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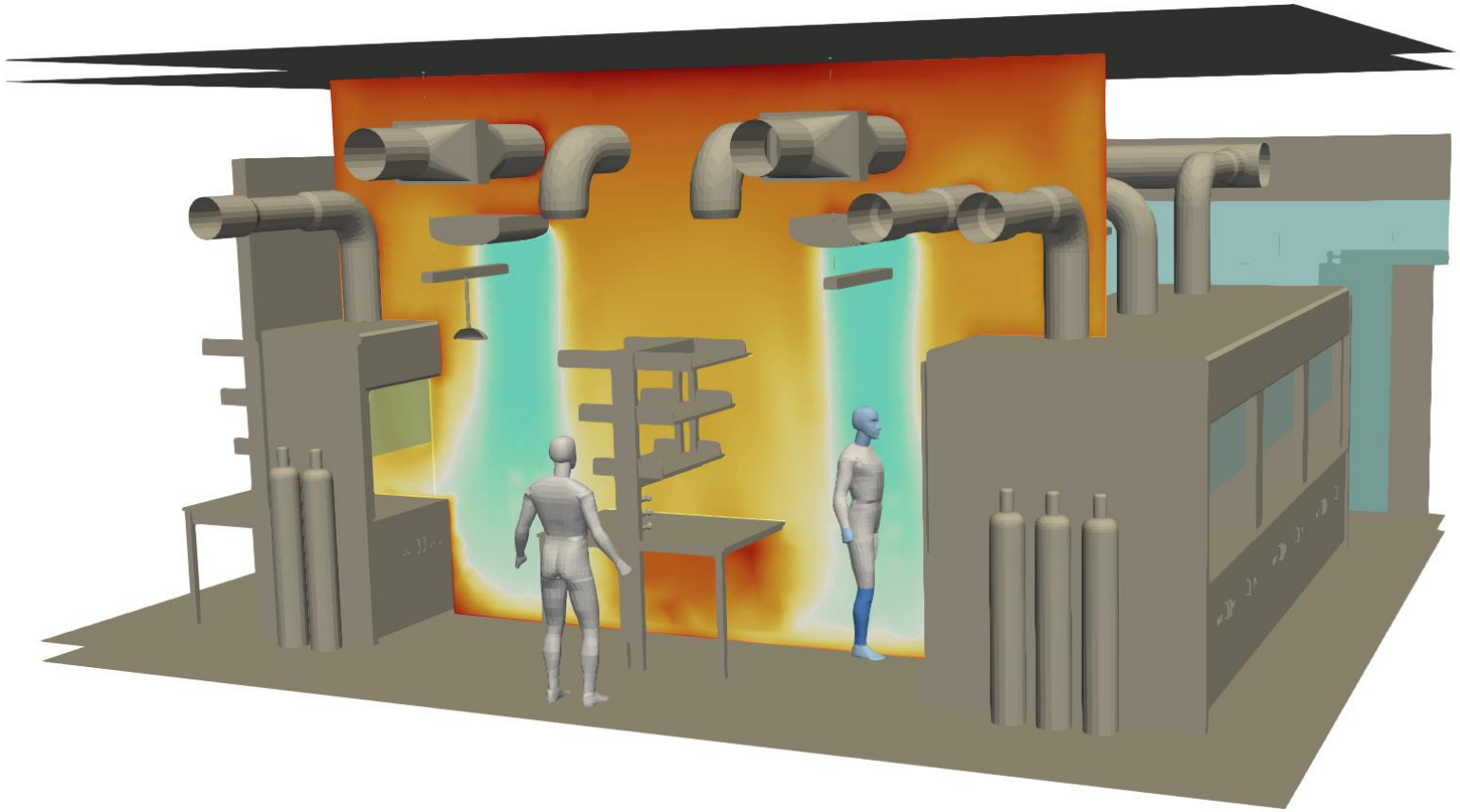
# Equity and Thermal Comfort

Nathaniel Jones, PhD



**IBPSA-Houston Performance Huddle**

21 October 2022

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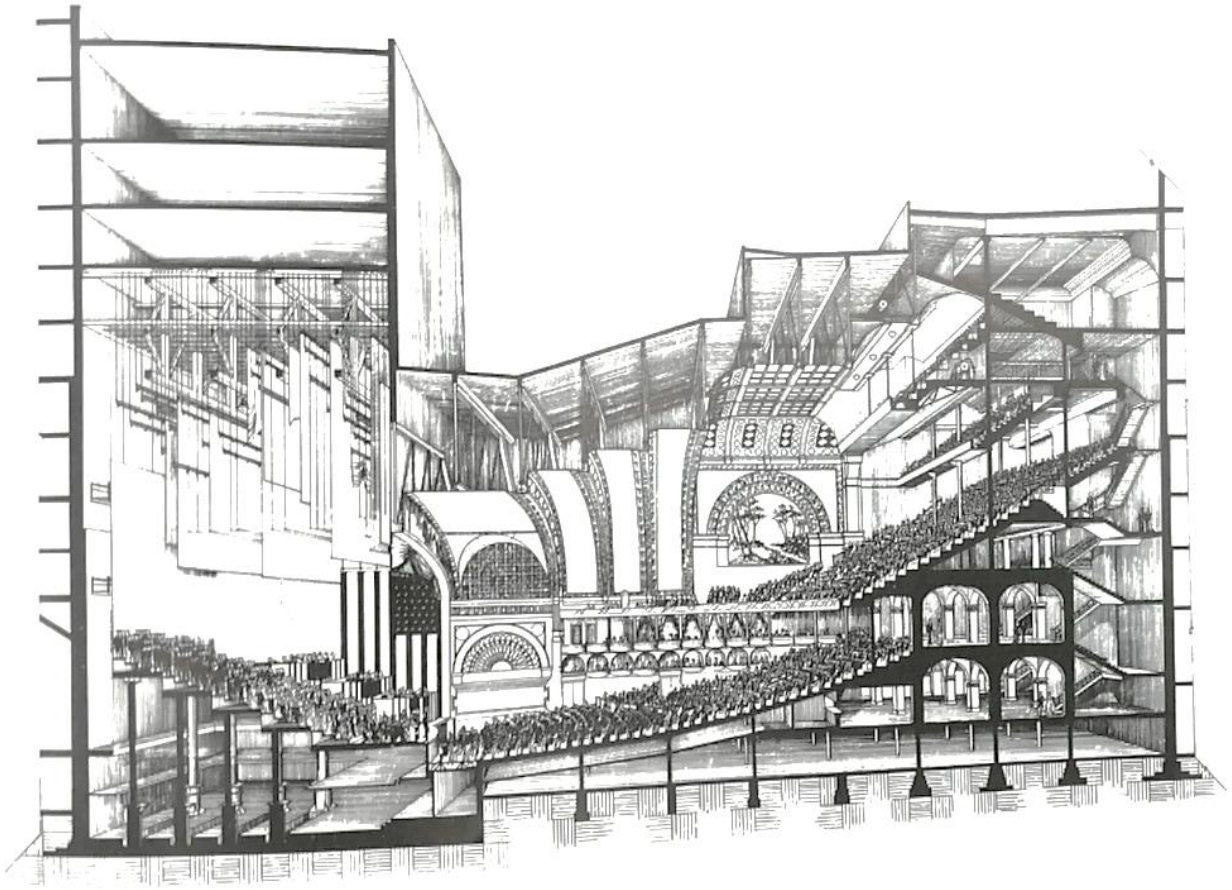
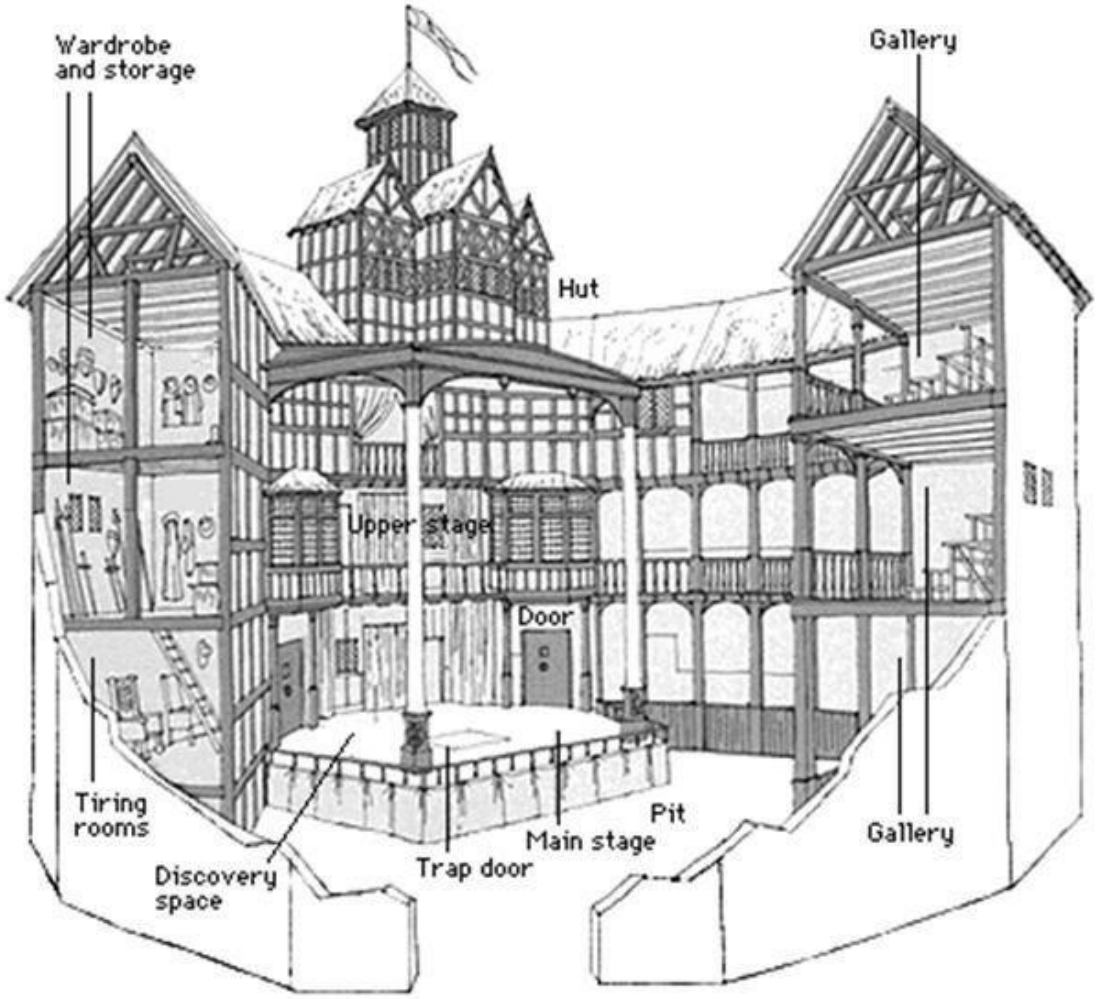


Chicago Auditorium Building, Louis Sullivan and Dankmar Adler




Globe Theatre

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TIVOLI
SCIENTIFICALLY AIR CONDITIONED
"DEAR RUTH"


TAMPA
"TAKE A LETTER DARLING"
ROSALIND RUSSELL
PARAMOUNT'S LATEST WAR NEWS
TAMPA'S COOL VACATIONLAND
McCASKILL CLOTHING CO.
TAKE A LETTER, Darling!


GABLE
POWELL
Essaness
BIOGRAPH
COOLED
BY REFRIGERATION


Because
we make our own
weather...
By Modern Scientific
AIR CONDITIONING

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THE NEW YORKER
AND TECH
The Warning Light on Richard Branson's Space Flight
A Life-Saving Checklist
ANNALS OF TECHNOLOGY
IS YOUR THERMOSTAT SEXIST?


The New York Times
Can an Office Temperature Be 'Sexist'? Women, and Science, Say So


npr
SIGN IN
NPR SHOP
DONATE
YOUR HEALTH
Women, There's A Reason Why You're Shivering In The Office
August 4, 2015 · 12:13 PM ET
RAE ELLEN BICHELL


NEW YORK POST
LIVING
Cold office temperatures are hurting women's productivity, study says

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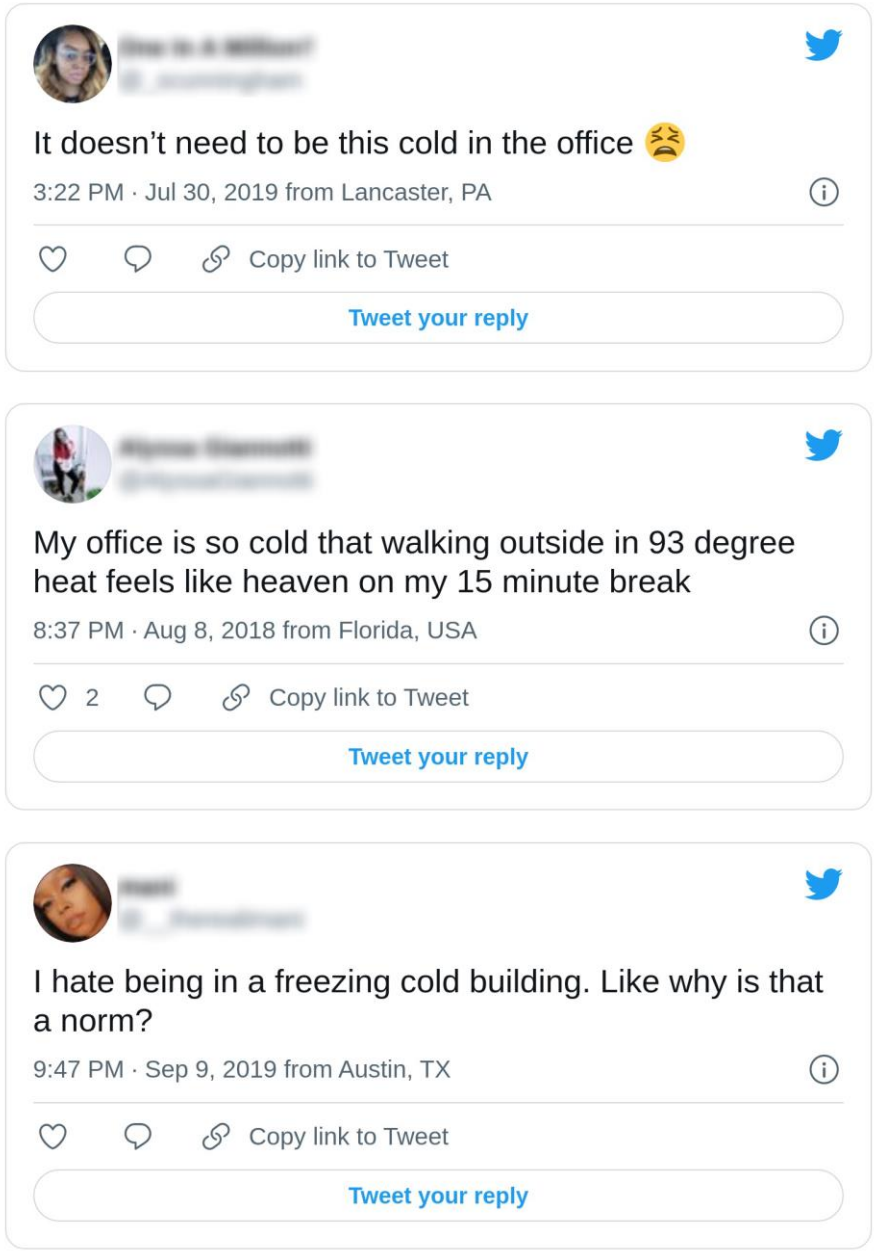


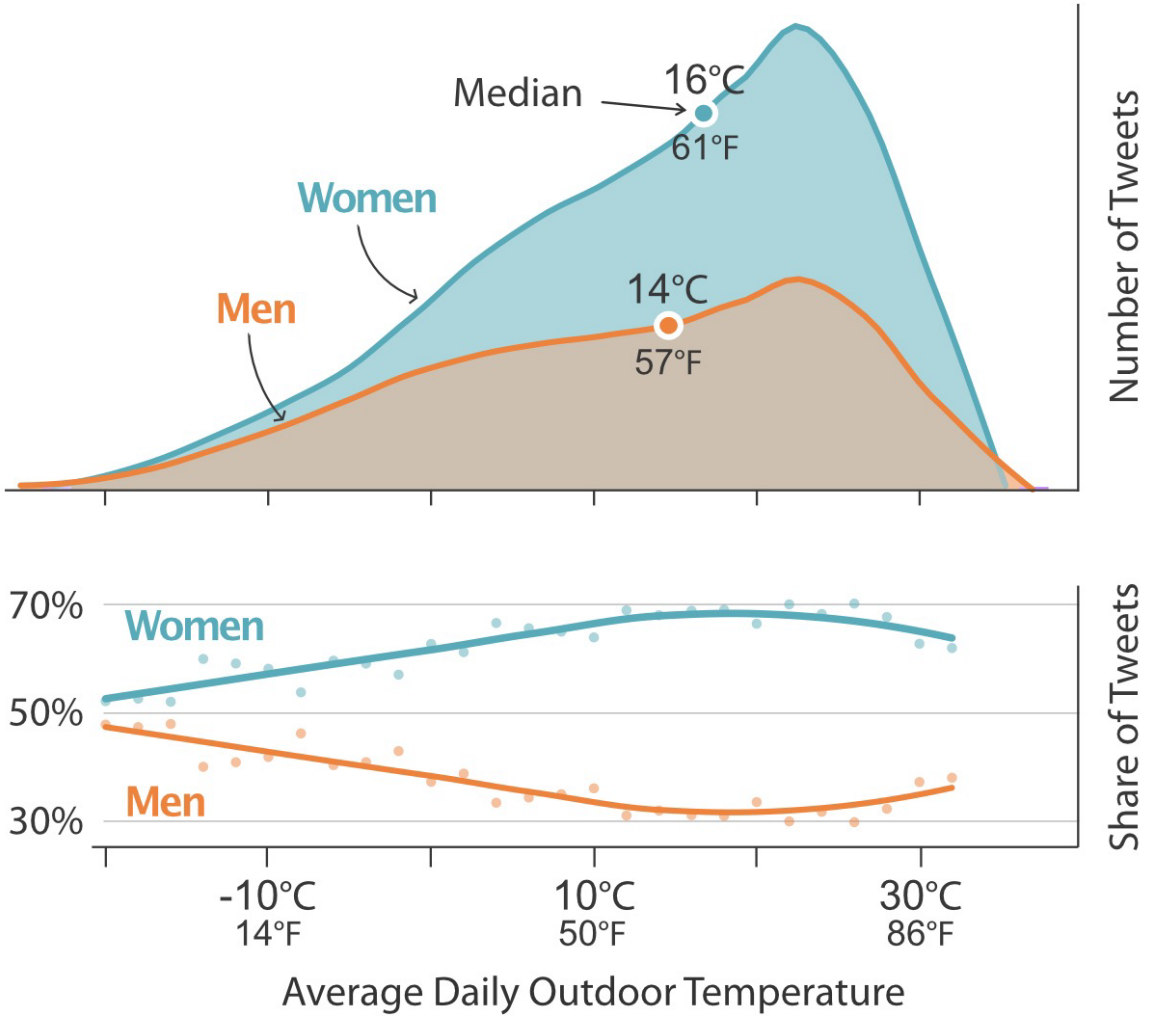


Parkinson *et al*., 2021. *Overcooling of Offices Reveals Gender Inequality in Thermal Comfort*. Scientific Reports.

Where did our “scientific” basis for thermal comfort come from?

**and**

How can we improve it?

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# Science of thermal comfort

## Colonial roots

Town Hall, Kolkata, India

St. Paul’s Cathedral, Kolkata, India

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*“It should be kept in mind that southern people, with their more sluggish heat production and lack of adaptability, will demand a comfort zone several degrees higher than those given here for the more active people of northern climates”*

*Heating, Ventilating, Air Conditioning Guide*, 1936

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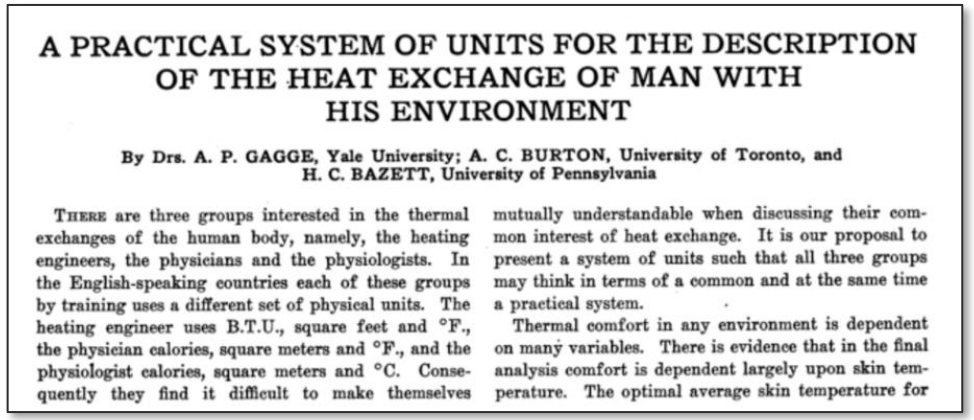


A PRACTICAL SYSTEM OF UNITS FOR THE DESCRIPTION OF THE HEAT EXCHANGE OF MAN WITH HIS ENVIRONMENT

By Drs. A. P. GAGGE, Yale University; A. C. BURTON, University of Toronto, and H. C. BAZETT, University of Pennsylvania

THERE are three groups interested in the thermal exchanges of the human body, namely, the heating engineers, the physicians and the physiologists. In the English-speaking countries each of these groups by training uses a different set of physical units. The heating engineer uses B.T.U., square feet and °F., the physician calories, square meters and °F., and the physiologist calories, square meters and °C. Consequently they find it difficult to make themselves mutually understandable when discussing their common interest of heat exchange. It is our proposal to present a system of units such that all three groups may think in terms of a common and at the same time a practical system.

Thermal comfort in any environment is dependent on many variables. There is evidence that in the final analysis comfort is dependent largely upon skin temperature. The optimal average skin temperature for

Gagge, Burton, and Bazett, 1941, *A Practical System of Units for the Description of the Heat Exchange of Man with His Environment*, Science 94(2445)

*metabolic rate* → **MET**

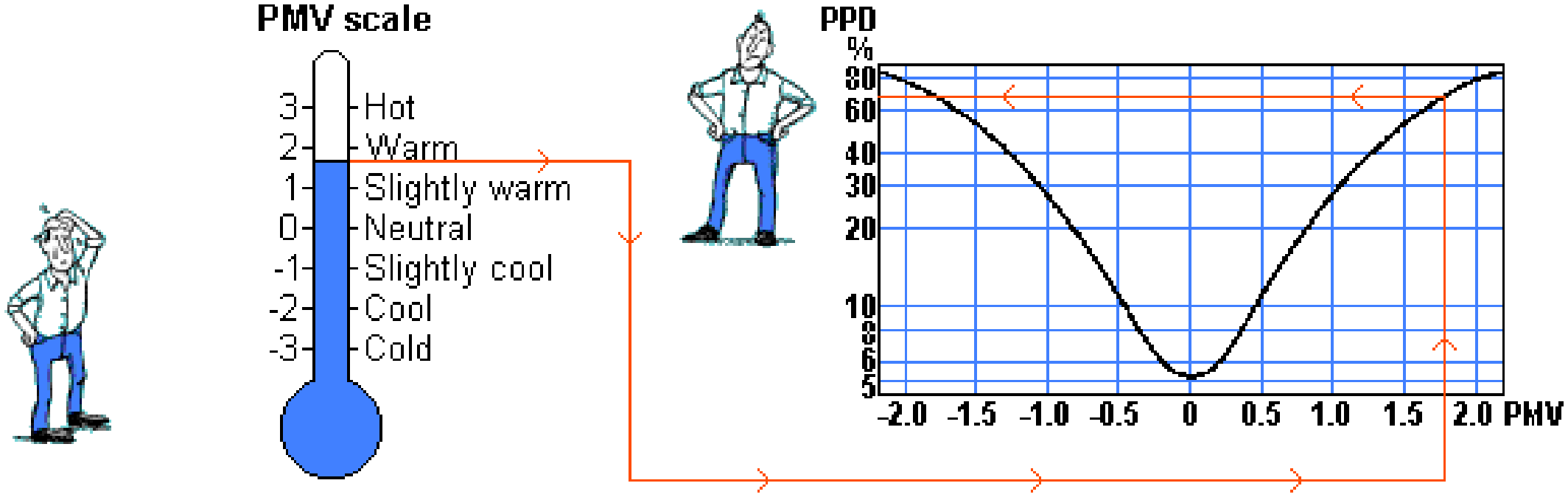
*clothing insulation* → **CLO**

# PMV and PPD

## ASHRAE 55

Predicted Mean Vote is the average of the subjective ratings of people in an environment

Predicted Percentage Dissatisfied tells how many people are unhappy with that environment



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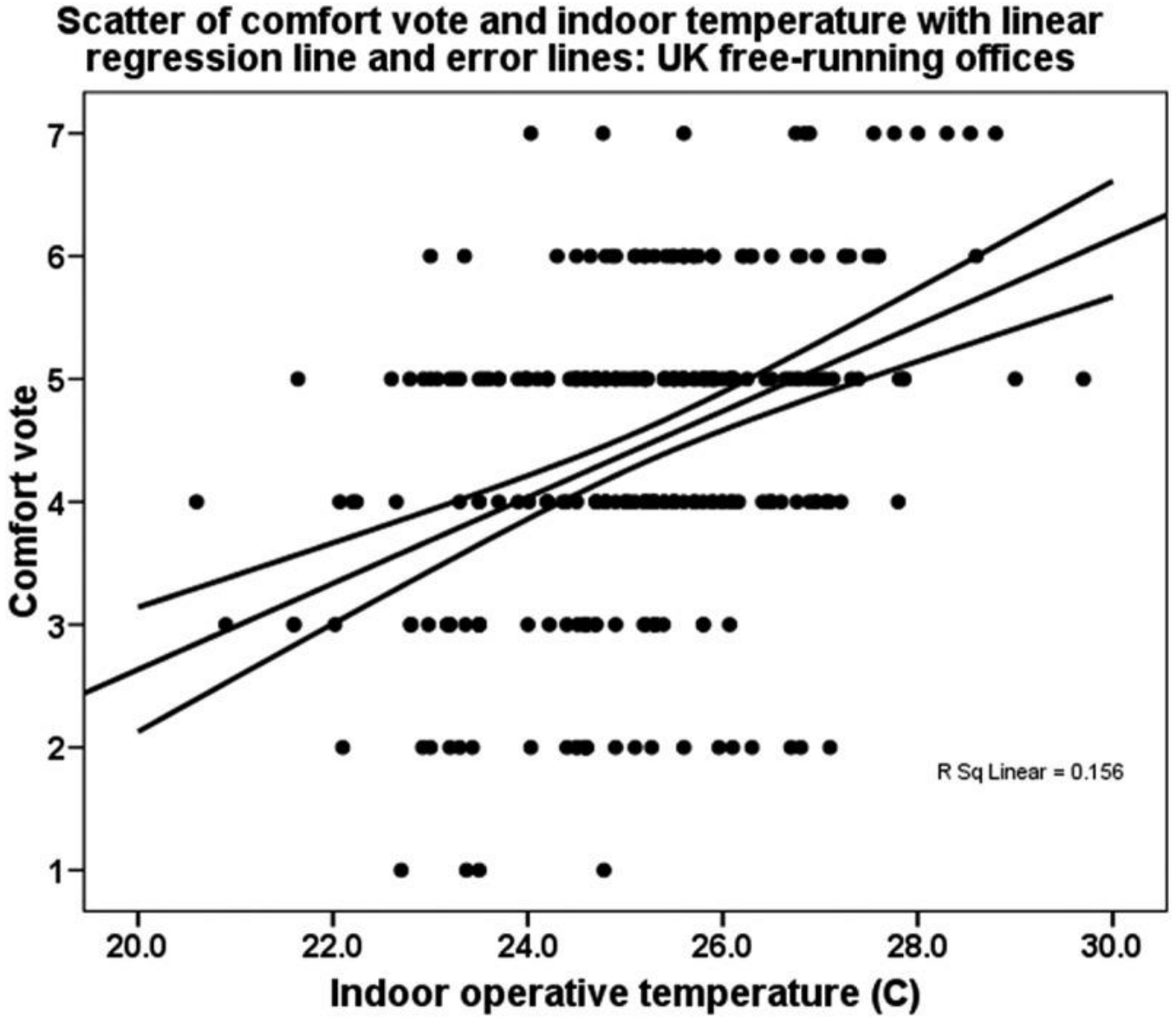


Nicol, Humphreys, and Roaf, 2012. *Adaptive thermal comfort: principles and practice*. London: Routledge.

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NASA CONTRACTOR REPORT

NASA CR-1855

NASA CR-1855



# A MATHEMATICAL MODEL OF PHYSIOLOGICAL TEMPERATURE REGULATION IN MAN

*by J. A. J. Stolwijk*

*Prepared by*
YALE UNIVERSITY SCHOOL OF MEDICINE
New Haven, Conn. 06510
*for*

[illegible] AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1971

The next phase contains the output statements which are not a material part of the program and which would normally depend on the purpose for which the simulation is intended.

```
C
C   BEGINNING OF OUTPUT SECTION
C
        CALL DATSW (0, K)
        GO TO (951, 950), K
  951   CONTINUE
        IF (ITIME -INT) 909, 909, 911
  909   PAUSE
  910   WRITE (1, 912)
  912   FORMAT ('TIME  S  M  EV  TB  TS  TH  TO  TR  TM  1  SBF  CO  COND  PWET')
        NN = 0
  911   IF (NN-42) 913, 913, 914
  913   WRITE (1, 915) ITIME, HFLOW, HP, EV, TB, TS, T(1), T(25), T(5), T(18), SBF,
        CO, 1 COND, PWET
  915   FORMAT (13, 3F7.1, 8F6.2, 2F6.1)
        NN = NN + 1
        GO TO 1100
  914   WRITE (1, 916)
  916   FORMAT (22(/) )
        GO TO 910
  950   CONTINUE
 1100   JTIME = JTIME + INT
        CALL DATSW (1, K)
        GO TO (917, 1102), K
```



Stolwijk, 1971. *A Mathematical Model of Physiological Temperature Regulation in Man*, NASA Contractor Report

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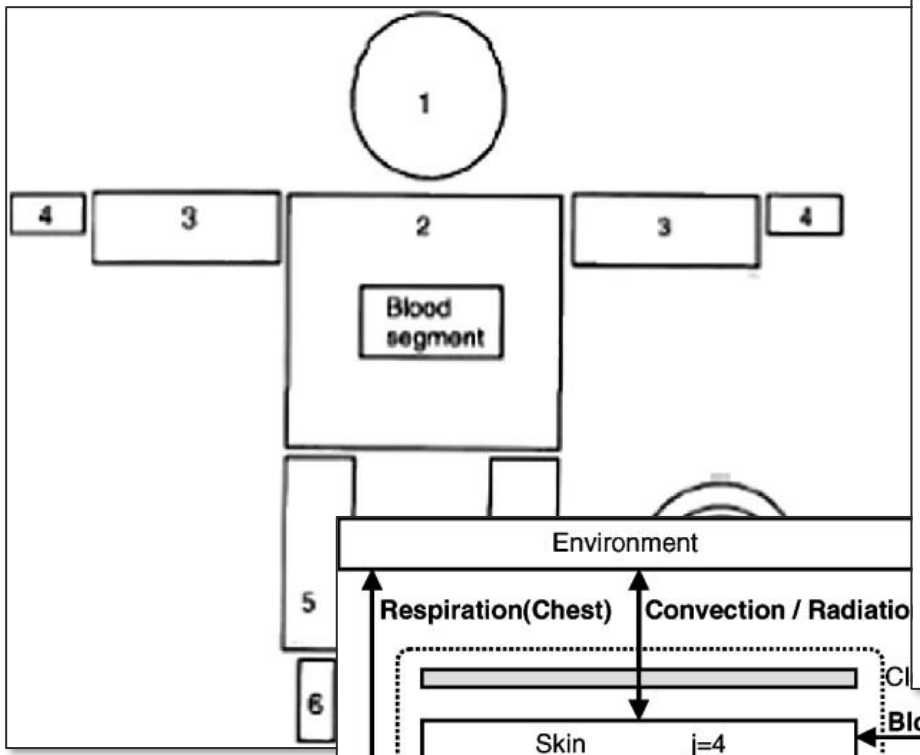
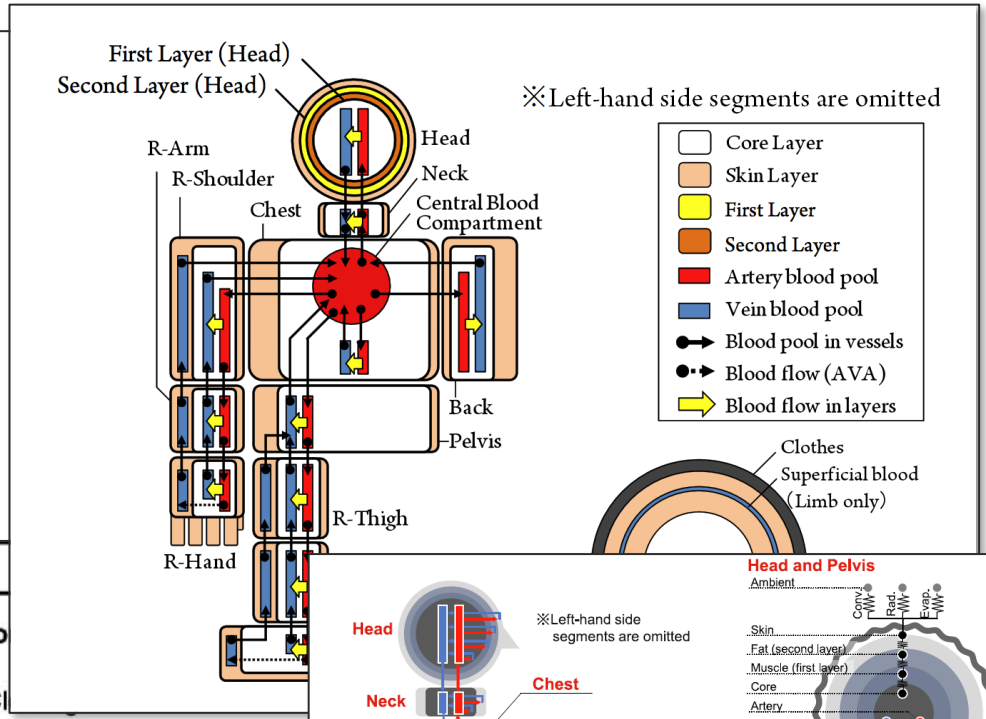
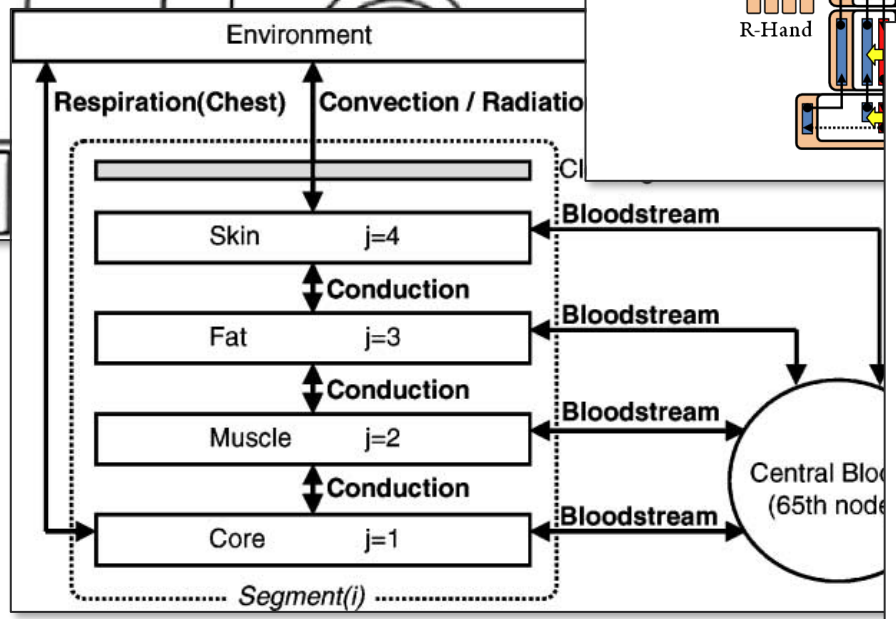
JOS-2

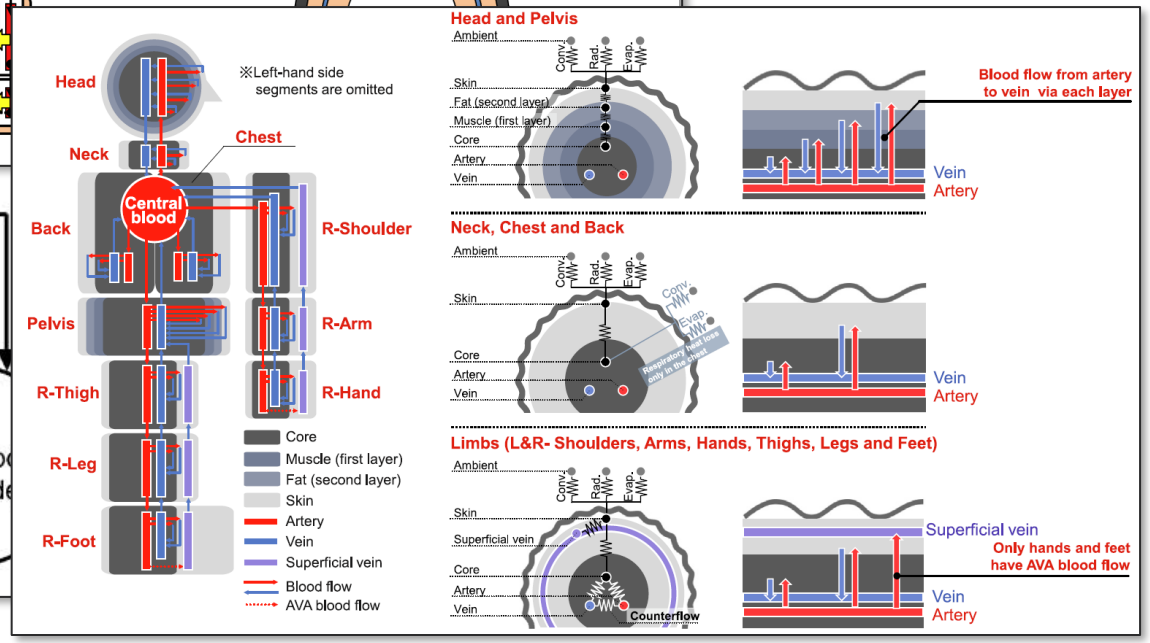



Stolwijk



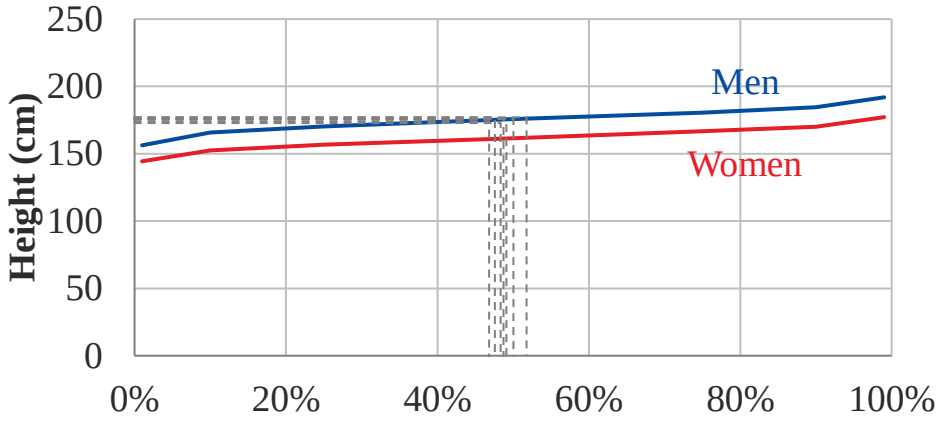

Tanabe

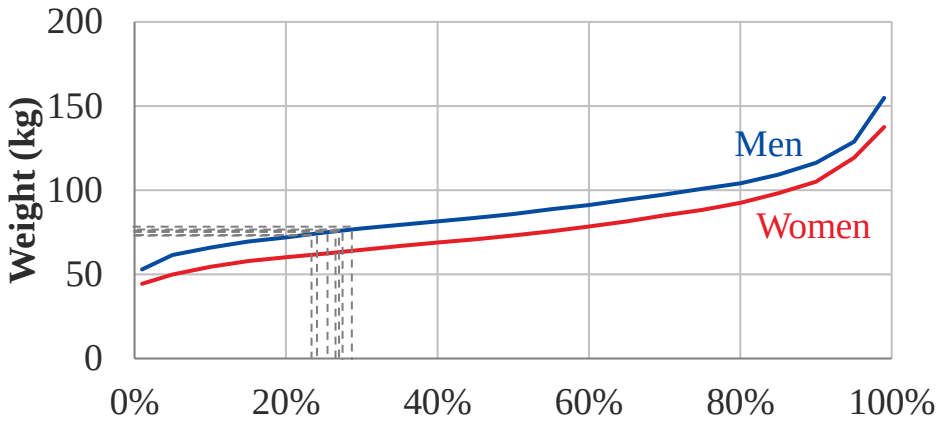


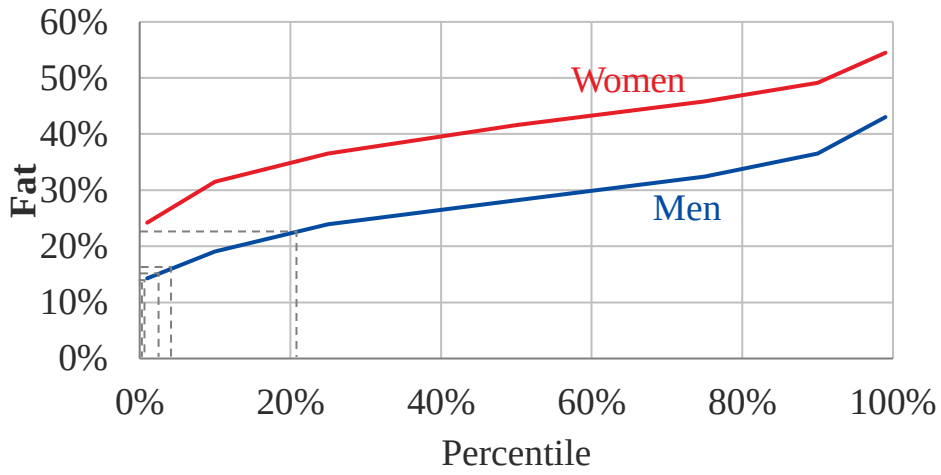

JOS-3

| Source | Height (cm) | Weight (kg) | Fat (%) |
|---|---|---|---|
| Stolwijk (1971) | 172 | 74.1 | 15 |

*"Six healthy, physically active men served as subjects."*




2005-2006 and 2015-2016 National Health and Nutrition Examination Survey, Centers for Disease Control

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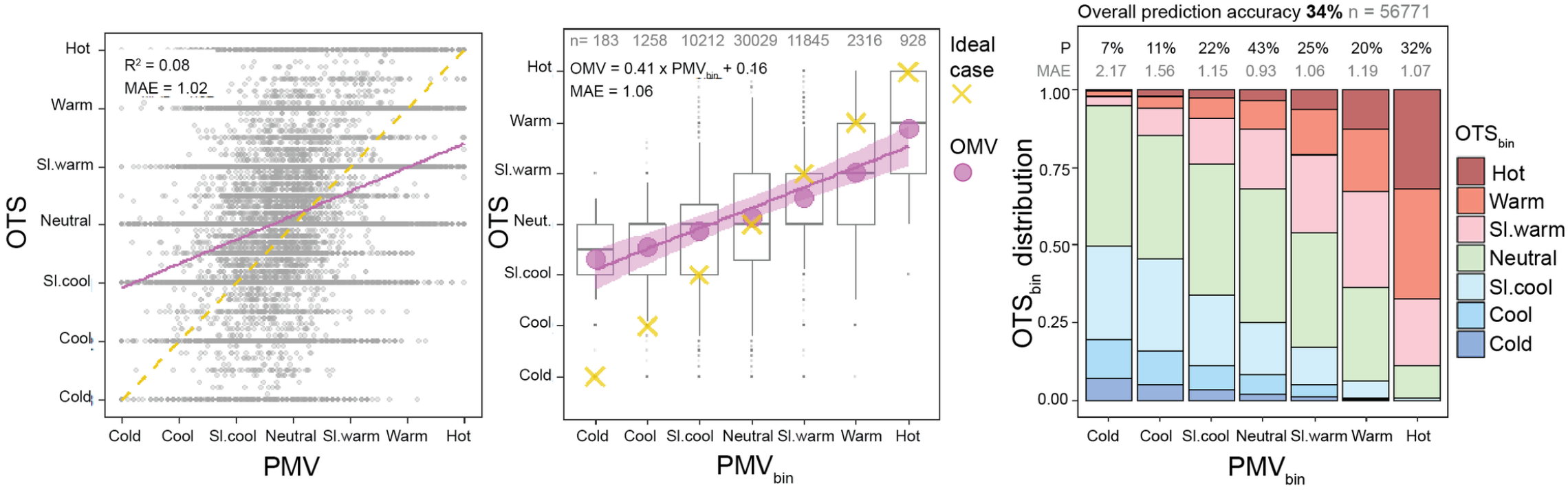
# Prediction accuracy: 34%

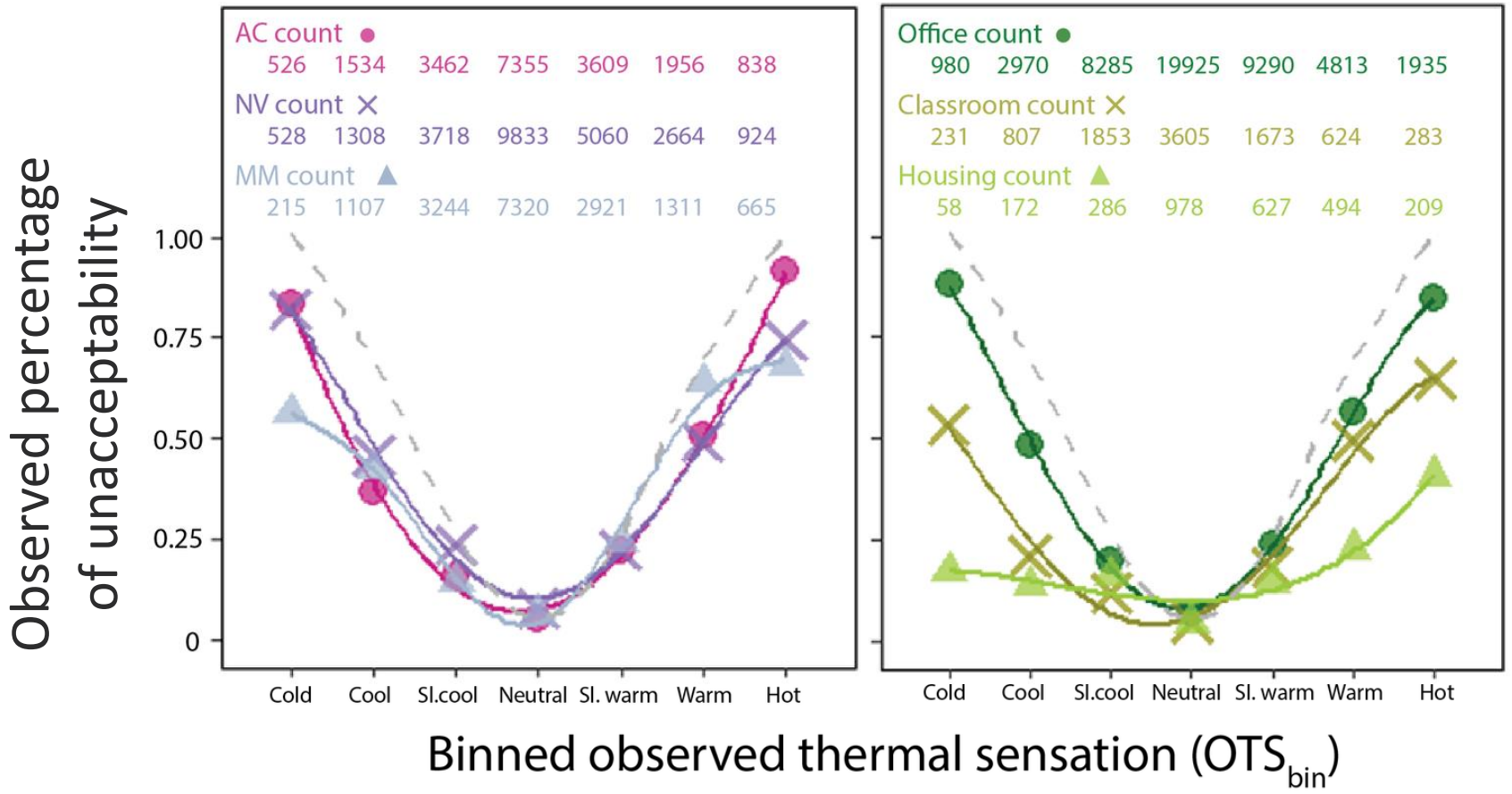
**Based on 56,771 surveys**




Cheung *et al*., 2019. Analysis of the Accuracy on PMV – PPD Model Using the ASHRAE Global Thermal Comfort Database II. *Building and Environment* 153(15)

# Building type

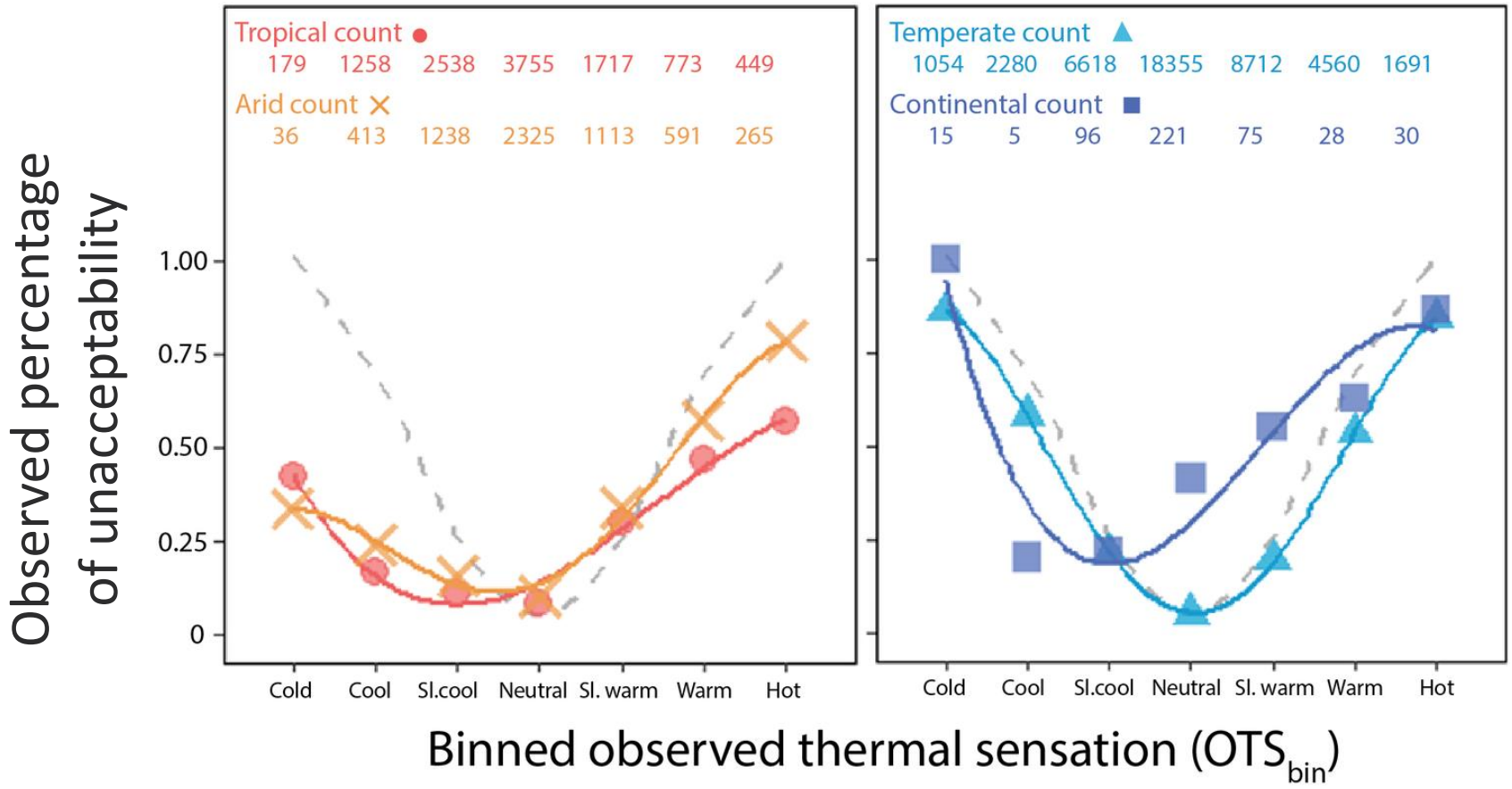
**PPD is for offices with air conditioning**




Cheung *et al*., 2019. Analysis of the Accuracy on PMV – PPD Model Using the ASHRAE Global Thermal Comfort Database II. *Building and Environment* 153(15)

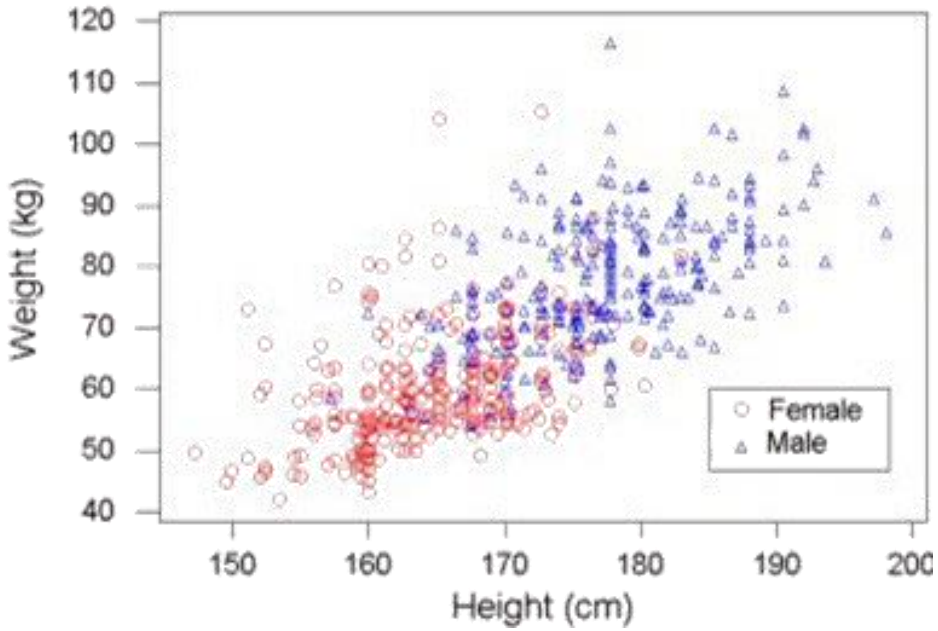
# Climate

**PPD is for temperate climates**




Cheung *et al*., 2019. Analysis of the Accuracy on PMV – PPD Model Using the ASHRAE Global Thermal Comfort Database II. *Building and Environment* 153(15)

# Gender in Thermal Comfort



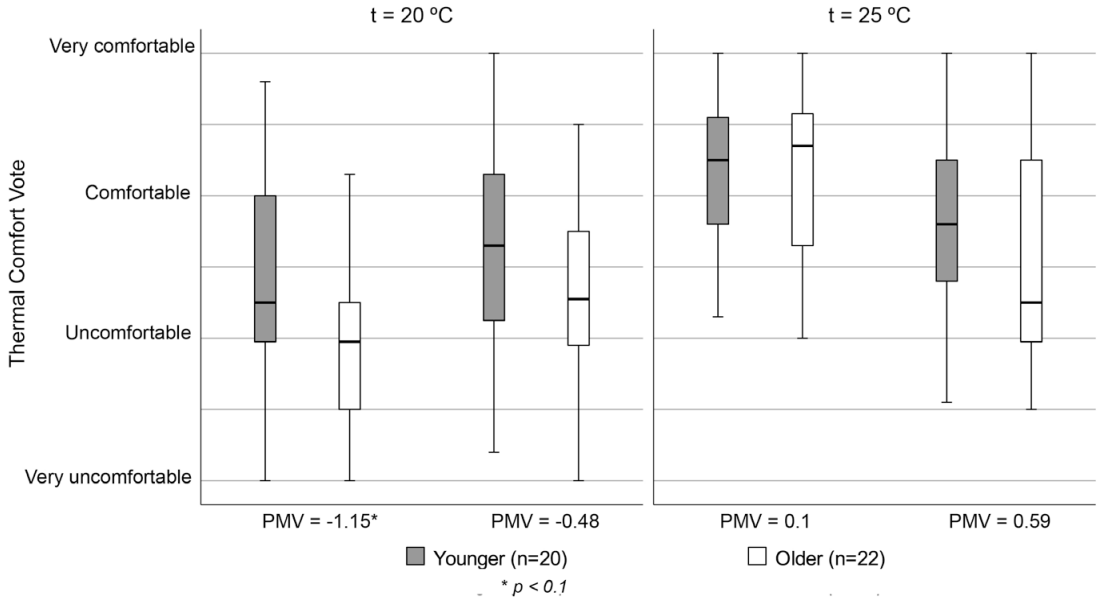

## Cultural

- Clothing insulation
- Skin coverage

## Physical

- Body mass
- Body fat
- Core temperature (menstrual cycle and menopause)

# Age in Thermal Comfort




Soebarto *et al., 2019. A thermal comfort environmental chamber study of older and younger people*. Building and Environment.

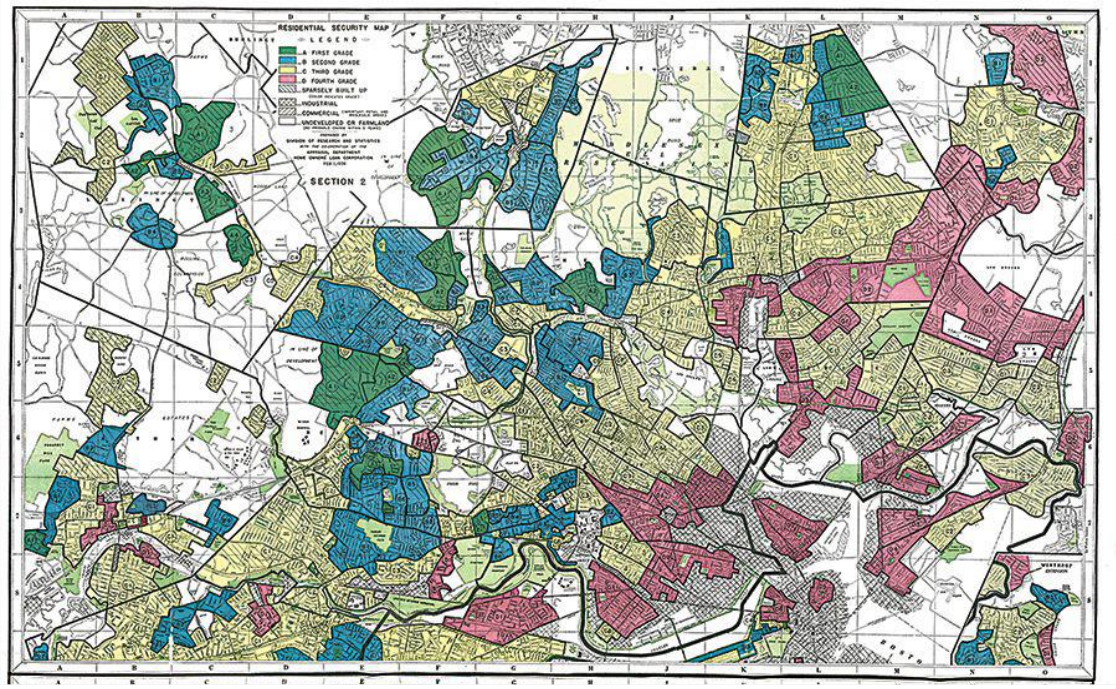
## Children

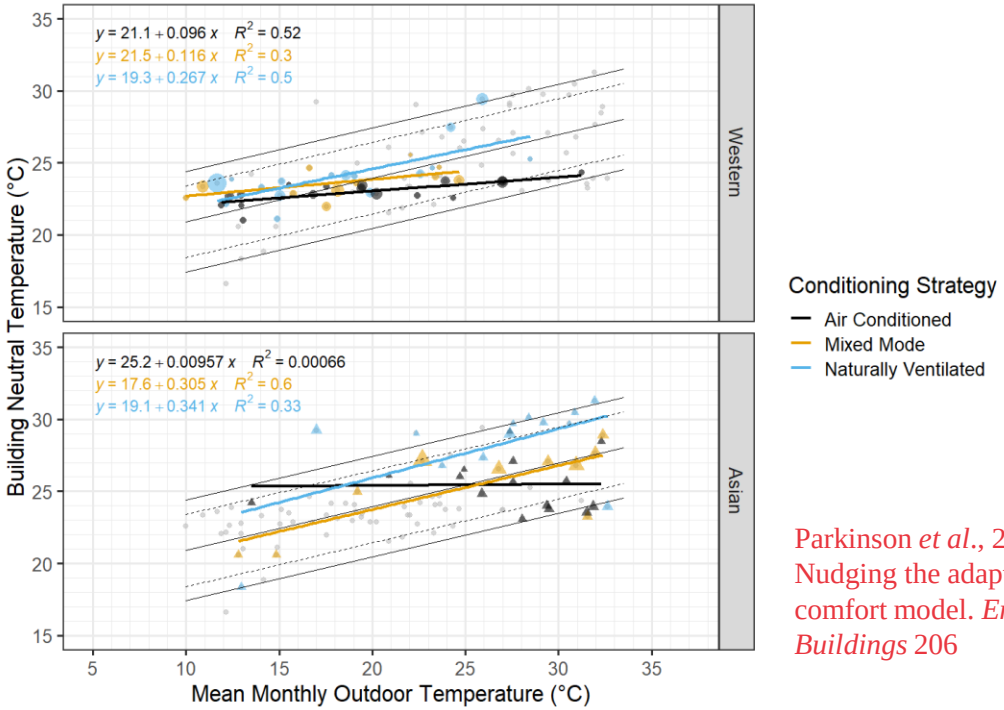
- Prefer lower temperatures than adults
- More sensitive to changes in metabolic rate

## Elderly

- Changes to metabolic rate, muscle and fat composition
- Decreased thermoregulatory and cardiovascular response
- Decreased heat tolerance

# Ethnicity in Thermal Comfort




Parkinson *et al*., 2020. Nudging the adaptive thermal comfort model. *Energy and Buildings* 206

## Socio-economic

- Access to air conditioning
- Occupational exposure
- Healthcare and language barriers

## Geography

- Asian thermostat setpoints tend higher
- Data scarcity

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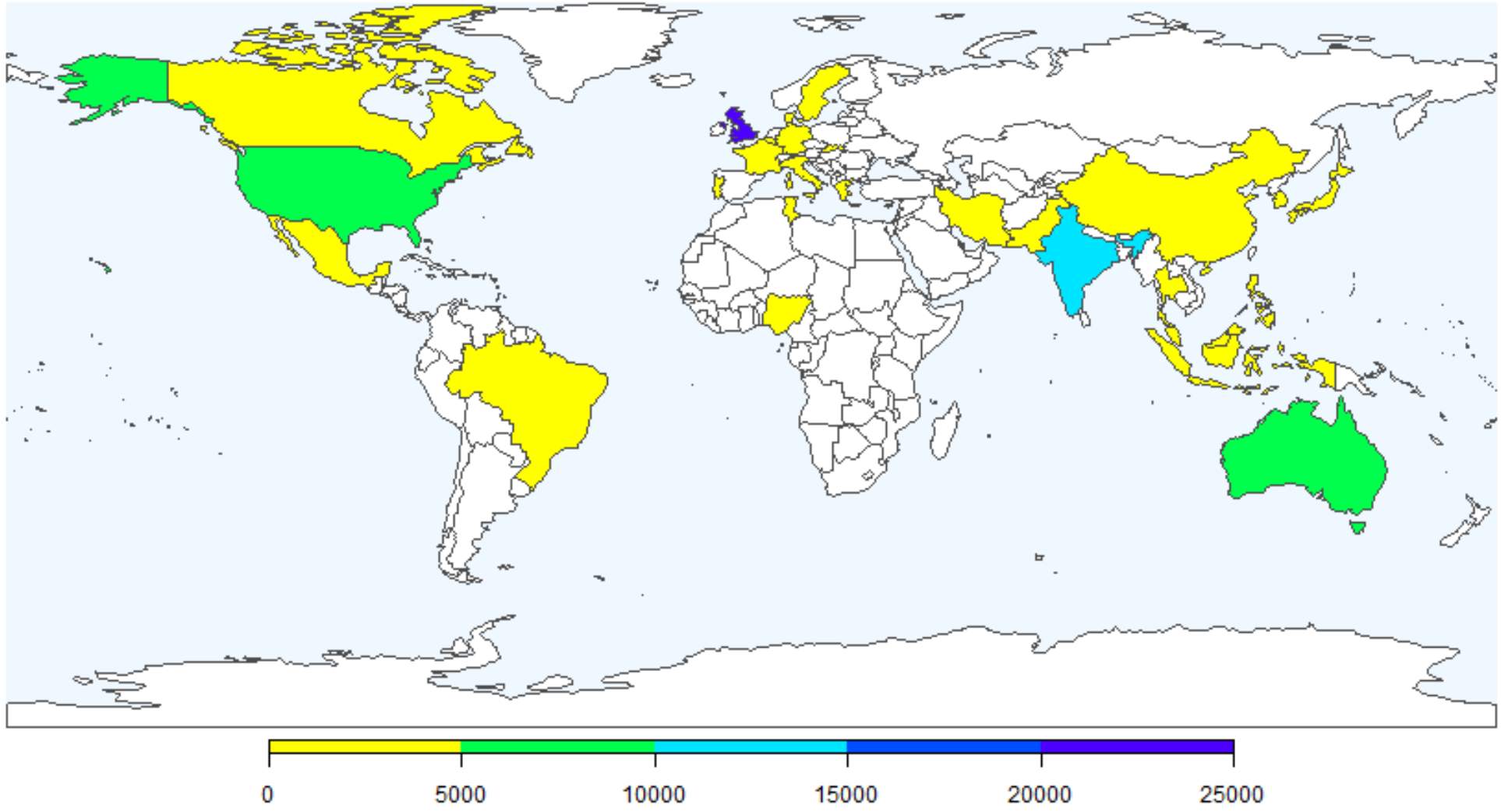
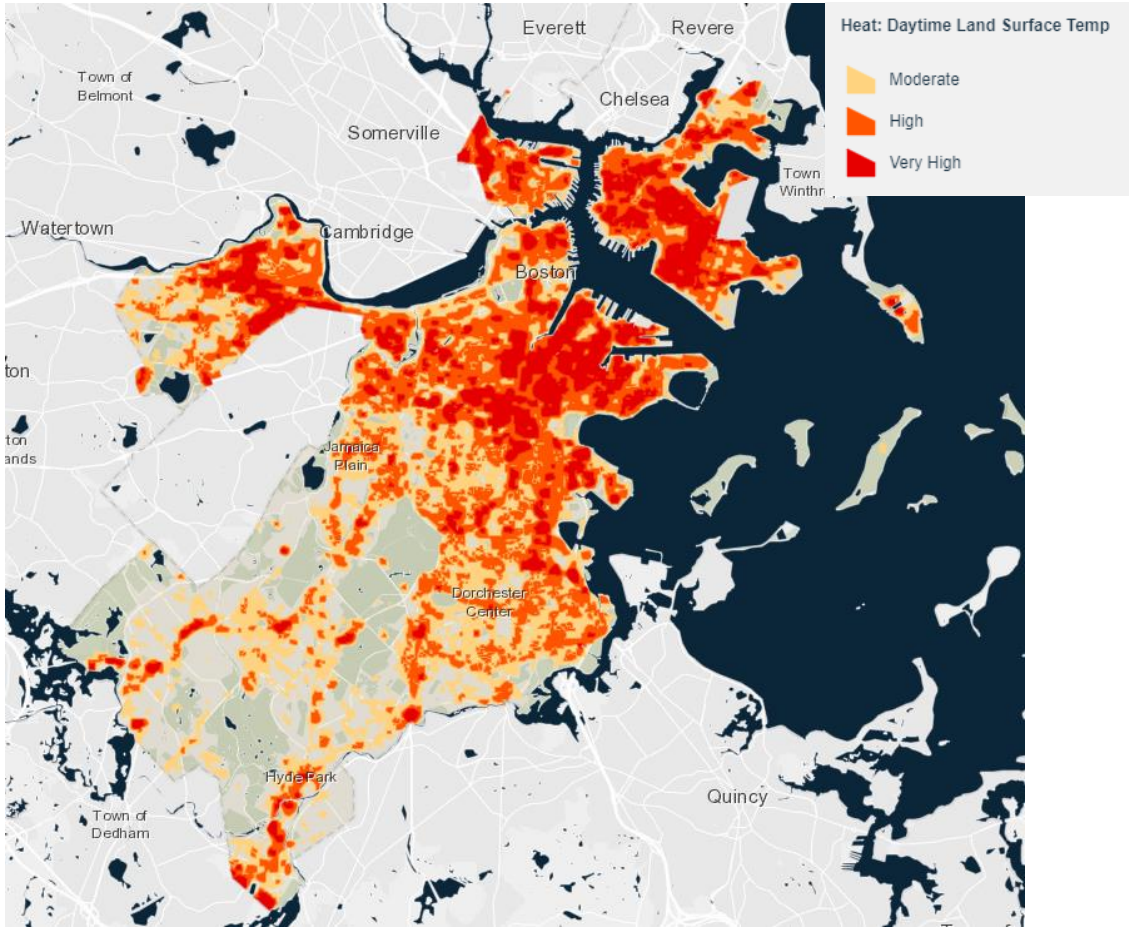
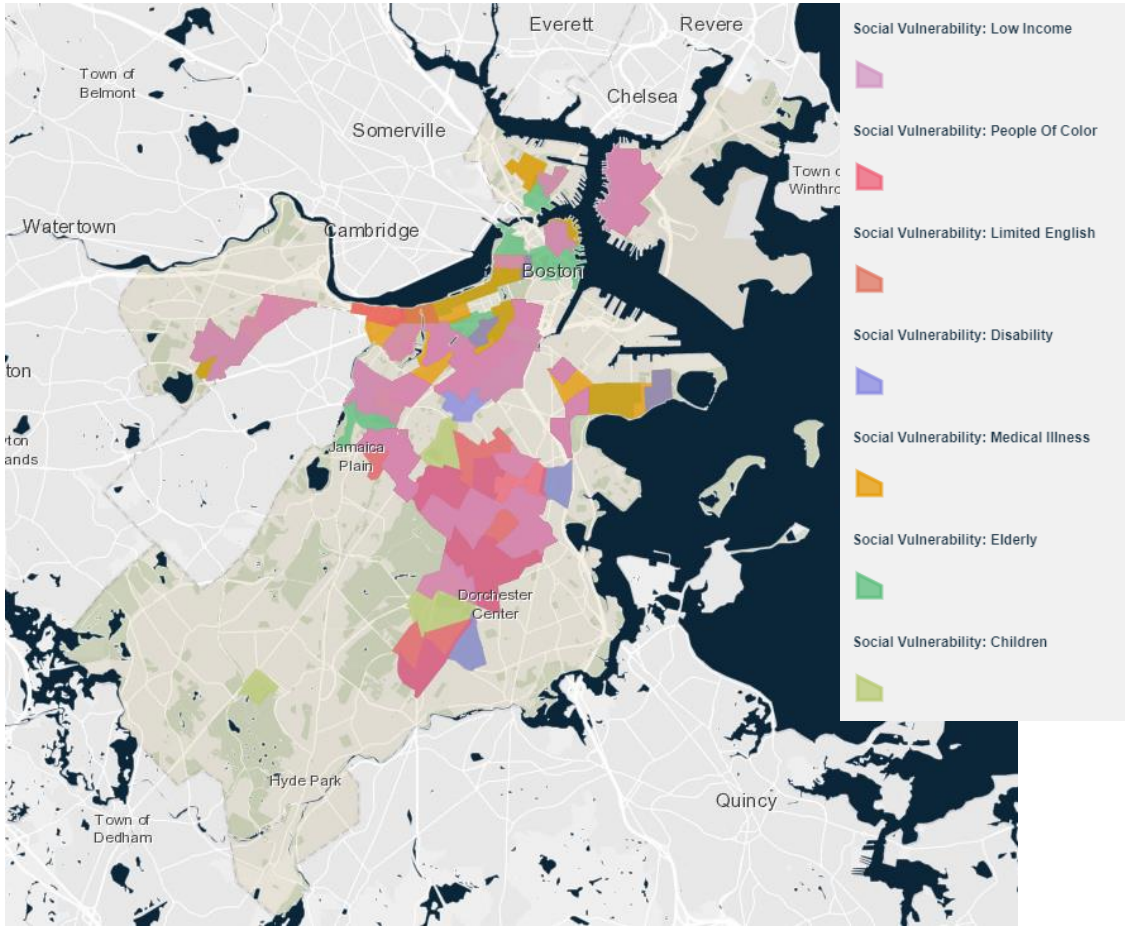



Parkinson *et al*., 2020. Nudging the adaptive thermal comfort model. *Energy and Buildings* 206

# Urban Heat Island

## Boston




*Climate Ready Boston Map Explorer*
https://www.boston.gov/departments/environment/preparing-heat

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The Indian EXPRESS Home India World Cities Opinion T20 WC

Home / Cities / Pune / India, Brazil saw biggest jump in heat-related deaths in 2018-19

SUBSCRIBE

# India, Brazil saw biggest jump in heat-related deaths in 2018-19

In India, the vulnerability to extremes of heat in 2019 was almost 31 on the index, which is 15 per cent higher than in the 1990s.


British Columbia

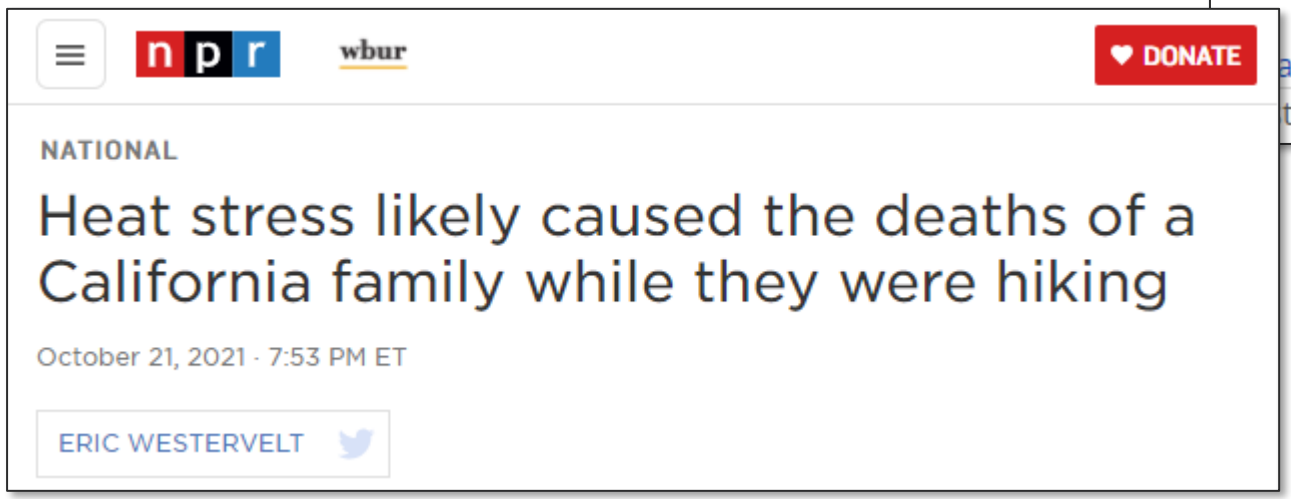
CBC

# 595 people were killed by heat in B.C. this summer, new figures from coroner show

More than 231 died on June 29 alone, during 'heat dome' that caused record temperatures, data says

anna Schmunk · CBC News ·

ted: Nov 01, 2021 9:17 AM PT | Last Updated: November 1


npr wbur DONATE

NATIONAL

# Heat stress likely caused the deaths of a California family while they were hiking

October 21, 2021 · 7:53 PM ET

ERIC WESTERVELT

# Areas that were redlined in the past are hotter today

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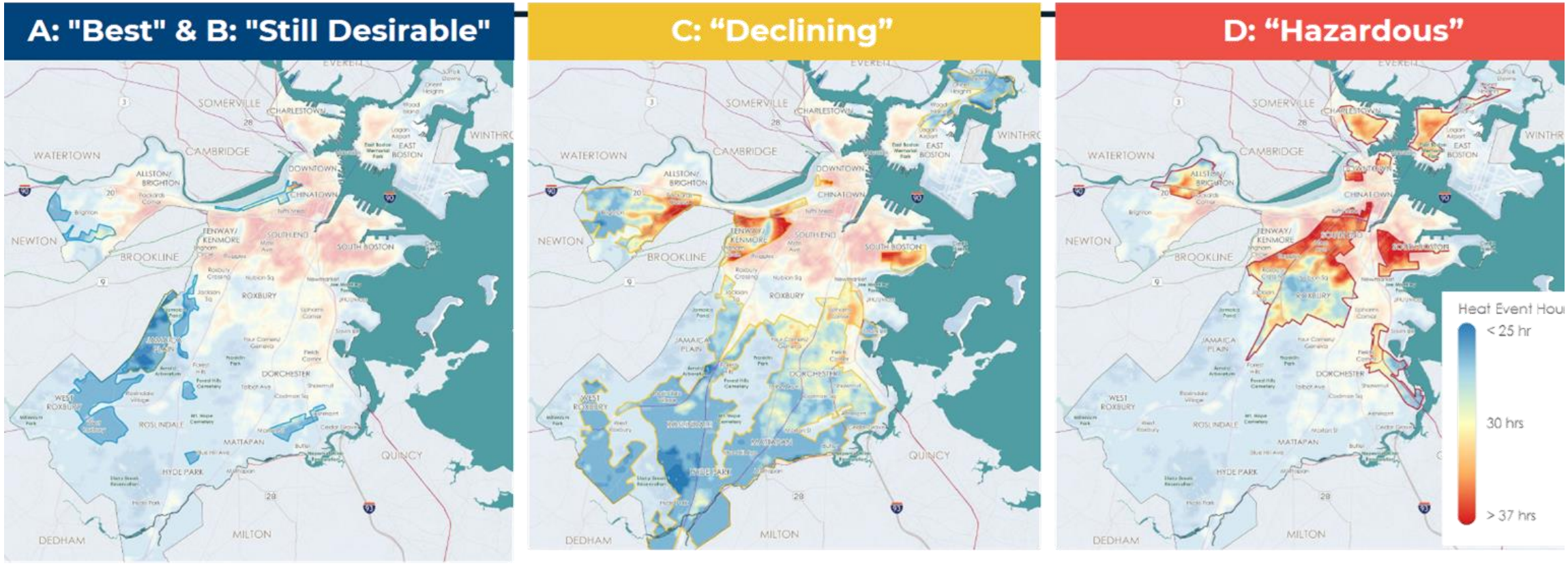



## Compared to Boston's citywide median ...

**A areas:**
4.2°F cooler in day
1.7°F cooler at night
4% more parkland*
32% more tree cover*

**B areas:**
1.3 F cooler in day
0.5°F cooler at night
18% less parkland*
7.5% more tree cover*

**C areas:**
(median temp same as city median in day and night)
12% less parkland*
2.2% more tree cover*

**D areas:**
3.3°F hotter in day
1.9°F hotter at night
16% less parkland*
7% less tree cover*

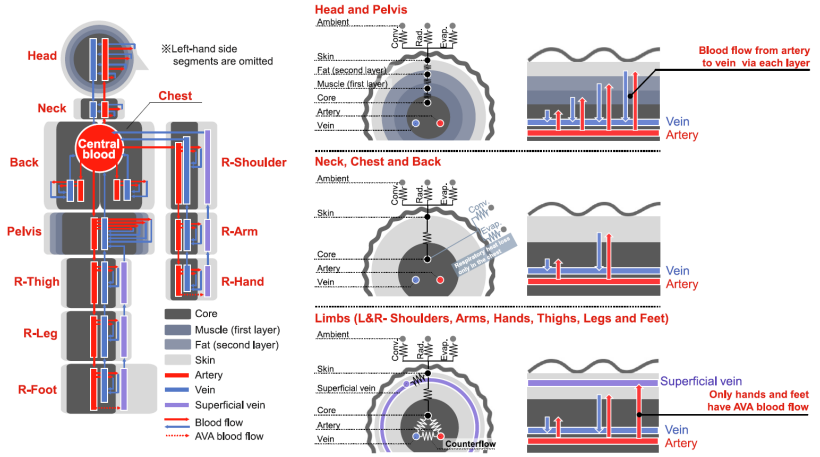
*percentage points

*Boston Heat Resilience Study*
https://www.boston.gov/departments/environment/preparing-heat

# comfort.arup.com

## Arup's response

+

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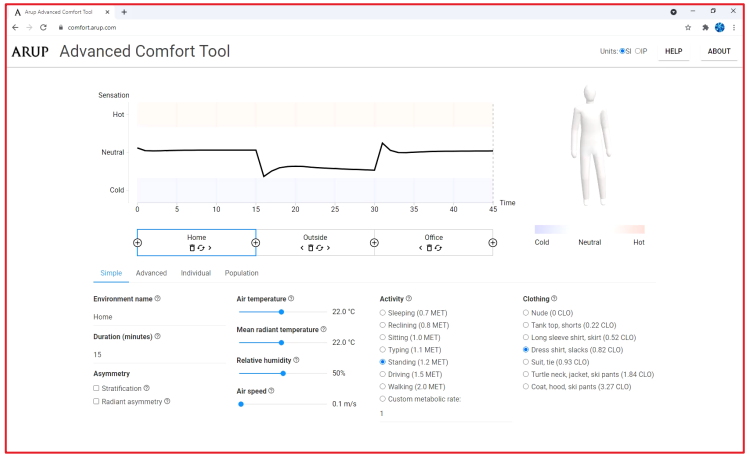


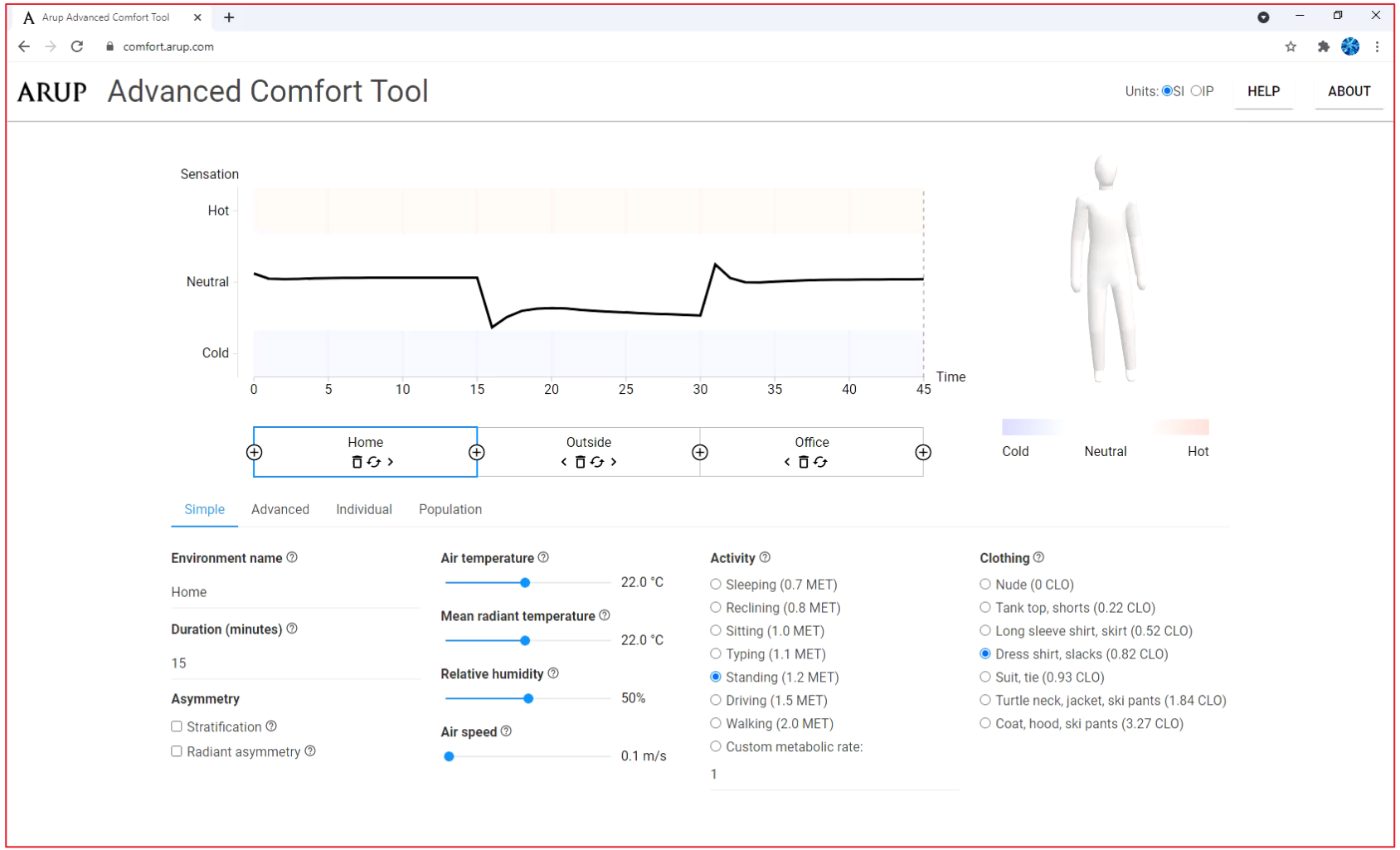

Zhang, *et al*. 2010. Thermal sensation and comfort models for non-uniform and transient environments. *Building and Environment*, 45(2).

Takahashi *et al.*, 2021. Thermoregulation model JOS-3 with new open source code. *Energy and Buildings* 231.

Jones *et al*., 2021. *Predicting thermal comfort for diverse populations.* Building Simulation 2021.

# comfort.arup.com

## Arup's response




Jones *et al.*, 2021. *Predicting thermal comfort for diverse populations*. Building Simulation 2021.

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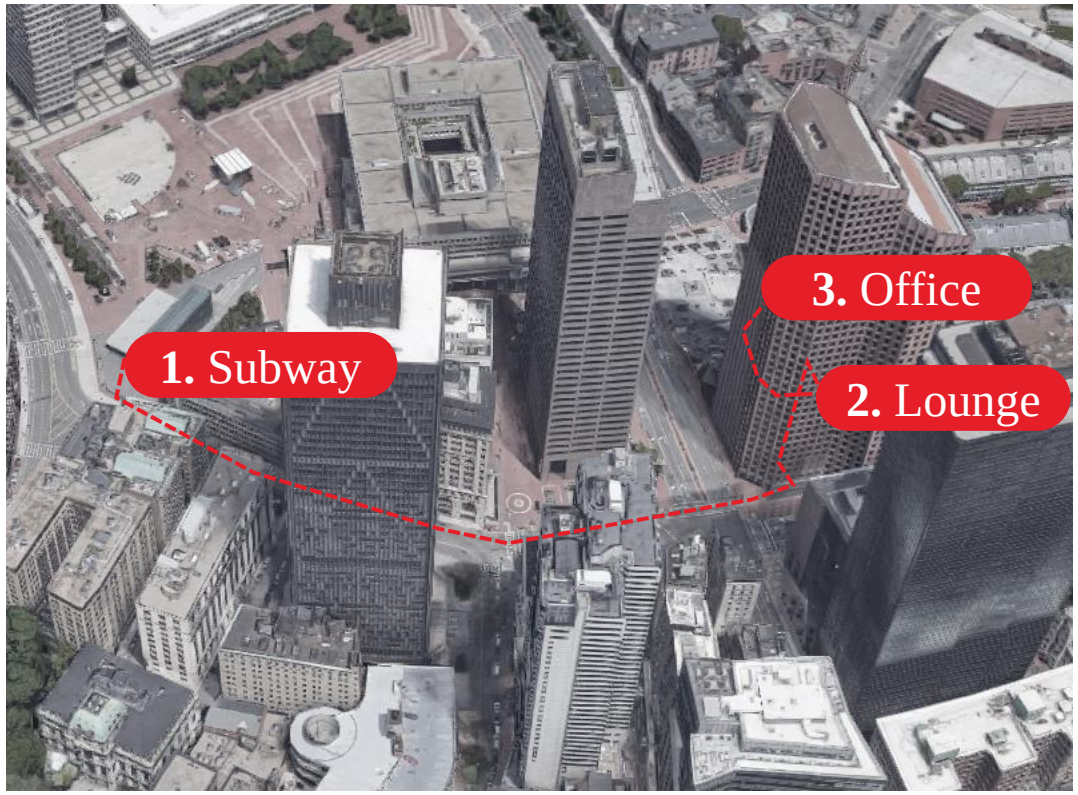
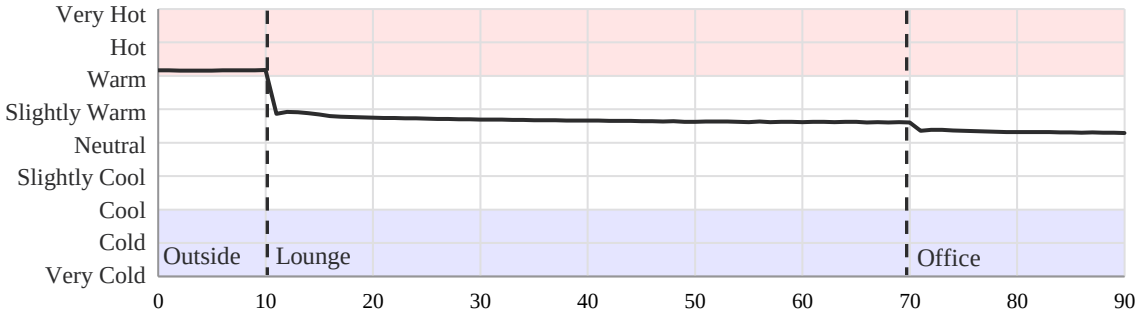


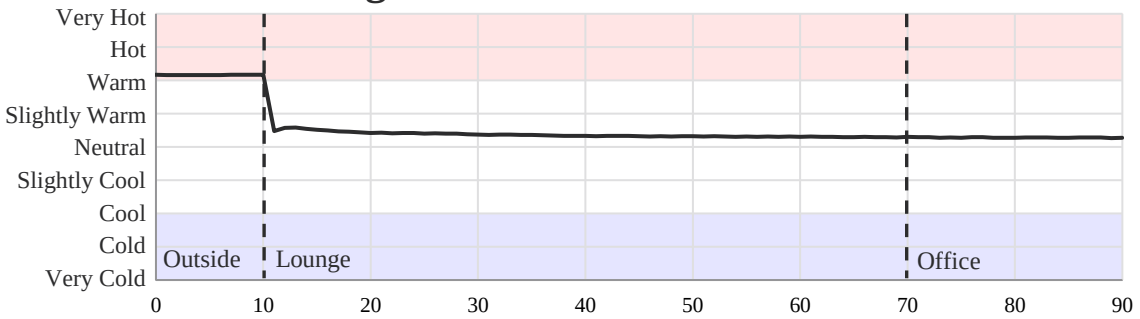

"Standard Man"

| Height | Weight | Fat |
|---|---|---|
| 5'8" | 163 lbs | 15% |

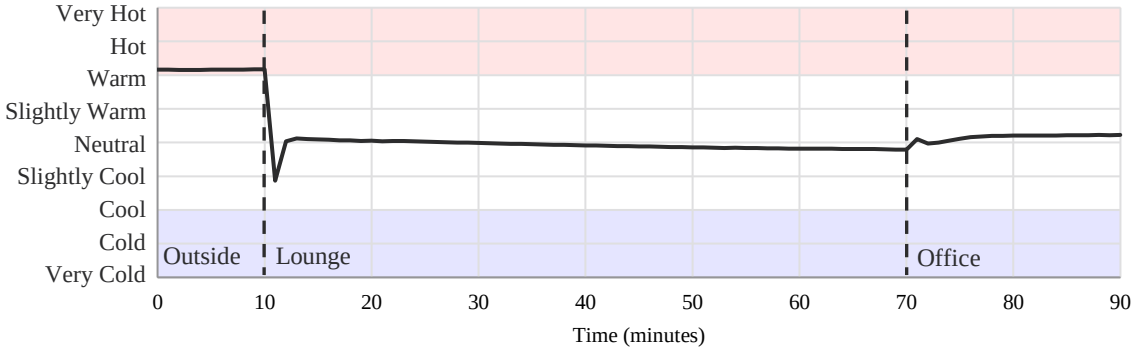
## No Treatment




## Add Air Conditioning




## Add Shading



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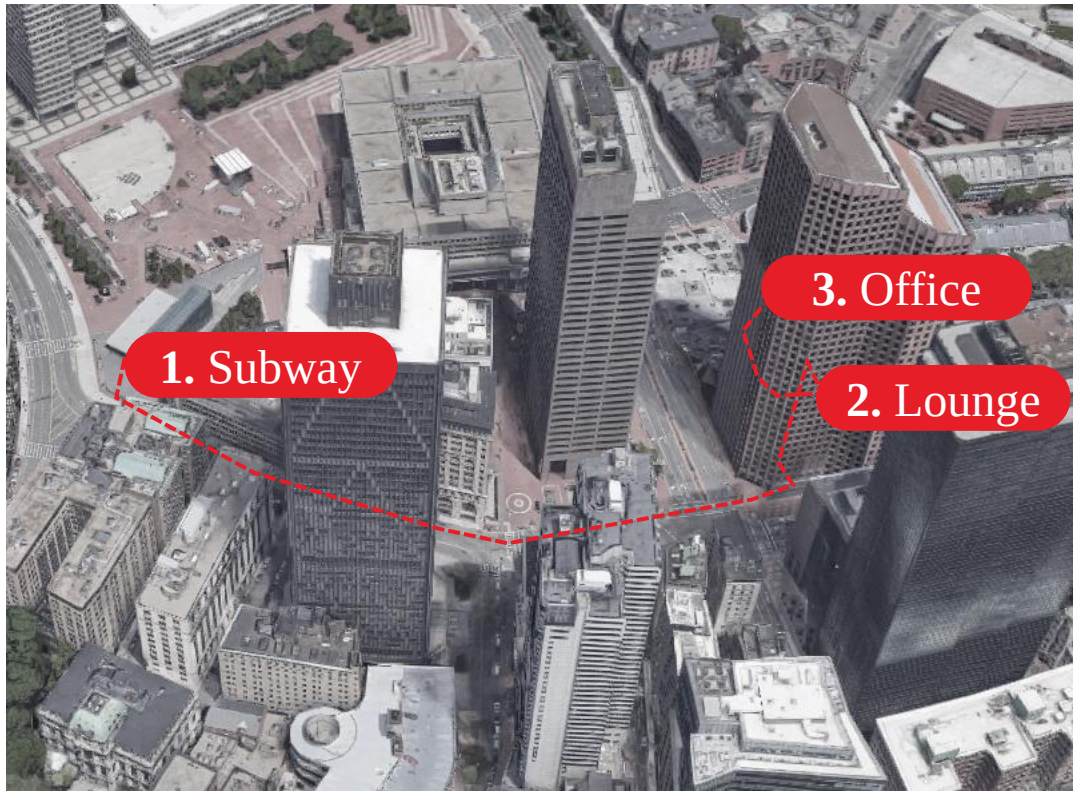
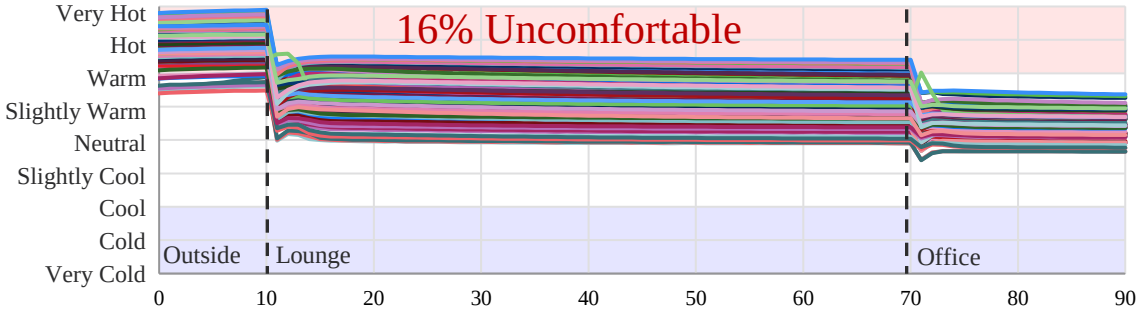



Middle 80% of US population

| | Height | Weight | Fat |
|---|---|---|---|
| Men | 5’5″ – 6’0″ | 145 – 256 lbs | 19% – 37% |
| Women | 5’0″ – 5’7″ | 120 – 232 lbs | 32% – 49% |

## No Treatment

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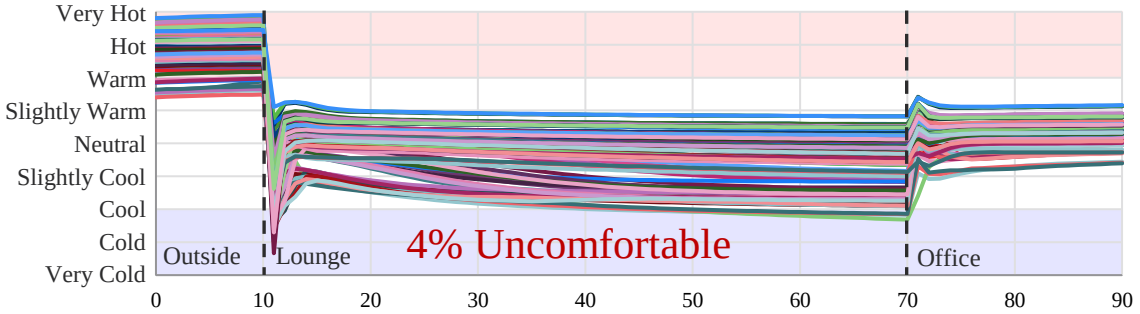


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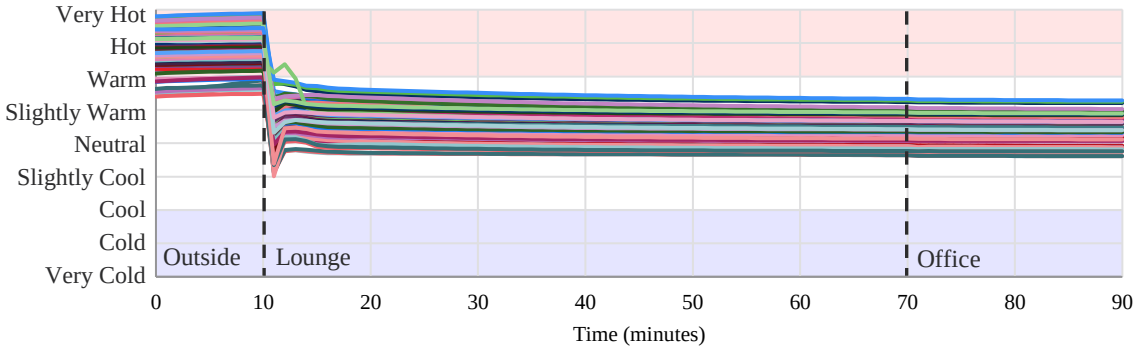

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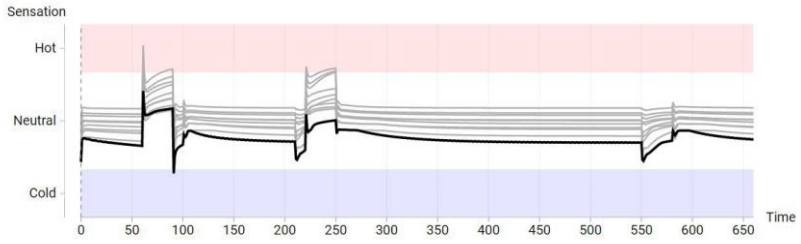
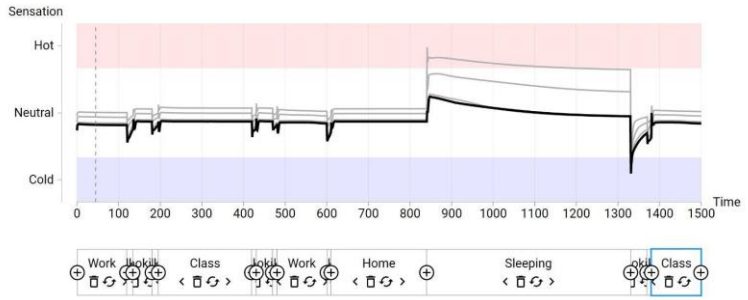
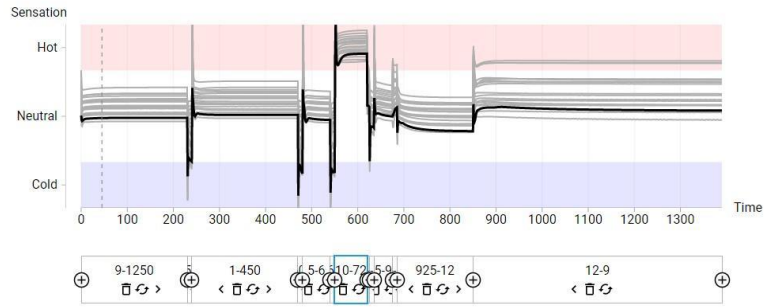
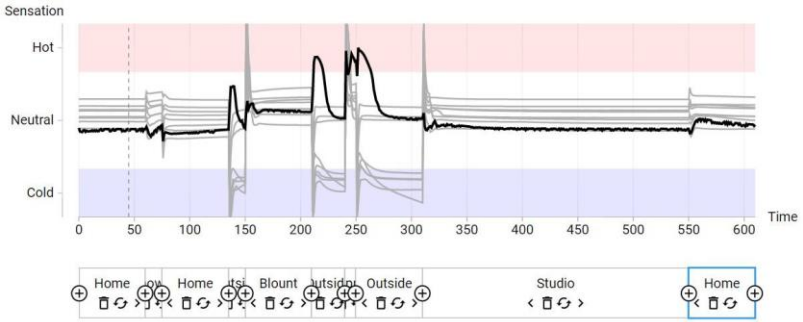
# Thermal Comfort Diary

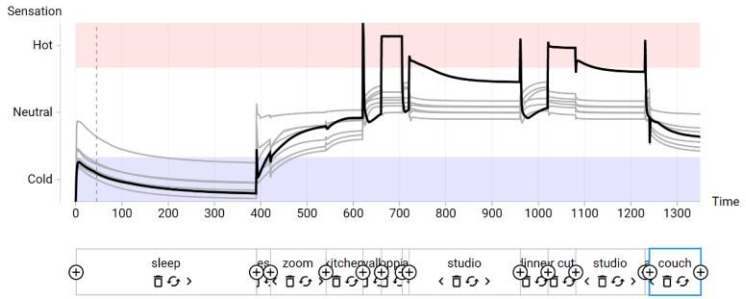
## Wentworth Institute of Technology

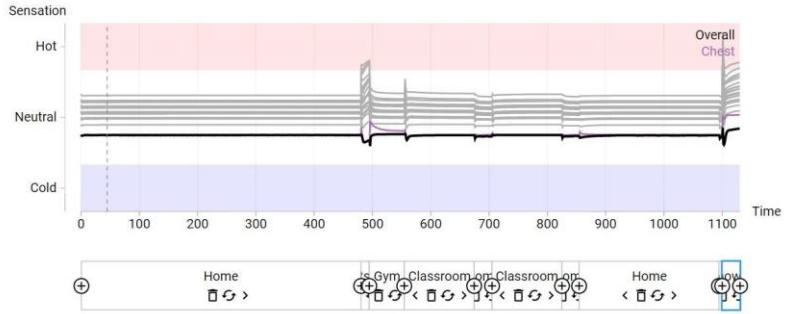


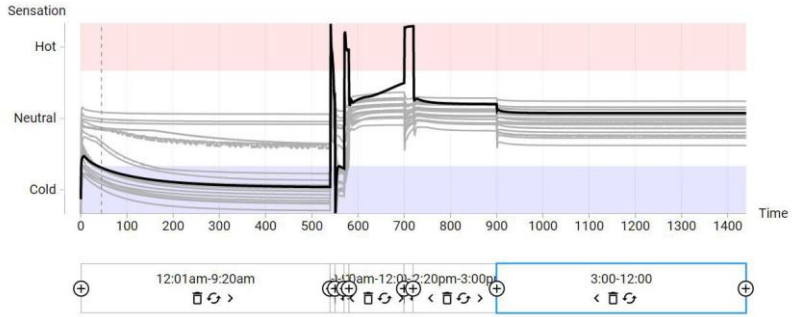



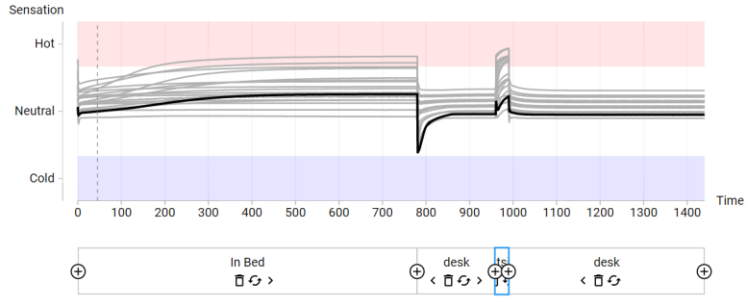



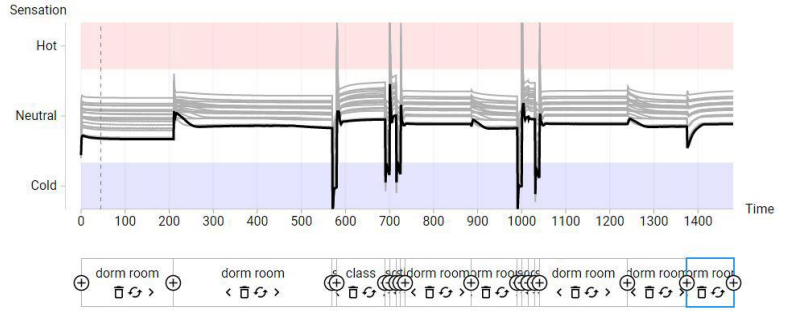



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# Synthetic Chemistry Lab

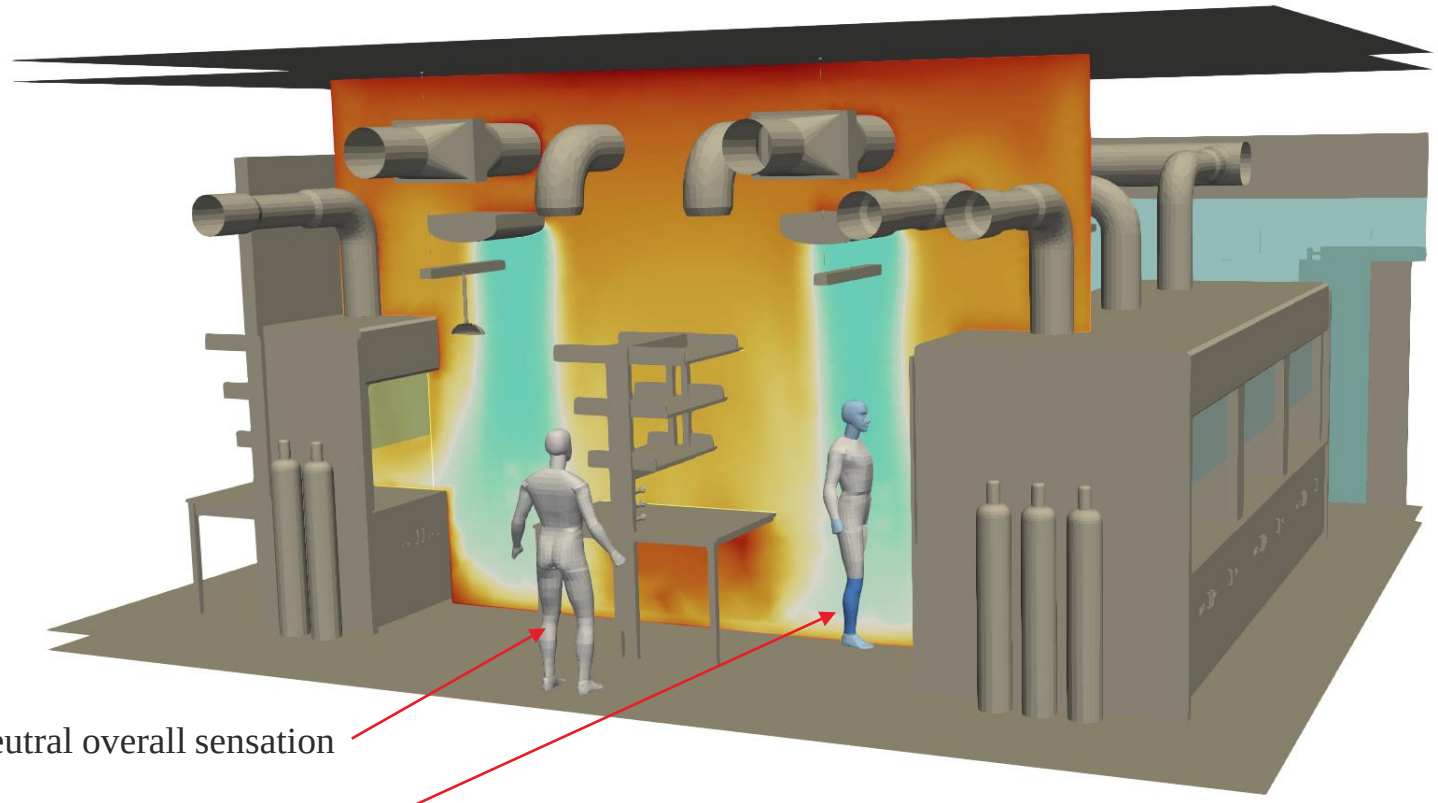
## Northeastern University EXP

Air

80 °F

70 °F

60 °F




Occupants

Hot

Warm

Neutral

Cool

Cold

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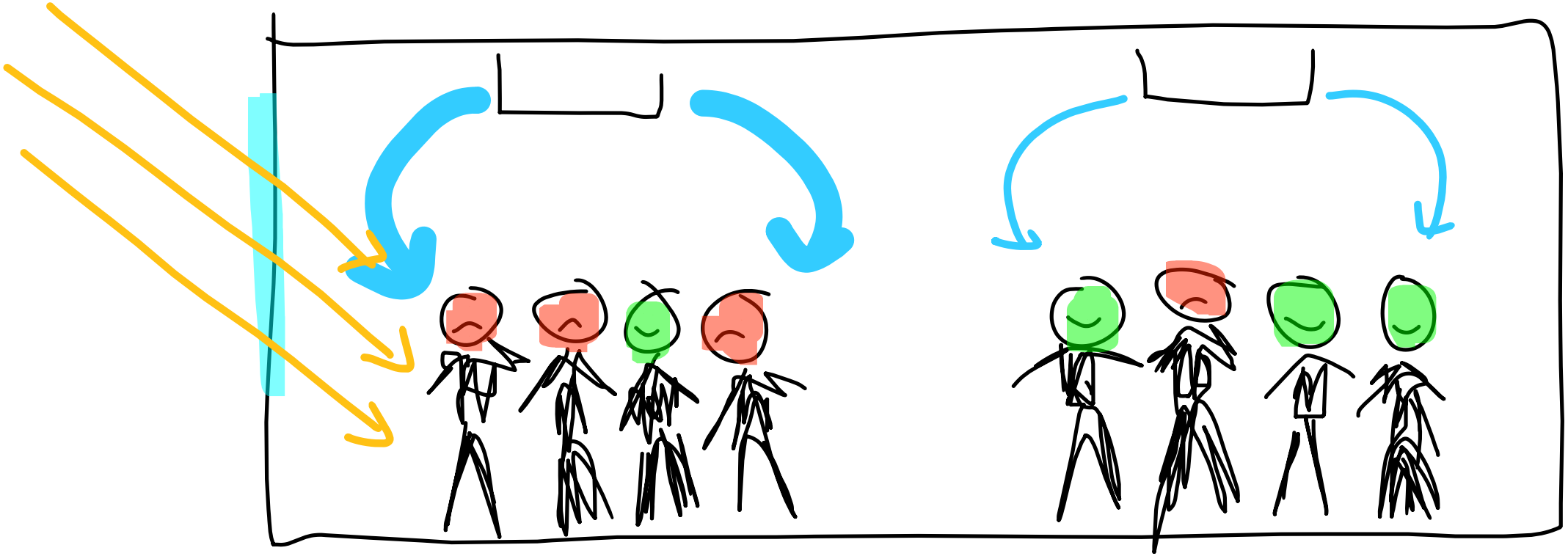
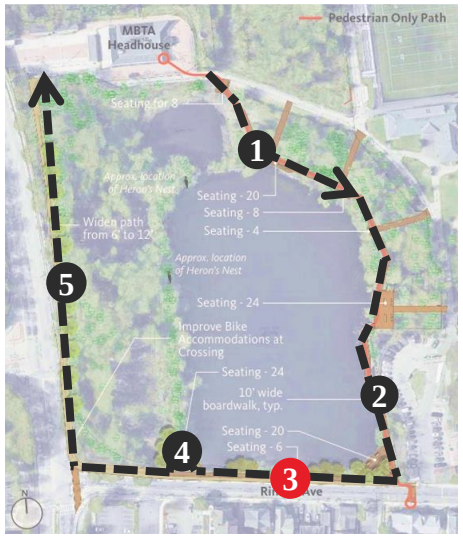


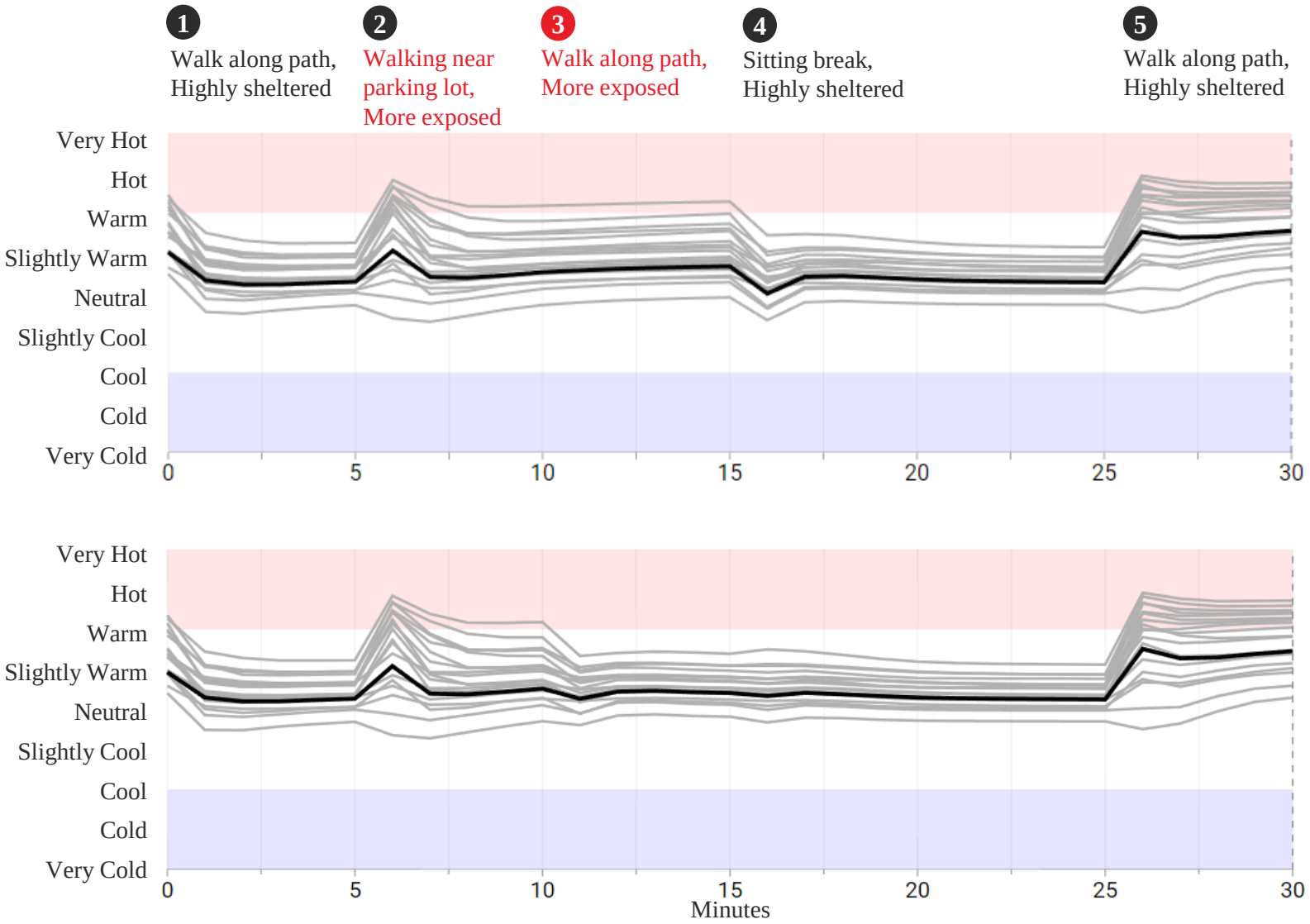
# Jerry's Pond

## Leisurely stroll in summer

**Proposed**



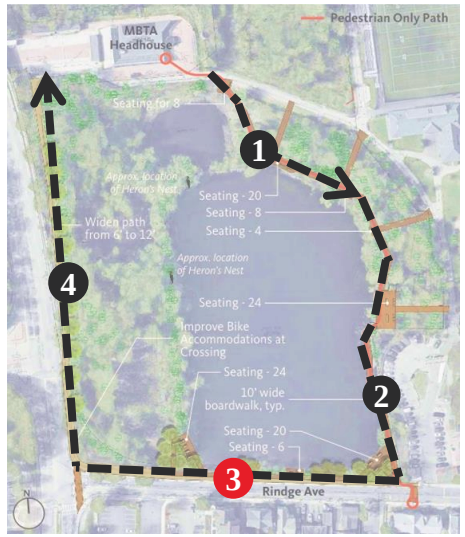

**Modified**

# Jerry's Pond

## Brisk jog in summer

**Proposed**



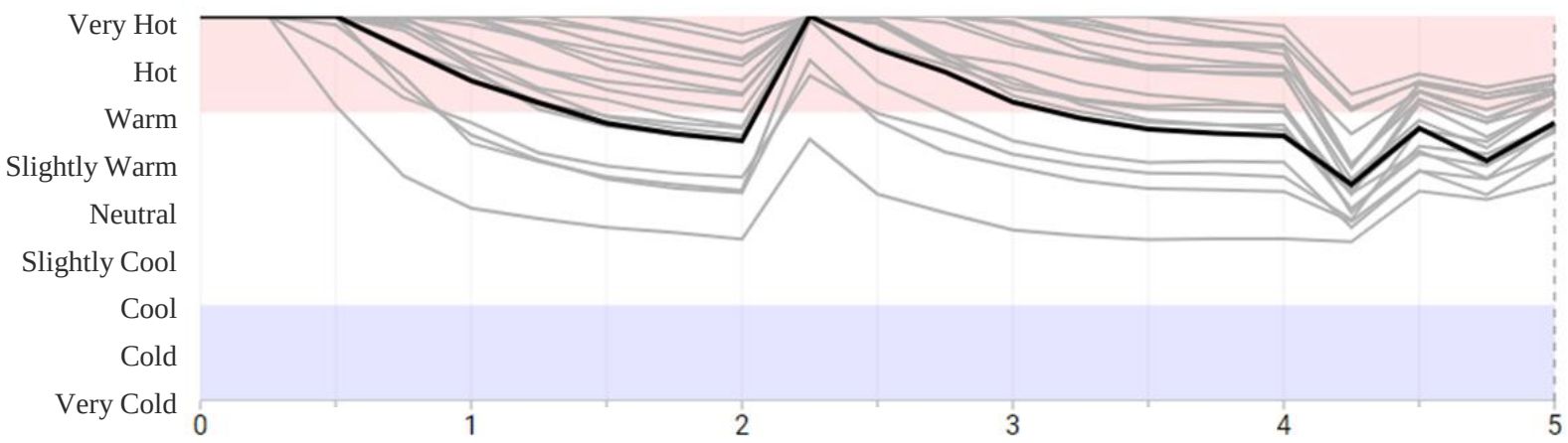

**Modified**

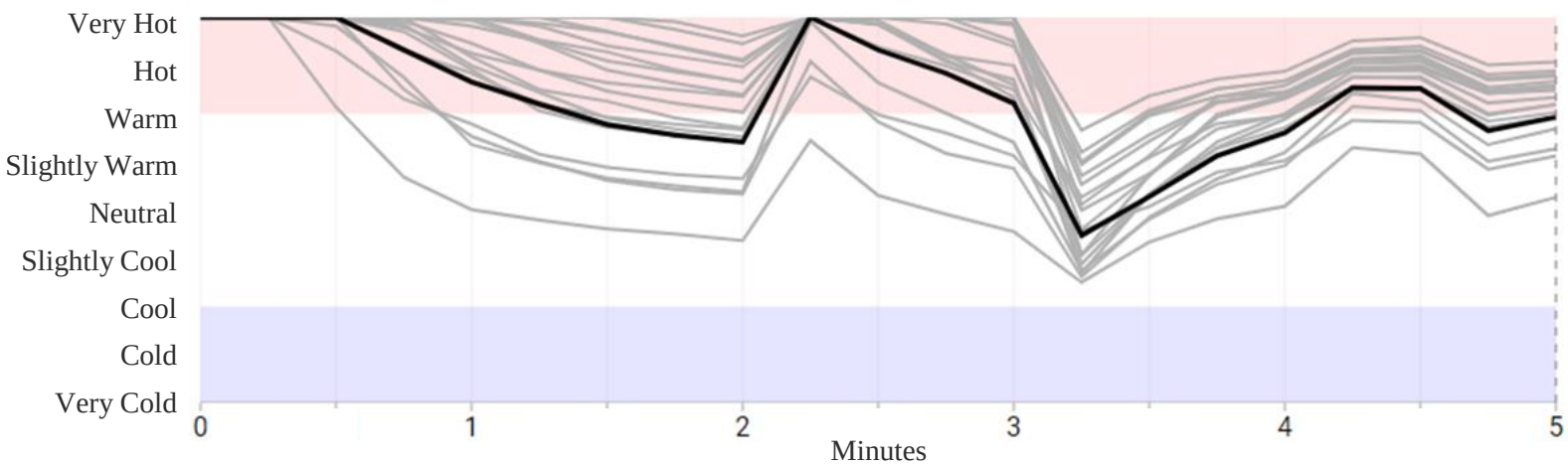

**1** Jog along path, Highly sheltered

**2** Jog along parking lot, More exposed

**3** Jog along Rindge Ave, More exposed

**4** Jog along path, Highly sheltered



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**Actual Sensation Vote** (Nikolopoulou, 2004); **Adaptive Thermal Index** (Humphrey, 1975); Apparent Temperature (Steadman, 1979); Discomfort Index (Thom, 1959); **Effective Temperature Scale** (Houghton et al.1923); **ETU** (Nagano& Horikoshi, 2011); **ETF**(Kurazumi et al., 2010); **Humid Operative Temperature** (Horikoshi et al., 1991); **Local_SET** (Kohri and Mochida, 2003); **New Effective Temperature ET*** (Gagge at al. 1971) **Outdoor Standard Effective Temperature** (Spagnolo and de Dear 2003); **Perceived Temperature** (Tinz and Jendritzky 2003); **Perceived Temperature** (Staiger, et al, 2011); **Physiologically Equivalent Temperature** (Höppe 1999); **Predicted Mean Vote, Predicted Percentage Dissatisfied** (Fanger, 1972); **Standard Effective Temperature** (Gagge et al. 1986); **Seven-Point Thermal Comfort Scale** (Bedford, 1936); **Temperature-Humidity Index** (Clarke & Bach, 1971) **UTCI** (ISB, 2009); **Thermal Comfort Zone** (Houghton & Yagloglou, 1923) **Wind Chill Index** (Steadman, 1971); **Wind Chill Temperature Index** (OFCM, *2003*);

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