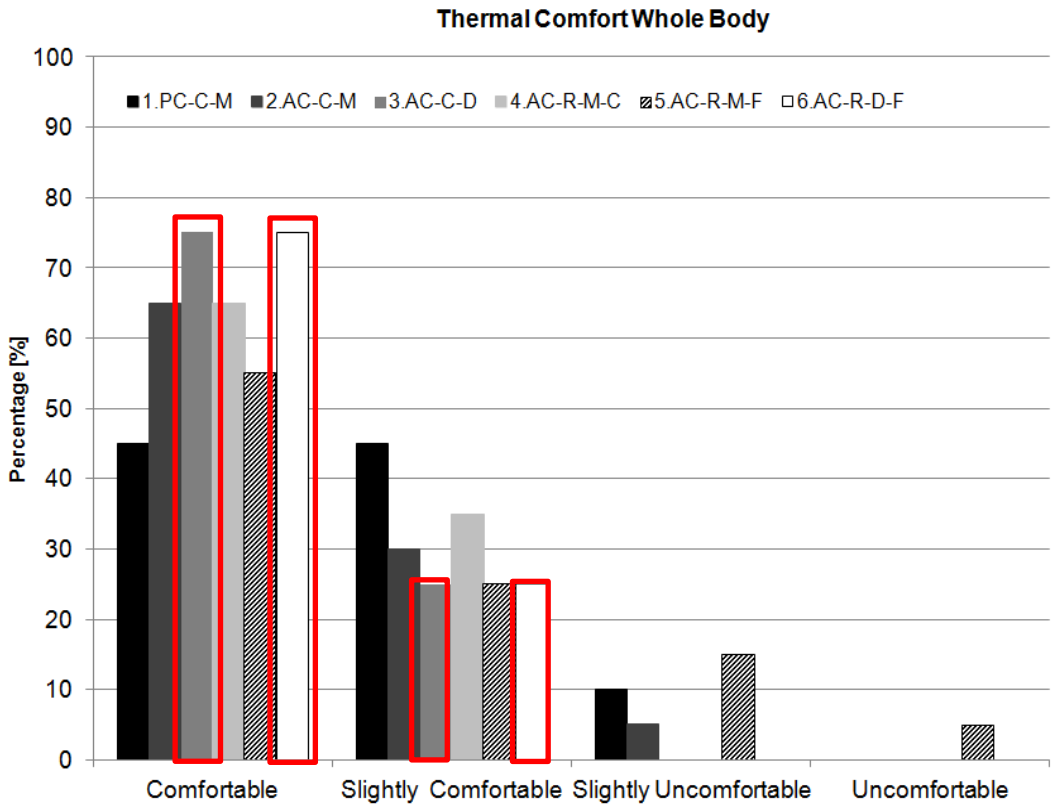
$T_{supply} = T_a$ $T_{supply} < T_a$ $T_{supply} < T_a$ $T_{supply} = T_a$ $T_{supply} = T_a$ $T_{supply} < T_a$



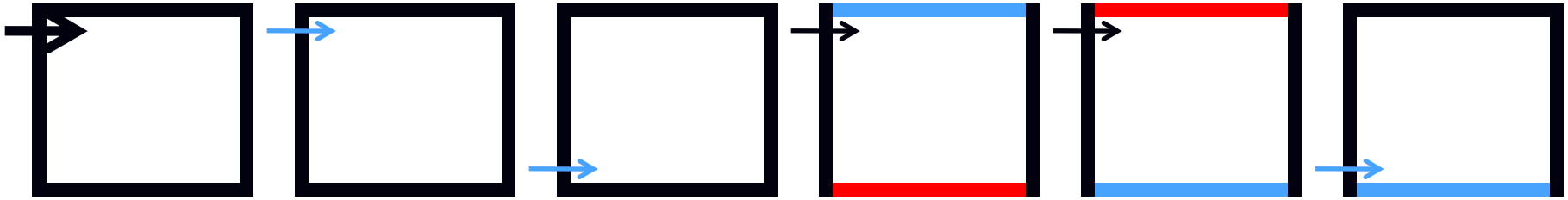
PMV = 0

Results - Males



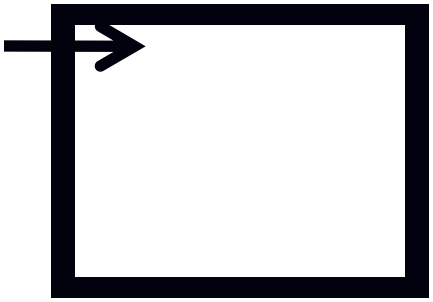


Results - Males



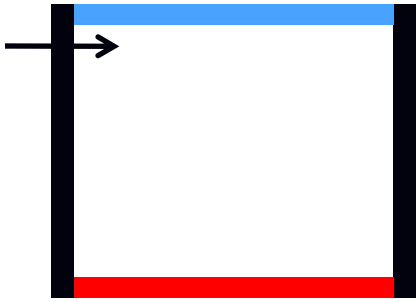
Variable	Norm	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
PD Draft (DR) [%]	<20						
PD Vertical air temperature difference [%]	<5						
PD Warm or Cool floor [%]	<10						
PD Warm or Cool Ceiling	<5						

Results – Males vs Females



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

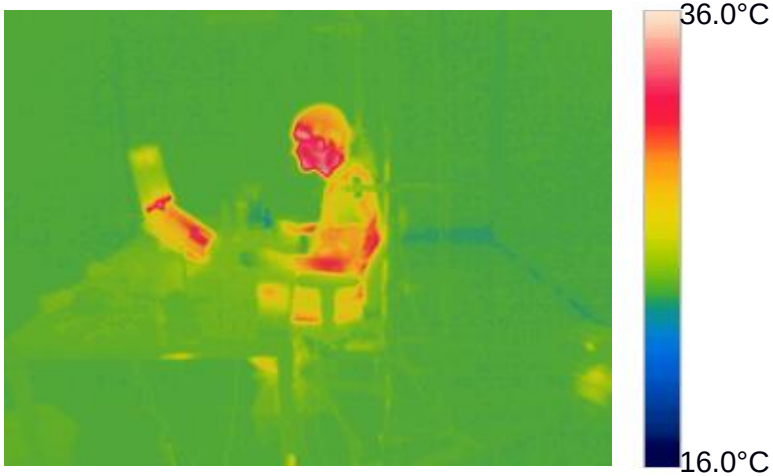
$T_{supply} = T_a$



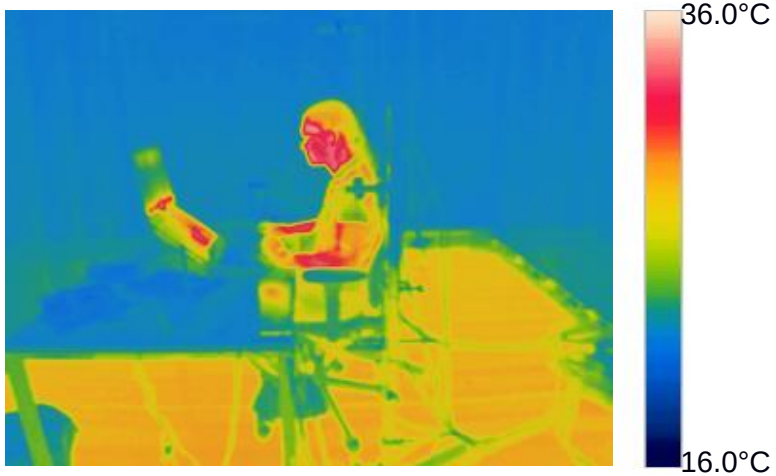
$T_o = 24.4 \pm 0.06°C$
$T_a = 24.1 \pm 0.08°C$
$T_{rm} = 24.6 \pm 0.04°C$
$v_a = 0.14 \pm 0.00$ m/s

$T_{supply} = T_a$

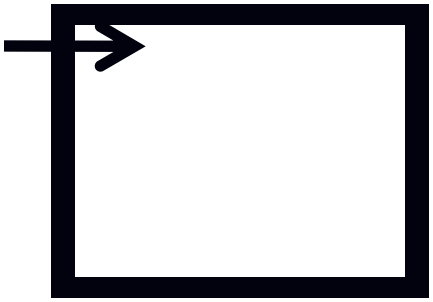
Passive cooling – Uniform (1)



Active cooling – Non-uniform (4)

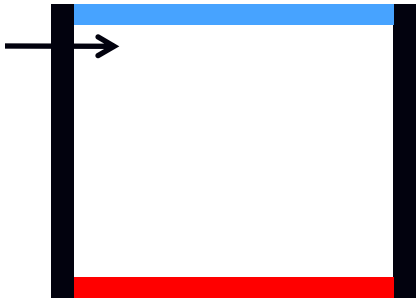


Results – Males vs Females



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

$T_{supply} = T_a$



$T_o = 24.4 \pm 0.06°C$
$T_a = 24.1 \pm 0.08°C$
$T_{rm} = 24.6 \pm 0.04°C$
$v_a = 0.14 \pm 0.00$ 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*,^

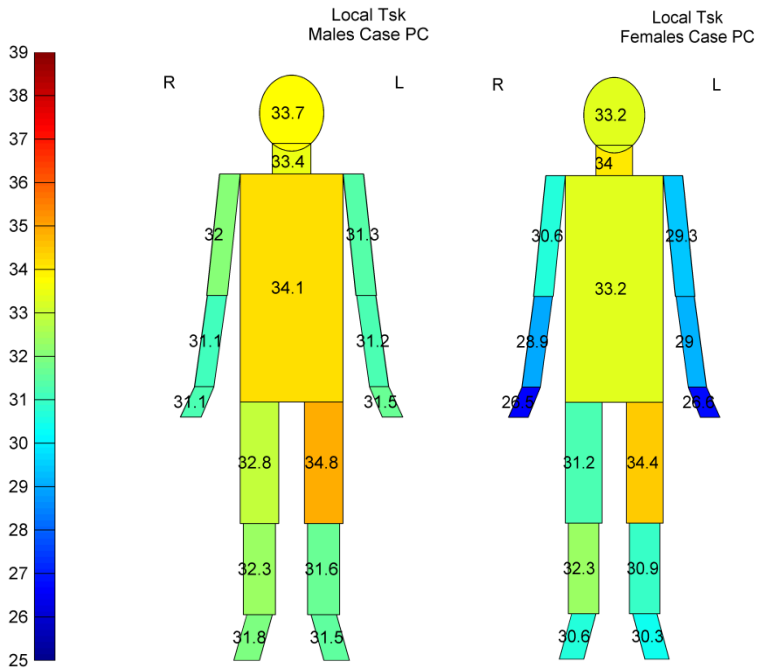
Variable	Males	Females
PMV [-]	0.1 ± 0.02#	0.0 ± 0.02^,#
AMV [-]	-0.3 ± 0.41*	-0.6 ± 0.69*,^

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

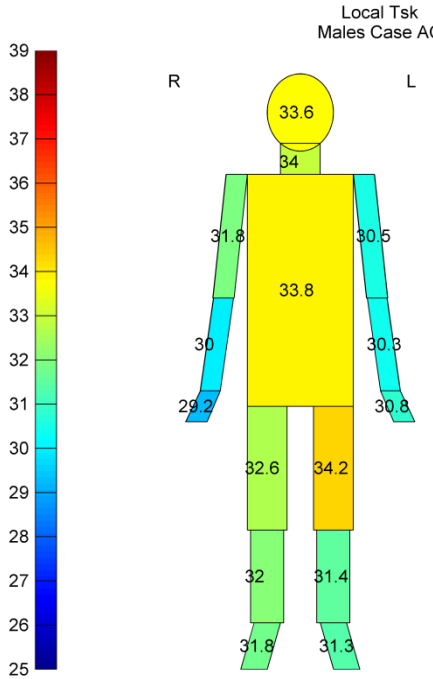
^ Significant different from males ($p<0.05$)

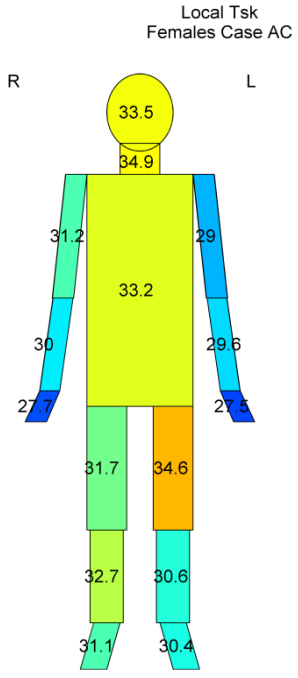
Significant different from case PC ($p<0.001$, within gender)

Results – Local skin temperatures

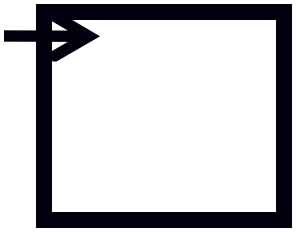


Males **Females**

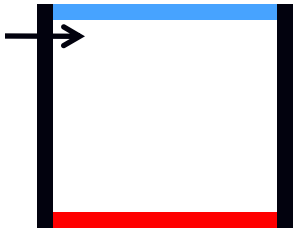




Males **Females**

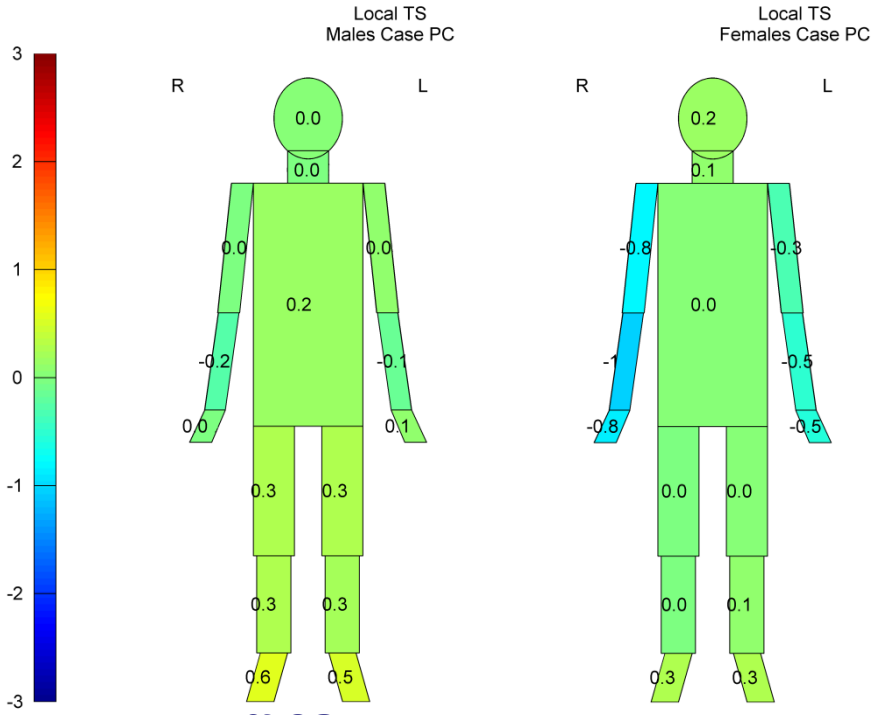


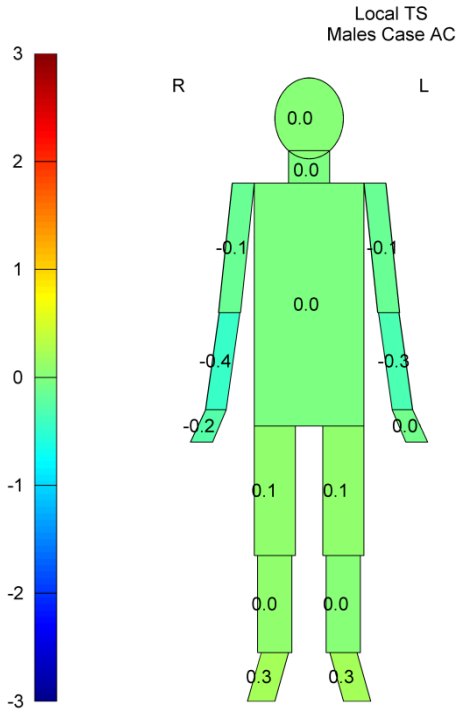
$T_{supply} = T_a$

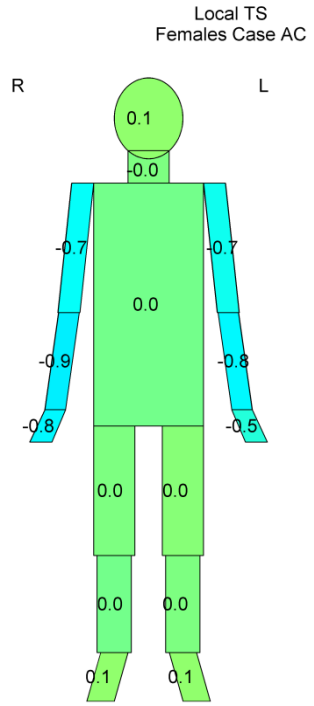


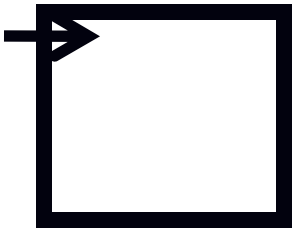
$T_{supply} = T_a$

Results – Local thermal sensation





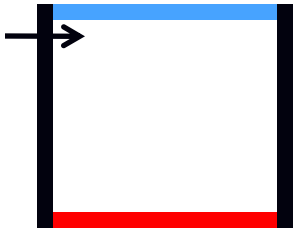




$AMV_{;WB;males} = -0.3 \pm 0.64$

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

$T_{supply} = T_a$

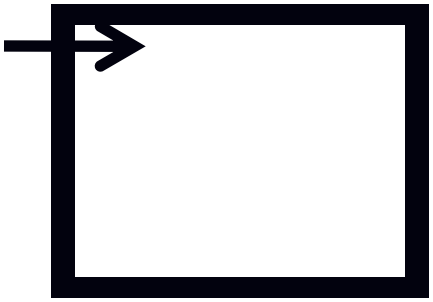


$AMV_{;WB;males} = -0.3 \pm 0.41$

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

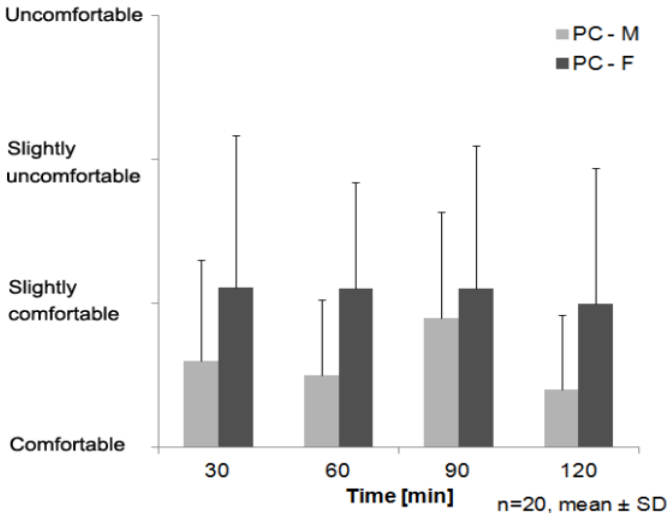
$T_{supply} = T_a$

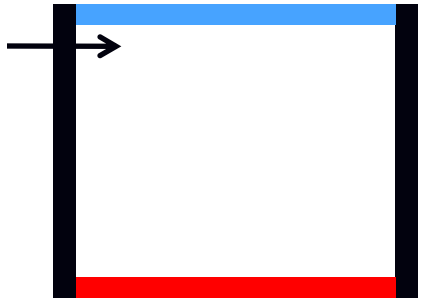
Results – Subject votes



$T_{supply} = T_a$

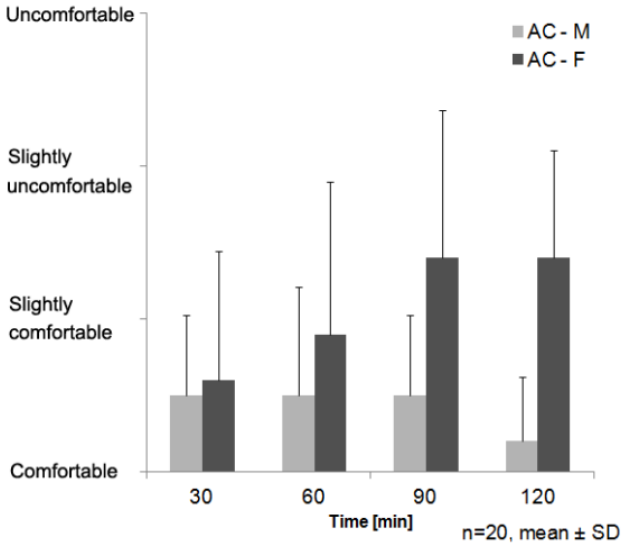
Passive cooling - Uniform





$T_{supply} = T_a$

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**

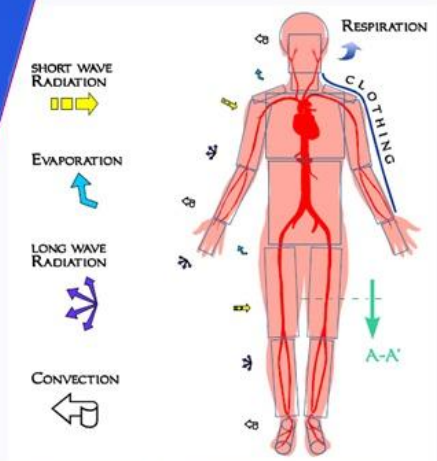
→ **Emphasis should be on a more individualized assessment** *[Schellen et al. 2010]*

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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