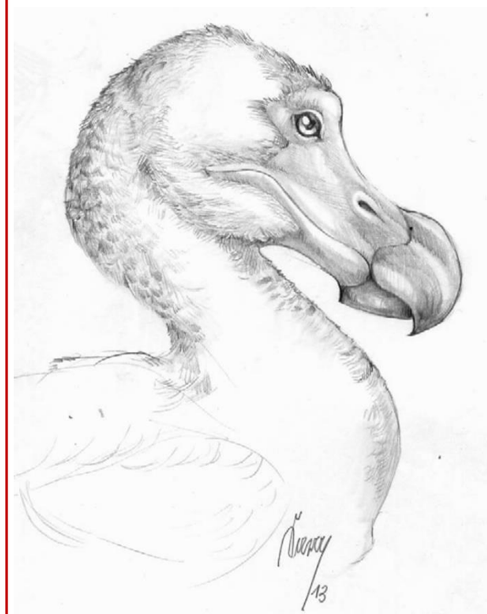

Adaptive Thermal Comfort: Practices and Policies

Deep Dive Workshop on Cooling, Asia Clean Energy Forum, June 5, 2018, Manila

Rajan Rawal CEPT University, INDIA
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What is thermal comfort?

"That condition of mind that expresses satisfaction with the thermal environment."

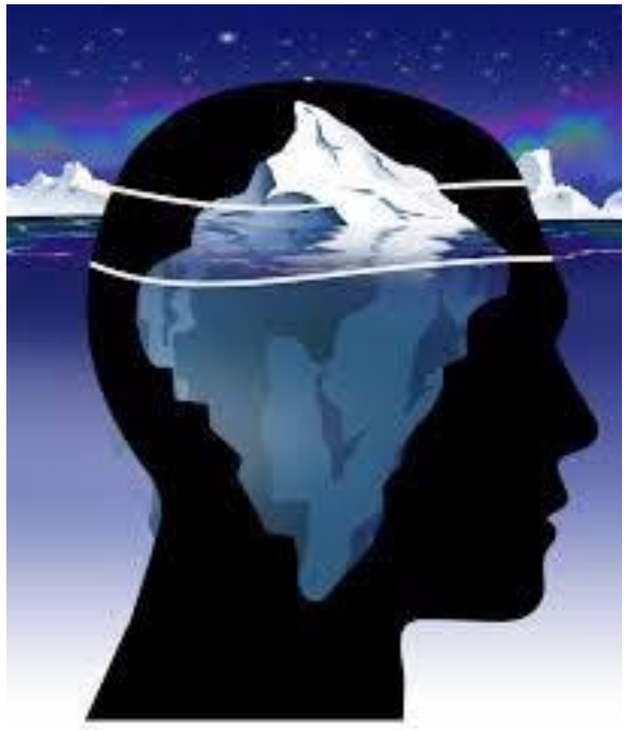
Reference: ASHRAE 55 - 2017

Reference: Sanyogita Manu, CEPT Un

- The conscious mind appears to reach conclusions about thermal comfort and discomfort from
  - direct temperature and moisture sensations from the skin
  - deep body temperatures
  - efforts necessary to regulate body temperatures

- In general, comfort occurs when
  - body temperatures are held within (narrow) ranges
  - skin moisture is low
  - physiological effort of regulation is minimized

Thermal Comfort



- Comfort also depends on behavioural actions that are initiated by
  - Altering clothing
  - Altering activity
  - Changing posture or location
  - Changing the thermostat setting
  - Opening a window
  - Complaining
  - Or leaving the space
- Conscious or unconscious
- Thermal and moisture sensations

Source: Thermal comfort, ASHRAE Fundamentals Handbook (SI)

Main Factors Affecting Thermal comfort

Environmental Factors

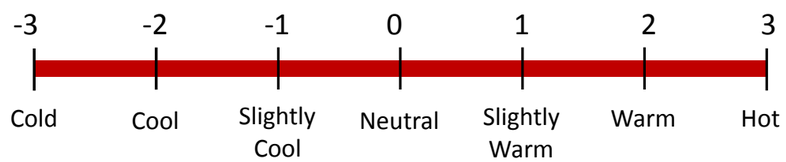
- Air temperature
- Mean Radiant Temperature (MRT)
- Humidity
- Air speed

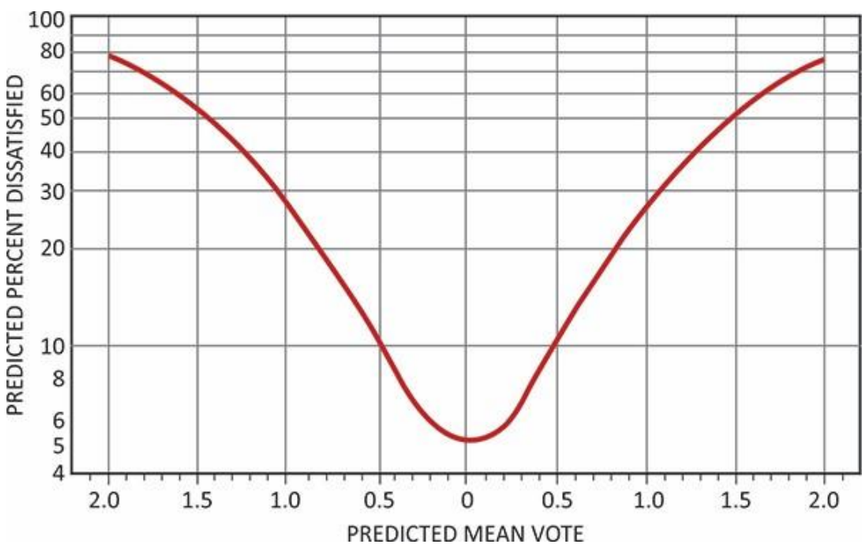
Personal Factors

- Activity (metabolic rate)
- Clothing

Reference: ASHRAE 55 - 2017

- It is possible to provide thermal satisfaction up to 80% of occupants





Reference: ASHRAE 55 - 2017

- The Predicted Mean Vote (PMV) refers to a thermal scale
- Cold (-3) to Hot (+3),
- Originally developed by Fanger and later adopted as an ISO standard.

PMV Thermal Indices

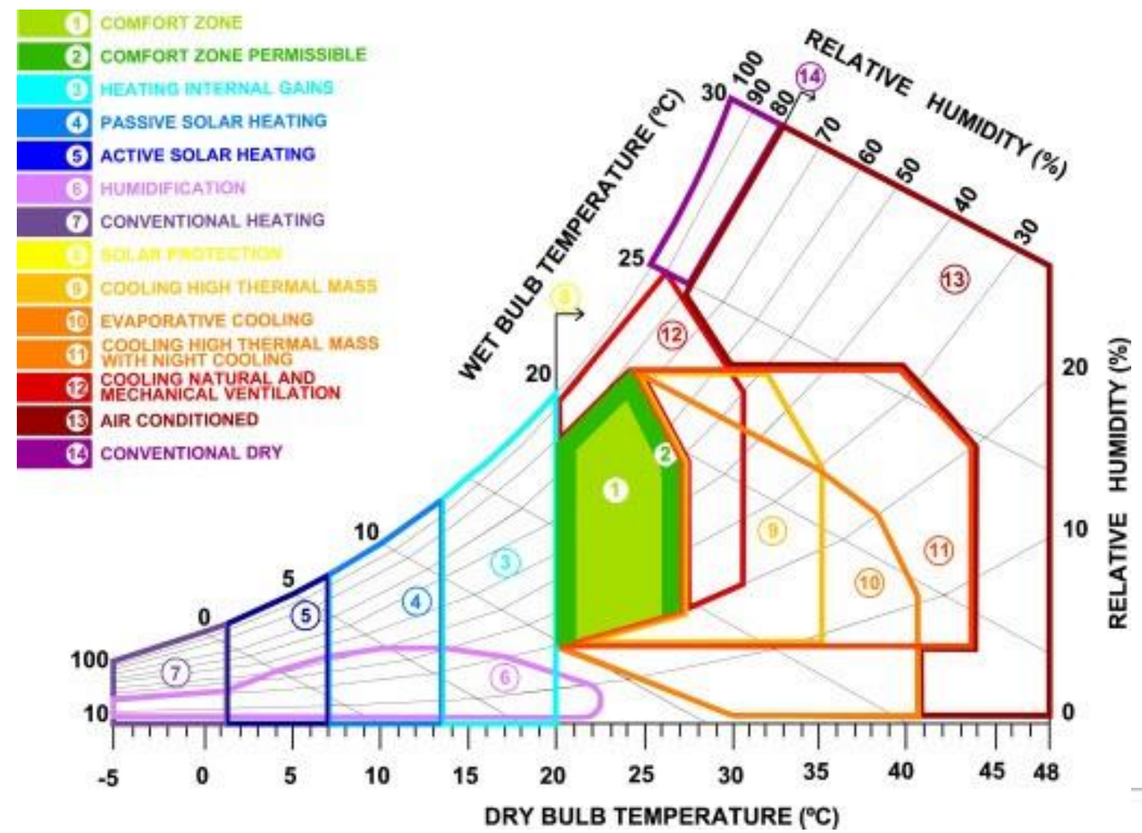
- Predicts the mean value of the votes of occupants on the seven point thermal sensation scale

Predicted Percentage Dissatisfied

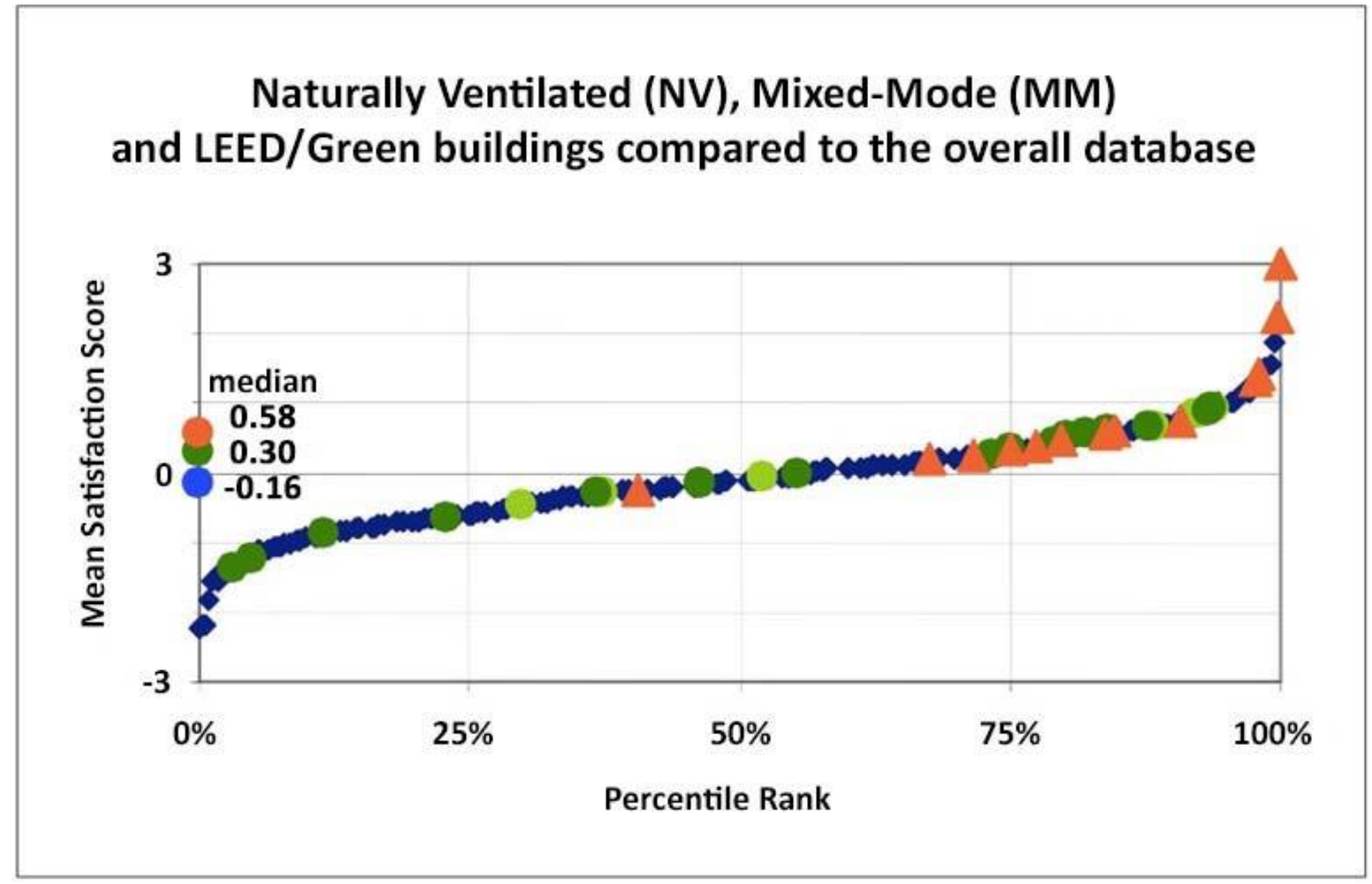
- Prediction of the percentage of thermally dissatisfied occupants

Reference: ASHRAE 55 - 2017

Are occupant thermally comfortable in buildings



Are occupant thermally comfortable in buildings



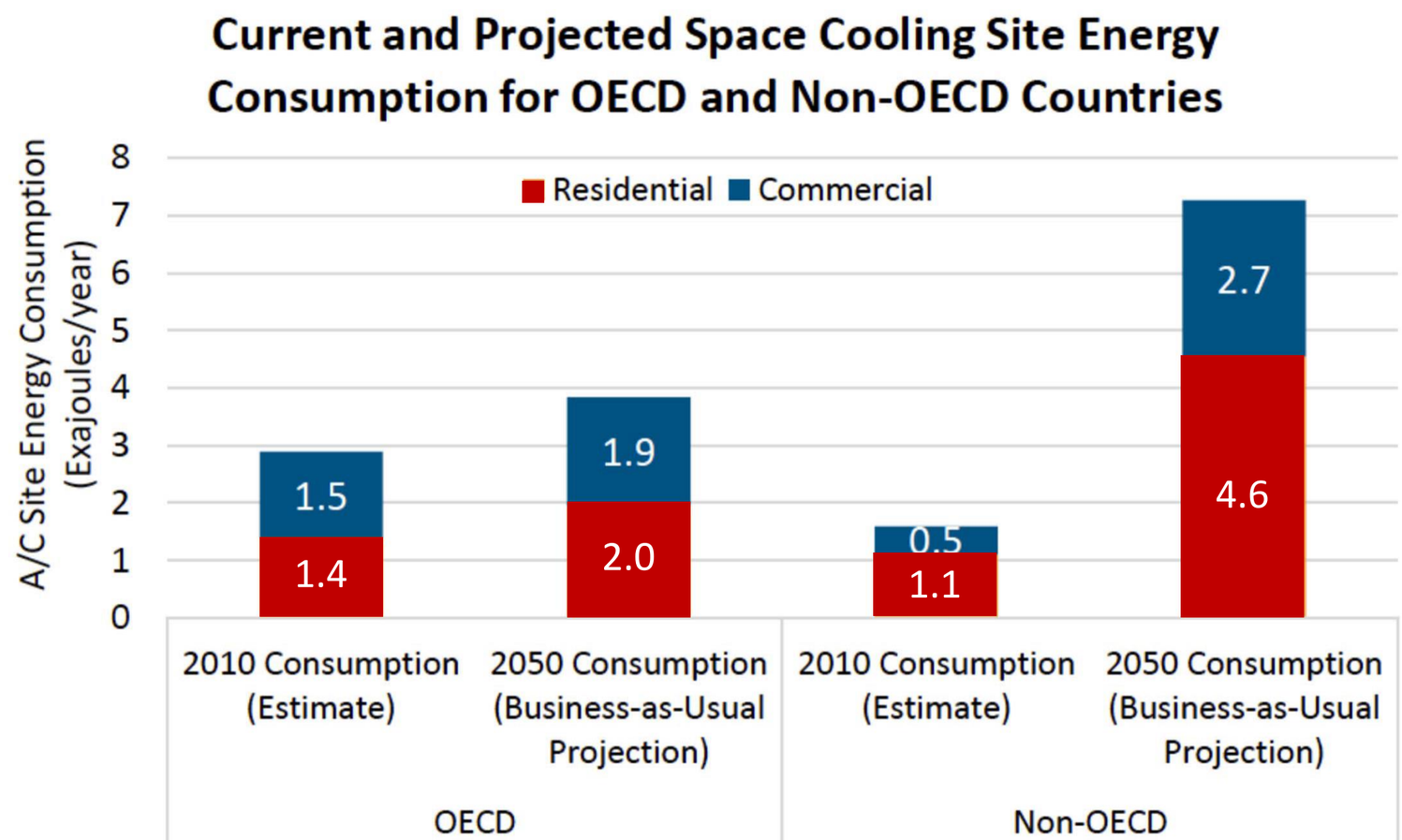
Database (n=267bldgs) LEED/green buildings(n=22) NV / MM buildings (n=13)

Source: Brager, G. and L. Baker. " Occupant Satisfaction in Mixed –Mode Buildings". Building Research & Information, Vol 37, No 4, July/August 2009, pp 369-380.

Do we need to look at the way India buildings are designed and operated?

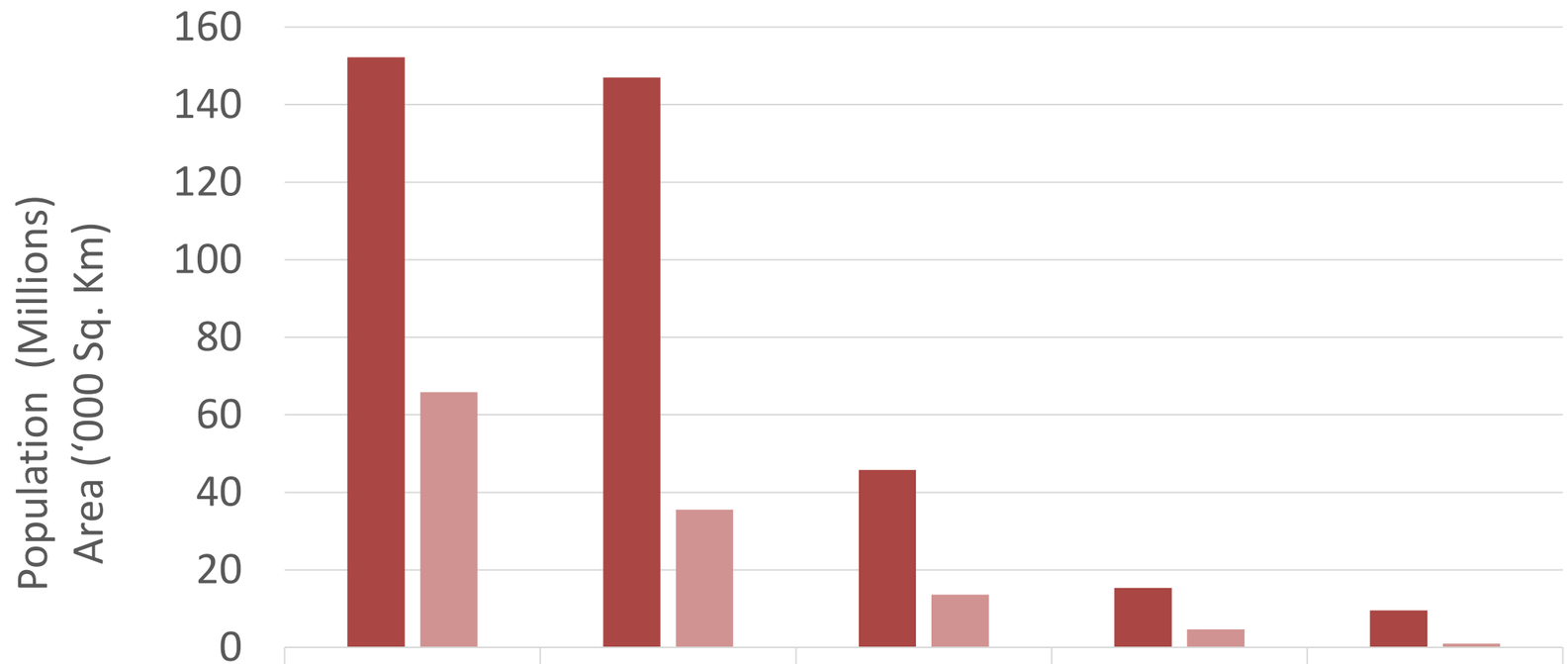
- The “static model” views comfort as part of a deterministic sequence of cause-and-effect and ignores the adaptive role of occupants
- Installing ever-increasing cooling capacity to deal with global warming is not a rational adaptive response; that’s maladaptation
- It is important that India doesn’t repeat the same mistakes and takes the opportunity of rolling out HVAC rationally the first time, and using natural ventilation when and where feasible

Do we need to look at the way India buildings are designed and operated?



Reference: Rocky Mountain Institute

Geographical Area and Population defined as Urban in Census 2011

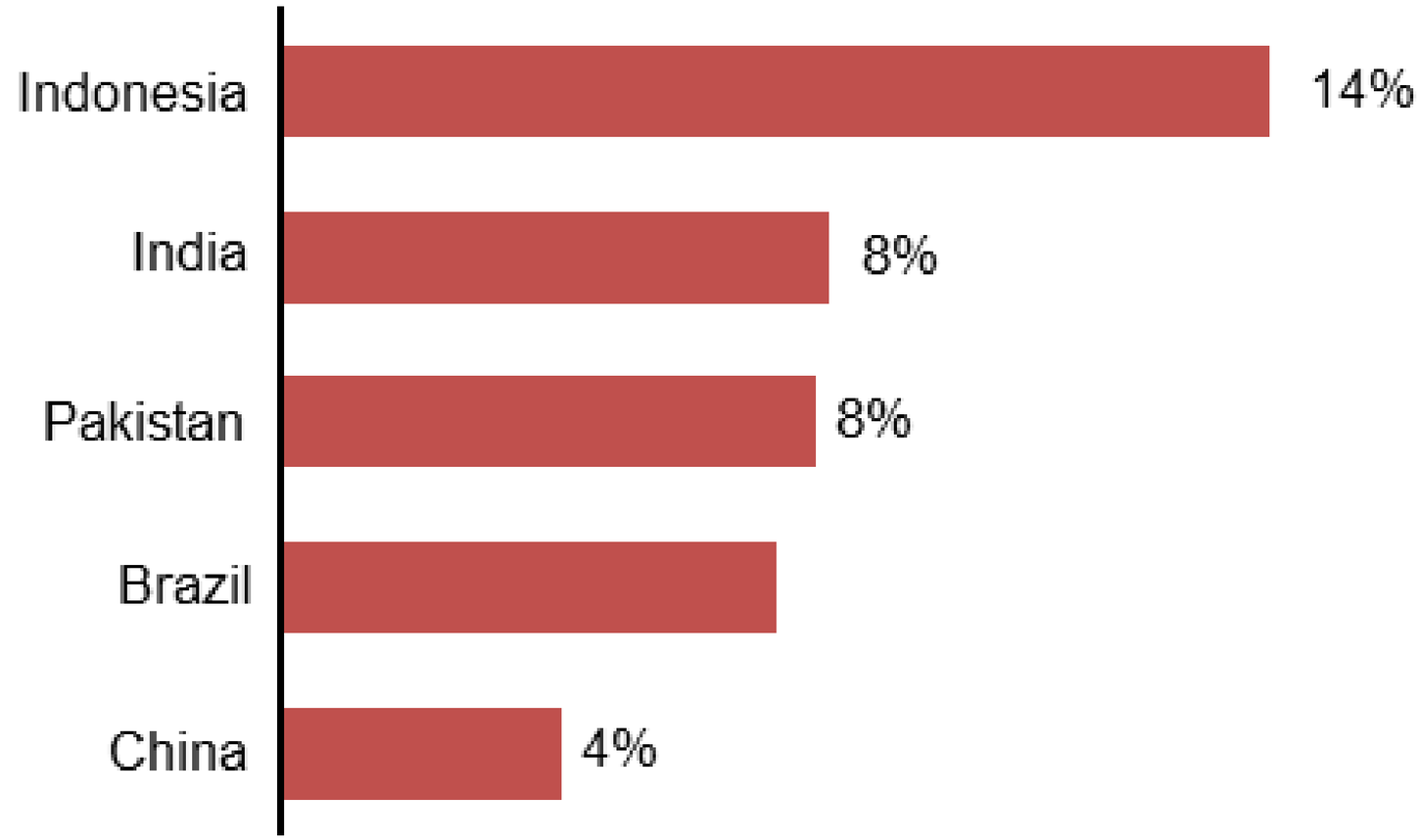


	Warm-Humid	Composite	Hot-Dry	Cold	Temperate
Population (Millions)	152.2	147.0	45.8	15.3	9.5
Area (in '000 sq. km.)	65.8	35.5	13.6	4.6	1.0

Population (Millions) Area (in '000 sq. km.)

Source: Census 2011, Government of India (http://www.censusindia.gov.in/2011census/dchb/DCHB.html)

Cooling costs as % of median household income

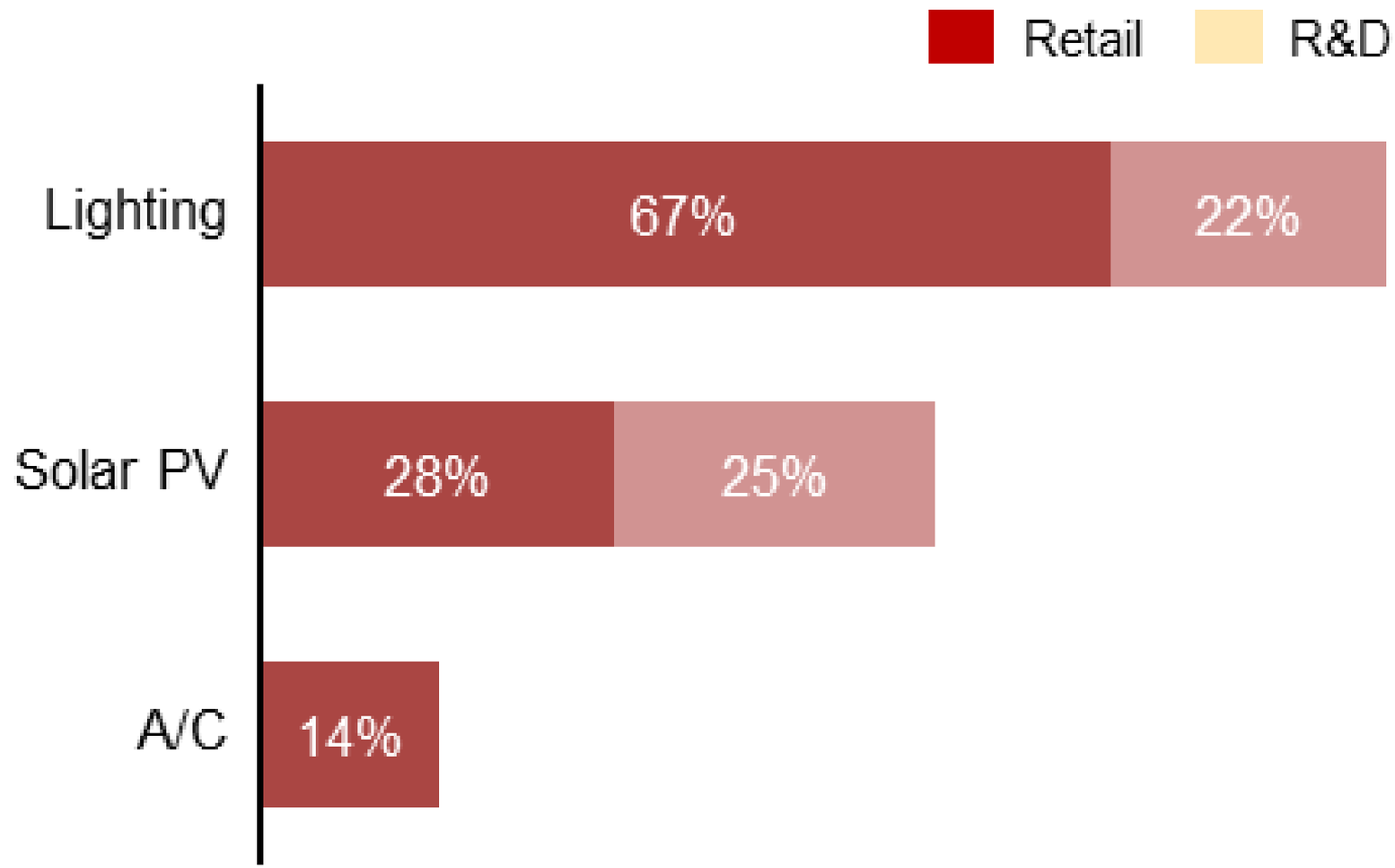


A burden to consumers

Cooling at current efficiency is unaffordable for the average consumer in developing countries

Source: LBNL Report: Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning (2015), Global Industry Analyst Market Research, Enerdata, UCSUSA , Eco Climate Network Article, NRDC (2015), IECS and Christian Aid Report (2017); IPCC, "Fifth Assessment Report", 2014.

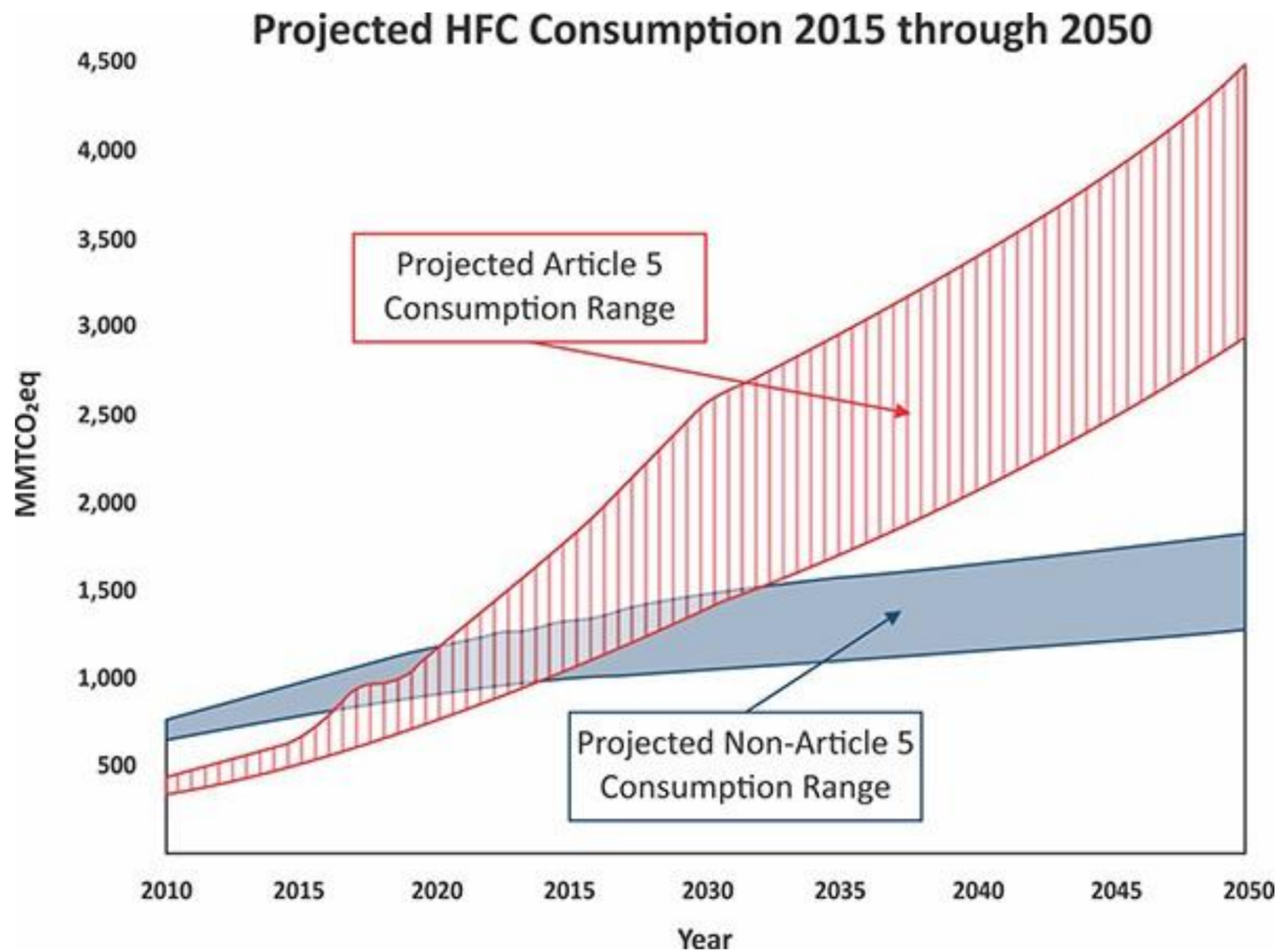
Industry progress toward theoretical max efficiency



Compared to other energy technologies, the AC industry has made little progress in approaching maximum theoretical efficiency

Source: Greentech Media, "Sunpower Again Holds Record for World's Most Efficient Rooftop Solar Panel", 2017; PHYS, "White LEDs with Super-High Luminous Efficacy Could Satisfy All General Lighting Needs", 2010; Fujitsu, 2017; CLASP, "AC Challenge Program for India", 2017; LBNL, "Addressing Air Conditioner Energy Efficiency Lost in Translation to Strengthen Policy", 2018.

Do we need to look at the way India buildings are designed and operated?



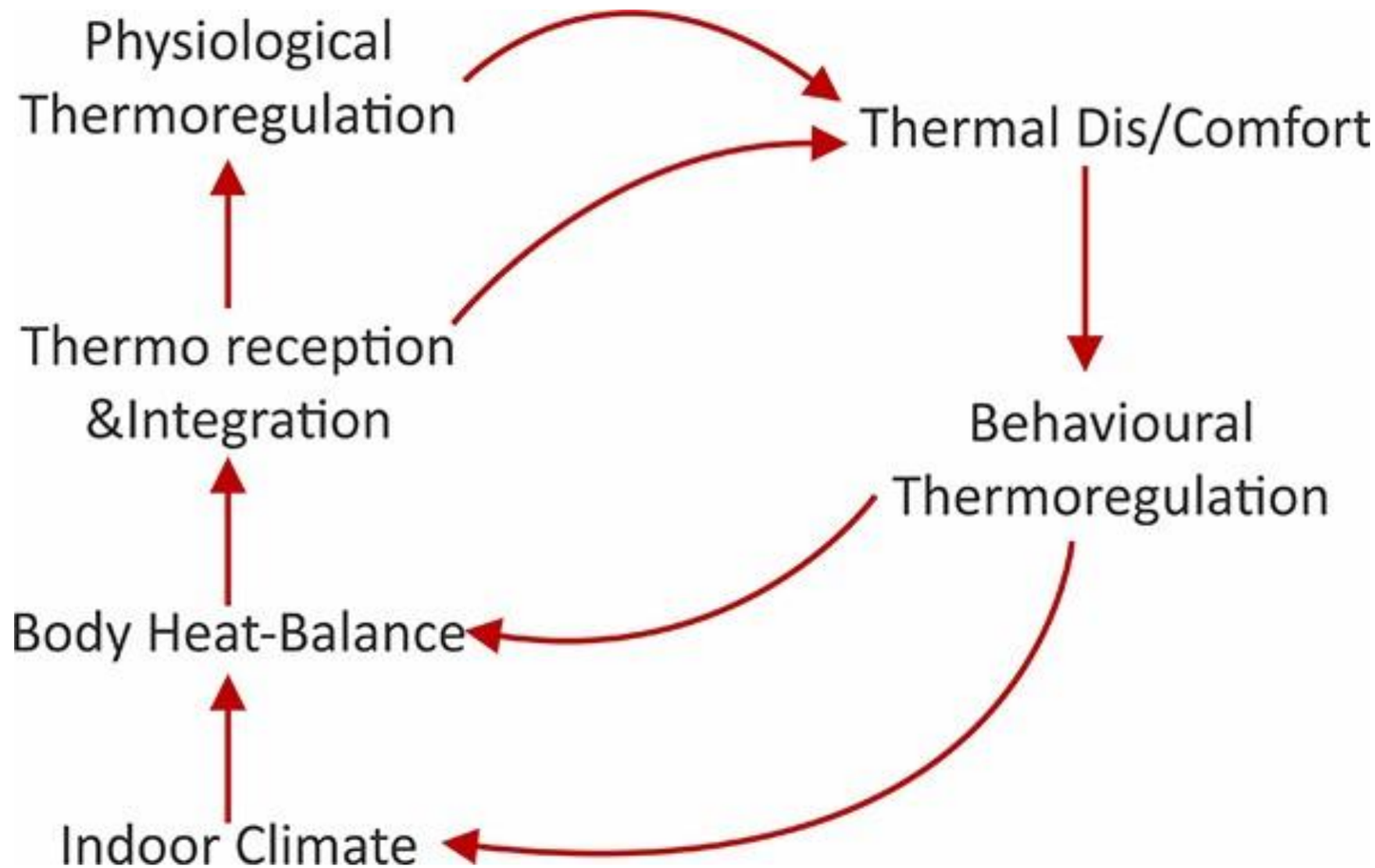
Reference: Rocky Mountain Institute

Adaptive Thermal Comfort Regime

Adaptive thermal comfort is a theory that suggests a human connection to the outdoors and control over the immediate environment allow them to adapt to (and even prefer) a wider range of thermal conditions than is generally considered comfortable

Reference: Rocky Mountain Institute

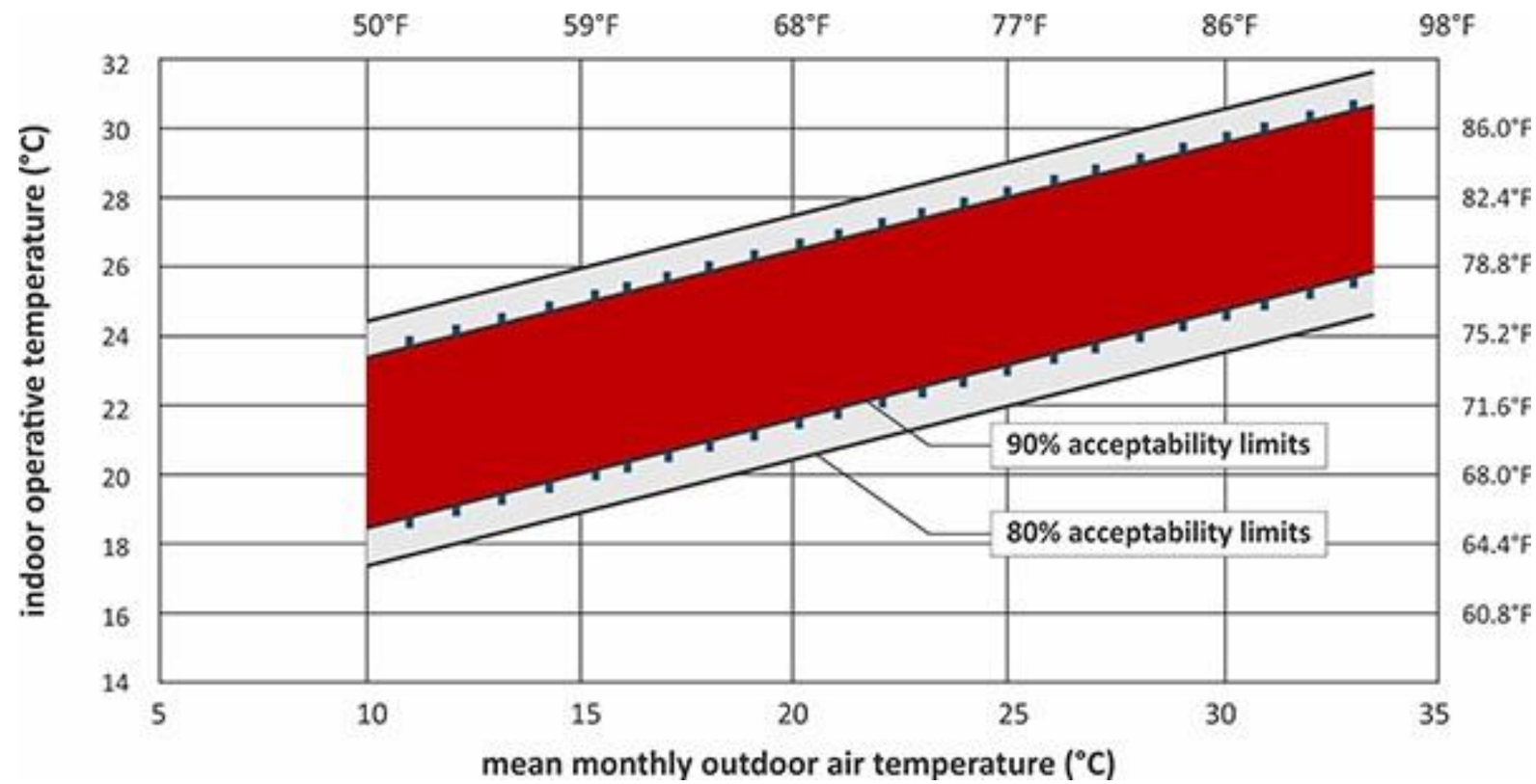
The Adaptive Thermal Comfort Principle



"If a change occurs that produces discomfort, people will tend to act to restore their comfort."

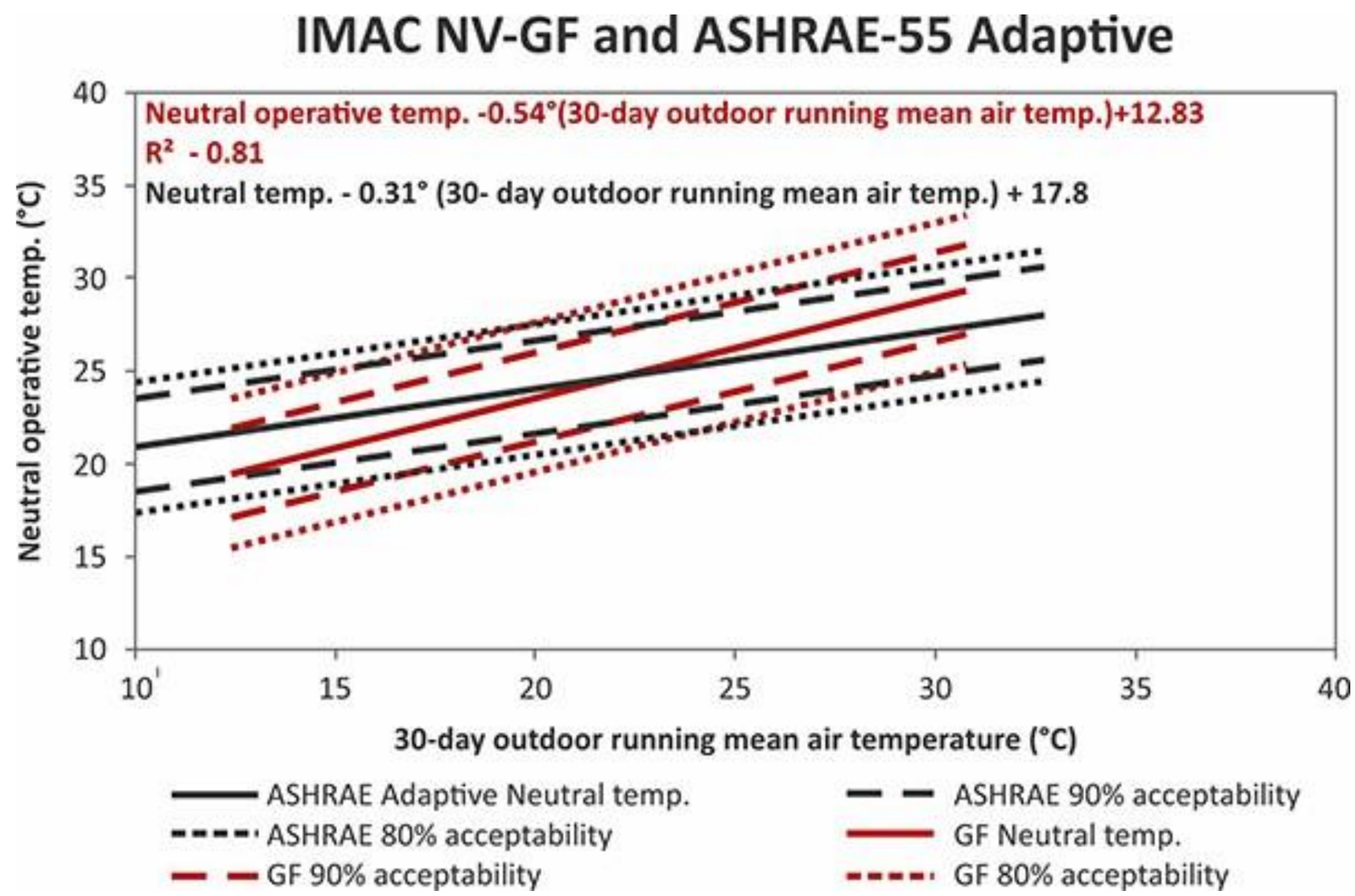
Reference: Sanyogita Manu, CEPT Un, and Richard de Dear

The Adaptive Thermal Comfort Principle



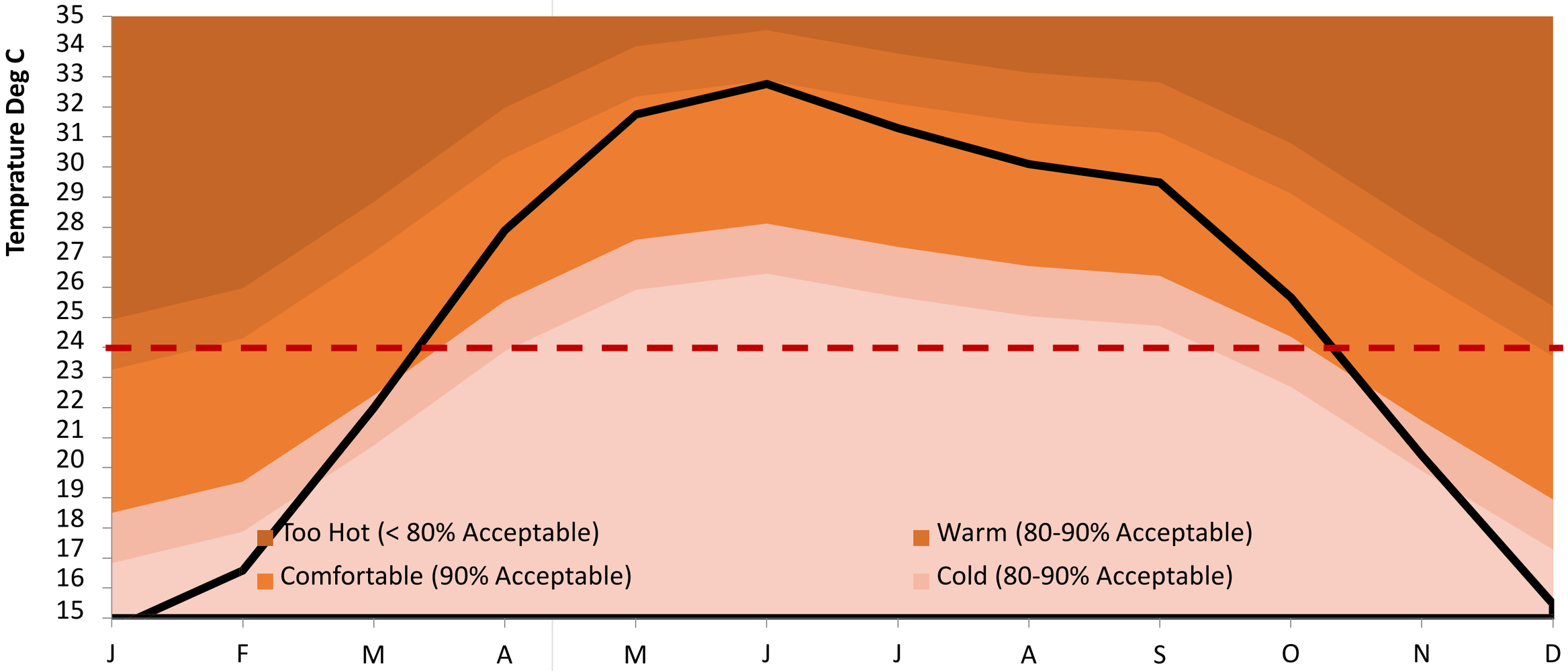
- Humphreys and Nicol (1998)
- Auliciems (1983)
- Nicol & Roaf (1996)
- Brager & de Dear et al (1998)

India Model For Adaptive *Thermal* Comfort (IMAC)



Reference: Sanyogita Manu, CEPT University

Operative Temperature Comfort Bands for NV spaces in New Delhi , India



India Model For Adaptive *Thermal* Comfort (IMAC)

Naturally Ventilated Buildings

Indoor Operative Temperature = (0.54 x outdoor temperature) + 12.83

- Where, indoor operative temperature (°C) is neutral temperature, & outdoor temperature is the 30-day outdoor running mean air temperature (°C).
- The 90 percent acceptability range for the India specific adaptive models for naturally ventilated buildings is ± 2.38°C.

For example, Indoor Operative Temperature for a naturally ventilated building in Delhi

= (0.54 x 33.0) + 12.83 = 30.68 °C

Mixed Mode Buildings

Indoor Operative Temperature = (0.28 x outdoor temperature) + 17.87

- Where indoor operative temperature (°C) is neutral temperature & outdoor temperature is the 30-day outdoor running mean air temperature (°C).
- The 90 percent acceptability range for the India specific adaptive models for mixed-mode buildings is ± 3.46°C.

For example, Indoor Operative Temperature for a mixed mode building in Delhi

= (0.28 x 33.0) + 17.87 = 27.1 °C

Air conditioned Buildings

Indoor Operative Temperature = (0.078 x outdoor temperature) + 23.25

- Where indoor operative temperature (°C) is neutral temperature & outdoor temperature is the 30-day outdoor running mean air temperature (°C).
- The 90 percent acceptability range for the adaptive models for conditioned buildings is ±1.5°C.

Energy Conservation Building Code (2017) India

National Building Code (India) 2016

GRIHA Rating 2017

Reference: ECBC 2017 , NBC 2016

India Model For Adaptive *Thermal* Comfort (IMAC)

NV Buildings:

Indoor Operative Temperature = (0.54 x outdoor temperature) + 12.83

Mixed Mode Buildings

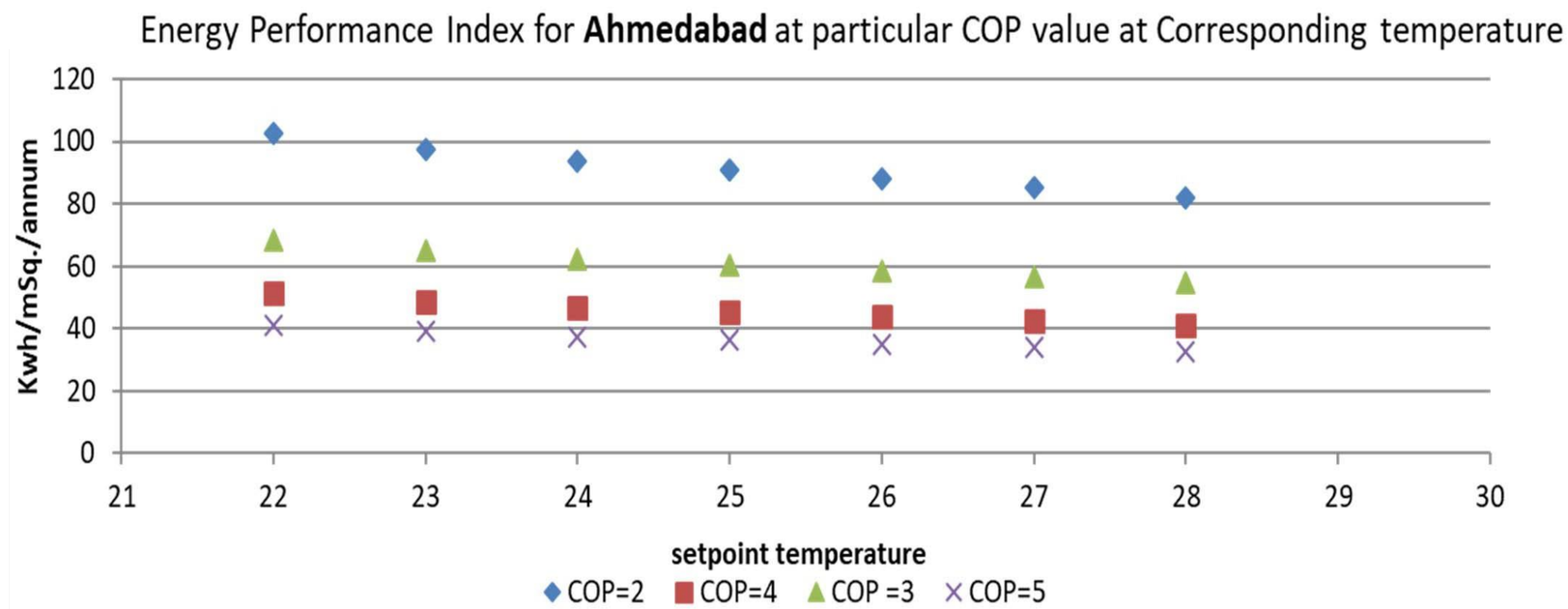
Indoor Operative Temperature = (0.28 x outdoor temperature) + 17.87

AC Buildings

Indoor Operative Temperature = (0.078 x outdoor temperature) + 23.25

Reference: ECBC 2017 , NBC 2016

Energy Benefits Of Adaptive Thermal Comfort Regime



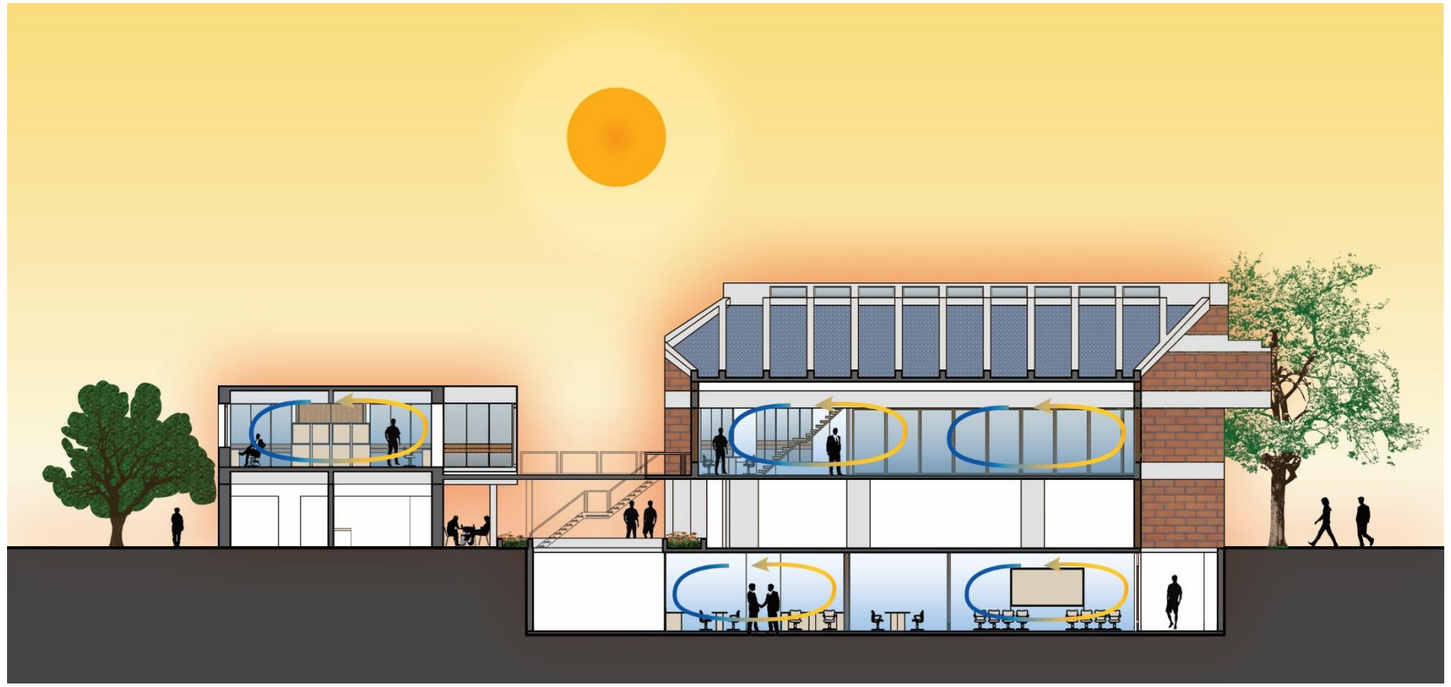
SETPOINT/COP	2	3	4	5
22	103	68	51	41
23	98	65	49	39
24	94	62	47	37
25	91	61	45	36
26	88	59	44	35
27	85	57	43	34
28	82	55	41	33

2	3	4	5
100%	67%	50%	40%
93%	62%	47%	37%
87%	58%	44%	35%
82%	54%	41%	33%
75%	50%	38%	30%
69%	46%	34%	28%
62%	41%	31%	25%

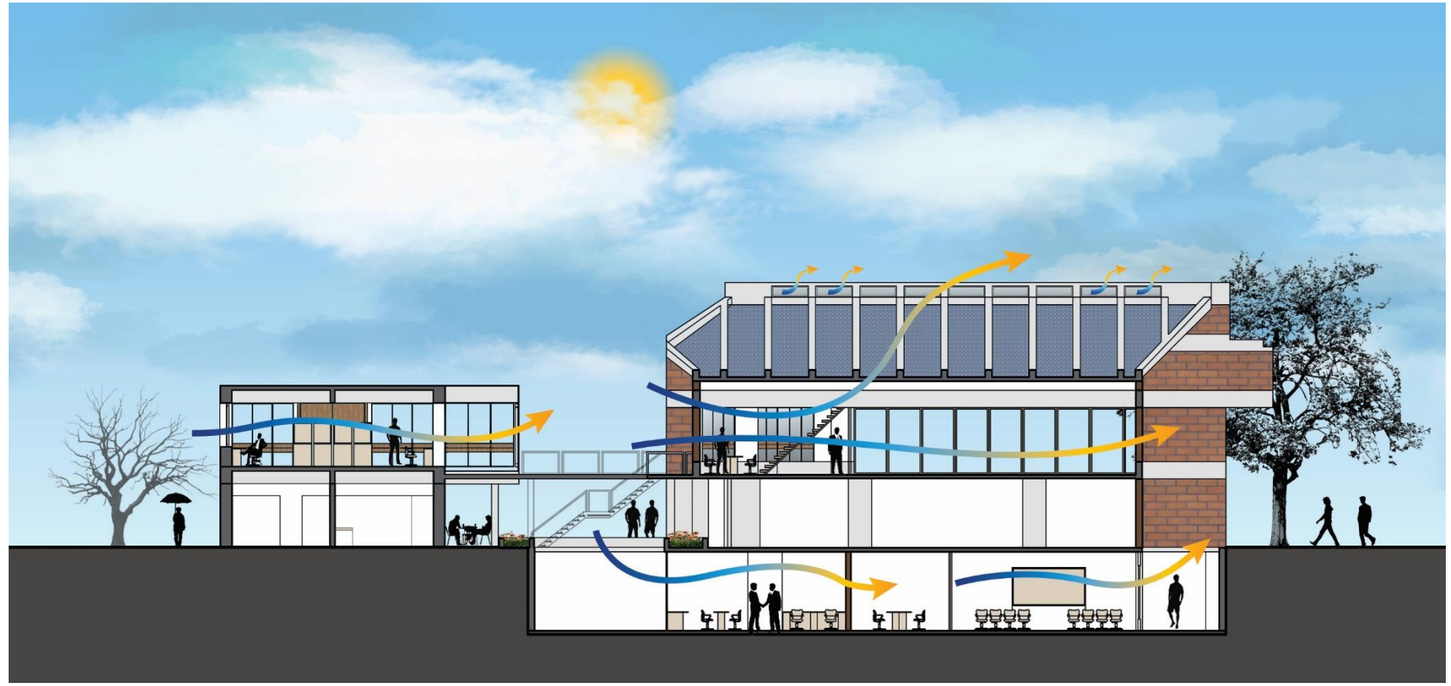
Reference:
Krutika Ghawghawe, Sanyogita Manu, Yash Shukla
PLEA2014 paper

Centre for Advanced Research and Building Science and Energy At CEPT University Ahmedabad

Mixed Mode Operation of Building



Take advantage of favourable outdoors when available



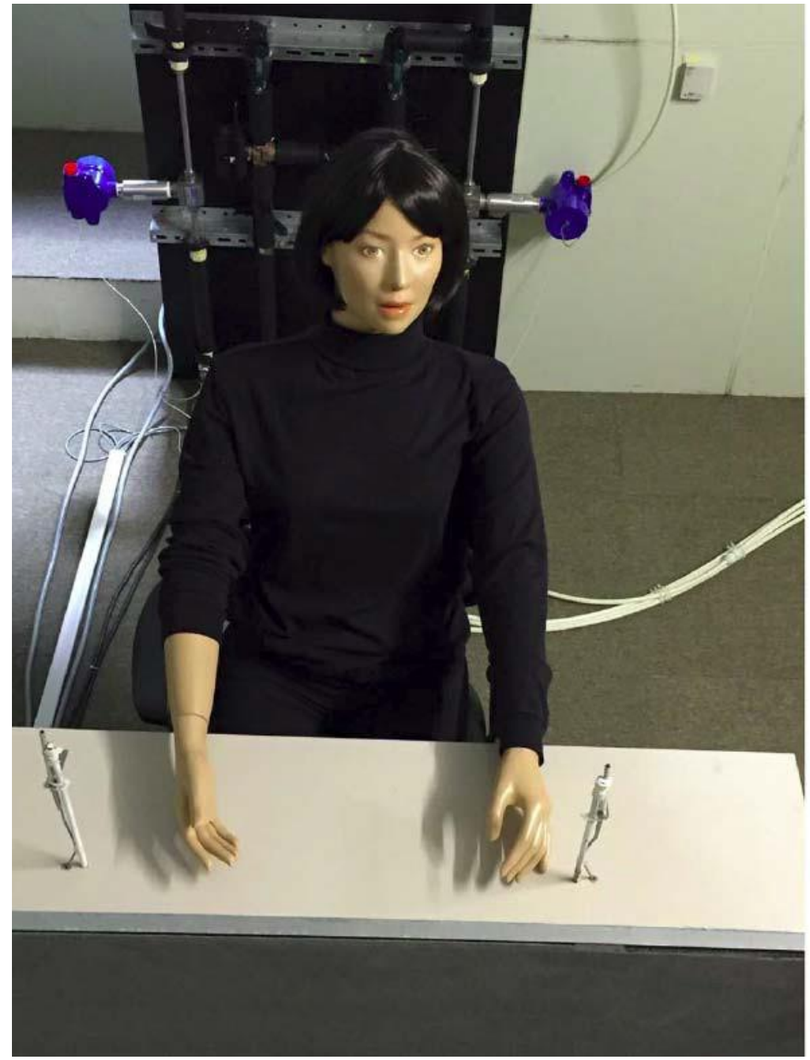
Air Velocity

Thermal Comfort Chamber Experiments

Study Method

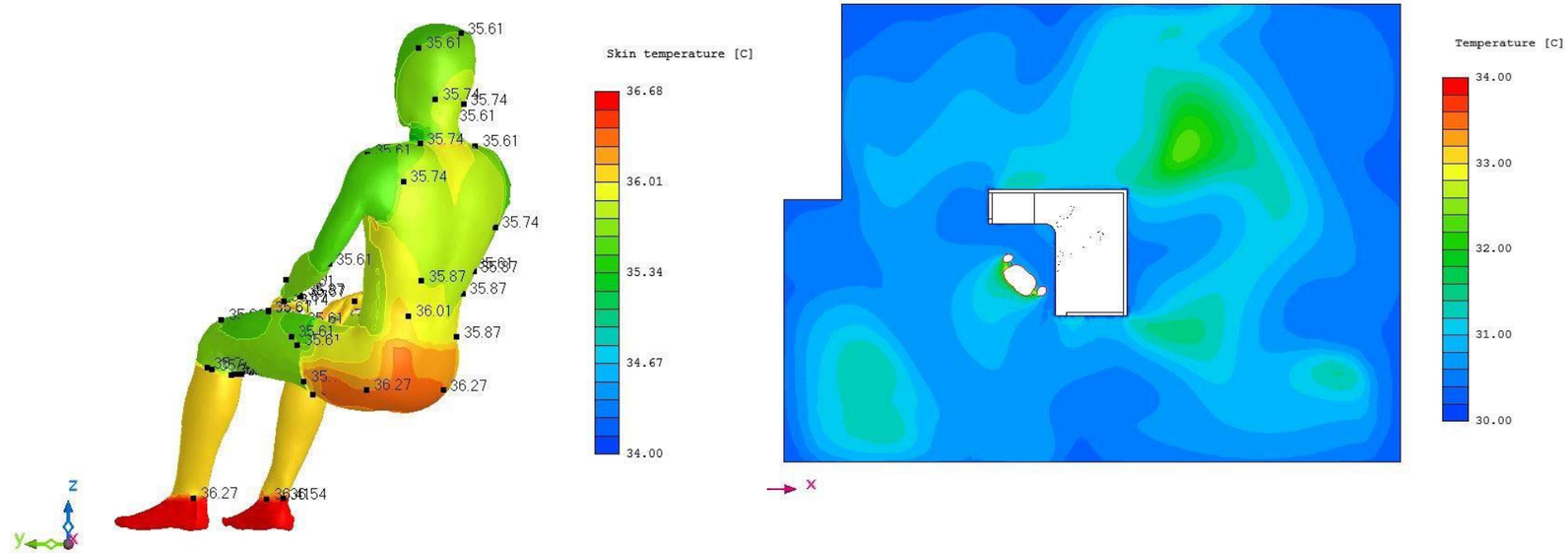
Personal Control and Comfort

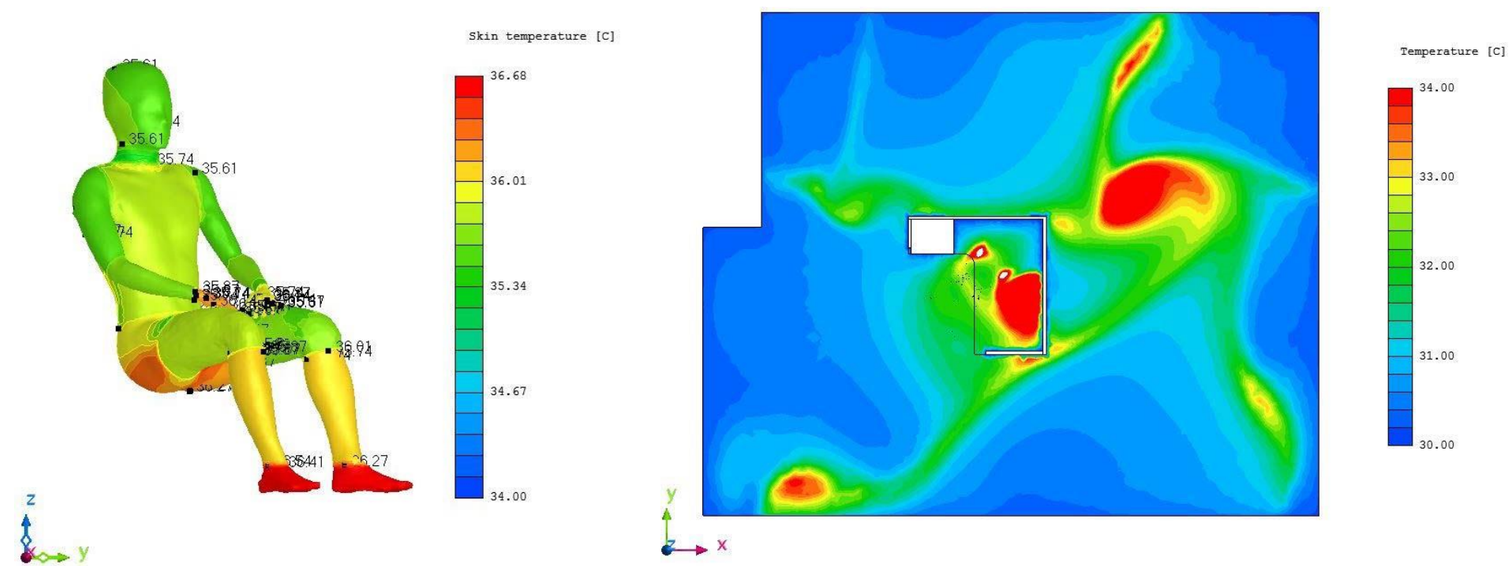
Thermal Comfort Chamber Experiments



Personal Control and Comfort

In Silica Digital Simulations for Comfort

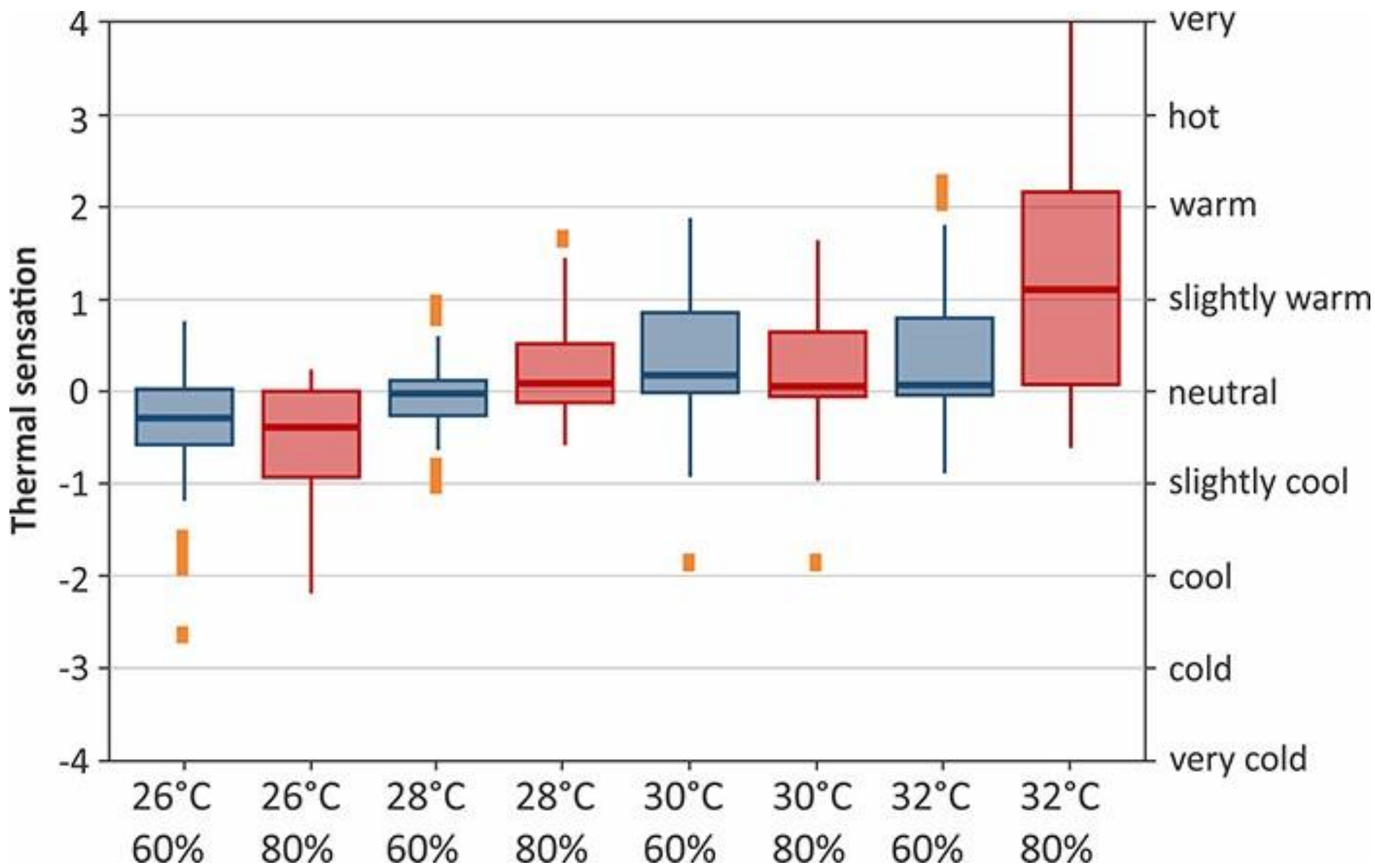




Air Velocity

Thermal Comfort Chamber Experiments

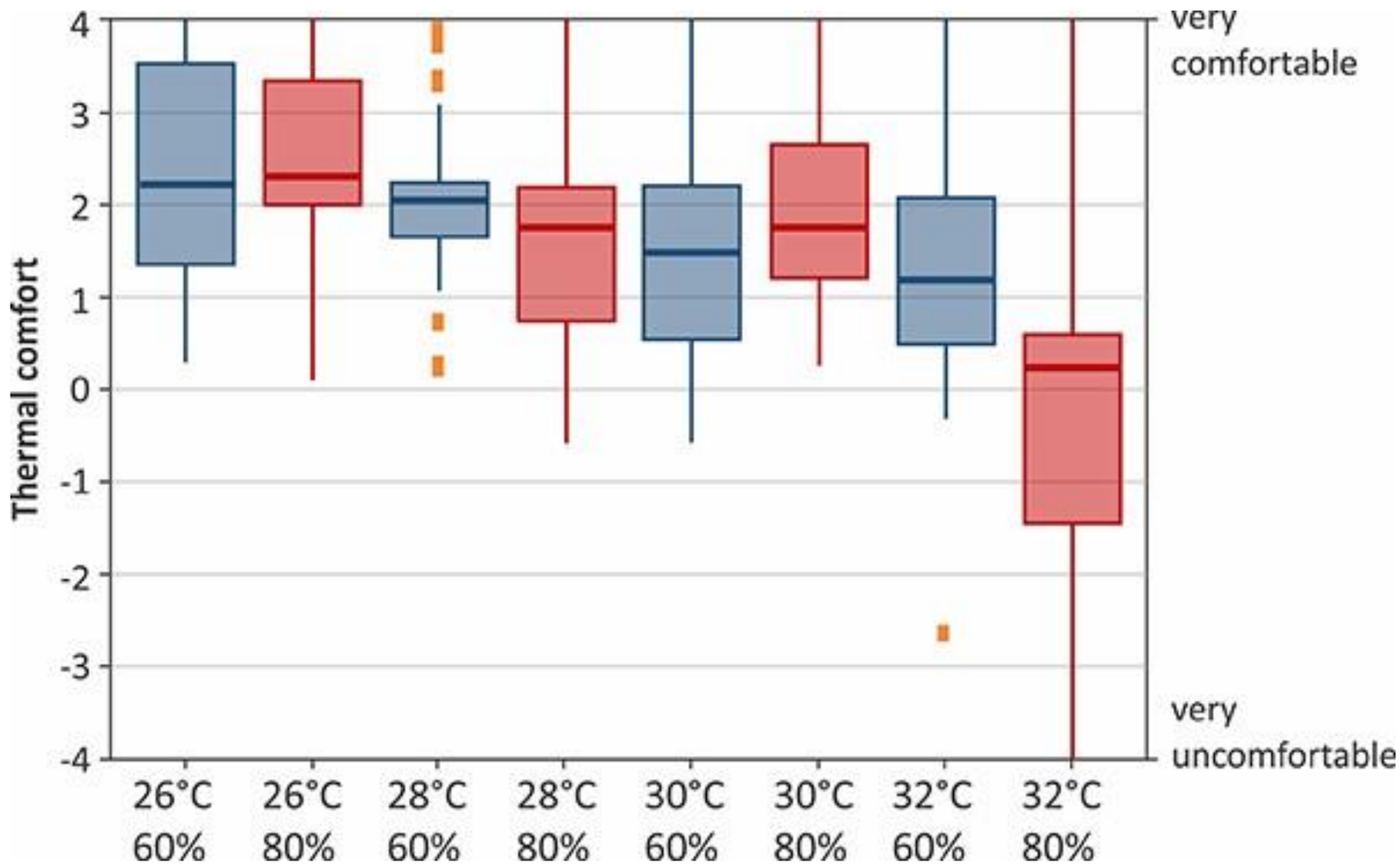
Thermal Sensation

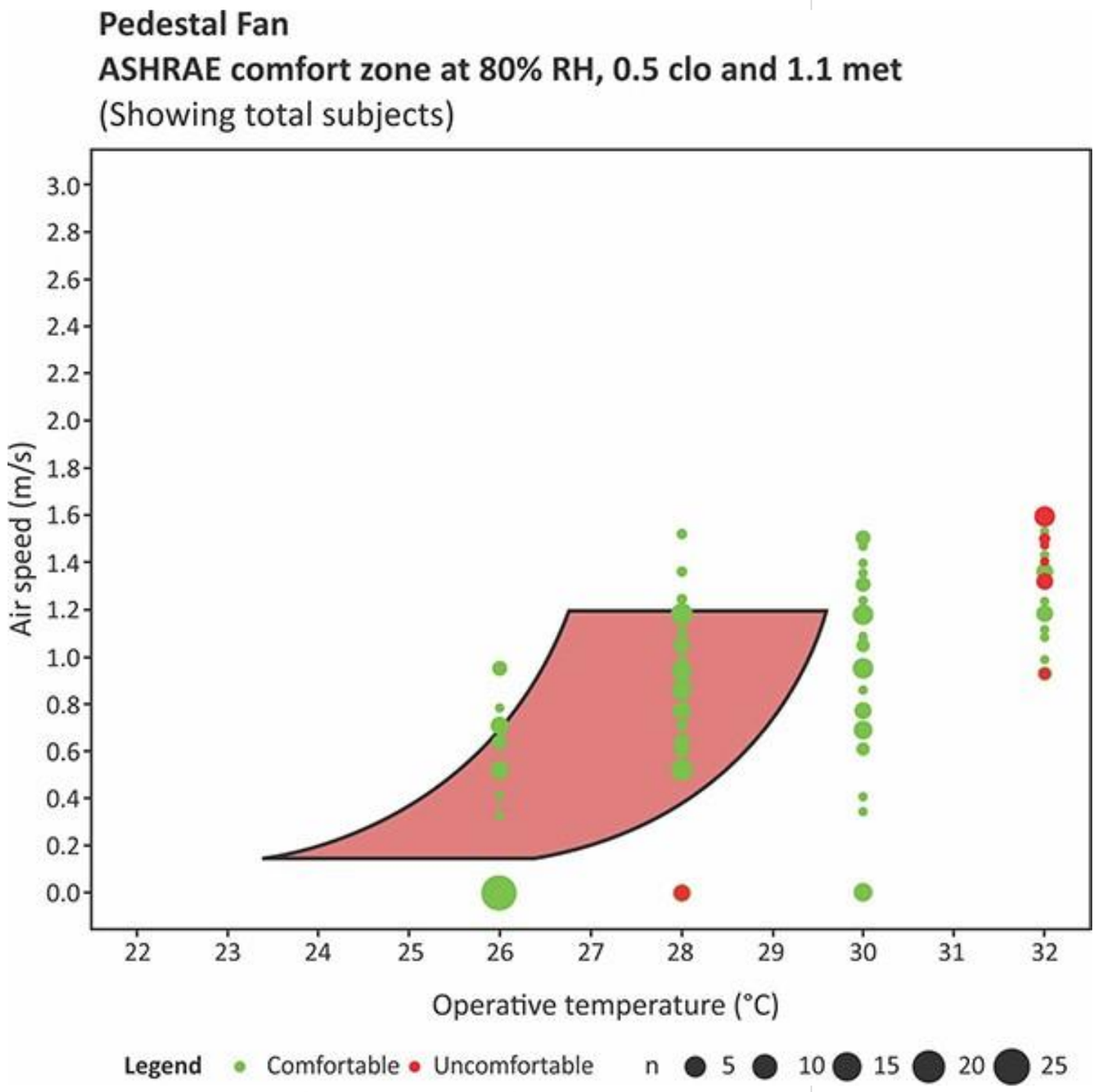


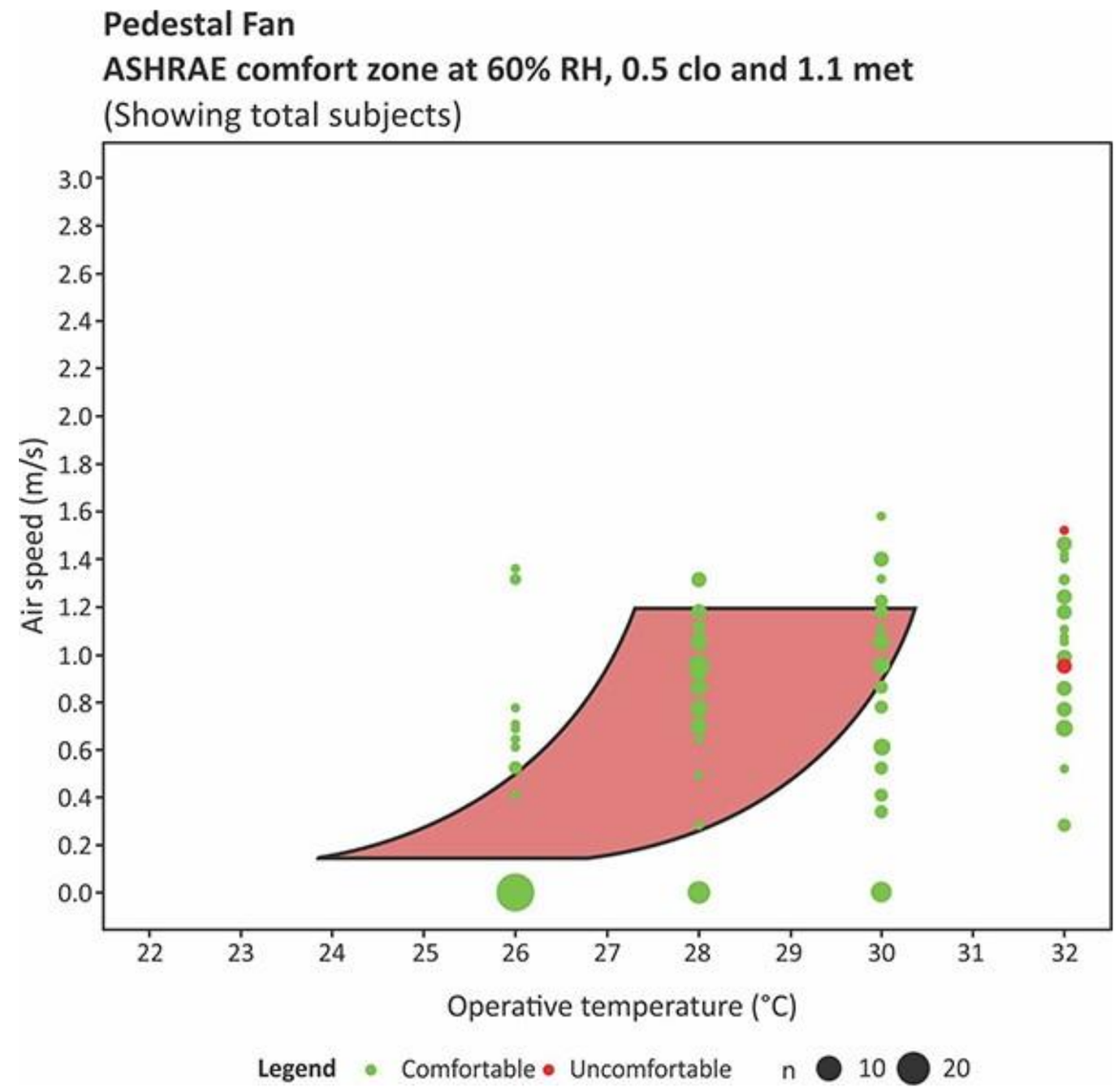
Air Velocity

Thermal Comfort Chamber Experiments

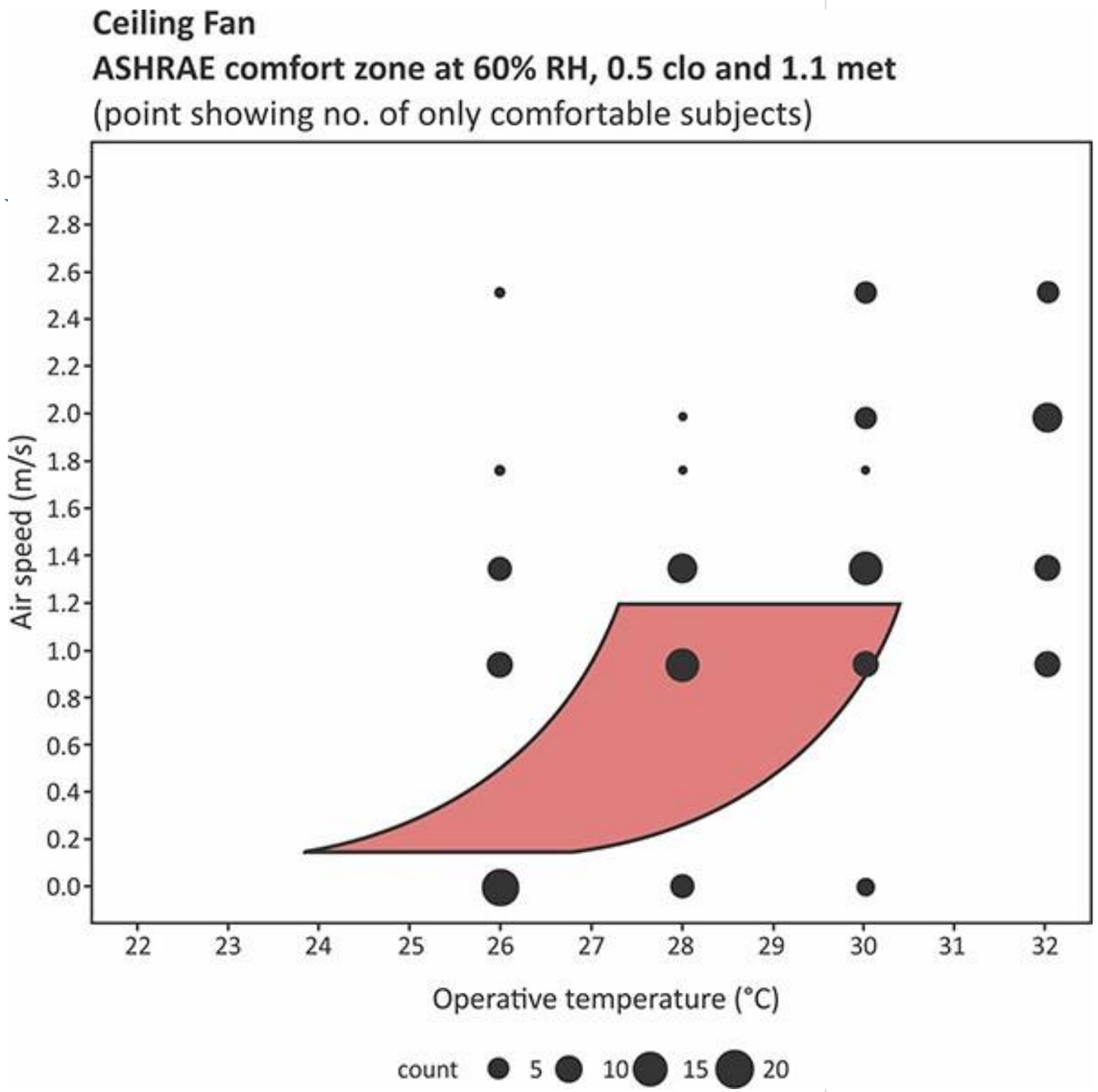
Thermal Comfort

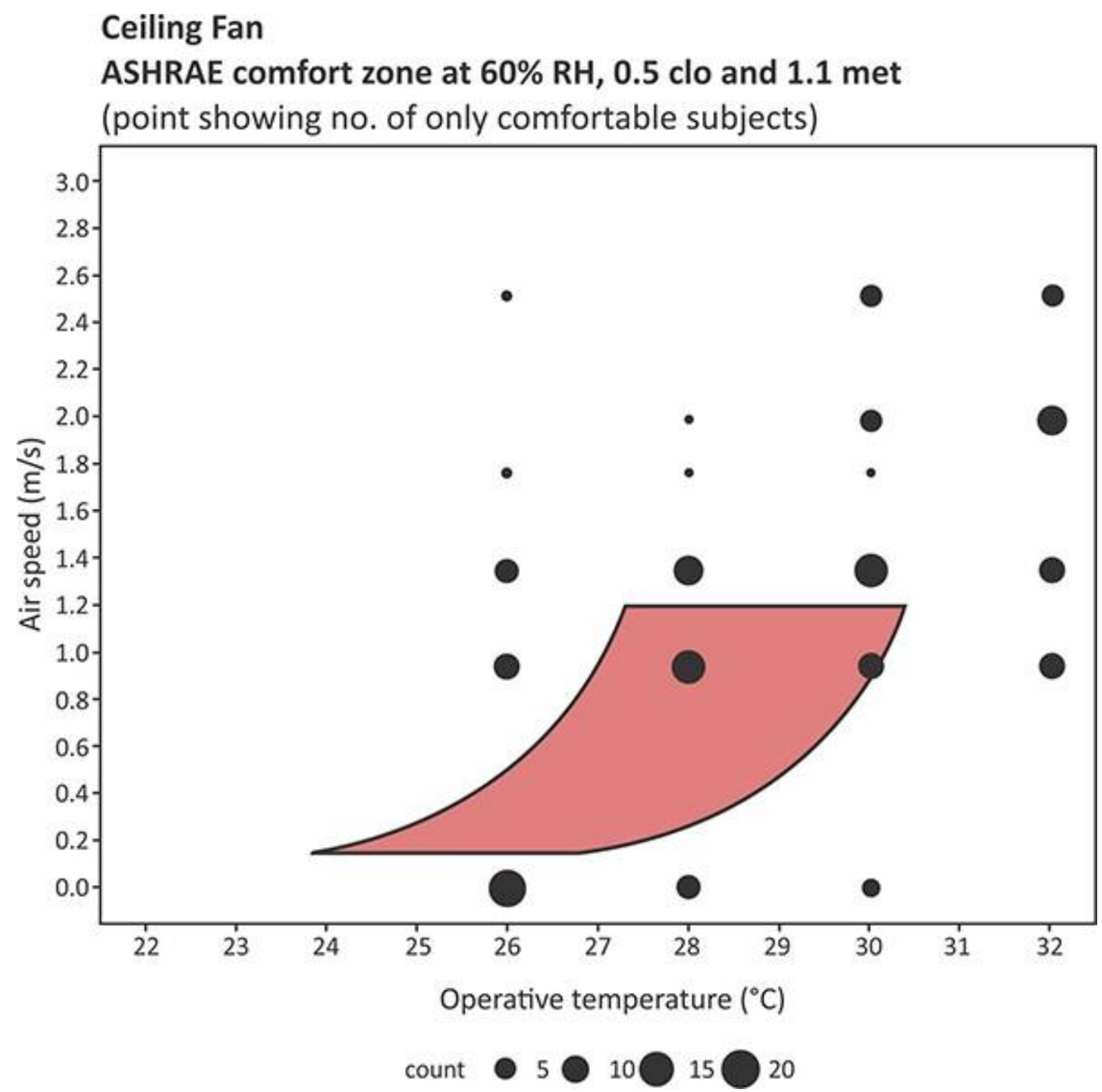






Pedestal fan Comfortable temperature, RH and selected air speeds against the ASHRAE comfort zone at 60% and 80% RH with elevated air movement





Ceiling fan Comfortable temperature, RH and selected air speeds against the ASHRAE comfort zone at 60% and 80% RH with elevated air movement

Adaptive Thermal Comfort regime

- Operate buildings in mixed mode
- Give controls to people
- Cooling versus comfort
  - Provide comfort to occupants
  - Do not cool buildings
- Floating set points, in sync with outdoors
- Reduction in cooling capacity (kW)
- Reduction in Energy Consumption (kWh)

Reference: ECBC 2017 , NBC 2016

INTRODUCTION

Global Cooling Prize

THE GLOBAL COOLING PRIZE

Residential Air Conditioning Poses a Critical Threat

THE PROBLEM

By **2030** over **1/2** of the world's population will live in hot climates

Cooling demand will boom **3x** by **2050**, posing a huge climate risk

2.5 B AC units will be in use globally by **2050** (compared to only 900 M today)

Only **14%** of theoretical efficiency has been reached by today's best AC technology (most ACs attain just 6%)

THE SOLUTION

Spurs climate-friendly residential cooling tech that uses **3–5x** less energy and fulfills 9 other requirements

Is led by a coalition of global partners that engage industry and markets to identify and scale a solution

Awards at least **US $3M** in prize money

Is just the start of an era of global innovation and transformation for the industry

THE IMPACT

Affordable access to cooling in parts of the world where it is becoming a critical need

Potential to mitigate **1°C** of global warming by **2100**

3,200 TWh in avoided grid capacity

A cooling technology in billions of homes that uses **5x** less grid energy

JOIN US: globalcoolingprize.org

MISSION INNOVATION
Accelerating the Clean Energy Revolution

ROCKY MOUNTAIN INSTITUTE

ROCKY MOUNTAIN INSTITUTE

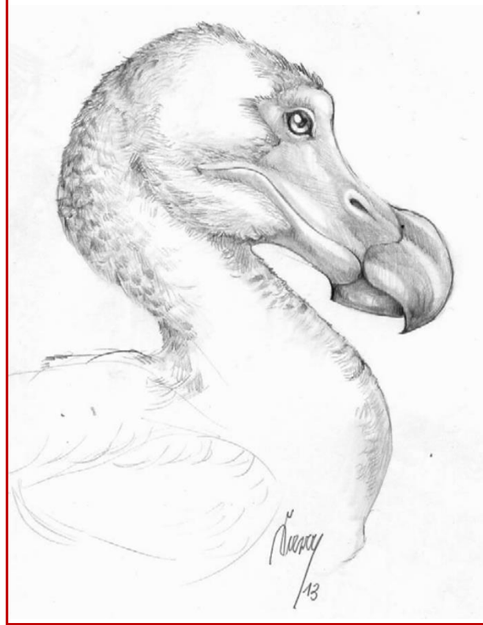
CONSERVATION X LABS

CEPT UNIVERSITY

Alliance for an Energy Efficient Economy™

Department of Science & Technology, Government of India
सत्यमेव जयते

MISSION INNOVATION
Accelerating the Clean Energy Revolution



- Dodo was incredibly easy to catch
- Never feared humans

Addiction to cooling *and not comfort* may lead us in big trouble

https://s3.amazonaws.com/lowres.cartoonstock.com/technology-winter-snowmen-air_conditions-repair_man-snowman-tmcn3194_low.jpg

Thank You

rajanrawal@cept.ac.in