



Bureau of Energy Efficiency



सत्यमेव जयते  
Government of India  
Ministry of Power



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# ANGAN

## Augmenting Nature by Green Affordable New-habitat

A Courtyard for Revolutionary Change in Building Energy Efficiency  
An International Conference on Building Energy Efficiency

9<sup>th</sup>-11<sup>th</sup> September, 2019 | Hotel The LaLIT, New Delhi





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THIS PRESENTATION WAS SHARED BY

**Rajan Rawal**

Executive Director, Centre for Advance Research in Building Science and Energy

FOR THE SESSION:

*“Occupant Comfort: Thermal, Visual, Acoustic, Indoor Air Quality”*

DURING ANGAN 2019

Knowledge Partner



**teri** | THE ENERGY AND  
RESOURCES INSTITUTE  
Creating Innovative Solutions for a Sustainable Future

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# Thermal Comfort For All

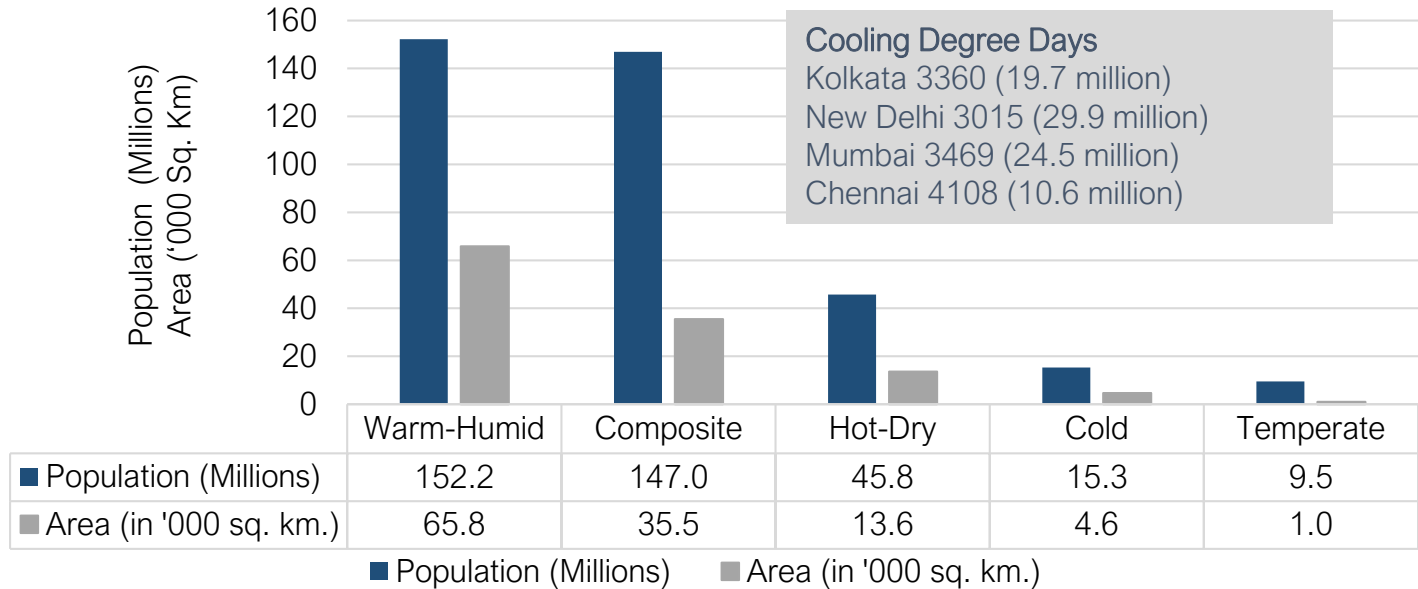
Occupant Comfort: Thermal, Visual, Acoustic, Indoor Air Quality

11<sup>th</sup> Sept 2019, Augmenting Nature by Green Affordable New-habitat, BEE INDIA

Rajan Rawal, CEPT University, Ahmedabad

# About Half of the India Leaves in Warm-Humid Climate

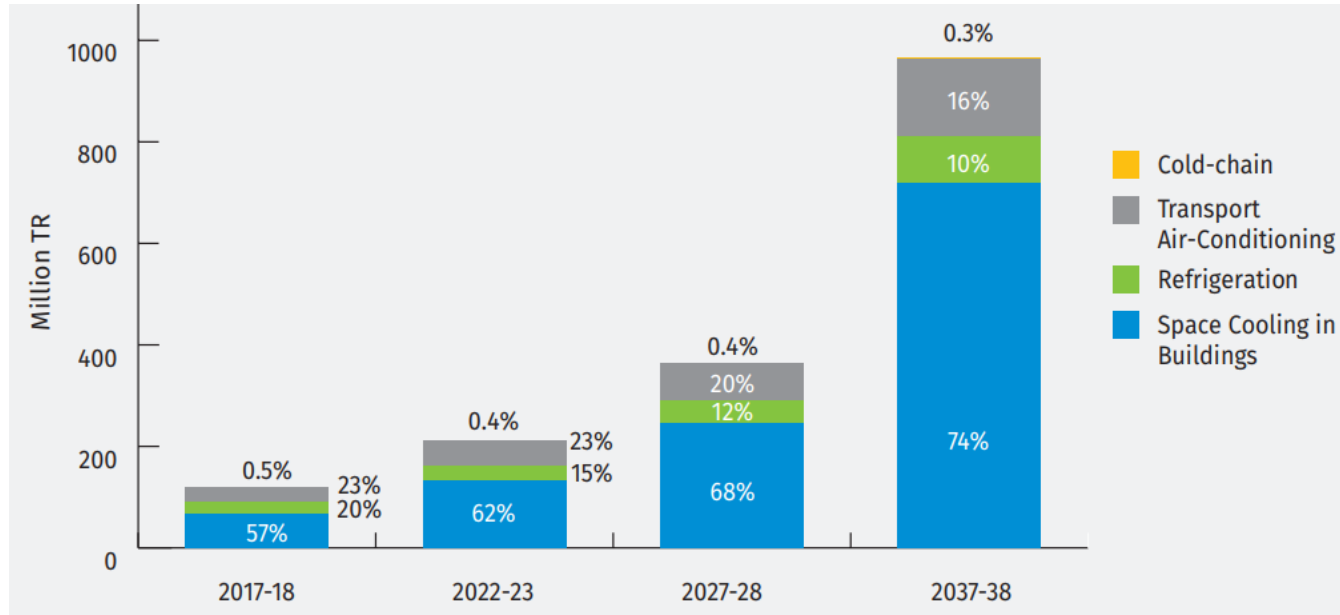
Distribution of urban population with climate zones in India



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

# Sector Wise Growth in India's Cooling Demand

8 times by 2037-38 as compared to the 2017-18 baseline  
building sector cooling demand will be 11 times as compared to the baseline



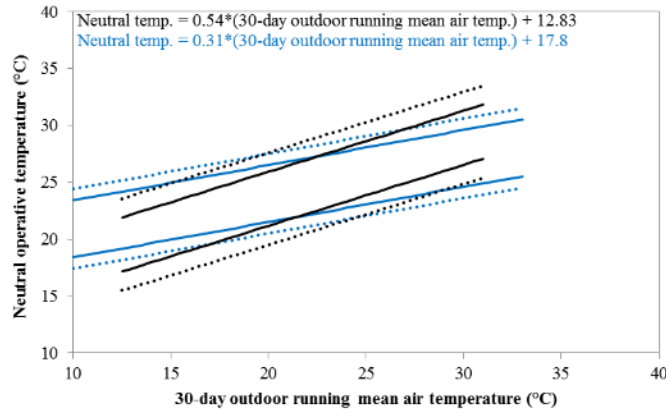
Source: India Cooling Action Plan

***Do we have tools to meet these challenges?***

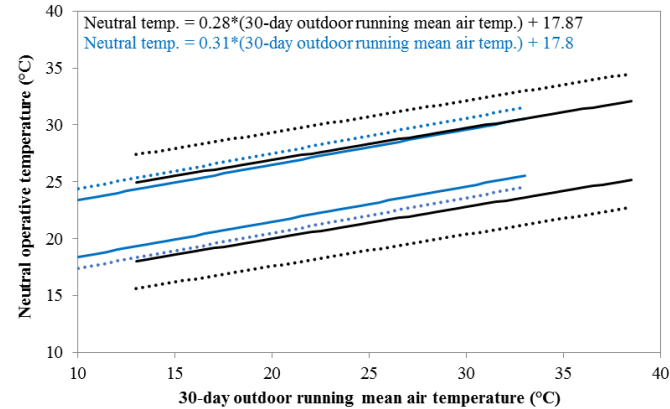
***Do we have Knowledge to meet these challenges?***

# Envelop Systems: Design for Adaptive Model

## NV thresholds

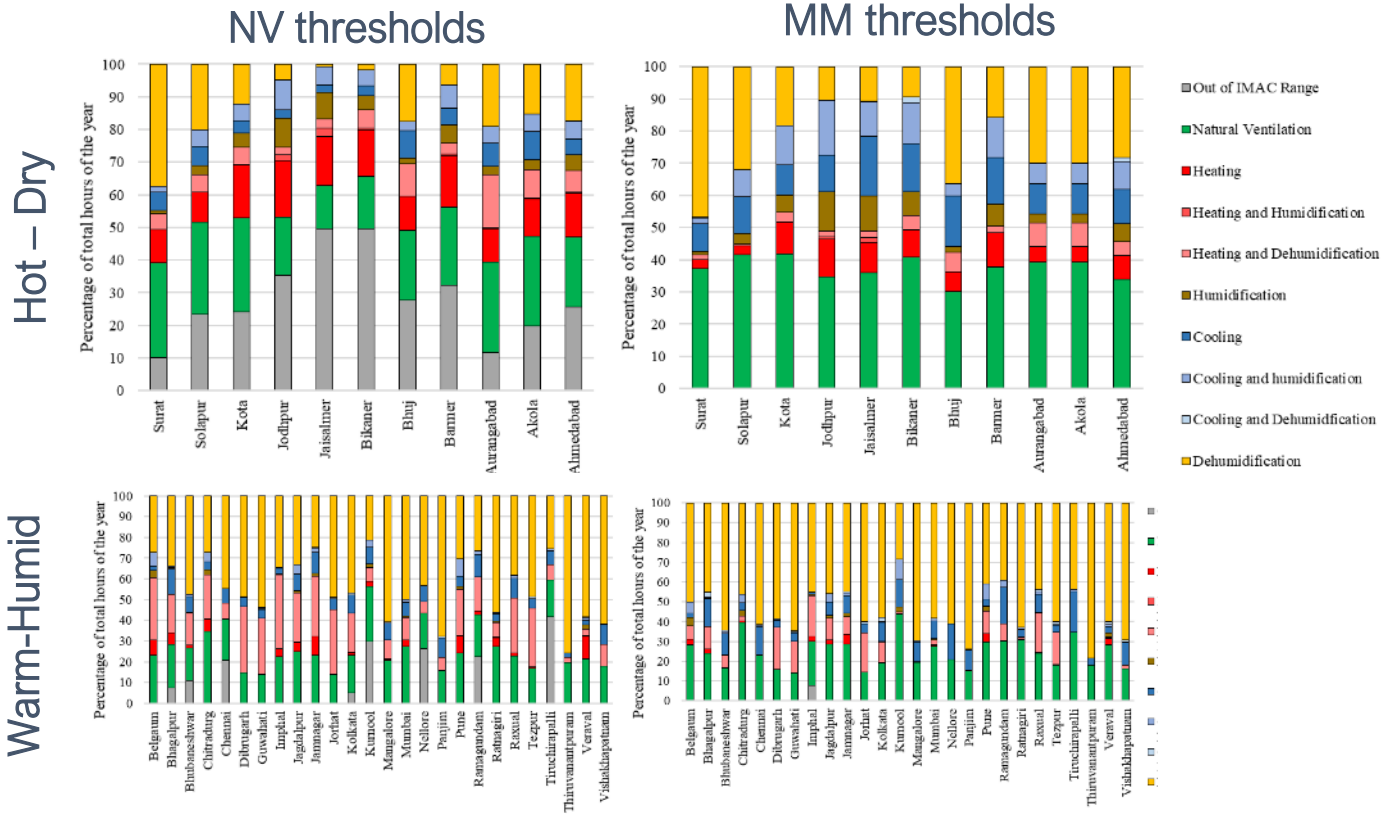


## MM thresholds



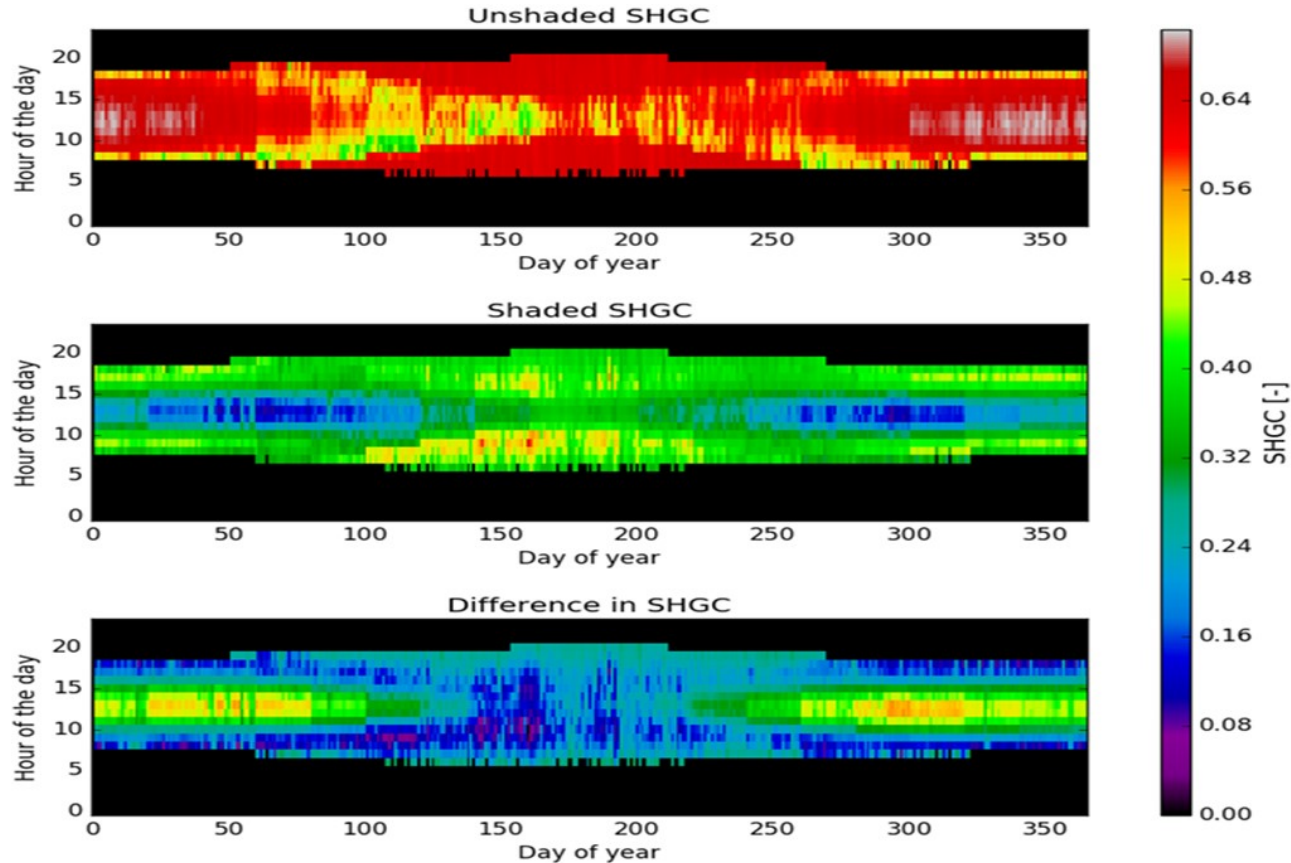
Source: Sanyogita Manu, Yash Shukla, Rajan Rawal, Leena E. Thomas, Richard de Dear, Field studies of thermal comfort across multiple climate zones for the subcontinent: India Model for Adaptive Comfort (IMAC), Building and Environment, Volume 98,2016, Pages 55-70, ISSN 0360-1323

# Envelop Systems: Design for Adaptive Model

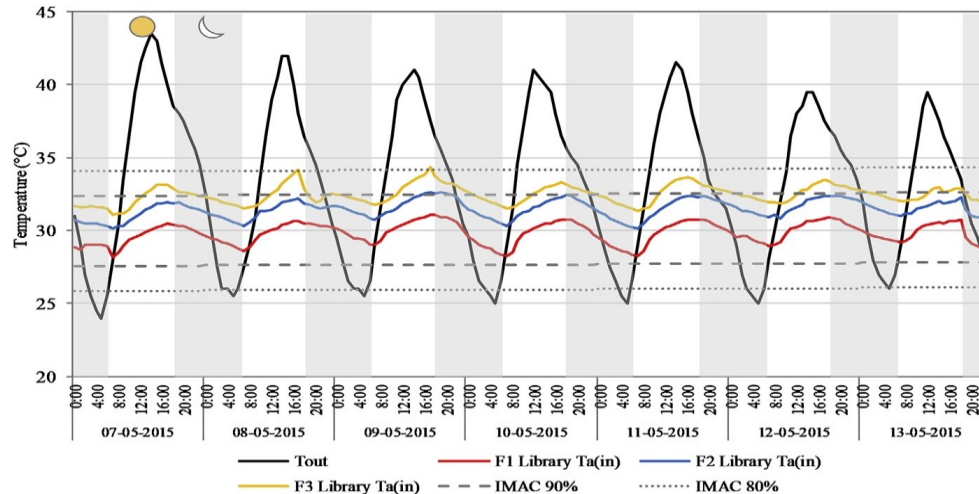
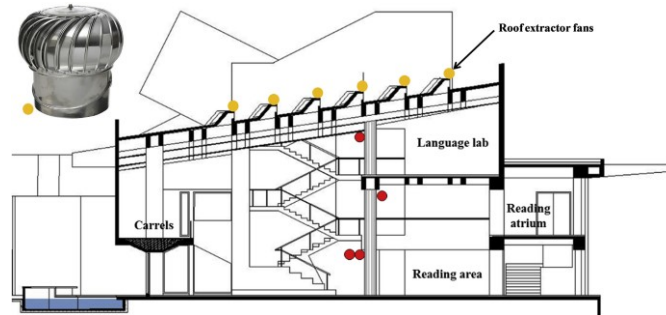


Source: Sanyogita Manu

# Passive Design Strategies: Shading



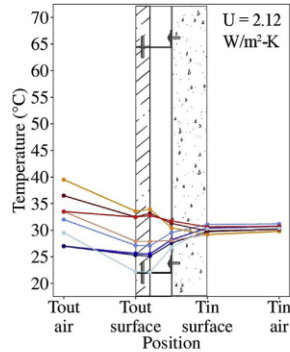
# Passive Design Strategies: Ventilation



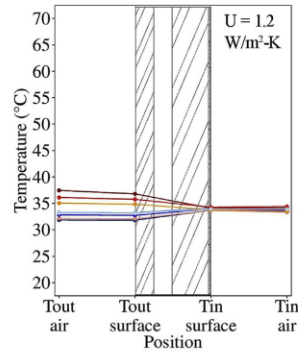
Source: Sanyogita Manu Et al, Performance evaluation of climate responsive buildings in India - Case studies from cooling dominated climate zones November 2018, Building and Environment 148

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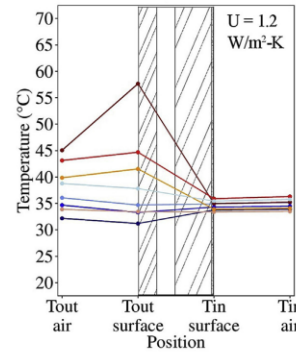
# Passive Design Strategies: Thermal Mass and Insulation



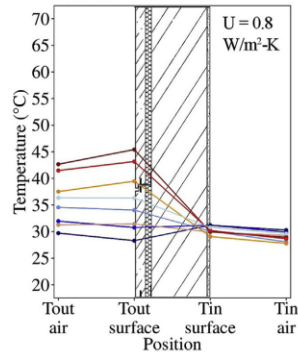
(a) WH1 - Wall



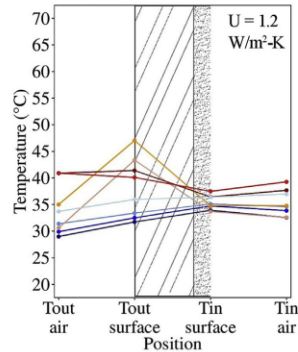
(b) HD1 (shaded) - Wall



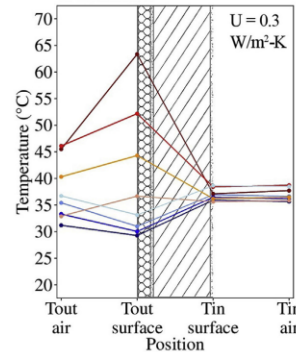
(c) HD1 (exposed) - Wall



(d) CT2 - Wall



(e) HD2 - Wall



(f) HD3 - Wall

Source: Sanyogita Manu Et al, Performance evaluation of climate responsive buildings in India - Case studies from cooling dominated climate zones  
November 2018, Building and Environment 148

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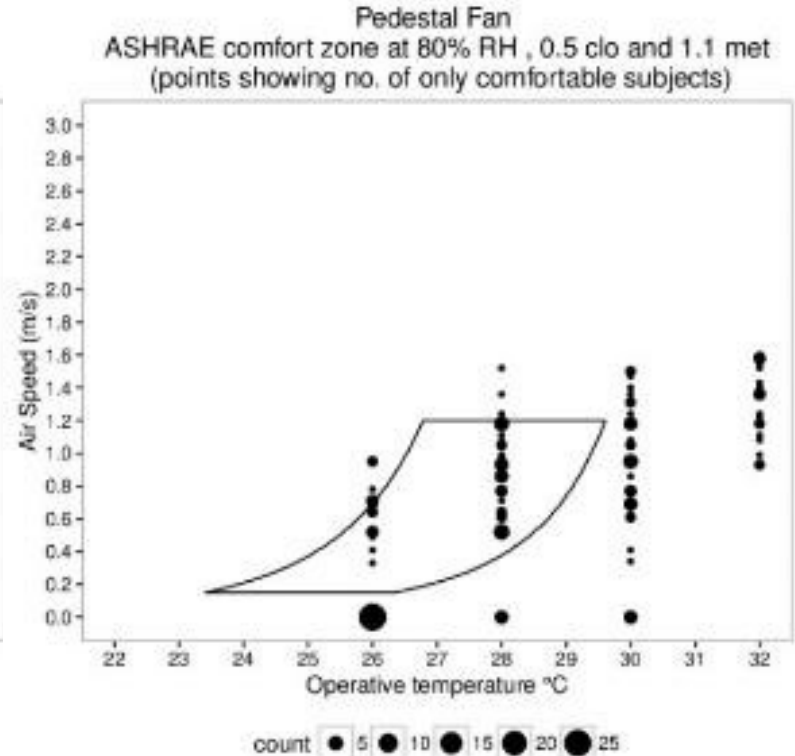
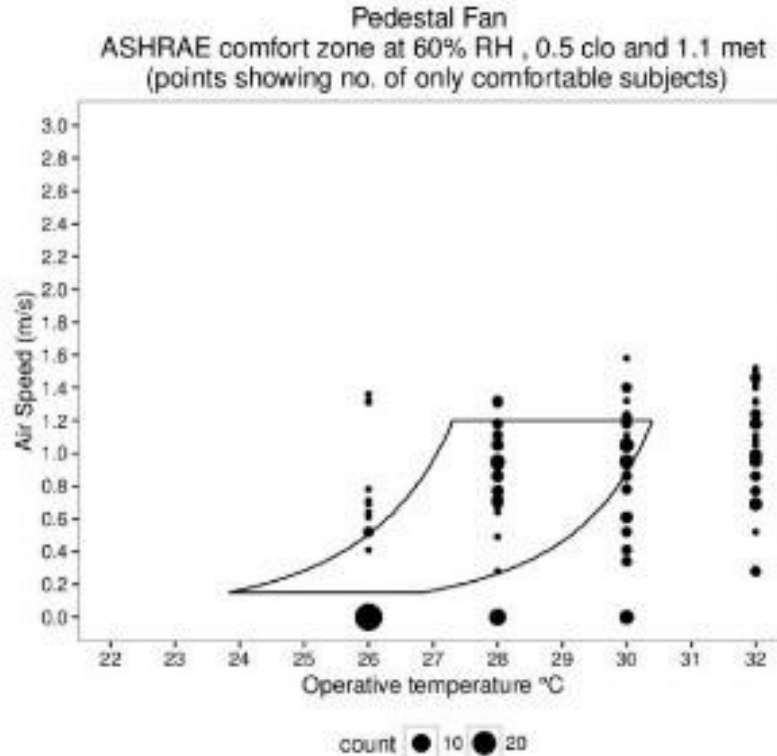
# Design and Operation of Mixed Mode Building



# Use and importance of the fan – air motion devices

Research Lead: Agam Shah, Yash Shukla

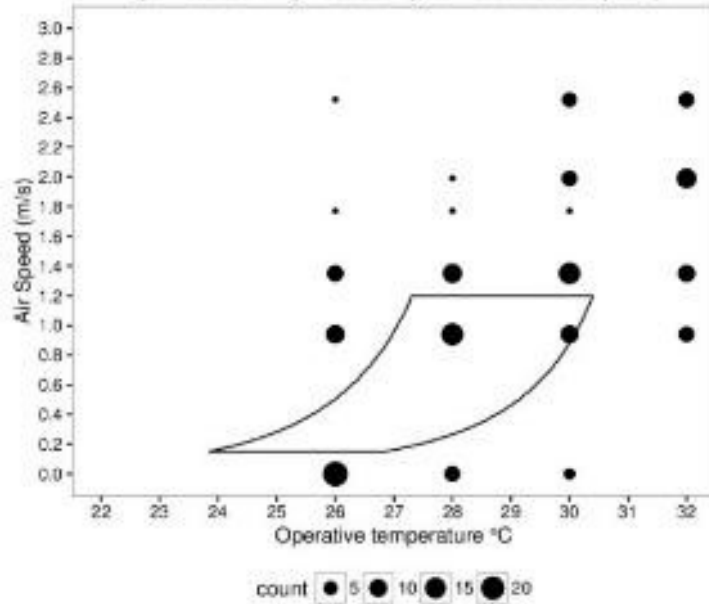
# Beyond IMAC, Impact of air velocity



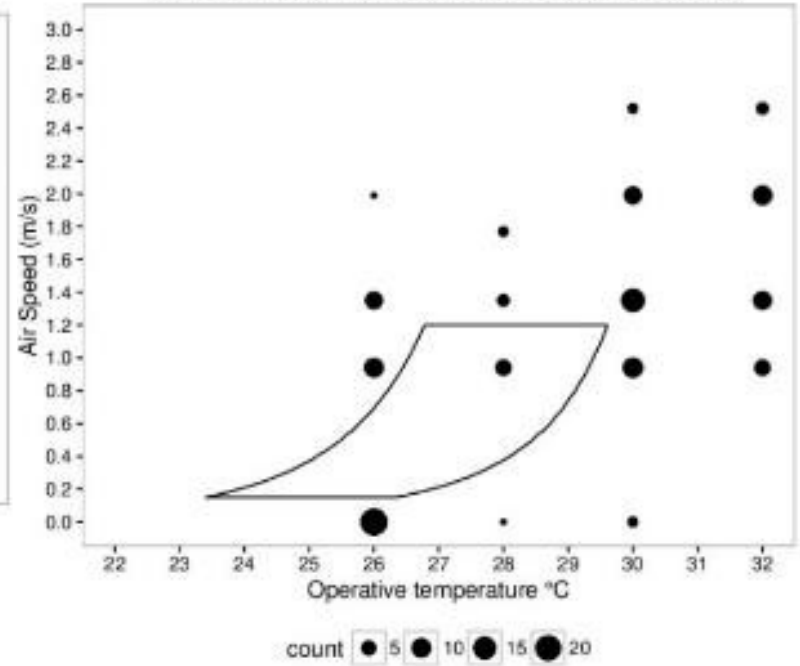
# Beyond IMAC, Impact of air velocity



Ceiling Fan  
ASHRAE comfort zone at 60% RH, 0.5 clo and 1.1 met  
(points showing no. of only comfortable subjects)

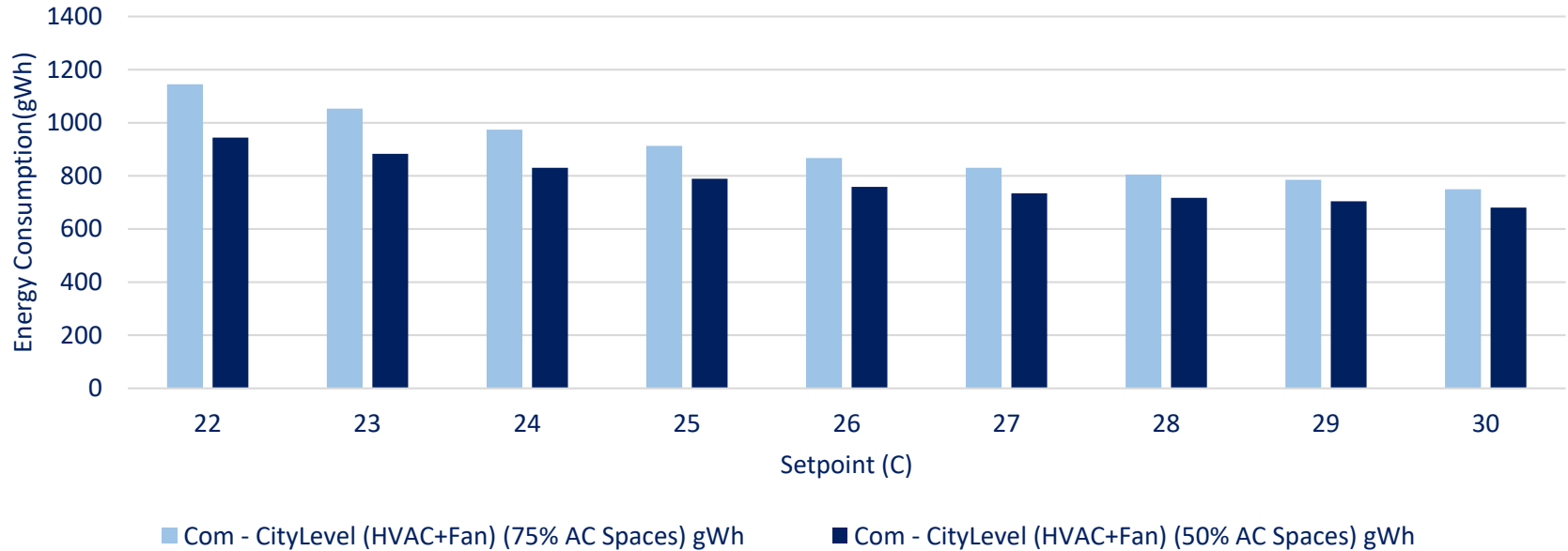


Ceiling Fan  
ASHRAE comfort zone at 80% RH, 0.5 clo and 1.1 met  
(points showing no. of only comfortable subjects)



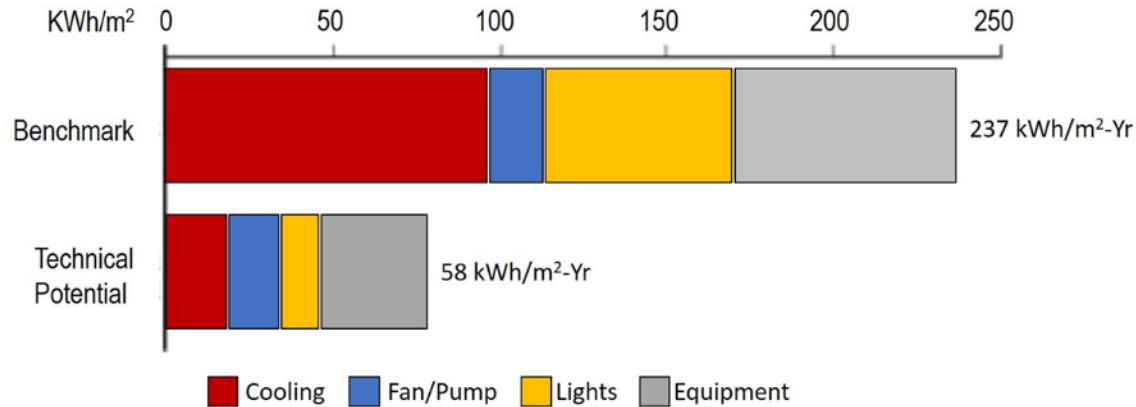
# Commercial Buildings – Indoor setpoint, Fan and EPI

City Level Energy Consumption for Commercial Buildings

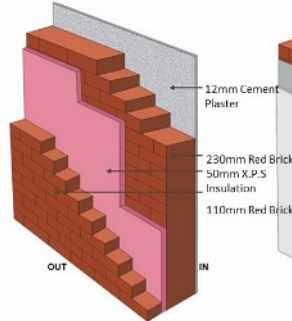


Reduction in energy consumption at City Level considering 75% and 50% of area of each commercial space in the city as air conditioned space.

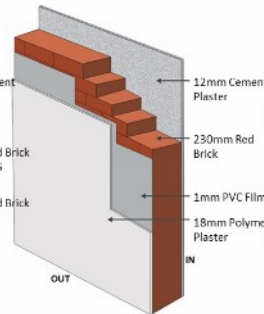
# Design and Operation of Mixed Mode Building



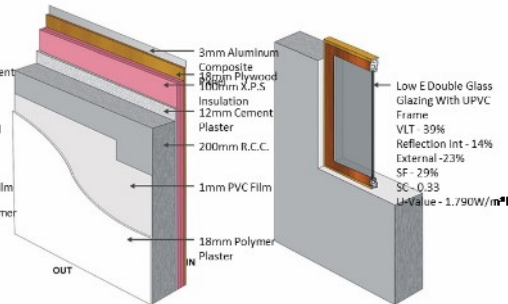
**3.1 WALL SUPER STRUCTURE**  
u - VALUE (W/m²)=0.42  
R - VALUE (m².K/W)=2.38



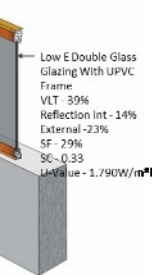
**3.2 WALL BASEMENT**  
u - VALUE (W/m²)=2.01  
R - VALUE (m².K/W)=0.50



**3.3 WALL BASEMENT**  
u - VALUE (W/m²)=0.28  
R - VALUE (m².K/W)=3.59



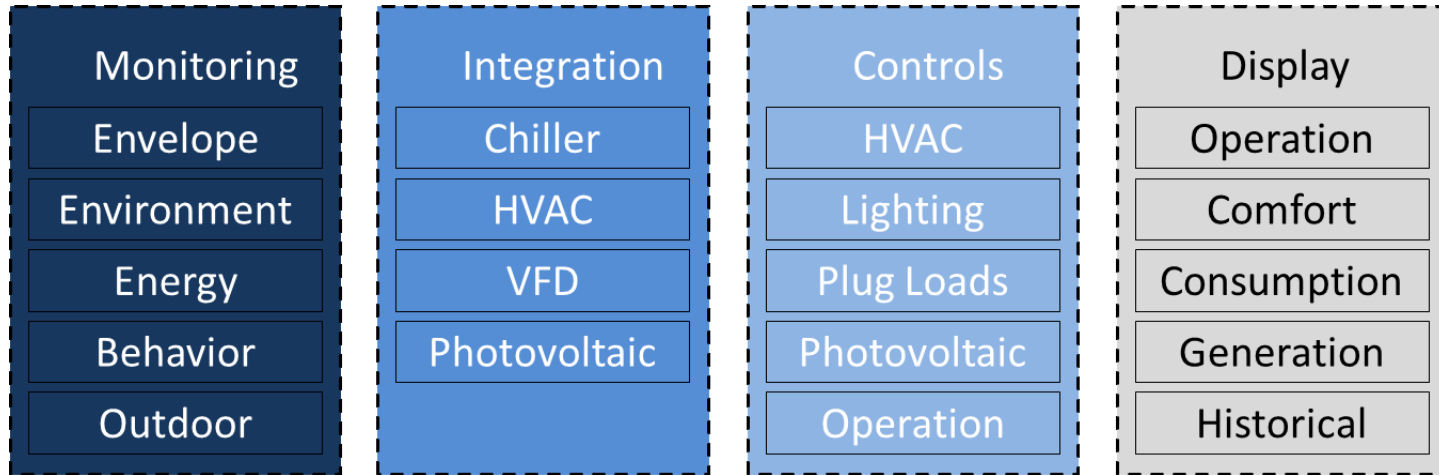
**3.4 WINDOW**  
u - VALUE (W/m²)=1.70  
R - VALUE (m².K/W)=0.588



Source: Rawal et al, Energy & Thermal Comfort Performance Evaluation of Net Zero Energy Building in Hot Dry Climate – A case study, CATE 2019 \_ Dubai

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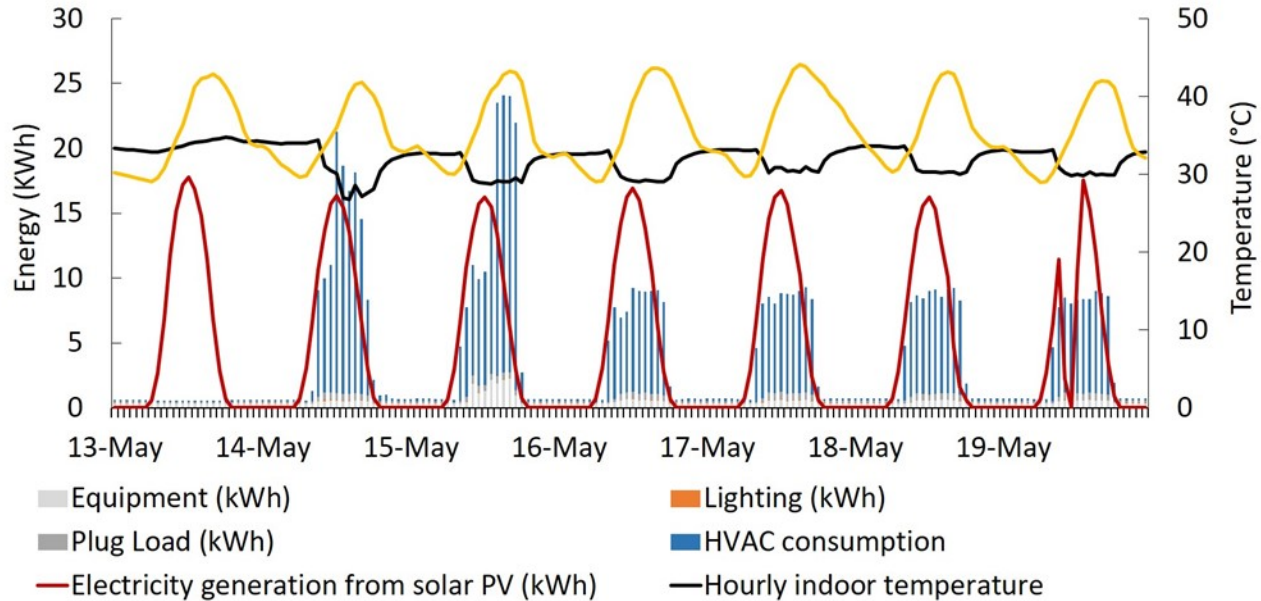
# Design and Operation of Mixed Mode Building



Source: Rawal et al, Energy & Thermal Comfort Performance Evaluation of Net Zero Energy Building in Hot Dry Climate  
– A case study, CATE 2019 \_ Dubai

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**Thermal Comfort for All: Rajan Rawal, CEPT University, Ahmedabad**

# Design and Operation of Mixed Mode NZEB

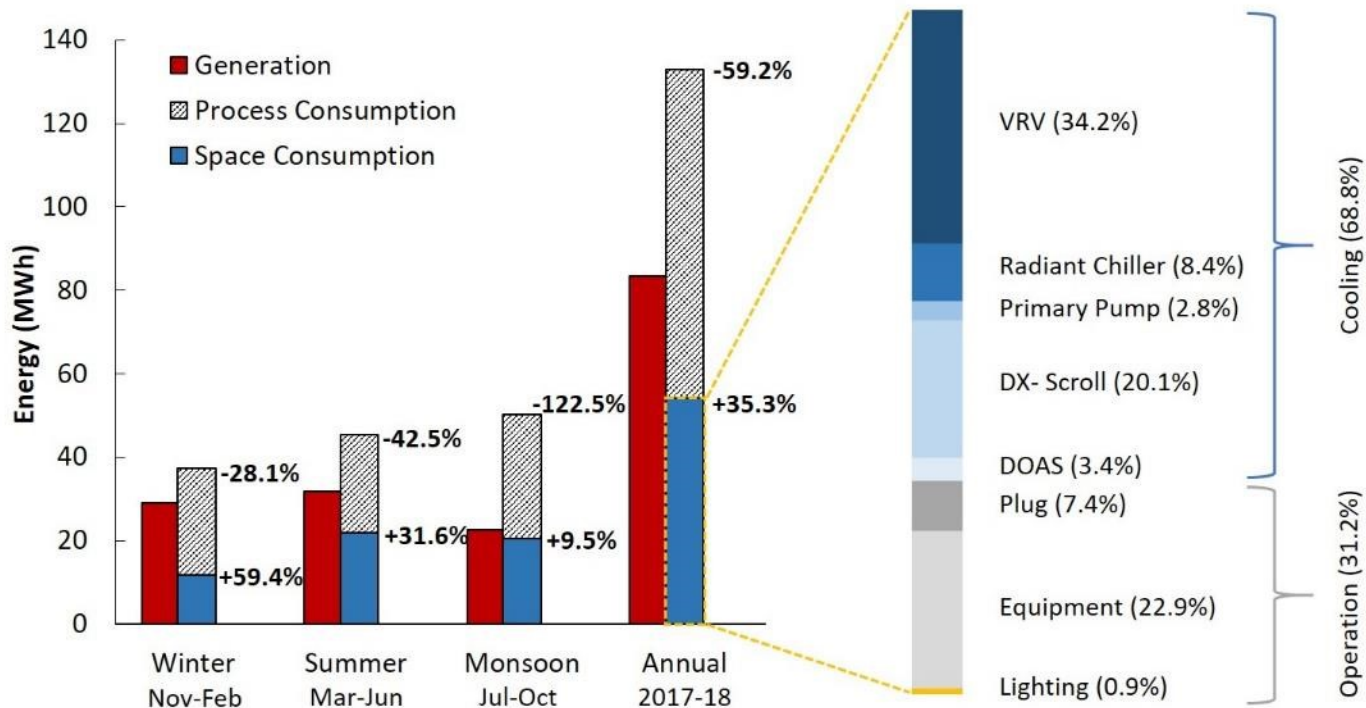


## Environment and energy-related parameters – typical summer week (2018)

Source: Rawal et al, Energy & Thermal Comfort Performance Evaluation of Net Zero Energy Building in Hot Dry Climate – A case study, CATE 2019 \_Dubai

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Thermal Comfort for All: Rajan Rawal, CEPT University, Ahmedabad

# Design and Operation of Mixed Mode NZEB

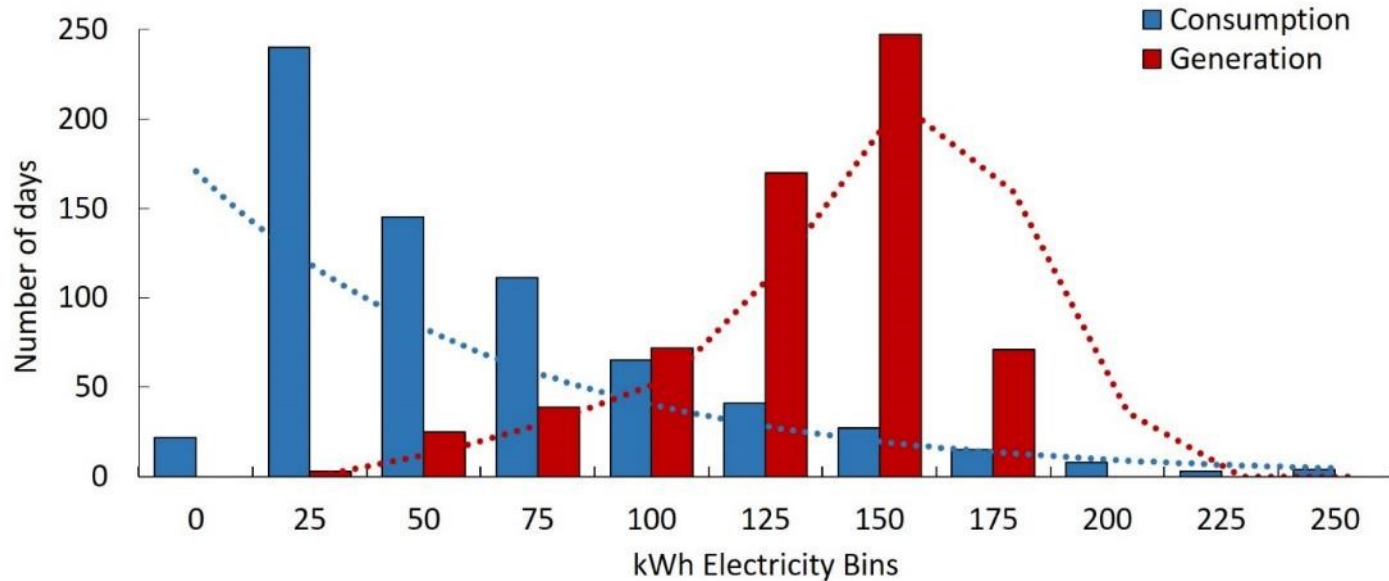


Energy generation, process consumption, and space consumption (2017-18) with operation and cooling loads

Source: Rawal et al, Energy & Thermal Comfort Performance Evaluation of Net Zero Energy Building in Hot Dry Climate  
 – A case study, CATE 2019 \_Dubai

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**Thermal Comfort for All: Rajan Rawal, CEPT University, Ahmedabad**

# Design and Operation of Mixed Mode Building with SPV

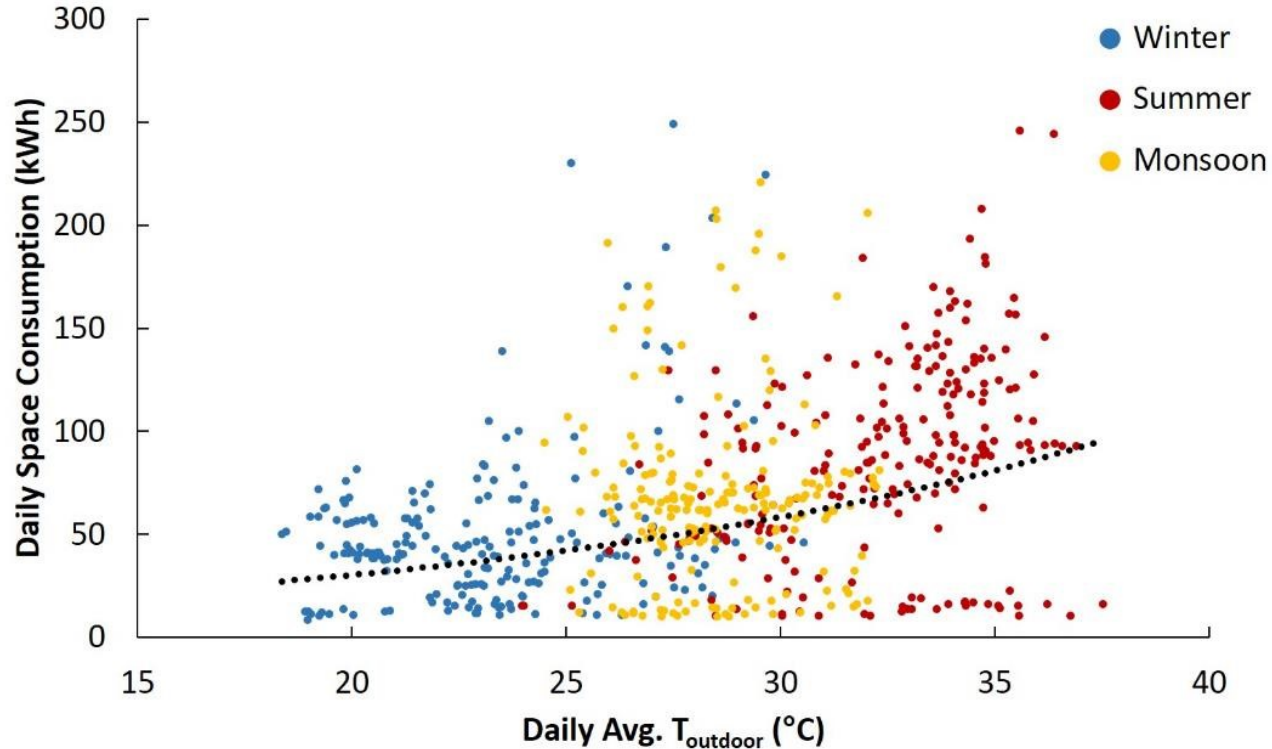


Number of days versus energy consumption/generation (2017-2018)

Source: Rawal et al, Energy & Thermal Comfort Performance Evaluation of Net Zero Energy Building in Hot Dry Climate  
– A case study, CATE 2019 \_ Dubai

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**Thermal Comfort for All: Rajan Rawal, CEPT University, Ahmedabad**

# Design and Operation of Mixed Mode NZEB



Total daily space consumption with daily average outdoor temperature (2017-2018)

Source: Rawal et al, Energy & Thermal Comfort Performance Evaluation of Net Zero Energy Building in Hot Dry Climate  
– A case study, CATE 2019 \_ Dubai

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# ***Integration of Building Envelop Systems and HVAC System is must***

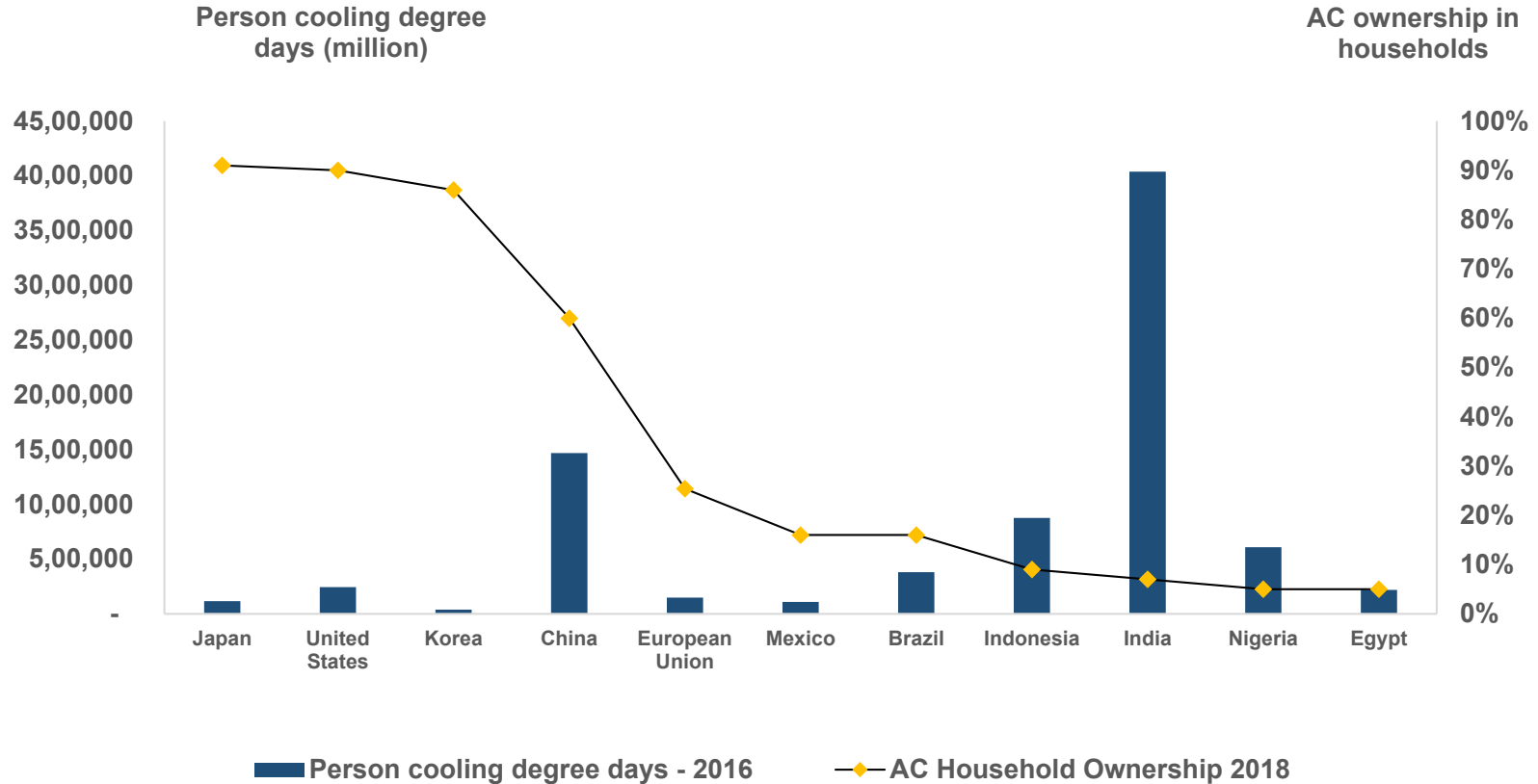


## Probable solution for the the Cooling Dilemma.....

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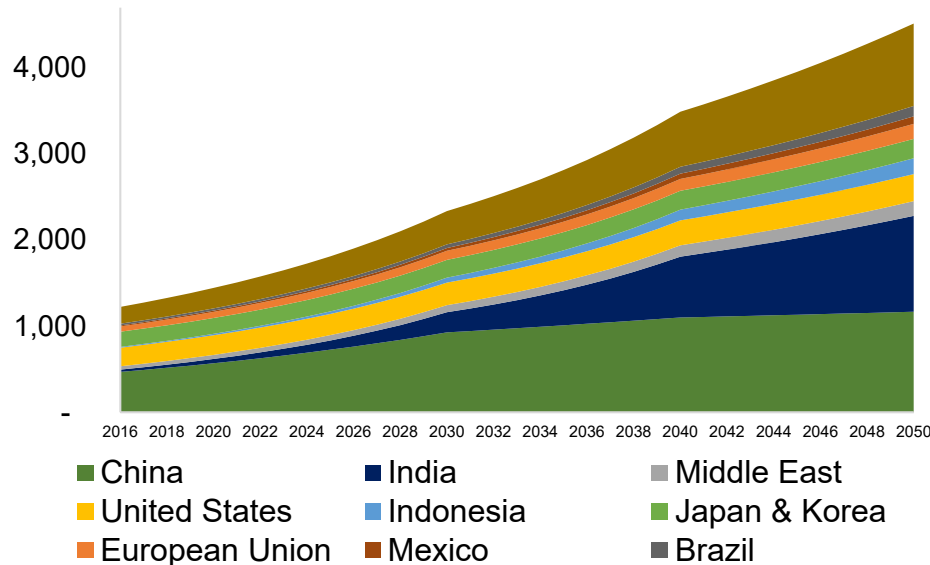
Increasingly seen as a Social Need but  
at an Environmental Cost we cannot  
afford

# Cooling in the rear-view mirror has not captured much attention .. looking to the road ahead cooling needs to be on everyone's agenda



# Entry level cooling is provided by the ubiquitous residential / room air conditioner (RAC) the number in operation could grow nearly fourfold by 2050

Expected global stock of room air conditioners, 2016-2050  
RAC units, millions



## PRESENT

Approx. 1.2 billion RAC units in the world; sales growing at 10-15% per year in developing economies.

## 2050

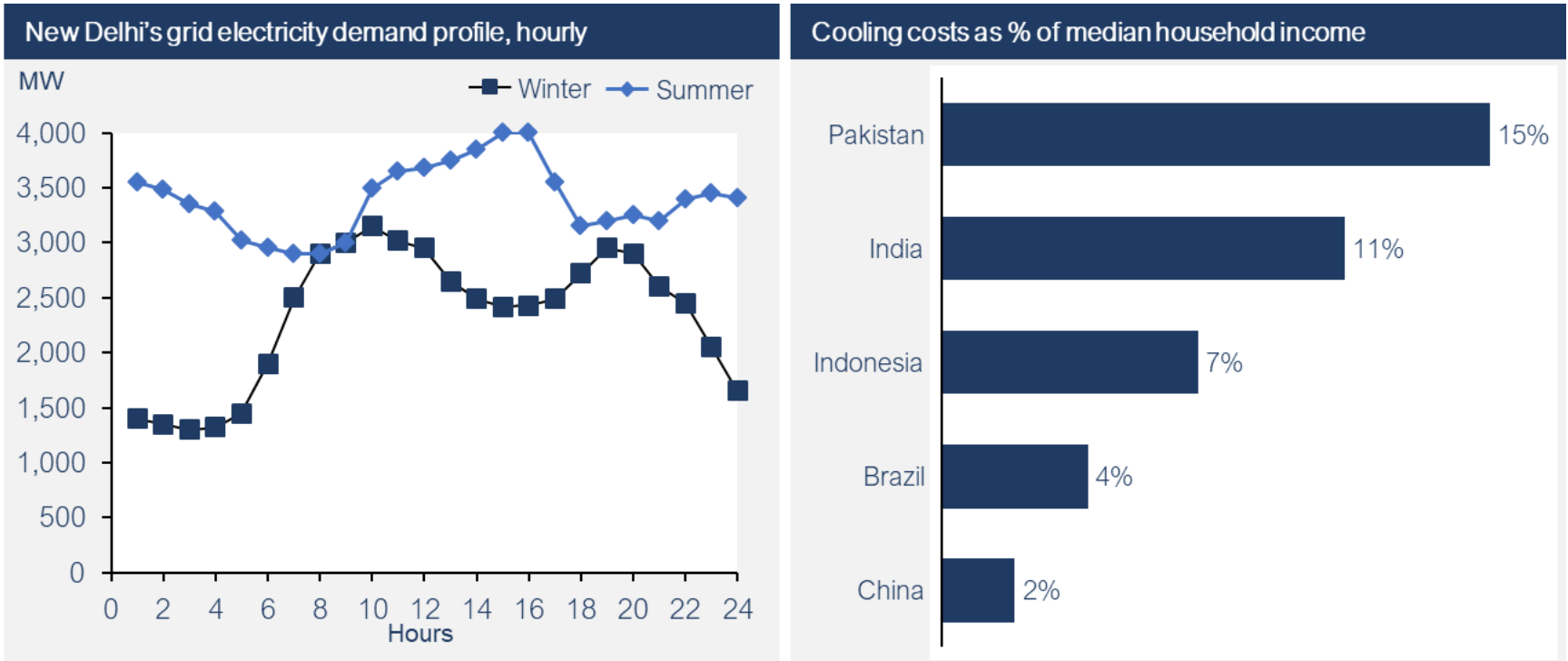
Approx. 4.5 billion RAC units in operation worldwide. Demand driven by non-OECD countries.

## 2100

50-fold increase in worldwide RAC energy demand from year 2000.

Source: International Energy Agency (IEA) (2018), *The Future of Cooling*. LBNL Report: *Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning* (2015), IPCC, "Fifth Assessment Report", 2014

# Air conditioning demand will place significant burdens on grids where it drives peak loads and consumers pockets

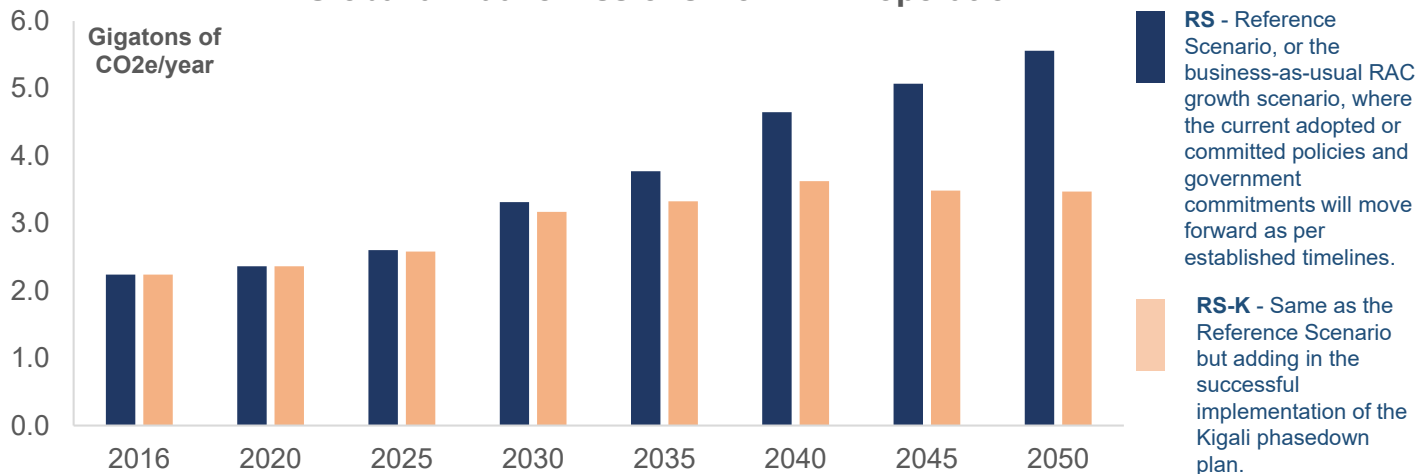


Source: LBNL Report: Benefits of Leapfrogging to Superefficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning (2015), Global Industry Analyst Market Research, Enerdata, UCSUSA, Eco Climate Network Article, NRDC (2015), IECS and Christian Aid Report (2017); IPCC, "Fifth Assessment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

# Successful implementation of the Kigali Amendment will significantly reduce cooling related emissions – but we need to do more



### Global annual emissions from RAC operation



While existing cooling  
emissions & efficiency  
efforts are critical, they are  
not sufficient

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We are building better buildings, and being smarter in how we operate them which helps reduce cooling loads



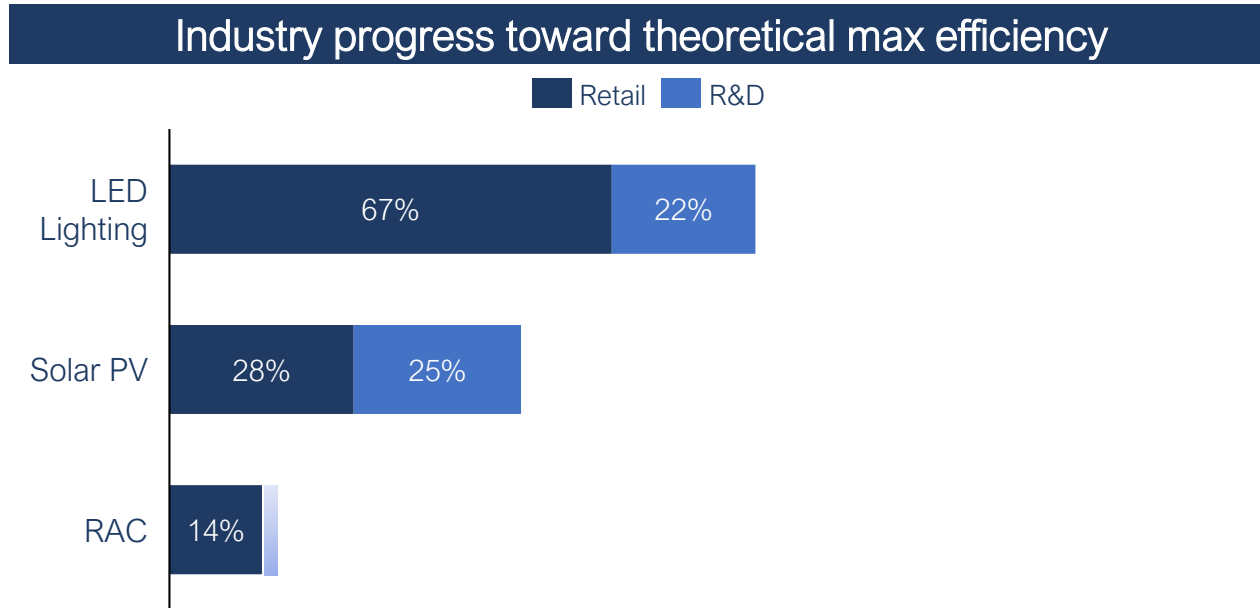
... but the energy consumption of the equipment serving these cooling loads remains a massive and critical component

# The efficiency opportunity remains largely unaddressed by the RAC industry due to lack of market and policy signals

- Consolidated industry
- Fewer than 500 AC companies worldwide
- 70% of global RAC production in only one country, concentrated within a few major manufacturers
  
- **Market Analysis**
- RAC segment is subject to a massive market failure - the focus on lowest upfront cost...and industry responds to market signals
- Mass market innovation has largely stalled
- Emerging & innovative technologies are unable to achieve scale

*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*

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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 allow inertia to define us or do we do what humankind has done through the ages and look for innovation to move us forward

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A prize has the potential to spur climate-friendly innovation and address the market failure in the cooling industry

# Global Cooling Prize










An innovation competition to develop a climate-friendly residential cooling solution



# Global Cooling Prize

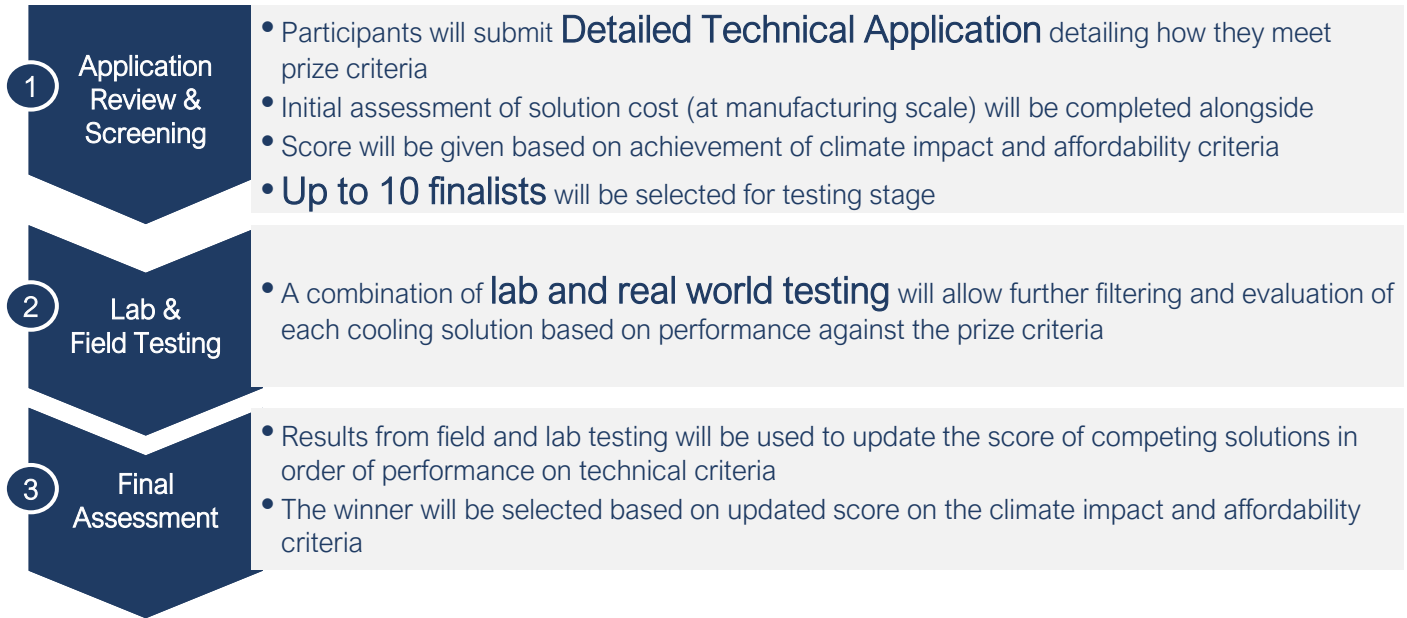
Our Prize Criteria will ensure that the next generation room air conditioners can meet the challenging conditions across all markets

- Primary criteria used to determine final award
- Supplementary criteria used to shortlist finalists

<b>CLIMATE</b> One-fifth of the life-time climate impact (electricity and refrigerant) of the baseline AC unit		<b>AFFORDABILITY</b> At manufacturing scale of 100,000 units, costs no more than twice the cost of the baseline AC unit to manufacture	
<b>POWER</b> Consumes less than 700W from the grid at rated cooling capacity or during test period		<b>EMISSIONS</b> Zero onsite emissions from any captive power or heat source	
<b>SCALABILITY</b> Usable in existing homes, no "designed in" solution; less than 2x volumetric size of the baseline unit		<b>OPERATION</b> Designed to have 1.5 TR cooling capacity at standard outdoor conditions and Maintains below 27°C DBT and 60% RH indoors for the duration of test period	
<b>WATER (if any is used)</b> Consumes an yearly average of 14 liters/day with daily maximum limit		<b>REFRIGERANTS (if any is used)</b> Zero ODP, lower toxicity, and compliance with safety standards	
		<b>MATERIALS</b> Minimal usage of high embodied carbon or rare earth materials	

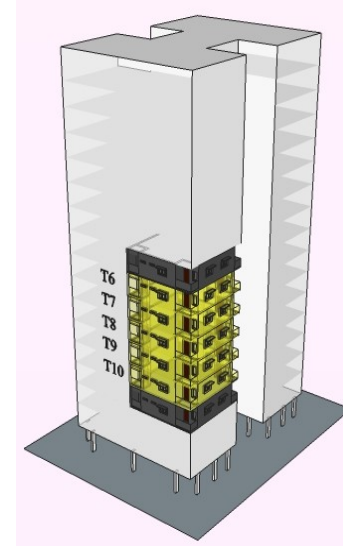
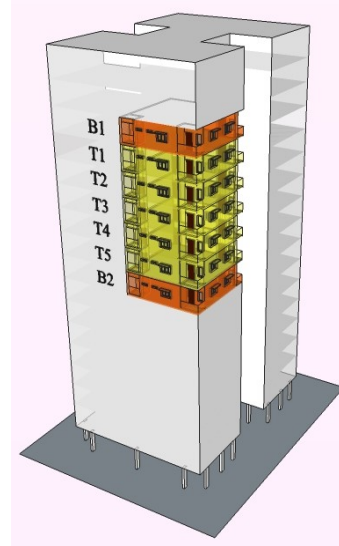
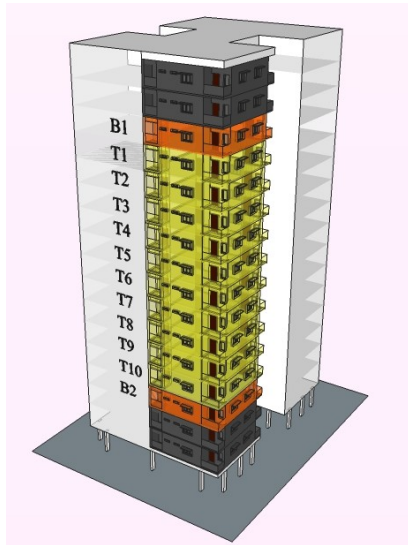
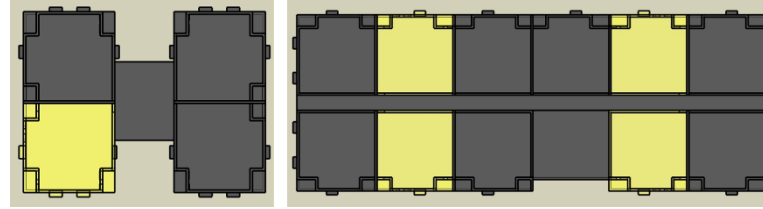
# Global Cooling Prize

Evaluation of the cooling solutions will occur across three stages in this competition



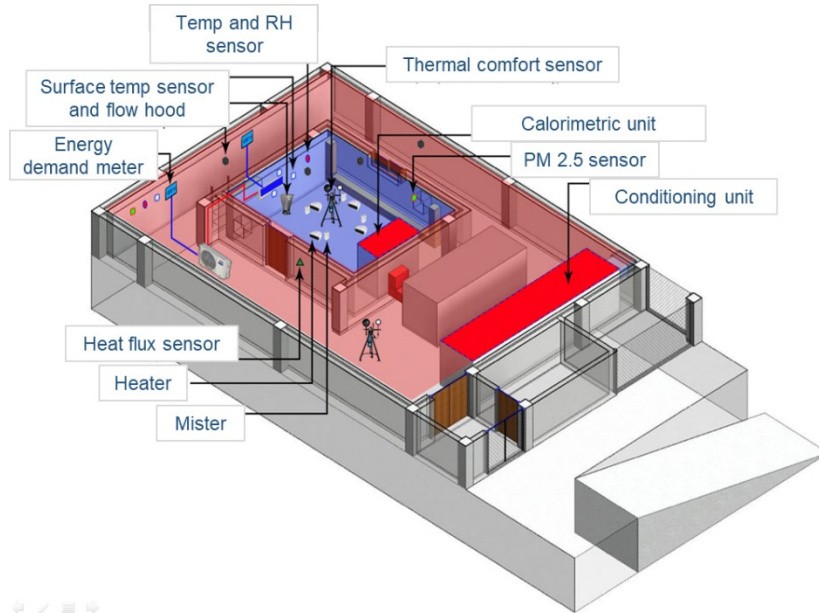
# Global Cooling Prize

## RAC Schematics of Field Testing



# Global Cooling Prize

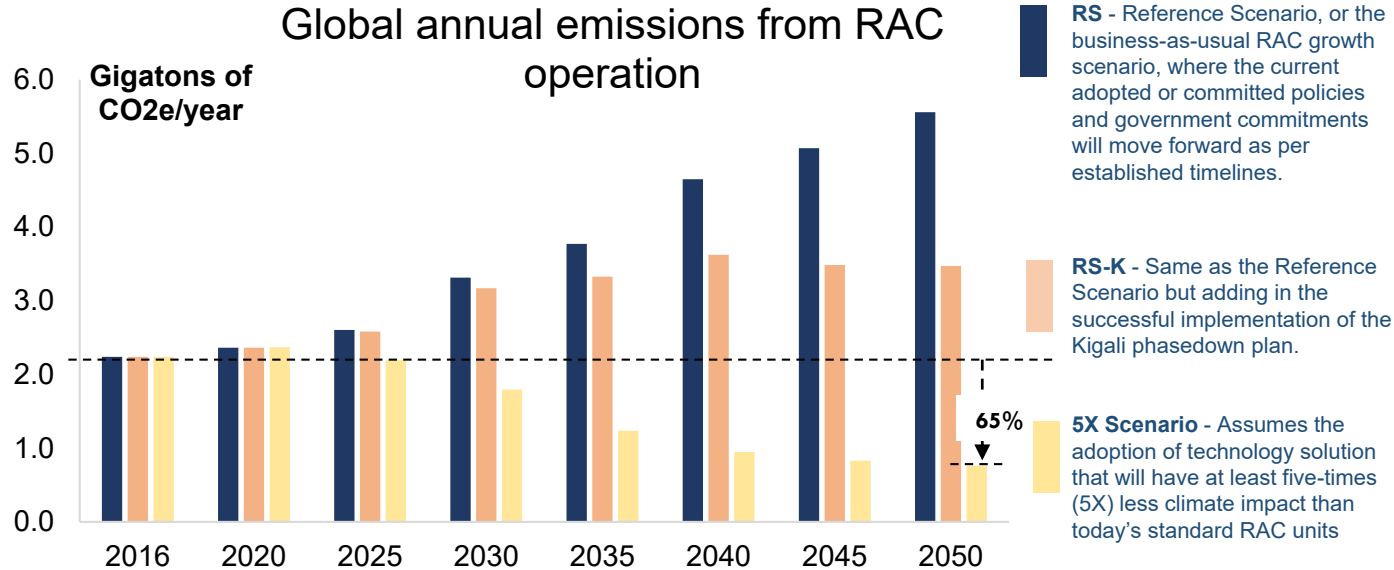
## RAC Laboratory Characterization Facility



# An overview of the Global Cooling Prize

<p>Goal</p>	<p>5x less Climate Impact</p>	<p>Identify, award, and scale an affordable and climate-friendly residential cooling solution</p> <ul style="list-style-type: none"> <li>• Has 5x less climate impact (electricity and refrigerant)</li> <li>• Operates within other predefined constraints on affordability, water, refrigerants (if used), full-load power consumption, scalability and operational requirements</li> </ul>
<p>Approach</p>		<p>A high profile competition supported by a global coalition to spur innovation and catalyze future demand</p> 
<p>Prize</p>	<p>USD3M+</p>	<p>Financial rewards to support prototype development and incentivize participation</p> <ul style="list-style-type: none"> <li>• At least USD2M to finalists for prototype development</li> <li>• At least USD1M to the winning technology</li> </ul>

# Globally scaling of the 5X solution will reduce RAC associated global annual emissions in year 2050 to a level that is manageable



**Key assumptions:**

- RMI analysis assumes an adoption curve for the 5X solution as follows: market adoption starts in 2022 with a 5% share; by year 2030 it gains an 80% share of the annual sales, and by year 2040 it achieves an almost 100% share of the annual sales.
- We assume that building envelope improvements (thermal insulation driven by building codes) have the potential to achieve a 7.5% reduction in cooling demand in 2050 in developed countries. For developing countries, we assume that a 15% reduction in cooling demand can be achieved in 2050 as a significant portion of the building stock is still to be built

# Globally, this may be the single biggest demand side action we can take to mitigate climate change

75+ GT

CO<sub>2</sub>eq emissions avoided through 2050



0.5°C

Global warming mitigation by 2100



## EQUIVALENT IMPACTS

Avoid over 2,000 GW of new generation capacity globally

Avoid up to 5,400 TWh of electricity generation, equivalent to electricity consumption of US, Japan, and Germany today

Make all 28 countries in the European Union carbon neutral tomorrow

Source: CLASP, "AC Challenge Program for India", 2017; LBNL, "Benefits of Leapfrogging to Super efficiency and Low Global Warming Potential Refrigerants in Room Air Conditioning", 2015; "Statistics", IEA (2018)



# Thank You

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