Climate, Buildings, Energy, and Comfort

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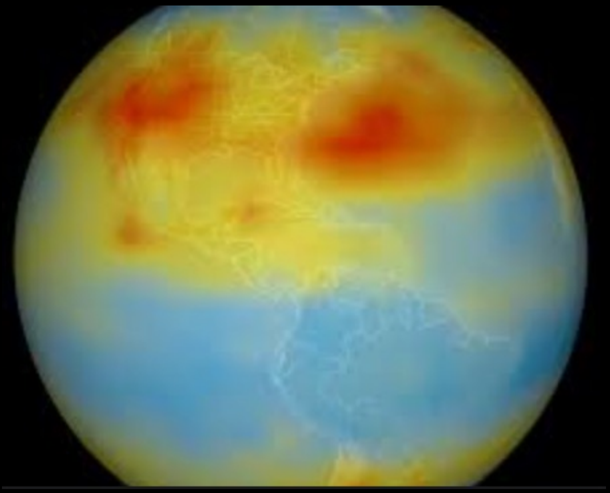
Synopsis of this Talk

- Climate is warming – at global scale due to anthropogenic greenhouse gases and also at local scale of cities due to densification and urban heat island effects.
- Demand for AC cooling is rising inexorably due to the confluence of **climatic change** *and* **demographic** and **economic** growth being concentrated in the hot and humid climate zones of the world.
- Apart from undermining greenhouse emissions abatement strategies, growing AC demand exacerbates peak electricity loads , further straining electricity grids.
- Tightening the energy performance requirements in building codes is essential to dampen that cooling energy demand, as is implementation of minimum energy performance standards for new AC equipment.
- Apart from the engineering, design, and policy responses mentioned above, there is significant untapped potential on the demand side of the energy equation – namely adaptive thermal comfort

Climate



World Meteorological Organization

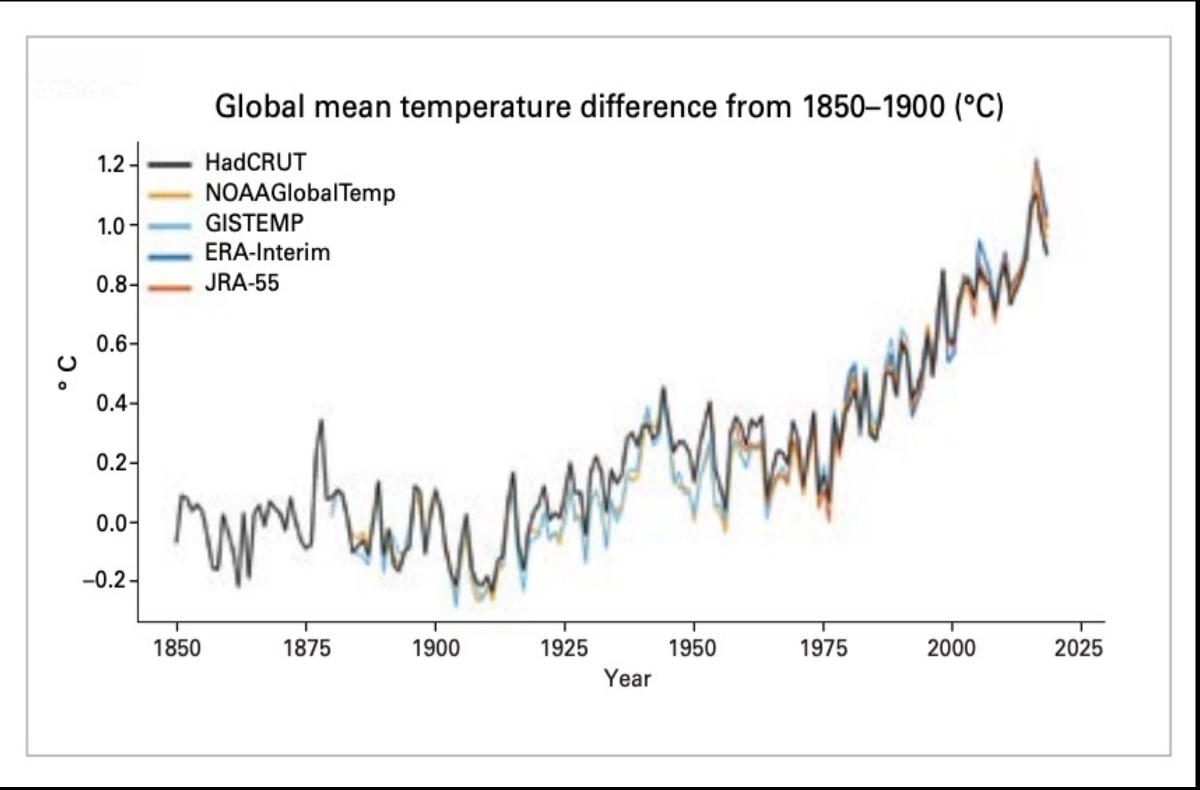
WMO State of the Global Climate in 2021

2016, 2019 & 2020 were the three warmest years on record

Ocean heat content is at a record high and global mean sea level continues to rise

Artic and Antarctic sea-ice extent is alarmingly below average

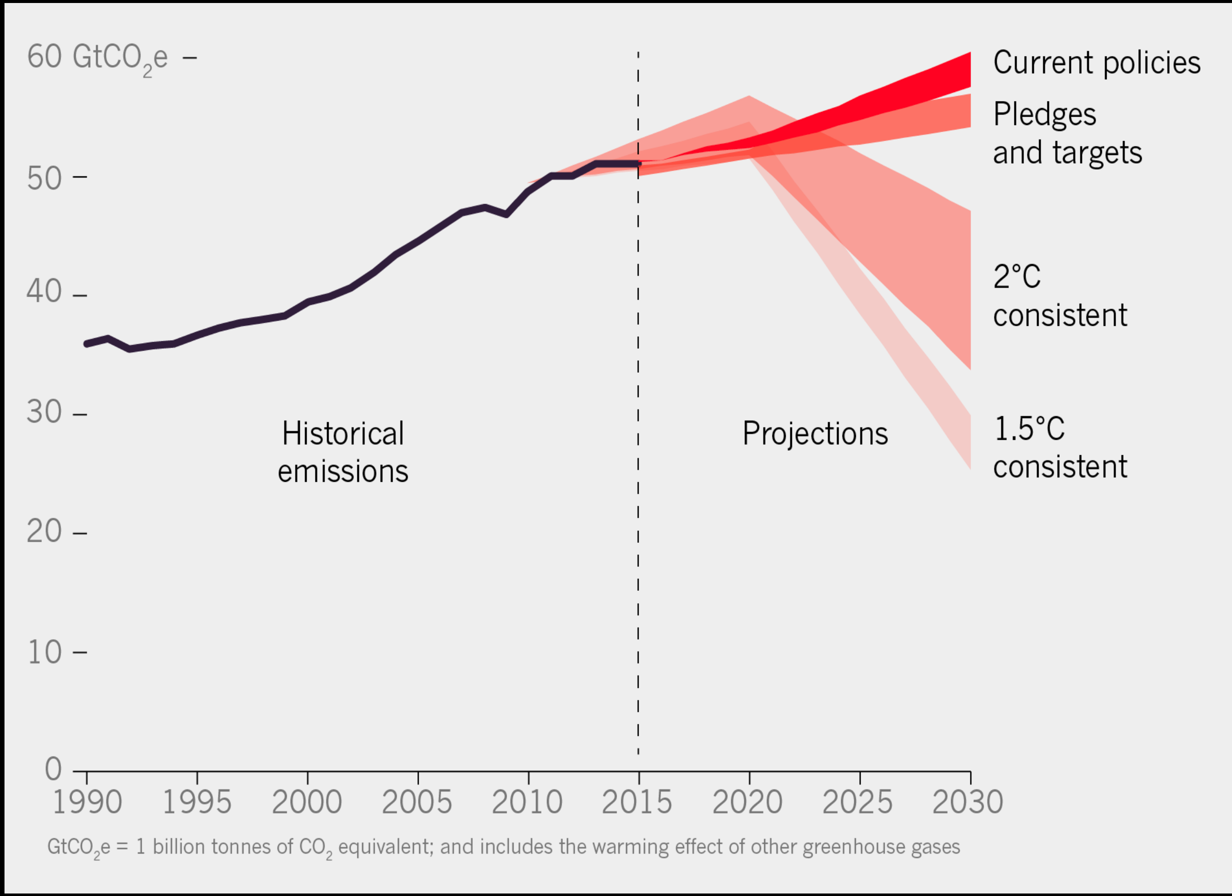
Average global temperature has now reached 1 °C above the pre-industrial baseline



CO_2 Emissions Continue to Rise

WMO declared that we are not on track to meet climate protection targets and rein in temperature increases.

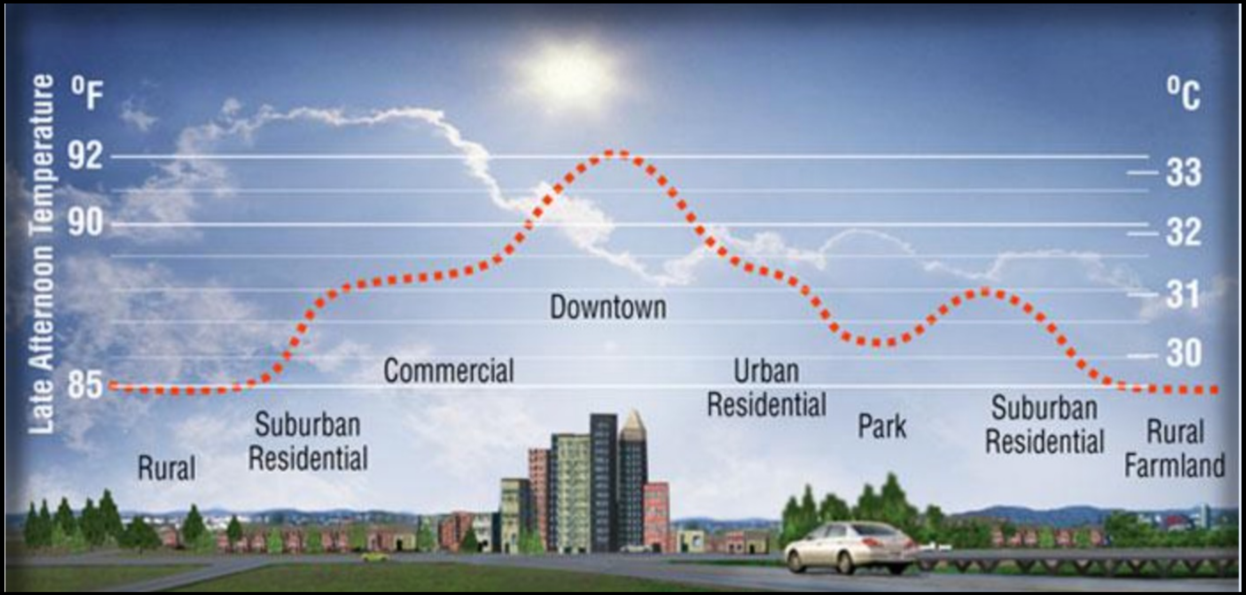
PARIS2015
UN CLIMATE CHANGE CONFERENCE



https://www.nature.com/immersive/d41586-019-02711-4/index.html

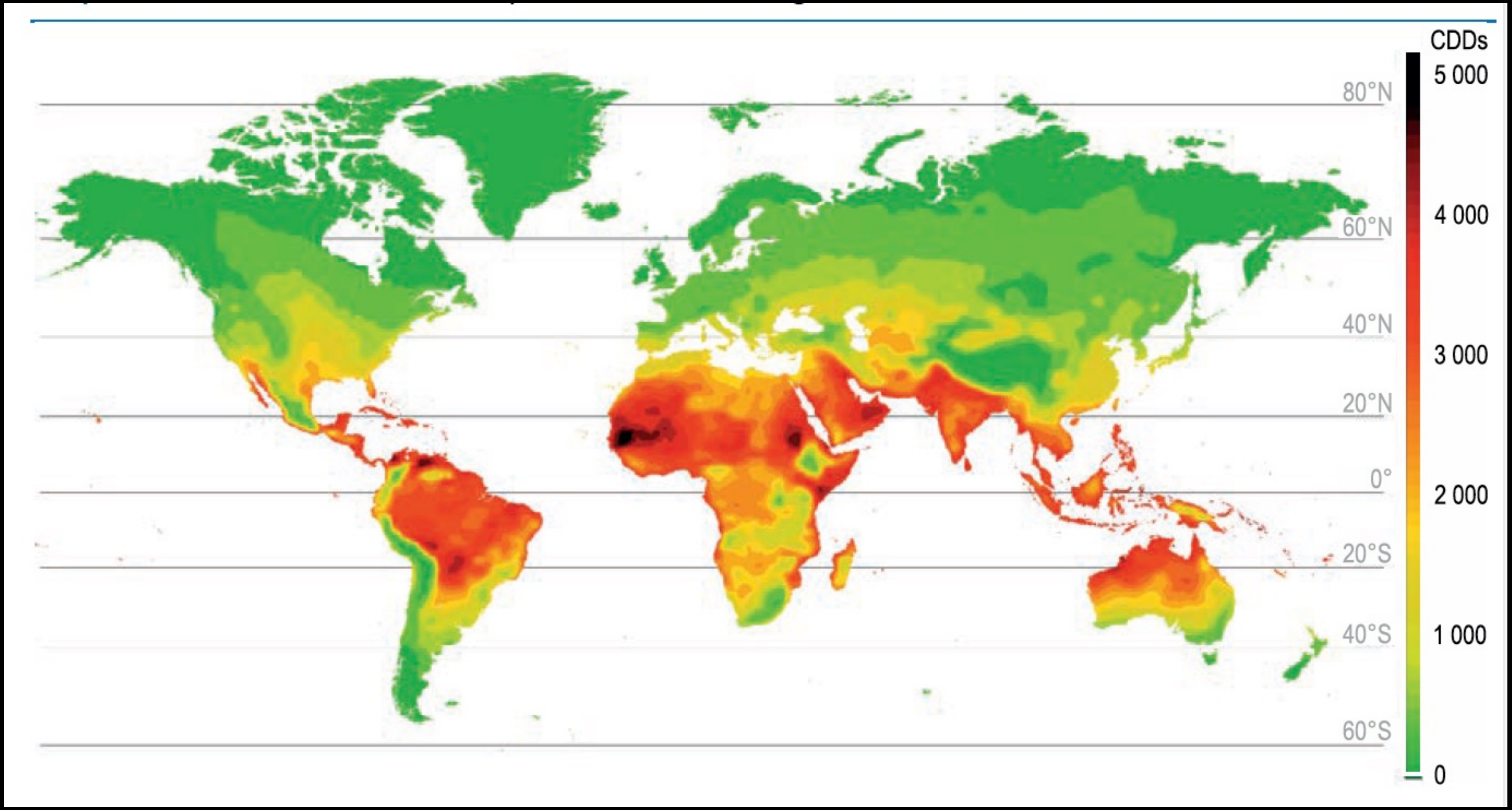
Urban Heat Island Effects Superimposed on Background Climate Warming

Urban morphology
Urban density
Urban Albedo
Materials
Emissivity
Waste heat (AC feedback)



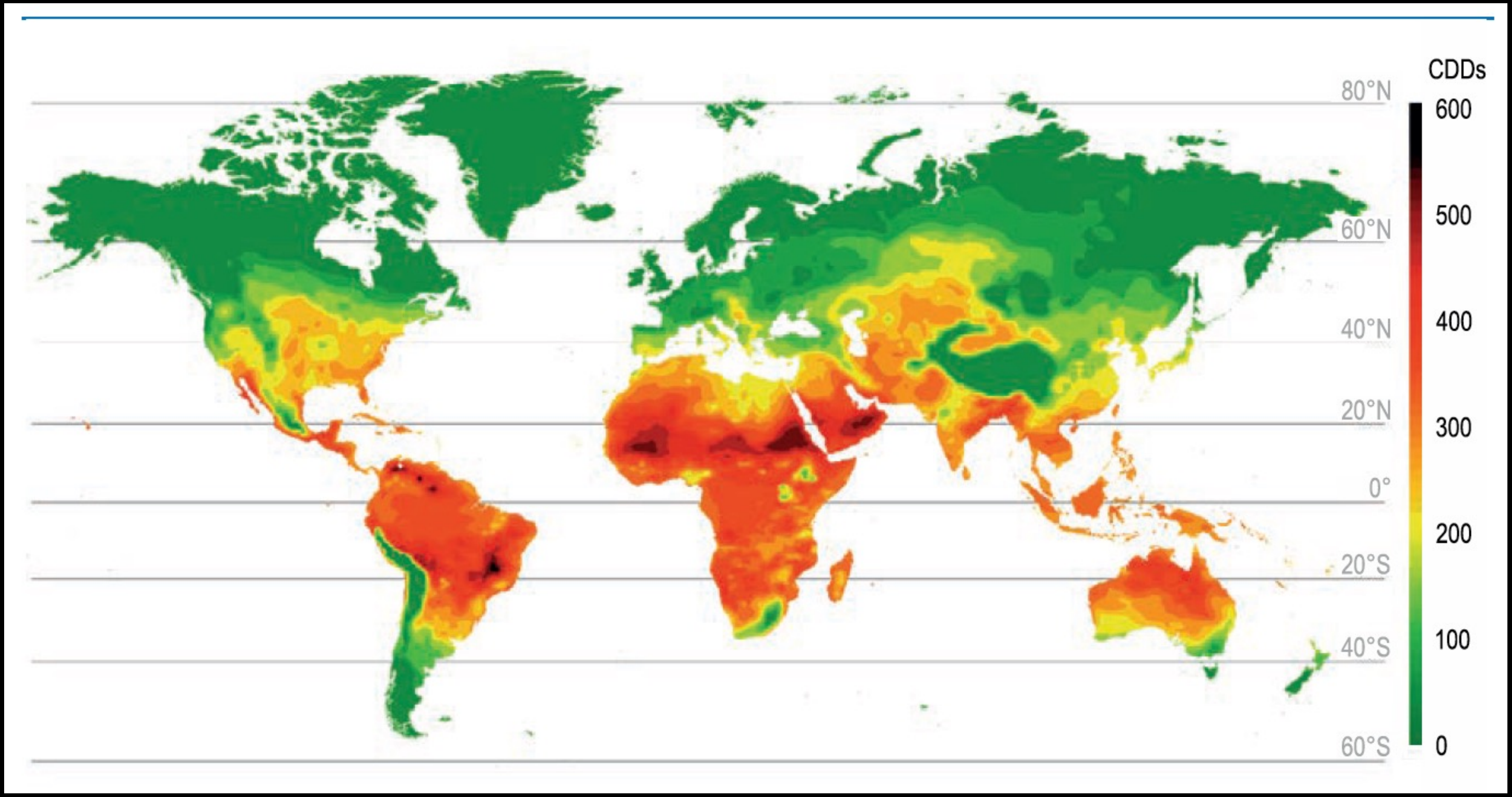
https://heatisland.lbl.gov/

Climatic Driver of Cooling Demand is Expressed as Cooling Degree Days (CDDs – 18^{o}C baseline)



IEA (2018) The Future of Cooling https://www.iea.org/reports/the-future-of-cooling

Cooling Degree Days Projected to Increase ~25% by 2050 – Mostly in Already Hot Countries



IEA (2018) The Future of Cooling https://www.iea.org/reports/the-future-of-cooling

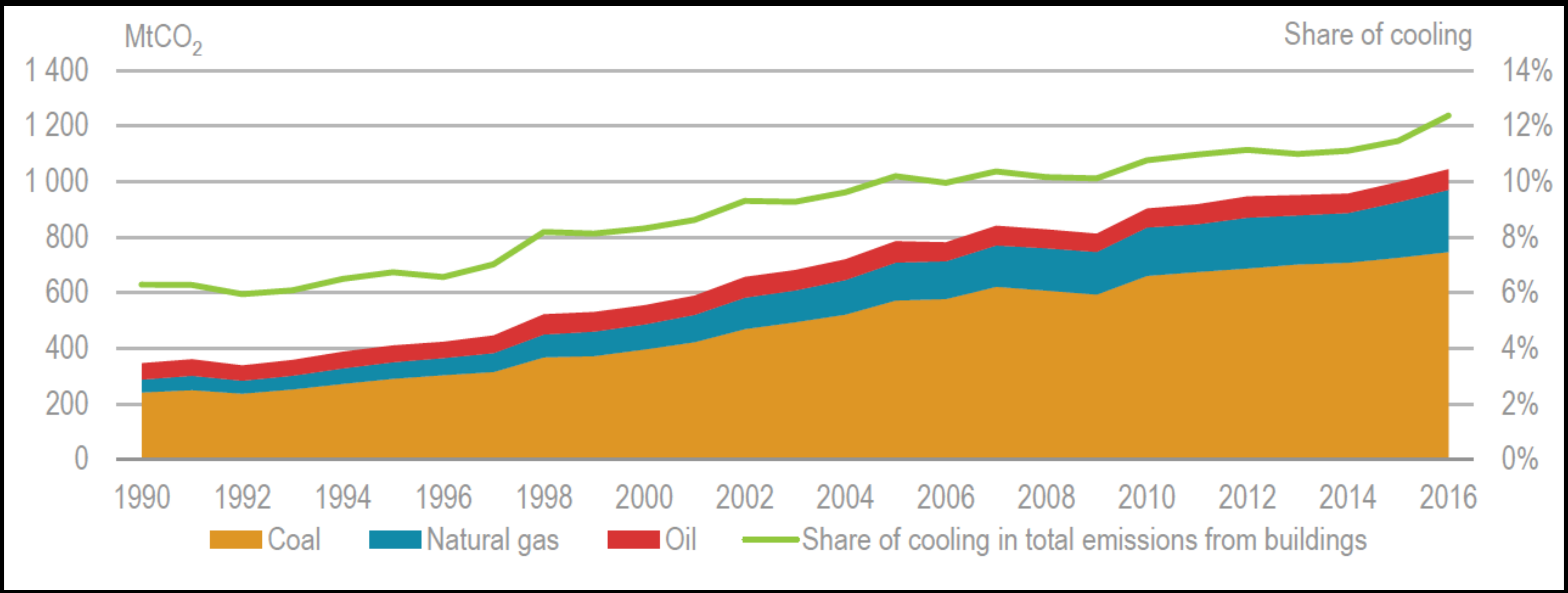
CDDs are growing fastest in places with fastest population and economic growth, precisely where cooling demand is not yet being fully met

Energy and Buildings

Cooling Represents the Fastest Growing Energy End-Use in Buildings Worldwide

- Space cooling energy tripled between 1990 and 2016 and at current growth trends, it will triple again by 2050 (6,200 TWh), with ~70% of the increase coming from the residential sector.
- The lion's share of the projected growth in energy use for space cooling by 2050 will come from the emerging economies, with just three countries – India, China and Indonesia – contributing half of global cooling energy demand growth.

World CO_2 Emissions From AC Cooling Energy Use by Source



Despite the match between AC cooling load and solar energy resource, the space cooling share in total CO_2 emissions doubled in 26 years – coal power stations

IEA (2018) The Future of Cooling https://www.iea.org/reports/the-future-of-cooling

AC Cooling Amplifies the Peak Electricity Demand

- The challenge of meeting cooling demand growth in an affordable and sustainable manner is exacerbated by its particular effect on peak electricity demand.

- The share of space cooling in peak electricity load is projected to rise sharply in many countries, with the biggest increases occurring in hot countries such as India, where, on current trend, the share jumps from just 10% today to 45% in 2050.

Most Response Strategies Focus on Building Envelope Efficiency

- Thermal mass
- Thermal insulation
- Material albedo
- Material emissivity
  (cool and super-cool roofs)
- Window-to-wall ratio
- High-performance glazing

All important, but expected AC energy savings are often thwarted by the “rebound effect”

Comfort

What is Comfort?

Conventional practice among HVAC engineers and facility managers suggests a narrow, static band: 21~23^{o}C

Majority of comfort research recent years has challenged this orthodoxy. In the adaptive model of comfort occupants and their indoor climate are viewed as an integrated, self-regulating feedback system

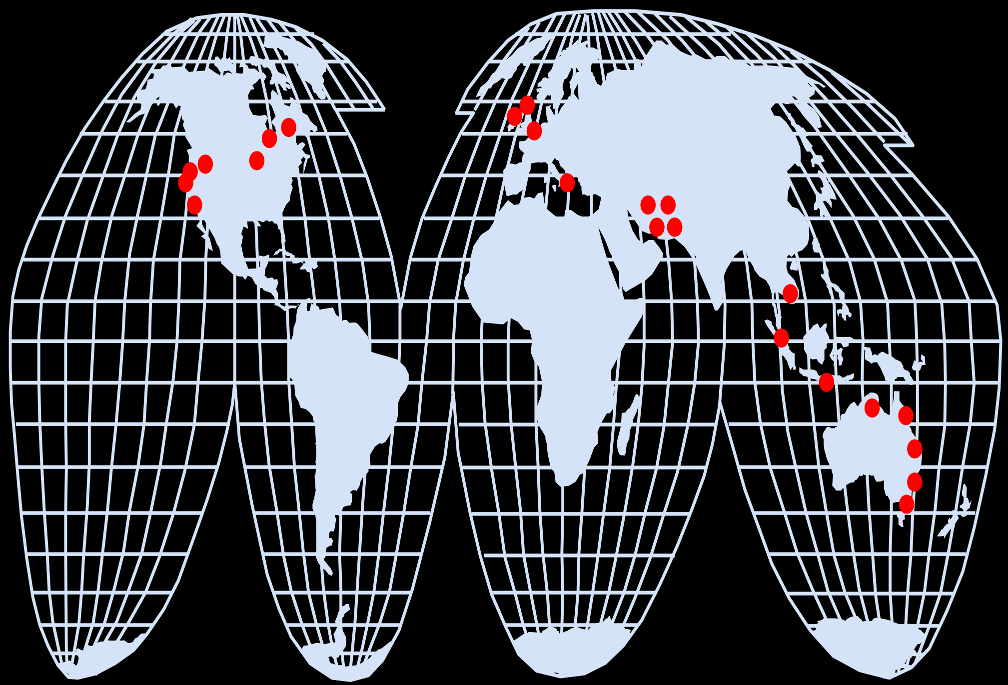
The Adaptive Comfort Principle: "*If a change occurs that produces discomfort, people tend to respond in ways that restore their comfort*"

- physiological adaptation (acclimatization, thermoregulatory set-points)
- behavioural adaptation (adjustment of body's heat balance)
- psychological adaptation (shifting comfort expectations)
- cultural adaptation (customs, attitudes, technology)

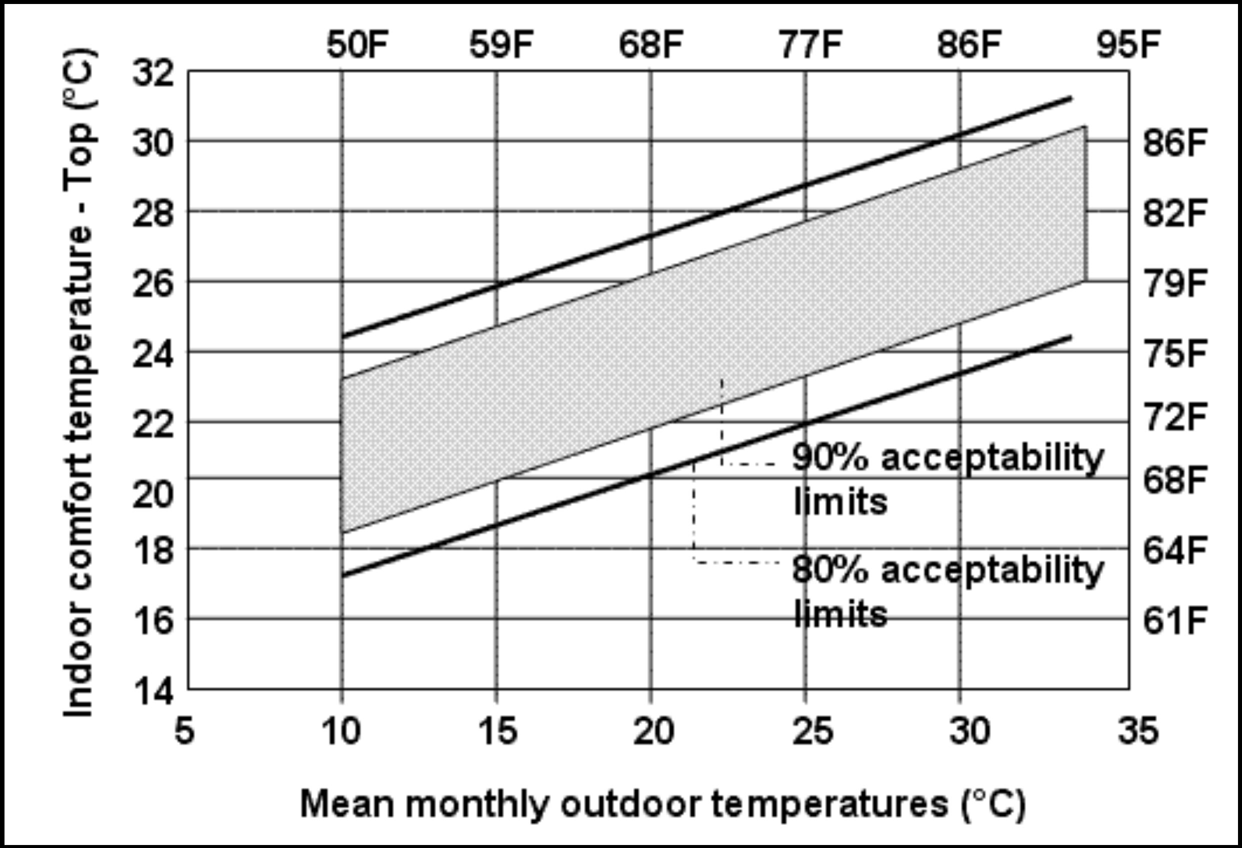
The ASHRAE Adaptive Comfort Project

(de Dear and Brager 1998 *ASHRAE Transactions*)

- circa 21,000 sets of data (indoor climate & comfort surveys)
  - 160 buildings
  - 4 continents
  - diverse climate zones
- Paired observations inside the buildings at the same time and same place:
  - *objective* indoor climate
  - *subjective* comfort



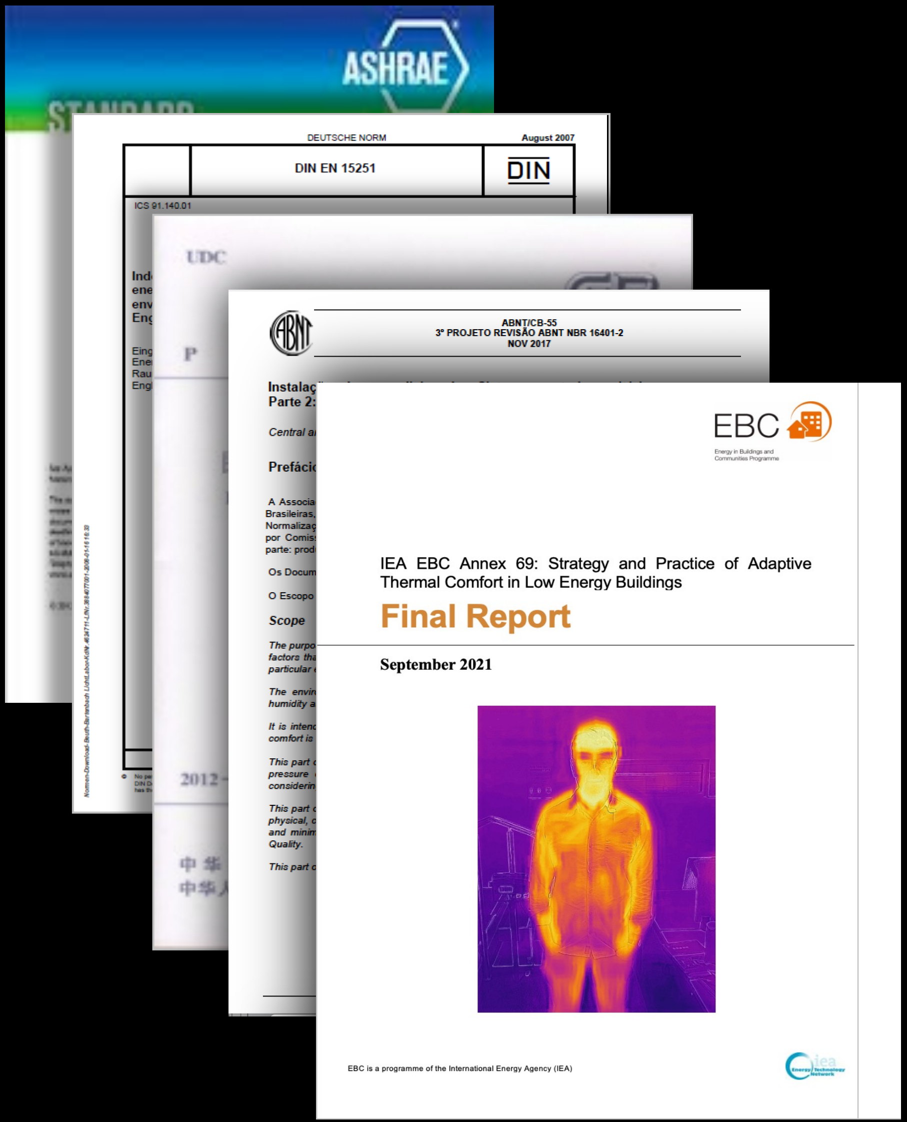
Adaptive Comfort Models are Meta-Analyses of Many Thermal Comfort Field Studies



Contemporary Adaptive Comfort Standards

Driven largely by concerns about global climate change the focus in the last two decades has been to bring adaptive comfort into practice through *standards and guidelines:*

- ASHRAE Standard 55-2004 … 2020
  "Thermal environmental conditions for human occupancy"
- CEN Std EN15251-2007 (EN-16798)
  "Indoor environmental input parameters for design and assessment of energy performance of buildings"
- China Standard GB/T 50785
  "Evaluation standard for indoor thermal environment in civil buildings "
- Brazil Standard ABNT NBR 16401-2
  "Air Conditioning Installations - Central and Unit Systems"
- IEA Annex 69 *"Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings"*



The Indian Adaptive Comfort Model - Residential

(Rawal, Shukla, *et al.* 2022 <u>*Building and Environment*</u>)

- circa 2179 complete sets of data (indoor climate & comfort surveys)
  - 294 residences
  - 8 cities
  - 5 climate zones

- Observations take inside the residences at the same time and same place:
  - *objective* indoor climate
  - *subjective* comfort

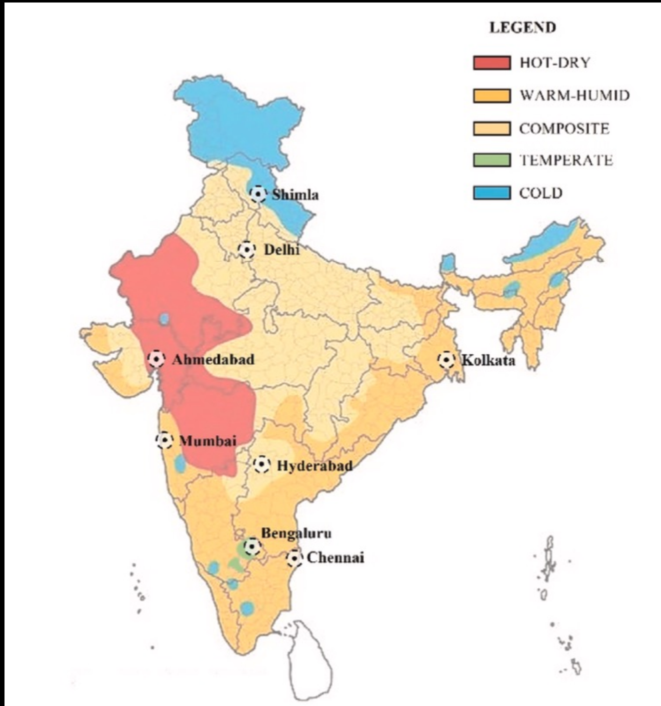
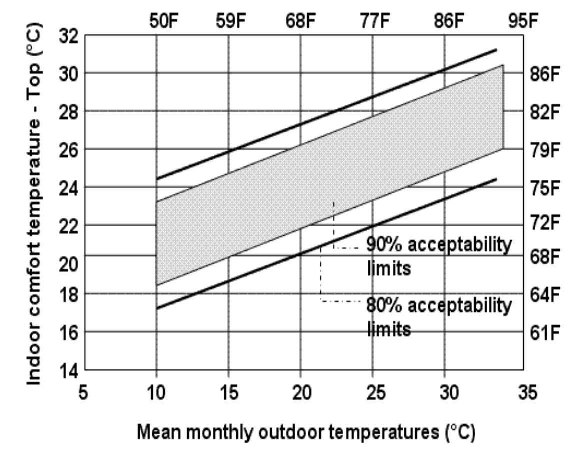
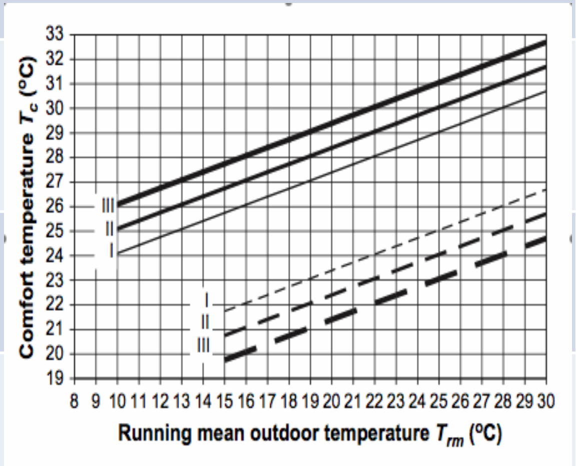


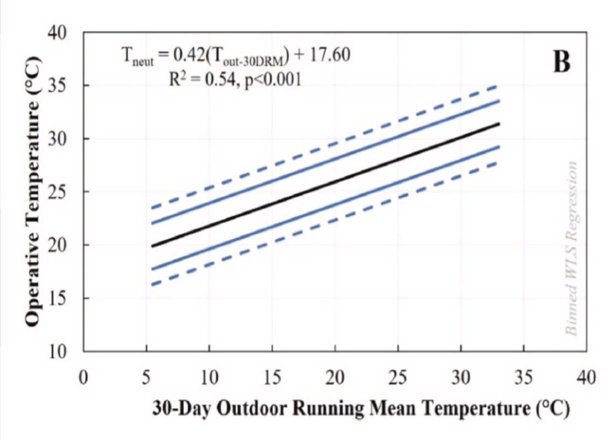
Fig. 1. The eight surveyed cities in the five Indian climate zones.

Similarities Between the European, ASHRAE, & Indian Adaptive Comfort Standards/Models

ASHRAE Standard 55 - 2004,2010,2013, 2017,2020	CEN Standard EN15252–2007 (EN-16798-2019)	India Model Adaptive Comfort – IMAC-R 2022
$T_{comf} = 0.31\ T_{outdoor} + 17.8$	$T_{comf} = 0.33\ T_{outdoor} + 18.8$	$T_{comf} = 0.42\ T_{outdoor} + 17.6$







What Are The Implications of the Adaptive Comfort Model for the Looming "Cooling Crunch"?

- People are comfortable in wider temperature ranges in naturally ventilated (NV) buildings
- Comfort setpoints for AC should nudged closer to outdoor temperatures,
- Mixed-mode designs are encouraged
- "Part-time-part-space" AC practices are encouraged

Columbia University, Gary C. Comer Geochemistry Buildings

Other Comfort-Related Demand-Side Management Strategies

Demand response (DR) provides an opportunity for consumers to play a significant role in the operation of the electric grid by reducing or shifting their electricity usage during peak periods in response to

- Time-of-use electricity tariffs
- Other forms of financial incentives

https://www.energy.gov/oe/activities/technology-development/grid-modernization-and-smart-grid/demand-response

Other Comfort-Related Demand Side Management Strategies

Personal Comfort Systems

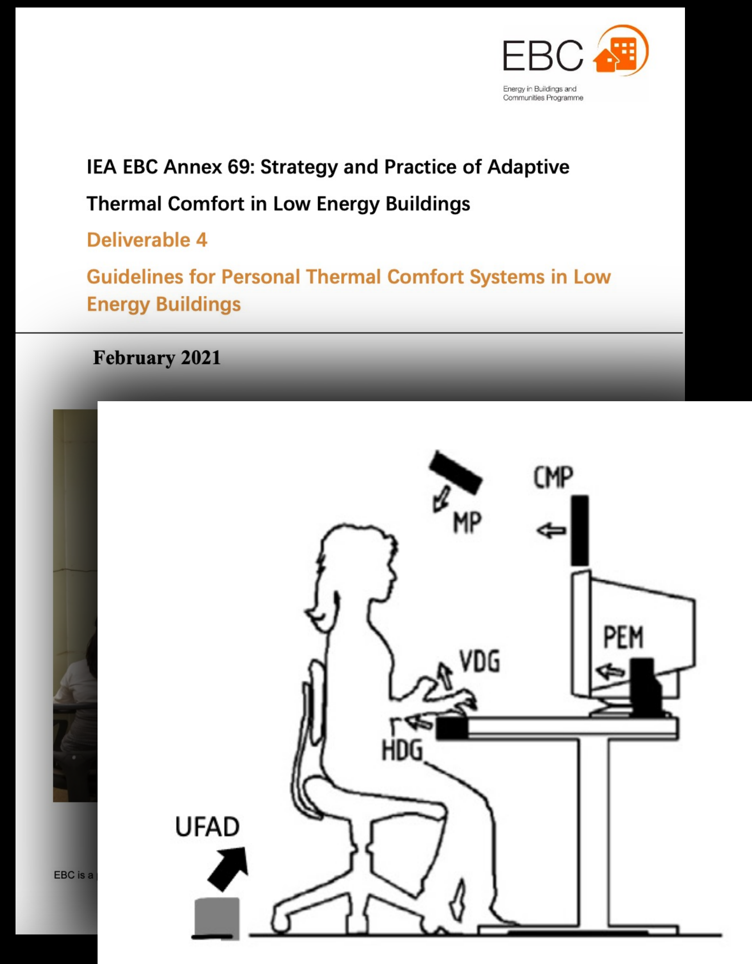
Conventional AC technologies follow a total-volume conditioning approach:

- It wastes energy on conditioning the unoccupied or transitory spaces,

- It assumes a one-size-fits-all approach to thermal comfort, which is patently false.

- UFAD, conditioned furniture, task conditioning …

- By conditioning the occupant directly we can reduce the cooling wasted on the ambient room environment



IEA-EBC Annex 69 Deliverable 4 – Guidelines for Personal Comfort Systems in Low Energy Buildings

Conclusions

- The convergence of climate change, population growth, economic development, and rapid urbanization mean India will be facing a “cooling crunch” in coming years.
- This poses a daunting challenge to India’s CO_2 emission abatement pledges, impeding the buildings sector’s transition towards zero-carbon.
- In preparing for this looming challenge most attention has been focused to date on the built environment – building envelope and mechanical services:
  - building energy efficiency (new build)
  - AC minimum energy performance standards (retrofit)
- More attention is required on the occupants – adaptive thermal comfort
  - Climatically appropriate comfort zone temperatures (passive and active systems)
  - Demand-Response strategies for AC
  - Personal Comfort Systems to deliver comfort to occupants, not the unoccupied space