GGGI

ASIA LOW CARBON BUILDINGS TRANSITION PROJECT

Life Cycle Assessment for Transitioning to a Low-Carbon Economy

2.3 Adaptive Thermal Comfort Design Strategies

November 2024

ASEAN CENTRE FOR ENERGY ACE

EESL

HEAT

Supported by:

Federal Ministry for Economic Affairs and Climate Action

IKI INTERNATIONAL CLIMATE INITIATIVE

on the basis of a decision by the German Bundestag

WHAT WILL YOU LEARN?

01 Understand human comfort perceptions

02 Factors affecting human thermal comfort

03 Understand dynamics of heat generation and dissipation from human body

04 The importance of optimal air movement in rooms

05 ASHRAE Standards for adaptive thermal comfort

06 Models for adaptive thermal comfort

07 Potential solutions

Image source: https://www.firstinarchitecture.co.uk/internal-environment-thermal-air-sound-and-light/

Human Comfort in Buildings

Indoor Environment

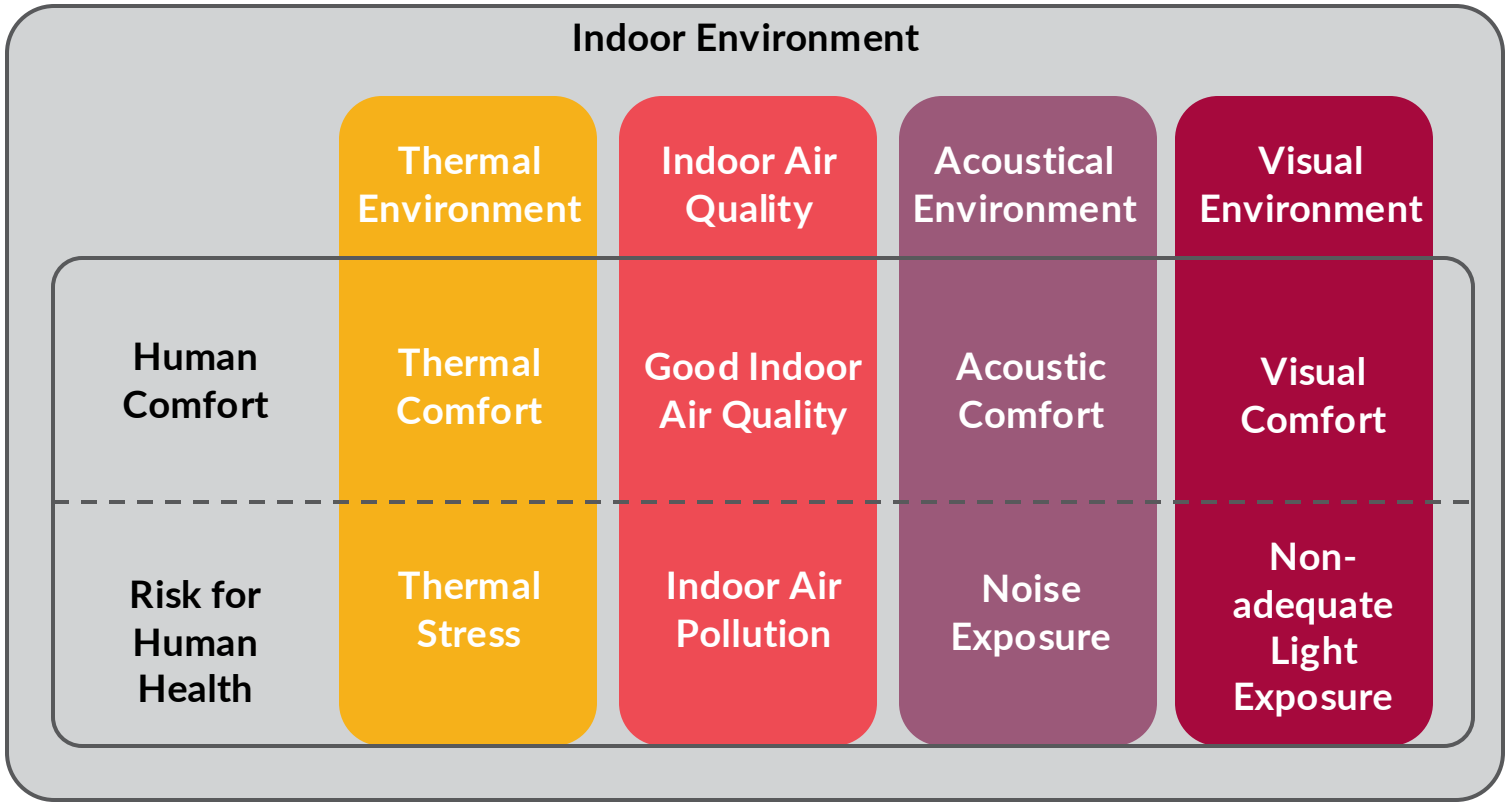
INDOOR ENVIRONMENT QUALITY

For human comfort

Human comfort within buildings can be categorized into four comfort parameters:

i. Thermal
ii. Visual
iii. Acoustical
iv. Indoor air quality

Each parameter can gradually impact **human health**, if not maintained to prescribed limits



Source: Fantozzi and Rocca, 2020

VISUAL COMFORT

Indoor environment

Sharp contrast or major change in light levels can **cause stress and fatigue**, as the human eye then has to constantly adjust to varying lighting levels

Both **too much and too little light** can be a cause of visual discomfort

Factors determining healthy visual environment include:

- Access to the outside view
- Adequate daylight without glare
- Uniformly distributed light within the space
- Adequate task lighting

Source: Franco, 2019

ACOUSTICAL COMFORT

Indoor environment

Four types of noise, emanating from the following sources, are usually experienced in buildings:

i. Exterior
ii. Interior
iii. Impact
iv. Equipment

These noises are transmitted through the building fabric.

The nature of the sounds and its perception by the human ear depends on its **reverberation and absorption within the building**

Source: Leardi, 2021

AIR QUALITY

Indoor environment

Health effects of poor indoor air quality:

i. Respiratory problems
ii. Headaches and fatigue
iii. Allergic reactions
iv. Long-term health risks

Common indoor air pollutants

i. Dust and particulate matter
ii. Mold and mildew
iii. Carbon monoxide
iv. Volatile organic compounds (VOCs)
v. Radon

Thermal Comfort

Adaptive Thermal Comfort

THERMAL COMFORT

And discomfort!!!

One person's comfort is another's discomfort

- The complaint of a person suffering warm, humid room condition may be legitimate
- But often, it is people in centrally air-conditioned rooms who complain of poor or excessive cooling

Cases of partially-sealed air supply duct outlets, installation of pedestal fans in air-conditioned spaces, and installation of split air conditioners in centrally air-conditioned rooms

Image source: SM Solutions

THERMAL COMFORT

Definition and influencing factors

Thermal comfort:

A state of mind that expresses satisfaction with the thermal surroundings

Influencing factors

- Activity (Metabolic Rate)
- Clothing
- Air Temperature
- Mean Radiant Temperature
- Air Movement
- Humidity

Depends on person specific activities

Depends on climatic conditions, building and HVAC design

Source: American Society of Heating, Refrigerating and Air-Conditioning Engineers

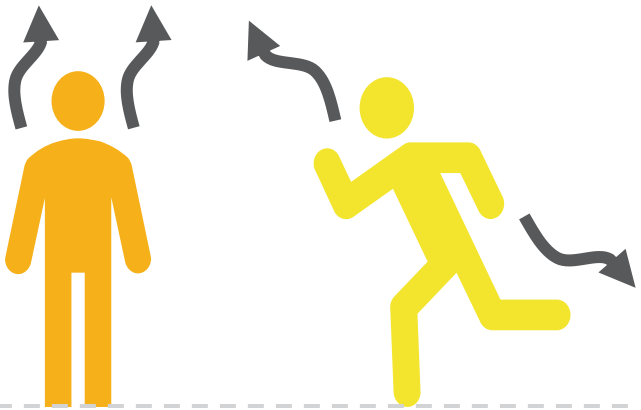
Image source: https://www.freepik.com/free-photo/1

THERMAL COMFORT

Facts

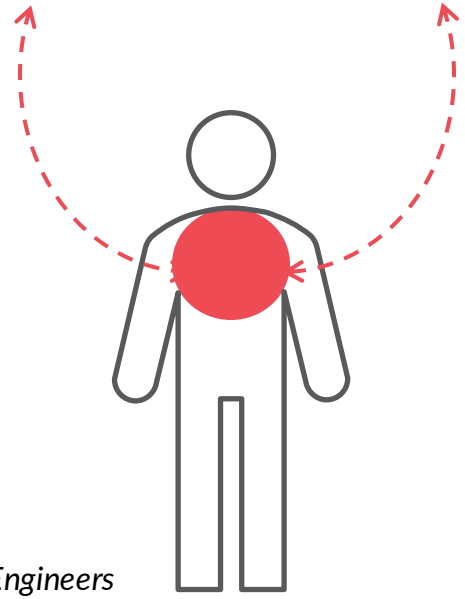
Static position
~105W

Physical activity
~400W

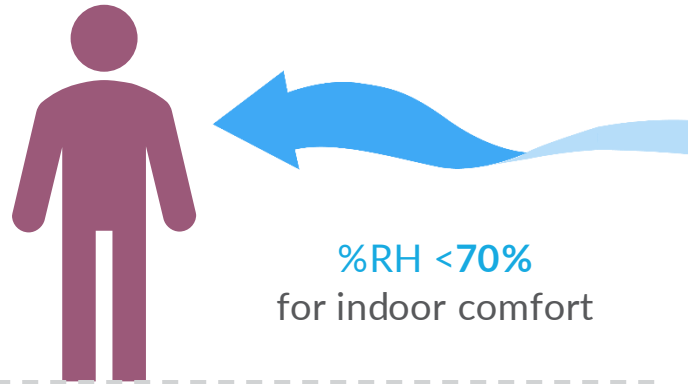


We feel comfortable when metabolic heat generated by the human body is dissipated at the same rate as it is produced

The human body needs to be maintained at **36°C ± 0.5°C** regardless of prevailing ambient conditions



Acceptable air velocity range **0.15m/s–0.50m/s** (at 23°C–26°C)



%RH <**70%** for indoor comfort

Air movement is essential for comfort as it enhances heat transfer between air and the human body and accelerates cooling of the human body

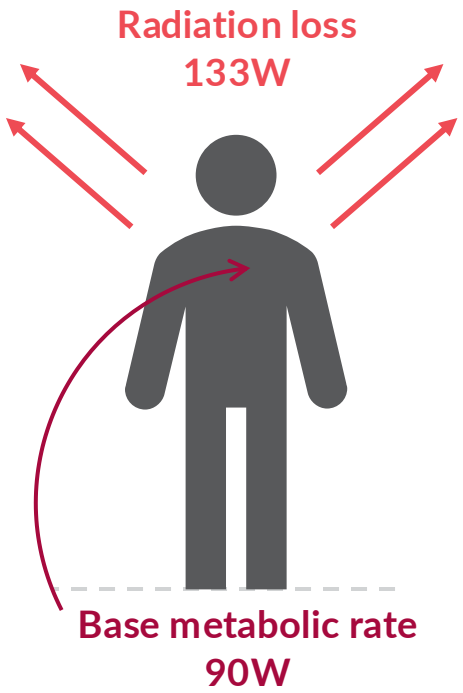
Source: American Society of Heating, Refrigerating and Air-Conditioning Engineers

COOLING OF HUMAN BODY

Radiation heat transfer dominates

An adult male (bare body) loses most of the heat through radiation (133W)

Since the base metabolic rate is 90W, without clothing, the person will feel cold

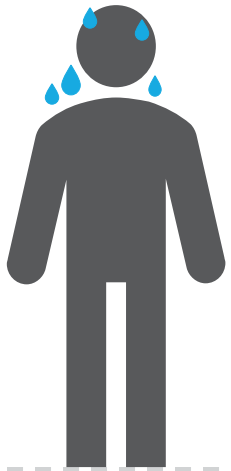


Perspiration
17 watts

Conduction
11 watts

Radiation
133 watts

Convection
(variable)



Skin
temperature
34°C

Ambient temperature
23°C

Basal production rate
≈ 90 watts

Source: BEEP Training Modules on Radiant Cooling

HUMAN COMFORT

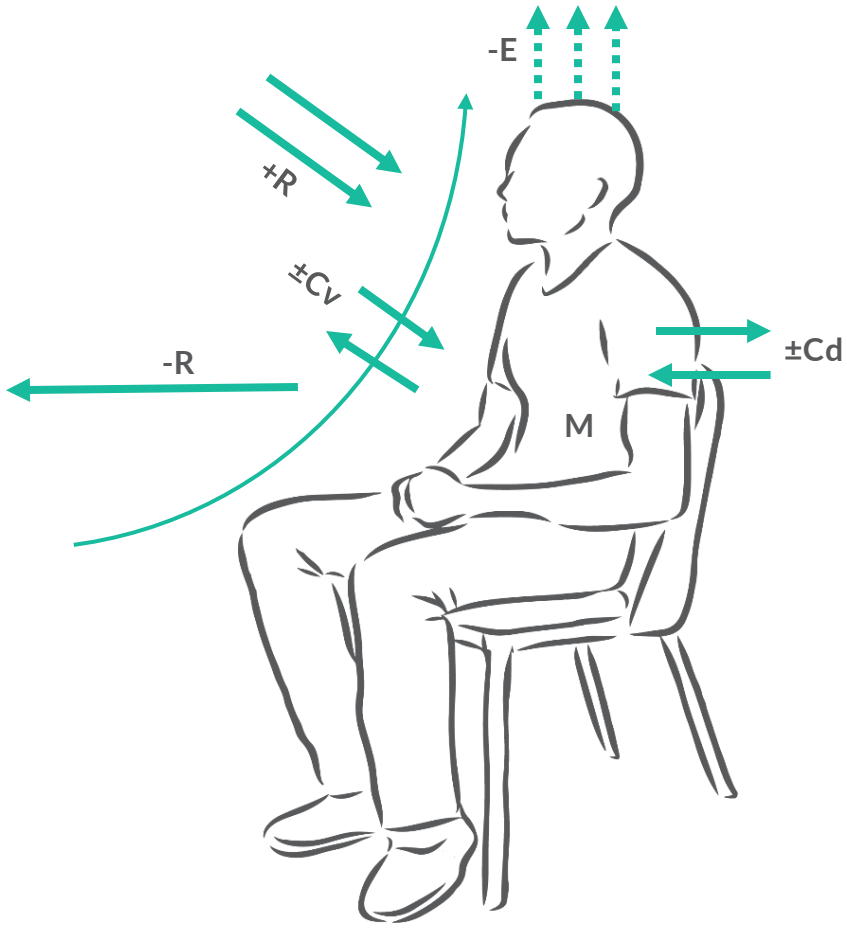
Human body heat balance

The body's heat balance can be expressed as:

M ± R ± Cv ± Cd - E = ΔS (W)

M = metabolic rate
R = net radiation
Cv = convection
Cd = conduction
E = evaporation heat loss
ΔS = change in heat stored

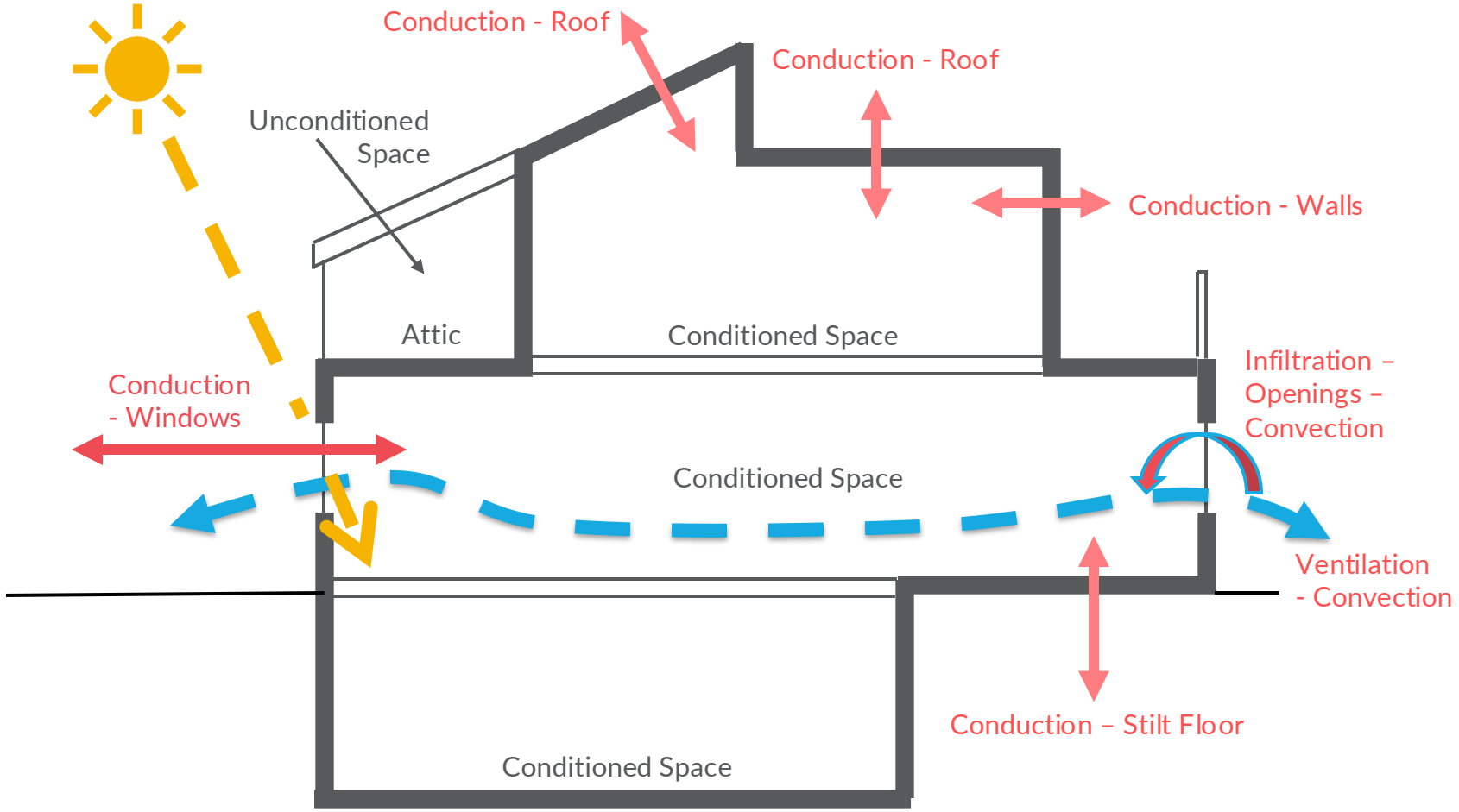
- If ΔS is positive, the body temperature increases; if negative, it decreases
- The heat dissipation rate depends on environmental factors, but the body is not purely passive, it is *homoeothermic*



BUILDING ENVELOPE

Its role in heat transfer

Building envelope design is the key to energy efficient building



THERMAL COMFORT

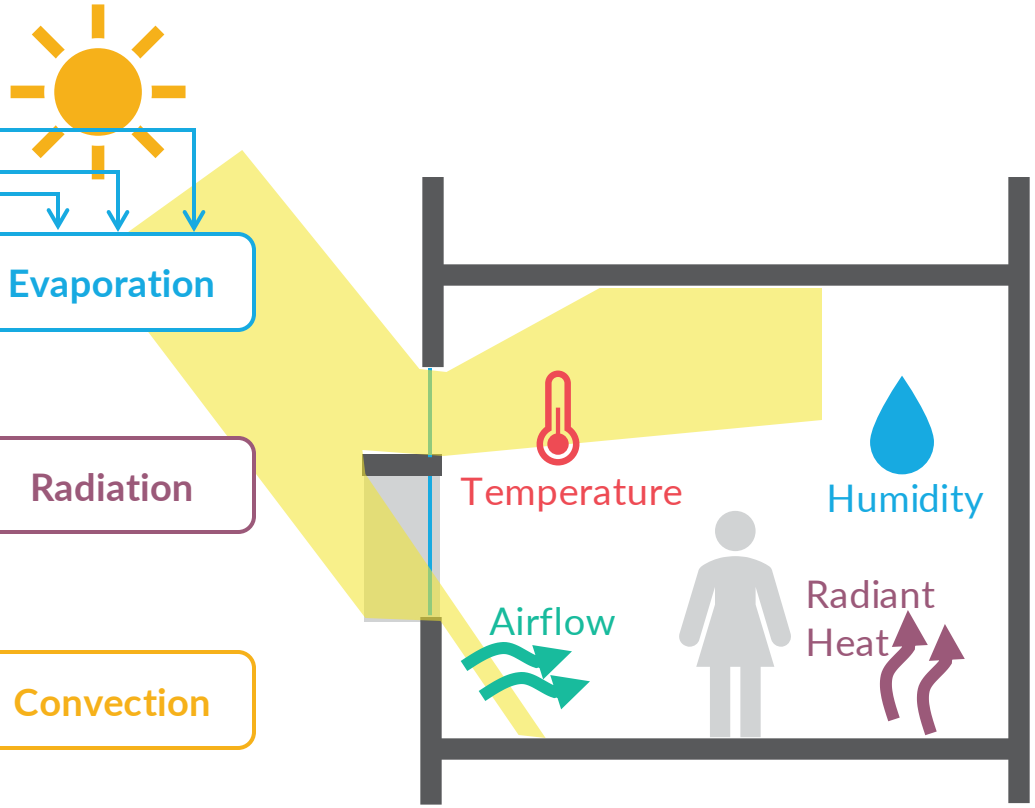
Important parameters

Air Temperature:
The temperature of the air surrounding the body

Mean Radiant Temperature (MRT):
Weighted average of the temperatures of all the surfaces in direct line of sight of the body

Air Movement:
Average speed of the air to which the body is exposed

Humidity:
Amount of water vapor in the room
(the amount of moisture that air can hold is a function of the temperature)



Source: BEEP Training Modules on Radiant Cooling

Thermal Comfort

Adaptive Thermal Comfort Band

ASHRAE STANDARDS

Building energy efficiency, adaptive comfort and ventilation

Internationally-accepted standards are:

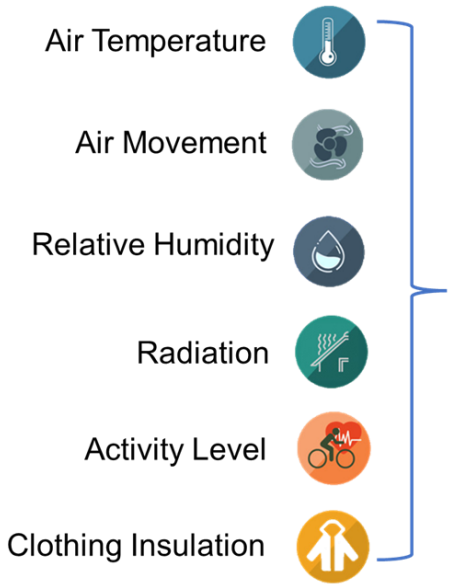
- **American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1:** Energy efficiency of the system
  - Heating, ventilation and air conditioning (HVAC)
  - Lighting
  - Equipment
  - Hot water
- **ASHRAE Standard 55:** Adaptive comfort
- **ASHRAE Standard 62.1:** Ventilation system including fresh air

ADAPTIVE COMFORT

Thermal preference

Thermal preference

Physiological response to Immediate indoor parameters



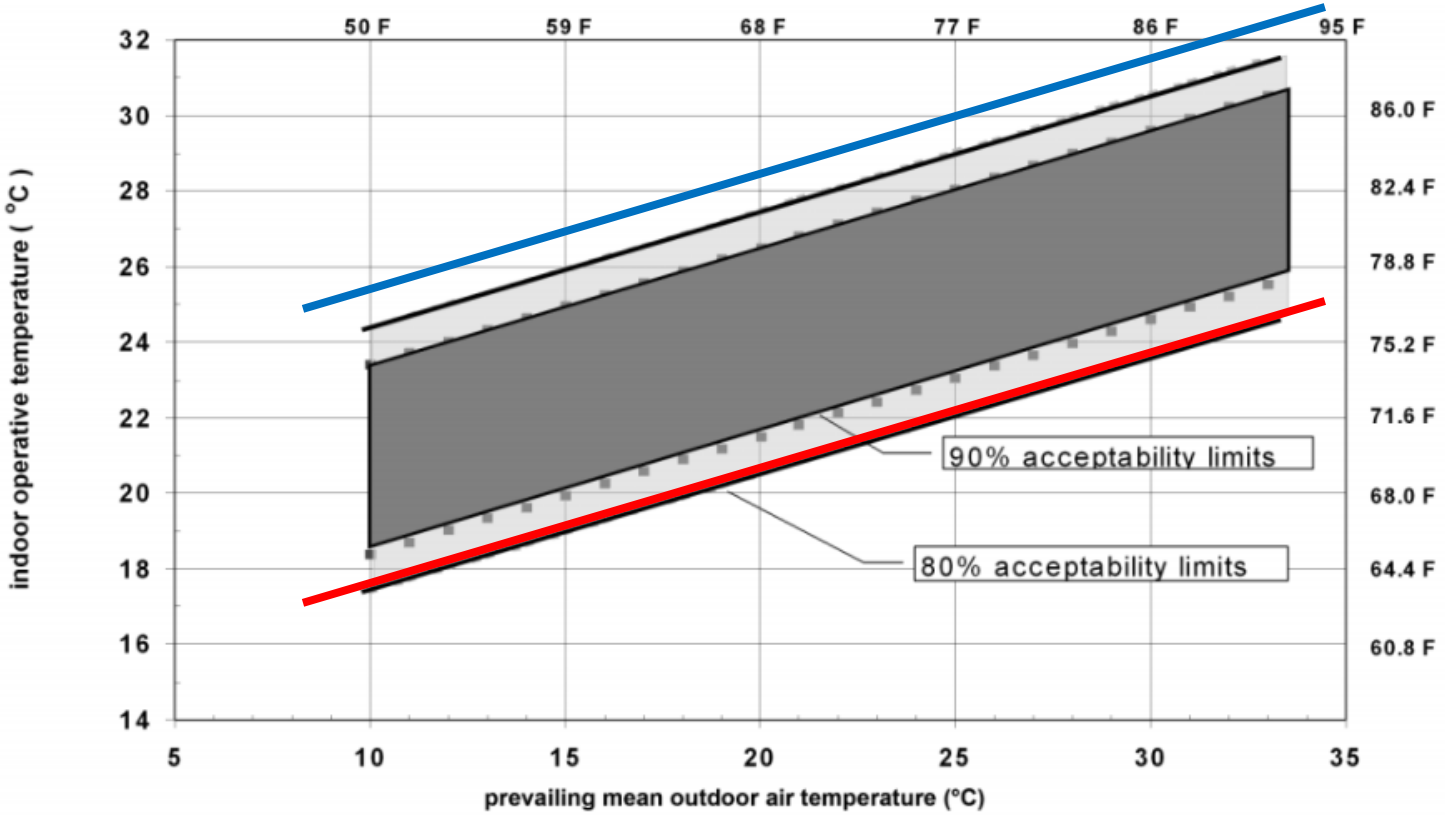
Climato-cultural determinants or recent past experiences & voluntary / adaptive adjustment

- altering activity,
- posture,
- clothing,
- opening or closing windows

ADAPTIVE COMFORT MODEL

ASHRAE

The acceptable indoor operative temperatures (t_o) can be determined from the graph



OR

using the equations

Upper 80% acceptability limit (°C)
$= 0.31\ t_{pma(out)} + 21.3$

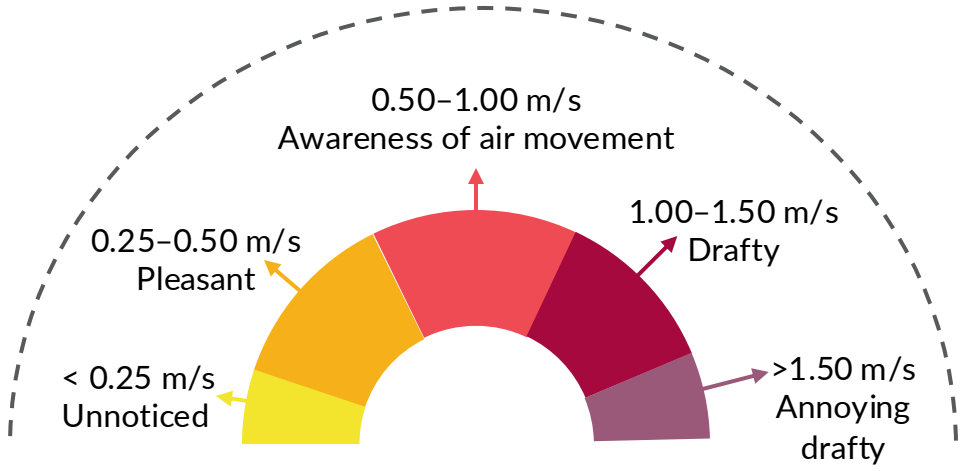
Lower 80% acceptability limit (°C)
$= 0.31\ t_{pma(out)} + 14.3$

$t_{pma(out)}$ is the arithmetic average of the mean daily outdoor temperatures over no fewer than 7 and no more than 30 sequential days prior to the day in question

AIR MOVEMENT

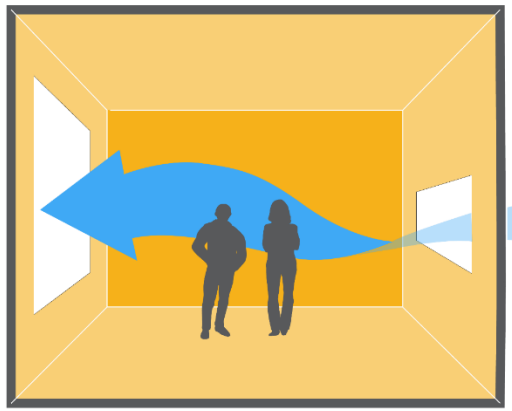
Essential for thermal comfort

It is common experience that air movement, be it natural breeze, or forced draft from a fan, has a cooling effect that depends on the velocity of that air movement

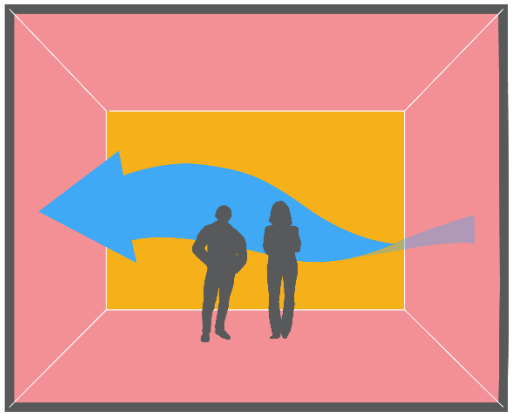


Average subjective reactions to various velocities under everyday conditions

Human responses to varied velocities depend on the temperature of the air



Under warm conditions, 1 m/s is pleasant and indoor air velocities up to 1.5 m/s are acceptable



In a heated room, stagnant air (velocities < 0.1 m/s) may be judged as 'stuffy'

ADAPTIVE THERMAL COMFORT

Works better with occupant participation and control

- Behavioral adaptation refers to any conscious or unconscious actions by a person to alter their body's thermal balance, e.g., choice of clothes, activity levels, using fans / heaters, and adjustment of diffusers or thermostats
- Behavioral adjustments offer the best opportunity for people to participate in maintaining their own thermal comfort with optimal energy consumption
- Providing ample opportunities for people to control the indoor climate is an essential strategy in the design of naturally-ventilated buildings. However, in most buildings, occupants have limited understanding and control

Case example: Integrating smart ceiling fans and communicating thermostats to provide energy efficient comfort

Source: Brager and de Dear, 2000

Image source: https://cbe.berkeley.edu/research/epic-integrating-smart-ceiling-fans-study/

ADAPTIVE COMFORT MODEL

Limitations of ASHRAE Standard 55

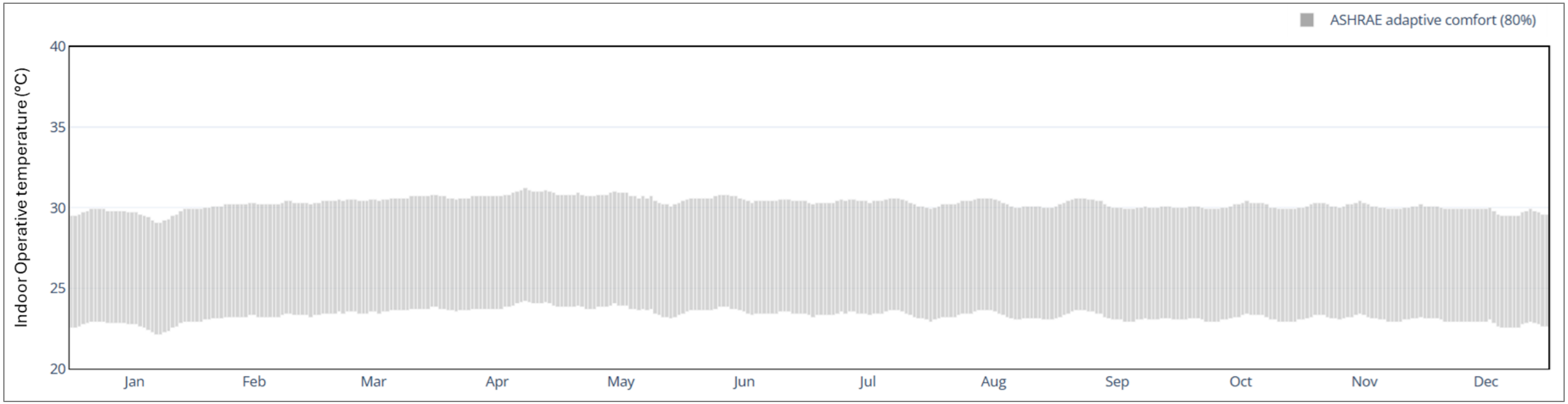
- Those advocating more flexible thermal comfort standard have long argued that the primary limitation of ASHRAE Standard 55 is its one-size-fits-all approach
- In ASHRAE 55, clothing and activity are the only modifications one can make to reflect seasonal differences in occupant requirements
- Using ASHRAE Standard 55 to determine acceptable indoor temperature ranges requires assumptions about the average metabolic rate and clothing worn by people
- In contrast, an adaptive model relates acceptable indoor temperature range to the mean monthly outdoor temperature, defined as the arithmetic average of mean monthly minimum and maximum air temperature

Source: Brager and de Dear, 2000

ADAPTIVE COMFORT MODEL

For Phnom Penh, Cambodia

Phnom Penh, Cambodia – ASHRAE Standard 55 – Comfort Band (80%)

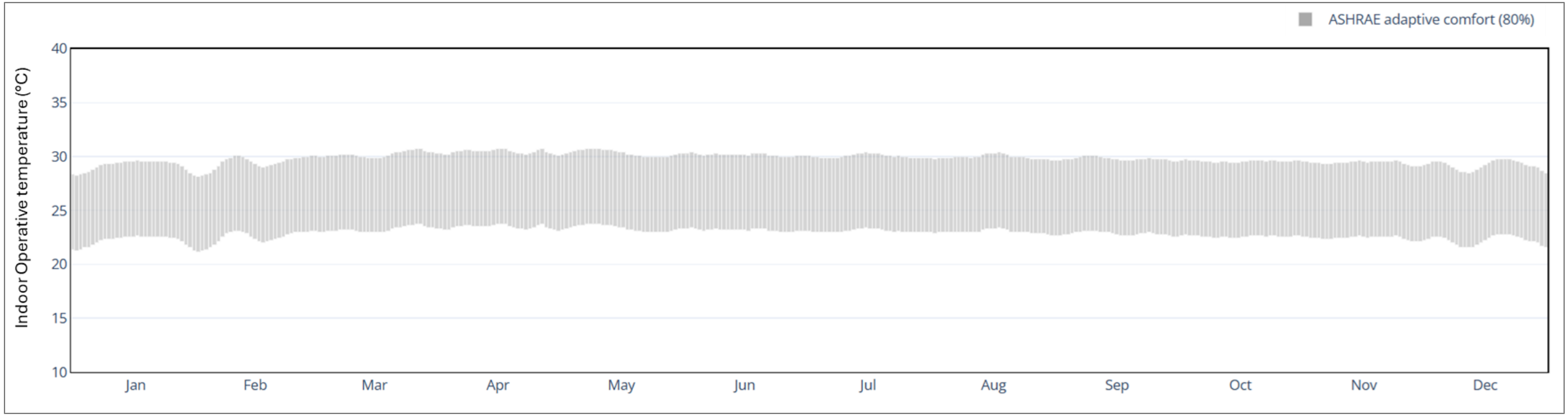


Source: Betti et al., 2023

ADAPTIVE COMFORT MODEL

For Battambang, Cambodia

Battambang, Cambodia – ASHRAE Standard 55 – Comfort Band (80%)



Source: Betti et al., 2023

INDIA'S IMAC

India's model for adaptive comfort

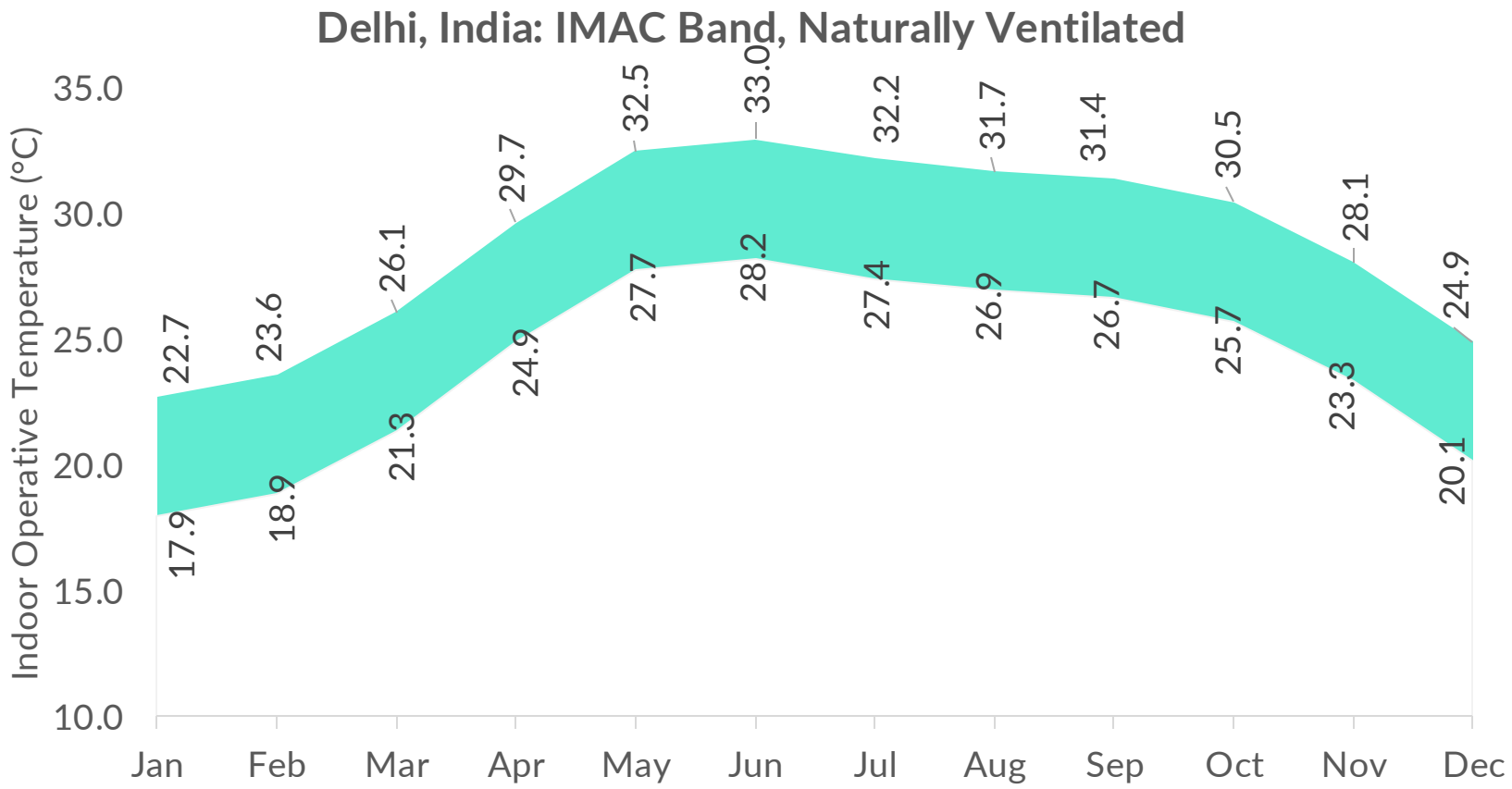
The India Model for Adaptive Comfort (IMAC) predicts the thermal comfort range in India for different months of the year, based on field studies in five cities. Some insights from the IMAC model are:

- A single adaptive model is proposed for 'naturally ventilated' and 'air conditioned' modes of operation
- Indian office occupants are more adaptive than predicted by ASHRAE-55 and EN15251 models
- International comfort standards are not appropriate for Indian office buildings
- Occupants in 'mixed-mode' offices are more adaptive than those in air-conditioned offices, and less adaptive than those in naturally-ventilated offices
- Use of fans and windows and appropriate clothing are significant adaptive measures in naturally-ventilated offices

Source: Manu et al., 2016

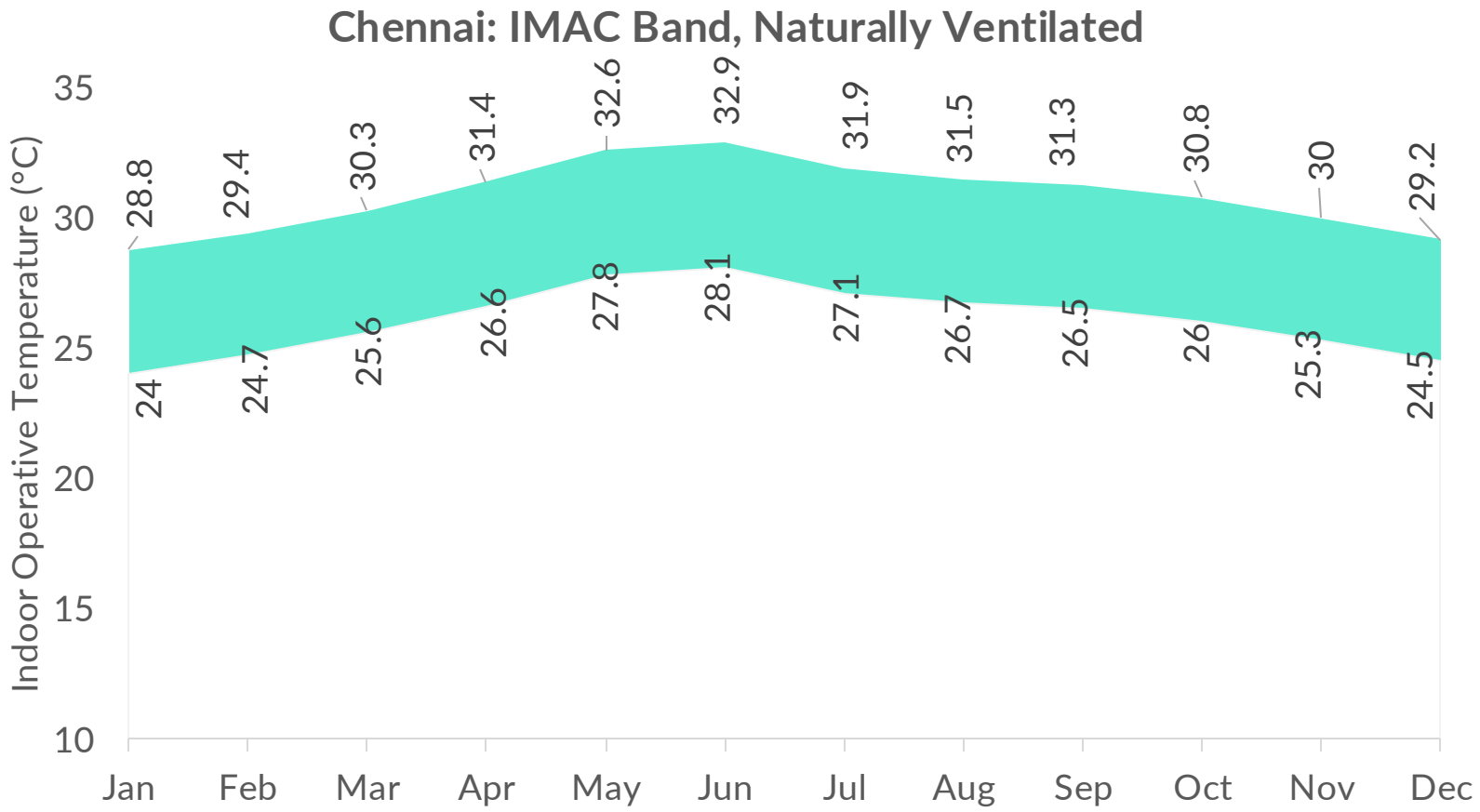
INDIA'S IMAC

Composite climate



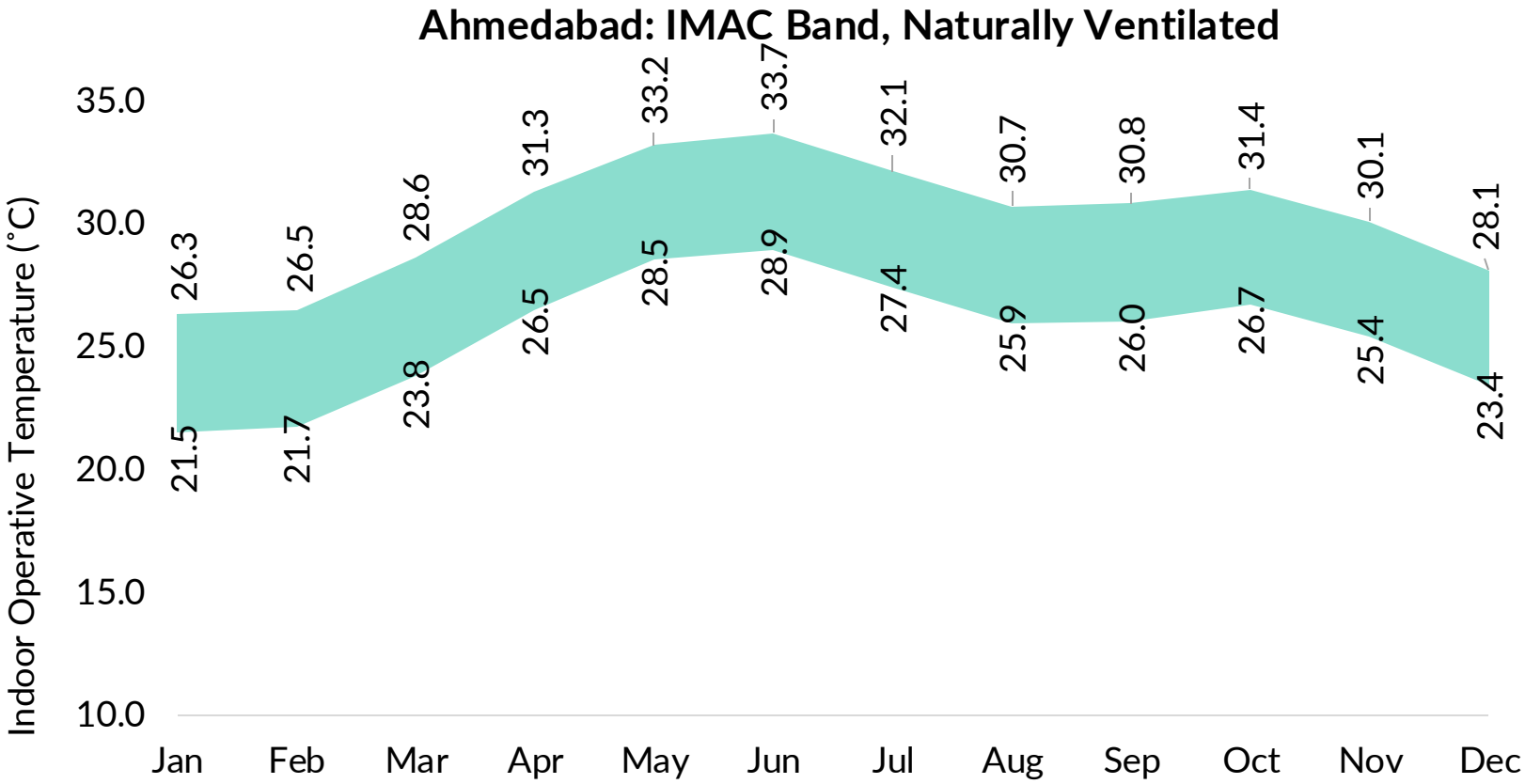
INDIA'S IMAC

Warm and humid climate



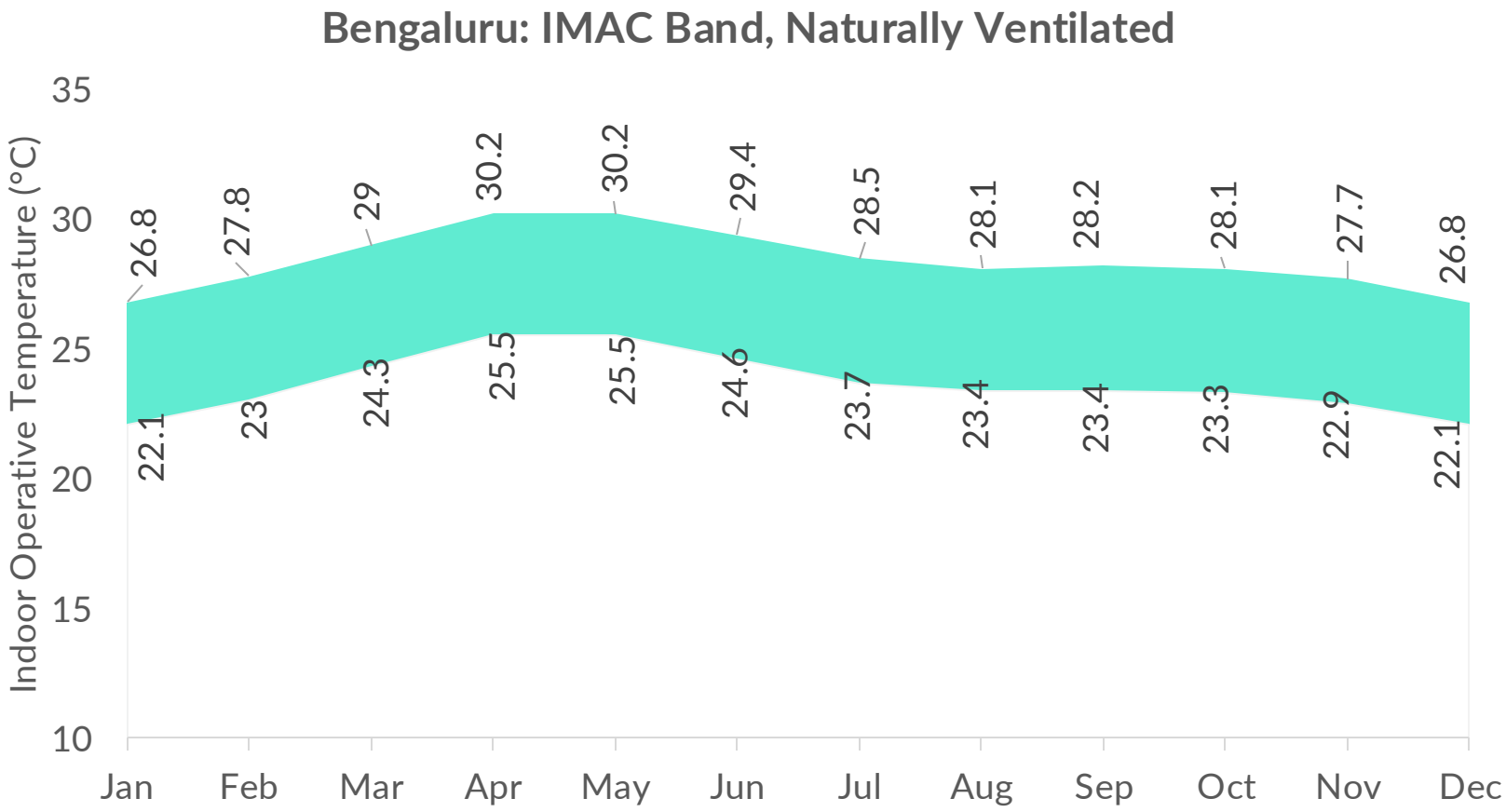
INDIA'S IMAC

Hot and dry climate



INDIA'S IMAC

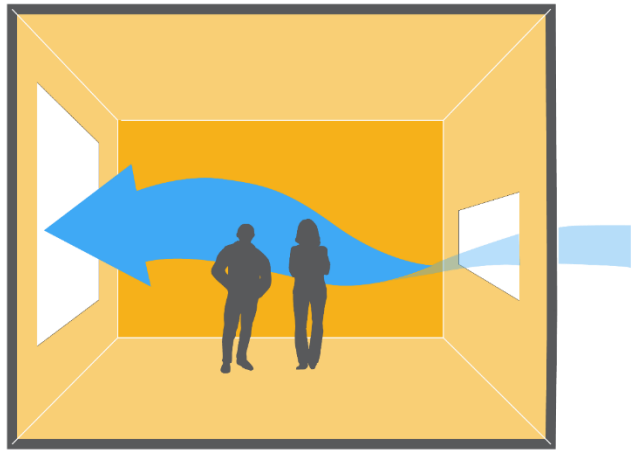
Temperate climate



TROPICAL SUMMER INDEX

For estimating room comfort temperatures with varying ambient temperatures

Naturally-ventilated Building

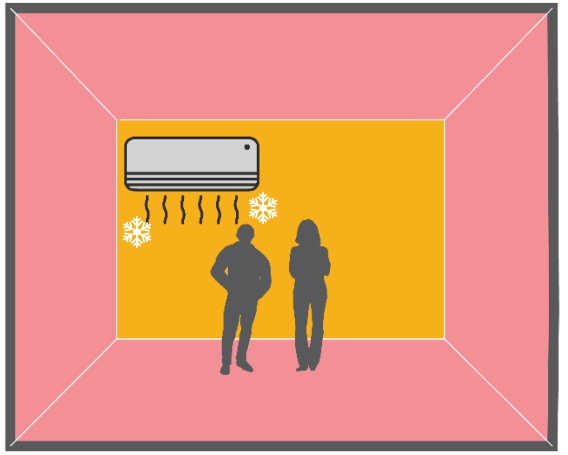


Indoor Operative Temperature, °C
= (0.54 x Outdoor Temperature) + 12.83

- Indoor temperature is neutral and outdoor temperature is 30 days outdoor mean air temperature
- 90% acceptability range for India-specific adaptive models is ± 2.38°C

e.g., **(0.54 x 33) + 12.83 = 30.68 °C**

Air-conditioned Building



Indoor Operative Temperature, °C
= (0.078 x Outdoor Temperature) + 23.25

- 90% acceptability range for India-specific adaptive models is ± 1.5 °C

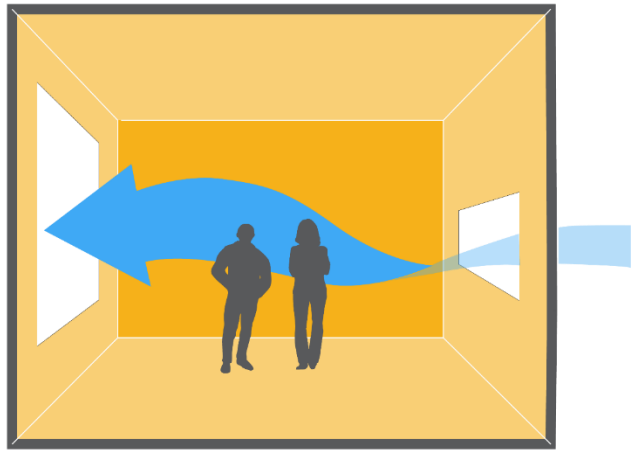
e.g., **(0.078 x 33) + 23.25 = 25.8 °C**

Source: Bureau of Indian Standards, Government of India, 2016b

COMFORT PERCEPTIONS

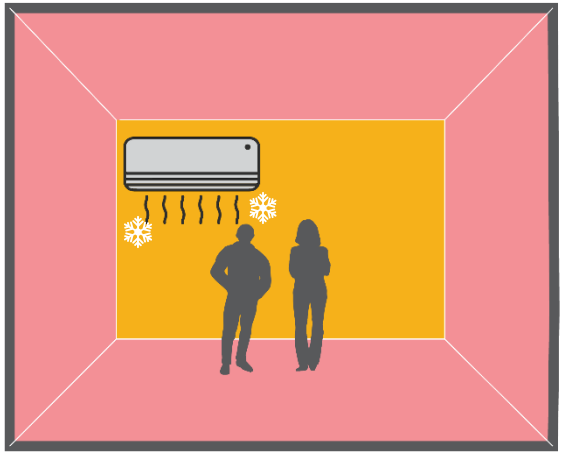
Human conditioning

Naturally-ventilated Building



Naturally-ventilated buildings, where occupants can open windows, create indoor conditions that are inherently more variable than buildings with centralized HVAC systems

Air-conditioned Building



Research has demonstrated that occupants of buildings with centralized HVAC systems become finely tuned to the very narrow range of indoor temperatures presented by the prevailing HVAC practice

Considerable research is now focusing on three primary modes of adaptation

Physiological **Behavioral** **Psychological**

Source: Bureau of Indian Standards, Government of India, 2016b

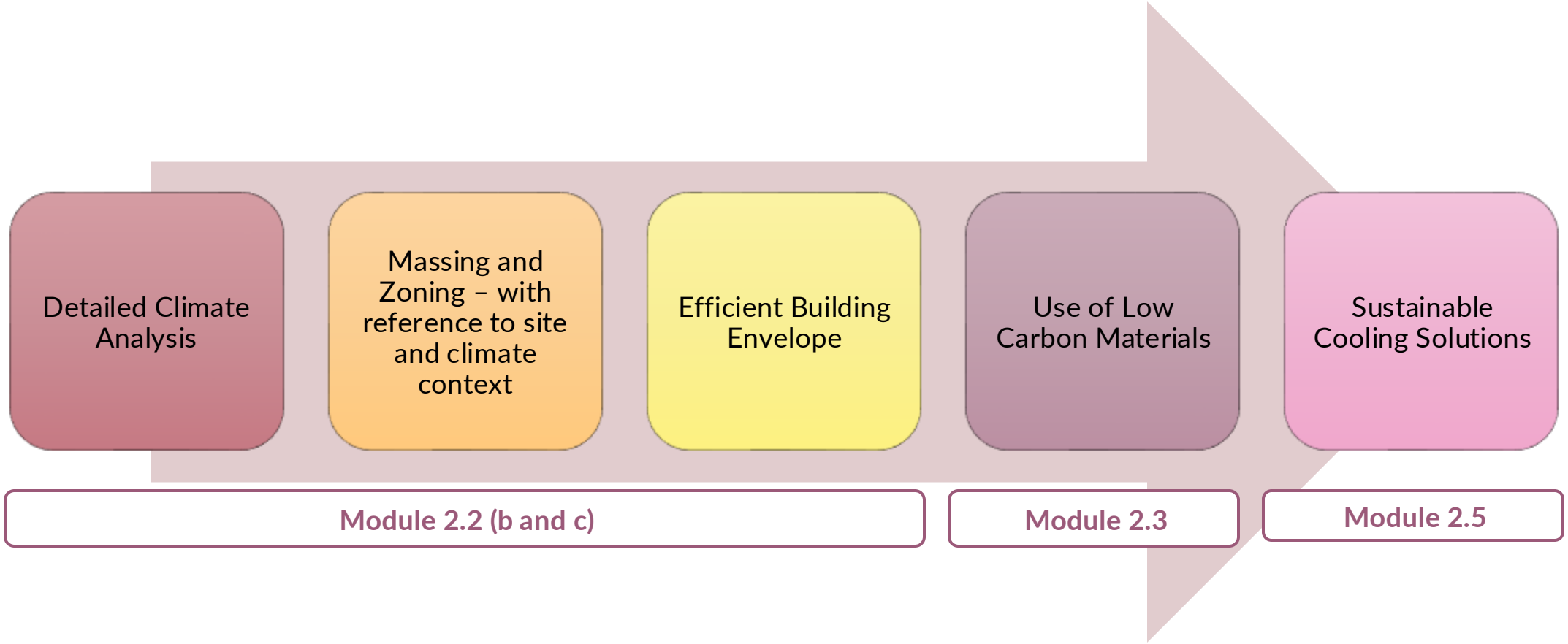
Adaptive Thermal Comfort

Potential Solutions

Image source: https://nzeb.in/a-paradigm-for-thermal-comfort-for-nzebs-in-tropics/

CLIMATE RESPONSIVE BUILDING DESIGN

Potential solutions are covered in subsequent sub-modules 2.2(b), 2.2(c), 2.3 and 2.5



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