Adaptive Thermal Comfort: Practices and Policies

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

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

Reference: ASHRAE 55 - 2017

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• 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

Reference: Sanyogita Manu, CEPT Un

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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

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

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• 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.

Reference: ASHRAE 55 - 2017
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

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Are occupant thermally comfortable in buildings?
Are occupant thermally comfortable in buildings


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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
### Geographic Area and Population Defined as Urban in Census 2011

<table>
<thead>
<tr>
<th>Climate Type</th>
<th>Population (Millions)</th>
<th>Area (in '000 sq. km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-Humid</td>
<td>152.2</td>
<td>65.8</td>
</tr>
<tr>
<td>Composite</td>
<td>147.0</td>
<td>35.5</td>
</tr>
<tr>
<td>Hot-Dry</td>
<td>45.8</td>
<td>13.6</td>
</tr>
<tr>
<td>Cold</td>
<td>15.3</td>
<td>4.6</td>
</tr>
<tr>
<td>Temperate</td>
<td>9.5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Cooling costs as % of median household income

- Indonesia: 14%
- India: 8%
- Pakistan: 8%
- Brazil: 8%
- China: 4%

A burden to consumers
Cooling at current efficiency is unaffordable for the average consumer in developing countries


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Industry progress toward theoretical max efficiency

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


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

Reference: Rocky Mountain Institute
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.
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

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The Adaptive Thermal Comfort Principle

- Humphreys and Nicol (1998)
- Auliciems (1983)
- Nicol & Roaf (1996)
India Model For Adaptive Thermal Comfort (IMAC)

Reference: Sanyogita Manu, CEPT University

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

- Too Hot (<80% Acceptable)
- Comfortable (90% Acceptable)
- Warm (80-90% Acceptable)
- Cold (80-90% Acceptable)

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India
National Building Code (India) 2016
GRIHA Rating 2017

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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


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Energy Benefits Of Adaptive Thermal Comfort Regime

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

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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

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Air Velocity

Thermal Comfort Chamber Experiments

Study Method
Personal Control and Comfort

Thermal Comfort Chamber Experiments

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Personal Control and Comfort

In Silica Digital Simulations for Comfort

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Air Velocity
Thermal Comfort Chamber Experiments

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Air Velocity

Thermal Comfort Chamber Experiments

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

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

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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)


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INTRODUCTION

Global Cooling Prize
## THE GLOBAL COOLING PRIZE
Residential Air Conditioning Poses a Critical Threat

### THE PROBLEM

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>By 2030</td>
<td>Over 1/2 of the world’s population will live in hot climates</td>
</tr>
<tr>
<td>Cooling demand will boom</td>
<td>3x by 2050, posing a huge climate risk</td>
</tr>
<tr>
<td>2.5 B AC units will be in use globally</td>
<td>By 2050 compared to only 900 M today</td>
</tr>
<tr>
<td>14% of theoretical efficiency</td>
<td>Has been reached by today’s best AC technology (most ACs attain just 6%)</td>
</tr>
</tbody>
</table>

### THE SOLUTION

<table>
<thead>
<tr>
<th>Requirement</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Spurs climate-friendly residential cooling tech</td>
<td>That uses 3–5x less energy and fulfills 9 other requirements</td>
</tr>
<tr>
<td>Is led by a coalition of global partners</td>
<td>That engage industry and markets to identify and scale a solution</td>
</tr>
<tr>
<td>Awards at least</td>
<td>US $3M</td>
</tr>
<tr>
<td>Is just the start of an era of global innovation and transformation for the industry</td>
<td></td>
</tr>
</tbody>
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### THE IMPACT

<table>
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<tr>
<td>Affordable access to cooling in parts of the world where it is becoming a critical need</td>
<td></td>
</tr>
<tr>
<td>Potential to mitigate</td>
<td>1°C of global warming by 2100</td>
</tr>
<tr>
<td>3,200 TWh</td>
<td>In avoided grid capacity</td>
</tr>
<tr>
<td>A cooling technology in billions of homes that uses</td>
<td>5x less grid energy</td>
</tr>
</tbody>
</table>

JOIN US: globalcoolingprize.org
• Dodo was incredibly easy to catch
• Never feared humans

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

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Thank You

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