

Local thermal discomfort caused by temperature stratification

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Temperature (thermal) stratification



Credit: (Left) Jack Cook, Woods Hole Oceanographic Institution; (Right) Tom Webster (2002), ASHRAE Journal

Vertical air temperature differences

- Large variation of suggested maximum stratification
- Different metrics to determine discomfort



8 °C

Simulated acceptable stratification varies with overall thermal sensation

• 7 °C stratification is acceptable at the center of thermal neutrality



Reproduced from Zhang et. al (2005)

Objective

Develop a local discomfort model to predict the percentage dissatisfied with vertical air temperature difference between head and ankles

Experimental setup

- Underfloor air distribution (UFAD) system with convective heaters
- Temp. controlled by a thermostat (1.1 m) for thermal neutrality



Six workstations (sedentary activity) (minimum effects by air movement)



Temperature at four heights (0.1, 0.6, 1.1 and 1.7 m)

Experimental conditions

 Temperature distribution 			— 0.4 °C	C/m 2.9 °C/m	— 5.9 °C/m —	8.4 °C/m
Temp. diff. 0.1 & 1.1 m °C	Averaged over 0.1, 0.6 & 1.1 m °C	ົ ວົຼ				
0.4	22.9	- <u>ໍ</u> 25 ຳ ຍ	54030			
2.9	22.8	ratui			1412	
5.9	21.7	- upe	2.4		ित्म प स.जाम्म इ.त. हिन्द	20 20 20 20 20 20 20 20 20 20 20 20 20 2
8.3	20.9	та 20 °			5 . S	
				6°9%		
• 66 female	s & 32 males	15				
— I _{cl} : 0.4 - 0.7 clo.			0.0	0.5 Heigl	1.0 nt (m)	1.5

7

Your full name (First Last)

Questionnaires

- Thermal sensation
 - Cold(-3) to Hot (3)
 - Whole body, head, feet
- Thermal comfort
 - Very uncomfortable(-3) to Very comf.(3)
 - Whole body, head, feet
 - Non-zero value
- Thermal acceptability
 - Clearly unacceptable(-3) to Clearly accep.(3)
 - Whole body
 - Non-zero value
- Thermal preference
 - Warmer, No change & Cooler

Your workstation number

A	D
В	E
с	F

Thermal environment for whole body

Rate your current whole body thermal sensation

Cold (-3)			Neutral (0)			Hot (3)		
-3	-2	-1	0	1	2	3		
			•					

Rate your whole body thermal comfort (select a non-zero value)

Very uncomfortable			Very comfortable			
-3	-2	-1	0	1	2	3

Protocol and discomfort metric

Thermal acclimation + three votes within 90 min

	Training & Adaptation	Vote	Test	Vote	Test	Vote	
0	3	0 4	0 5	56	5 8	0 90	min

- Criterion for local discomfort due to thermal stratification
 - Sub-dataset with "No change" thermal preference
 - uncomfortable cold ankles (TC<0 & TS_ankle <0)</p>

or

uncomfortable warm head ($TC < 0 \& TS_{head} > 0$)

Results - thermal sensation

 Warm-head-cold-ankles is related to high thermal stratification



Results – local thermal comfort

Comfort level at head and ankles reduces with temperature difference



Acceptable vertical air temperature difference between head and ankles

- Allowed stratification depends on whole-body thermal sensation
- ~4-5.5°C (7.5-9°C) difference causes 10% (20%) dissatisfaction



Summary

- Whole-body thermal sensation affects local discomfort with thermal stratification
- We developed a new model to predict percentage dissatisfied with vertical air temperature difference (*PPD_VATD*) between head and ankles
- For 10% (20%) dissatisfaction, the allowed temperature difference could be 4-5.5°C (7.5-9°C), larger than ASHRAE 3 °C
- The finding may lead to building energy savings

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Predicted percentage dissatisfied with vertical air temperature difference (*PPD*_*VATD*)

• Logistic regression (0 = dissatisfied; 1 = satisfied)



16

Results - thermal sensation

- Warm-head-cold-ankles is related to high thermal stratification
- Males have a negligibly higher overall & ankle thermal sensations

