TOO HOT TO STAY AT HOME

Residential heat vulnerability in urban India

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Abstract

- Rising temperatures leading to increased cooling demand
- Mass production of affordable housing in India
- Envelope performance to minimise need for active cooling

Recent climate trends show that India could suffer from **deadly heat waves** within a few decades – bringing portions of the sub-continent close to the threshold of survivability and accelerating the demand for cooling. The share of space cooling in peak electricity load is projected to rise sharply in India. Simultaneously, the country's **population is expected to continue to grow**, peaking by mid-century. Rapid urban development, particularly mass production of affordable housing presents an opportunity to optimize the design of building envelopes. This will minimize the demand for active cooling while keeping the inhabitants safe, even during periods of **prolonged heat stress.**

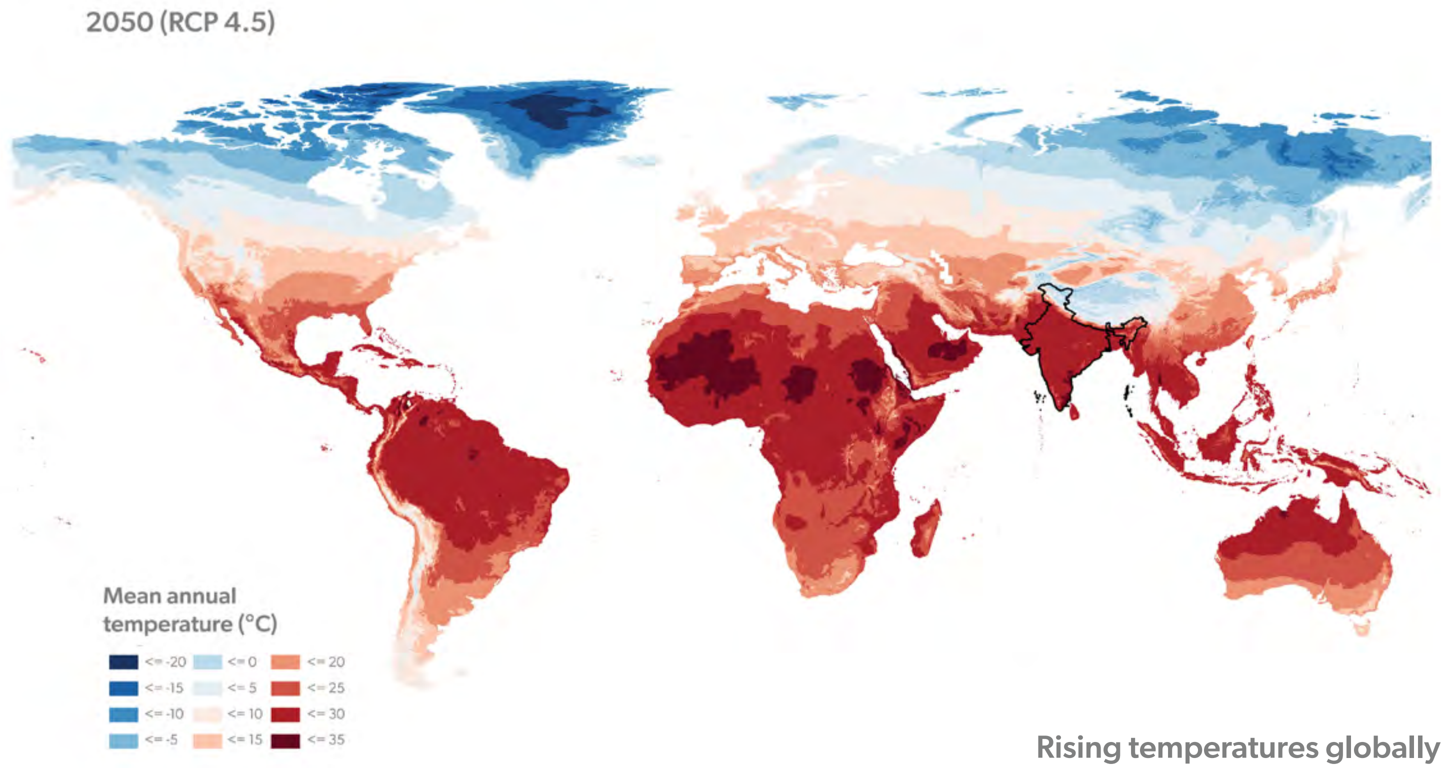
Heat vulnerability is a public health and safety concern. A recently launched building energy code for India - Residential ECBC (Eco-Niwas Samhita 2018) limits the thermal transmittance of the envelope. It aims to improve the thermal comfort in non-air-conditioned apartments while reducing the health-related heat wave impact. However, the code's simplified approach has limitations, for example, requirements do not vary with climate zones within the country. Additionally, it is not adapted to future climate conditions where parts of the country are expected to be too hot in summer for over 74% of the time. This study focuses on indoor occupant comfort and the severity of overheating during summer, in common building assemblies in the hot and dry climate zone. Using common envelope assemblies, the study found that a minimally code compliant building would need air conditioning 90% of the time in summer. With the same layout but improved envelope performance, a highly efficient iteration could reduce this need by a third, providing a big saving potential. In the future though, the energy code needs to evolve to address the rising temperatures. This analysis illustrate the vulnerability of current construction techniques to extreme heat, and aims to **avoid a long-term lock-in of inefficient, high energy consuming residential buildings.**

Key words: thermal comfort, heat vulnerability, passive survivability, envelope performance

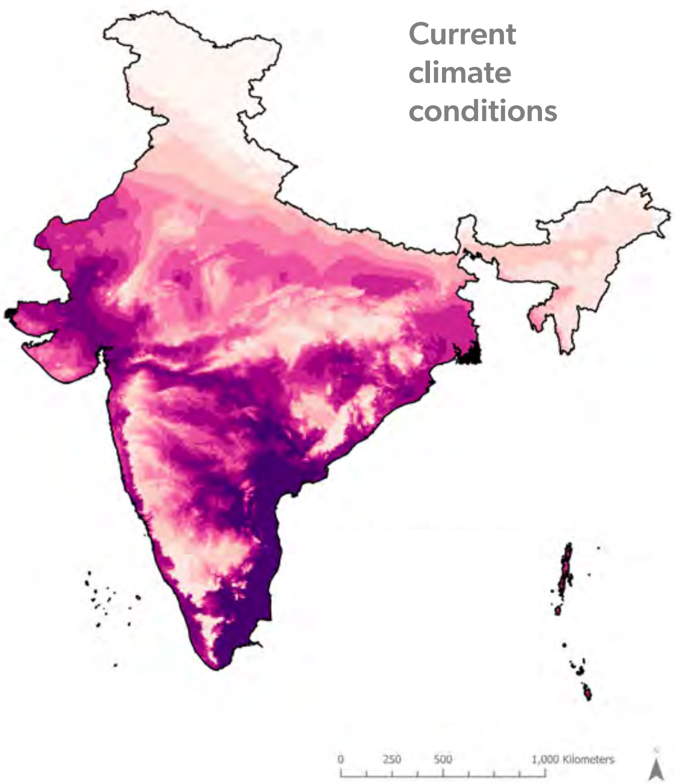
Image source: Charlotte McLaughlin, "How to Improve Sustainable AC Use in India?," Medium (blog), April 30, 2018, https://medium.com/naturalrefrigerants/how-to-improve-sustainable-ac-use-in-india-d0193a8c398a.

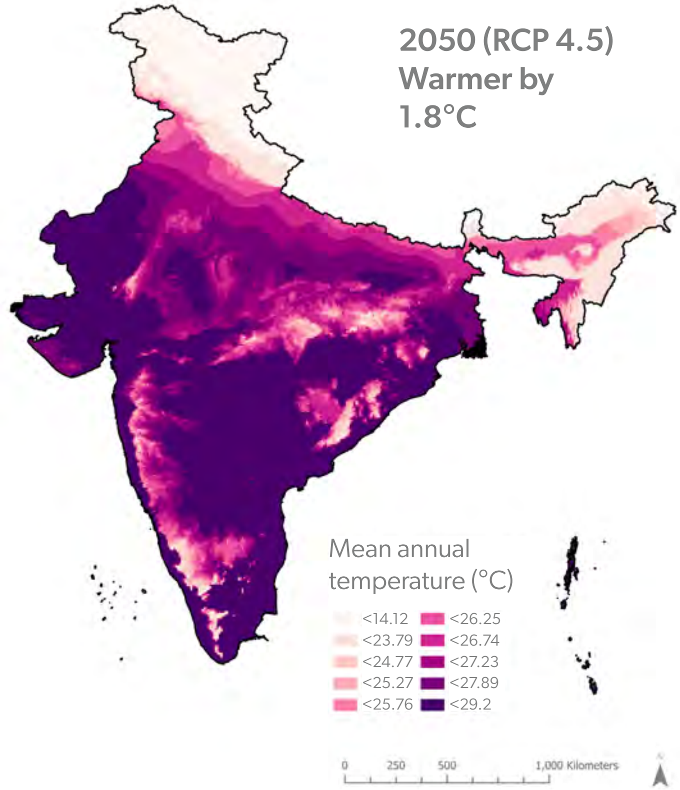
RESEARCH QUESTIONS

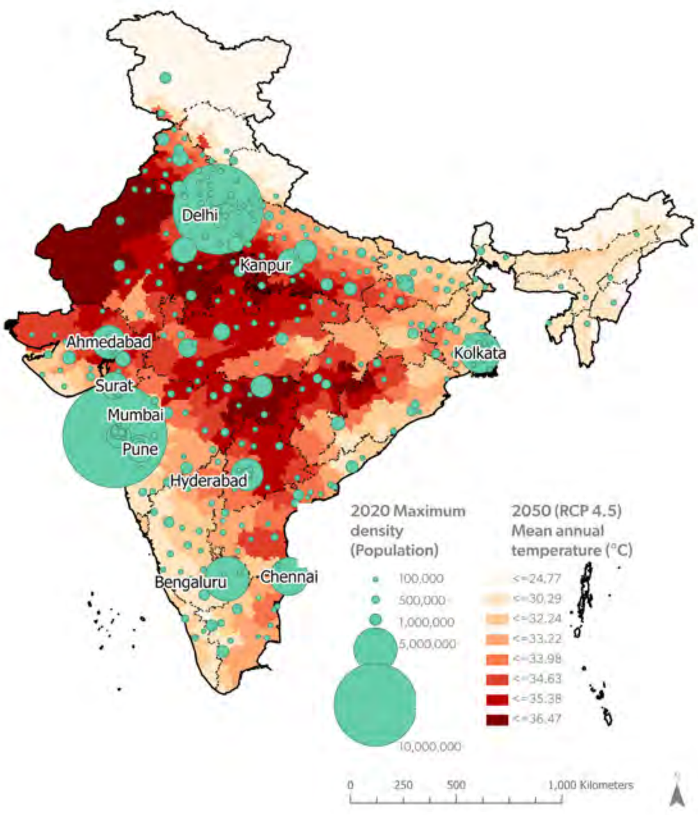
1. How do the current **building envelope design standards** in India reduce heat vulnerability of the rapidly growing urban centers, in the hot-dry climate zone?
2. How can the massive upcoming building stock of **affordable housing (multi story residential buildings)** be adapted to tackle the increase in cooling demand in the near future?



Rising temperatures globally





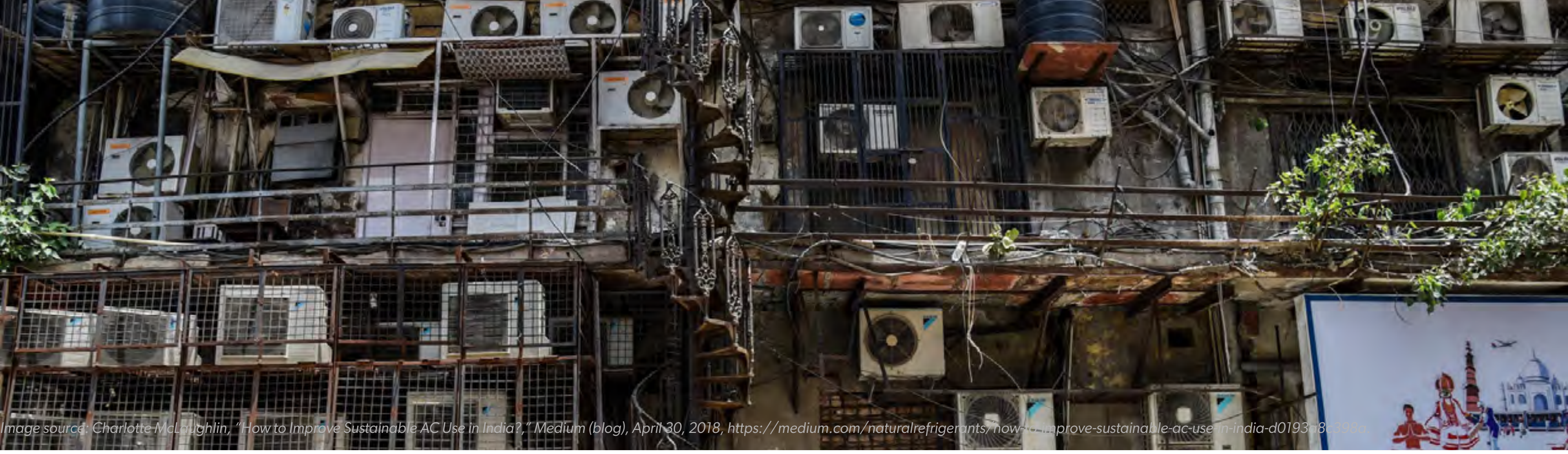


Rising temperatures in India

India follows this global trend while simultaneously, the country's population is expected to continue to grow particularly in urban centers.

A recent analysis of climate trends in several of South Asia's biggest cities found that India, among others, could suffer from deadly heat waves within a few decades, if we continue with business as usual i.e. without a significant reduction in carbon emissions. The most extreme, once-in-25-years heat waves would increase wet-bulb temperatures to about 31°C to 34.2°C, bringing us very close to the threshold of survivability (35°C or 95F).

Thus, large swathes of the population will become vulnerable to extreme heat conditions.



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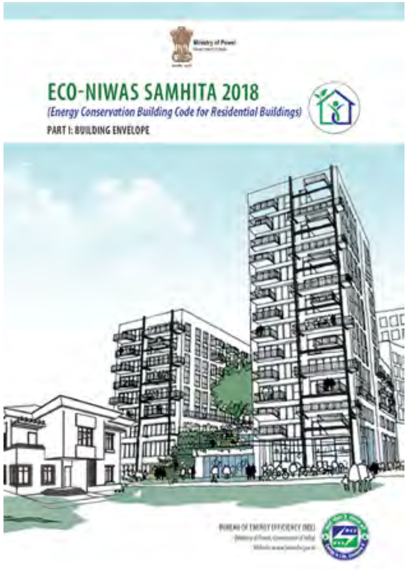
The residential sector is already responsible for 23% of total electricity use in the country

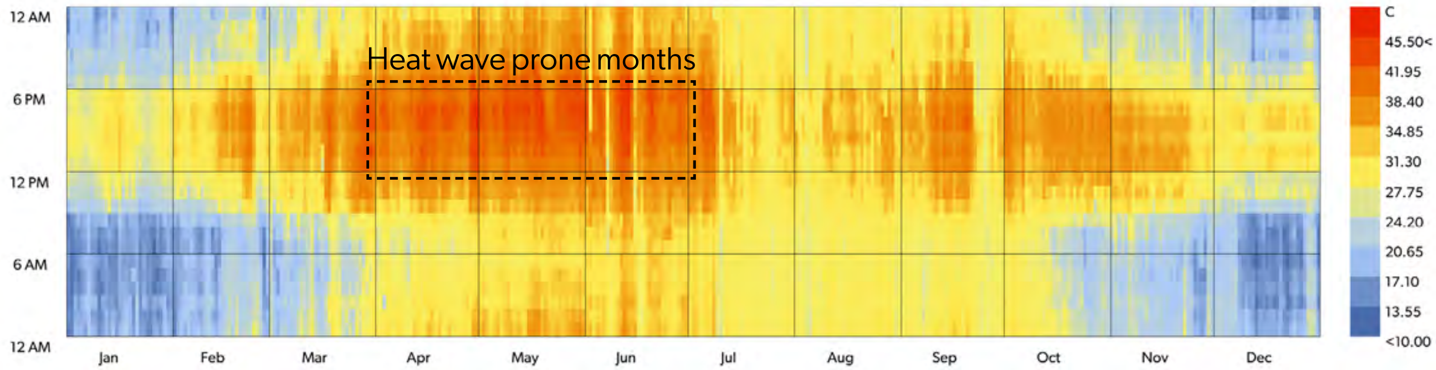
	Electricity demand (TWh)			
Sector	**2012**	**2022**	**2030**	**2047**
Industrial	336	494	703	1,366
Residential	175	480	842	1,840
Commercial	86	142	238	771
Agricultural	136	245	336	501
Others	29	71	121	233
Total	**762**	**1,433**	**2,239**	**4,712**



India's latest voluntary energy code in India is called the **Energy Conservation Building Code (ECBC-R)** (December 2018)

- The improved thermal comfort in non-air-conditioned apartments will reduce the health-related heat wave impact
- The cooling energy demand in air-conditioned apartment will be reduced by 20-40%

	Thermal Transmittance	Maximum
U_{roof}	Transmittance value (u value)	1.2 W/m^{2}K (minimum R 4.7)
RETV	Mean heat gain rate (over the cooling period) through the building envelope divided by the area	15 W/m^2



Current weather - Ahmedabad, Gujarat (hot-dry climate zone)

- This code's simplified approach has limitations, for example, requirements do not vary with climate zones within the country.
- Additionally, it is not adapted to future climate conditions where parts of the country are expected to be too hot in summer for over 74% of the time.

Climate conditions	Comfortable (% of time)	Too hot (% of time)	Too cold (% of time)
Current	47.35	25.89	26.76
Future (RCP 4.5 2026-2045)	44.23	32.92	22.85

COMFORT ANALYSIS

This study focuses on the Hot Dry climate zone, with **Ahmedabad, Gujarat** taken as a representative large urban center likely to experience rapid growth.

Months		Current		Future (RCP 4.5 2026 -2045)	
		Min temp. (°C)	Max temp. (°C)	Min temp. (°C)	Max temp. (°C)
Winter season	Jan, Feb, Nov, Dec	22.22	27.39	23.87	30.78
Mid-seasons	Mar, July to Oct	24.31	31.70	24.69	31.70
Summer season	Apr, May, Jun	25.70	31.70	25.70	31.70

Two climate scenarios analyzed:

- Current climate: TMYx 2004 to 2018
- Future climate: RCP 4.5 (50%) 2026-2045

Maximum comfort range:
25.7 to 31.7°C (78 to 89 F)

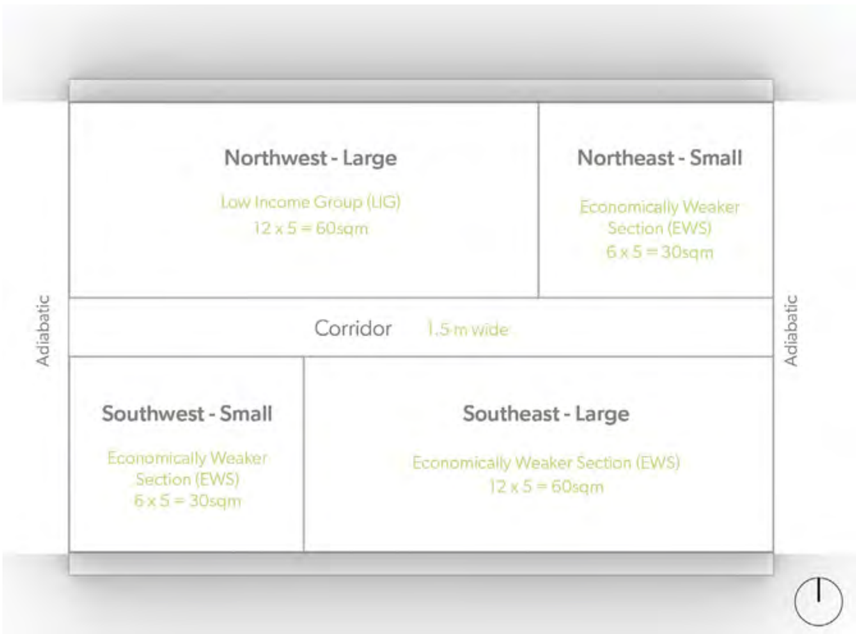
This study focuses on the hottest period of the year, i.e. the months of April, May and June (AMJ) - the period most susceptible to heat waves.

	Worst case		Moderate case		Best case	
Component	Description	U value with air films (W/m^2K)	Description	U value with air films (W/m^2K)	Description	U value with air films (W/m^2K)
Wall	230mm Brick wall with cement plaster	3.39	200mm autoclaved aerated concrete (AAC) blocks with cement plaster	0.88	200mm Porotherm blocks with lime plaster	0.58
Roof	150mm RCC slab with 10mm PUF insulation	1.30	150 mm RCC with 40 mm polyurethane foam (PUF) insulation	0.49	150mm RCC slab with 100mm PUF insulation	0.22
Glass in windows	Clear double glazing SHGC 0.7, VLT 79%	2.66	Double glazing with low e coating SHGC 0.27, VLT 69%	1.36	Triple glazing with low e coating	0.85

95% of the shortage in affordable housing is estimated in the Economically Weaker Sections (EWS) and Low Income Group (LIG) categories.

Dwelling unit sizes:
Low Income Group (LIG)
= Large (60 sqm/645 sq.ft.)

Economically Weaker sections (EWS)
= Small (30 sqm/320 sq.ft.)



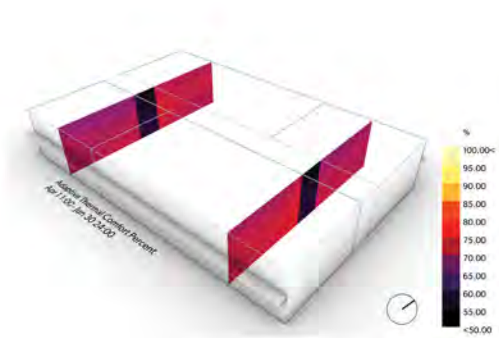
Cases for analysis:
- Current climate - Worst case
- Current climate - Moderate case
- Current climate - Best case
- Future climate - Worst case
- Future climate - Moderate case
- Future climate - Best case

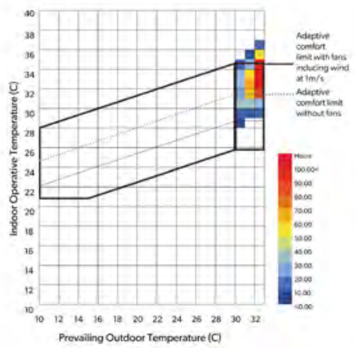
Thermal Transmittance	Maximum allowable	Worst case	Moderate case	Best case
U_{roof} (W/m^2K)	1.2	1.16	0.45	0.21
RETV (W/m^2)	15	14.67	6.35	4.86

Constants:
North and South facades – 30 % window to wall ratio (WWR); Continuous sunshade of 0.6m depth; External windows shades closed and opened as per season; East and West facades - no windows, adiabatic; Occupancy – 24/7; Ceiling fans at 1m/s

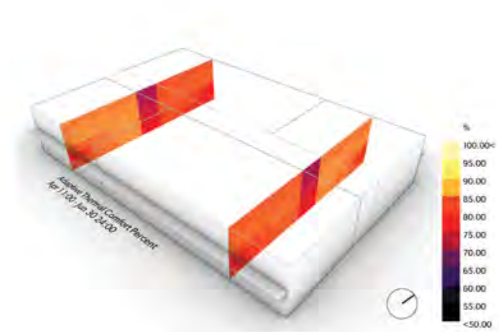
Image source: Climate Signals, "Climate Signals | India Heat Waves 2019," Climate Signals, June 19, 2019, https://www.climatesignals.org/events/india-heat-waves-2019.

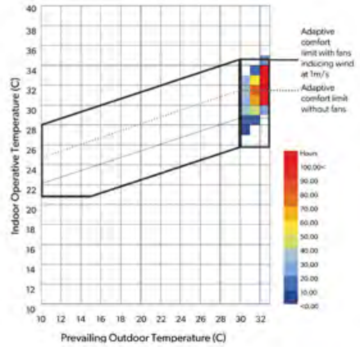
Worst case (minimally code compliant)



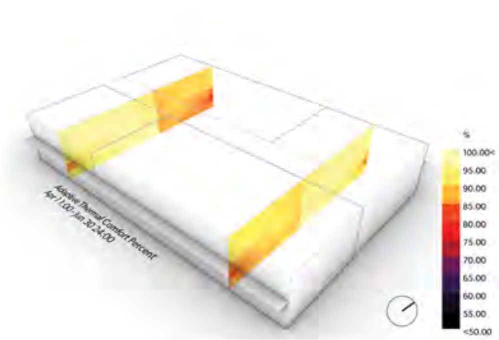


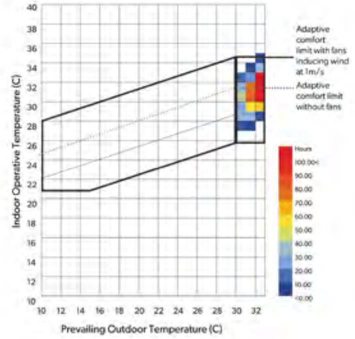
Moderate case





Best case (highly efficient version)





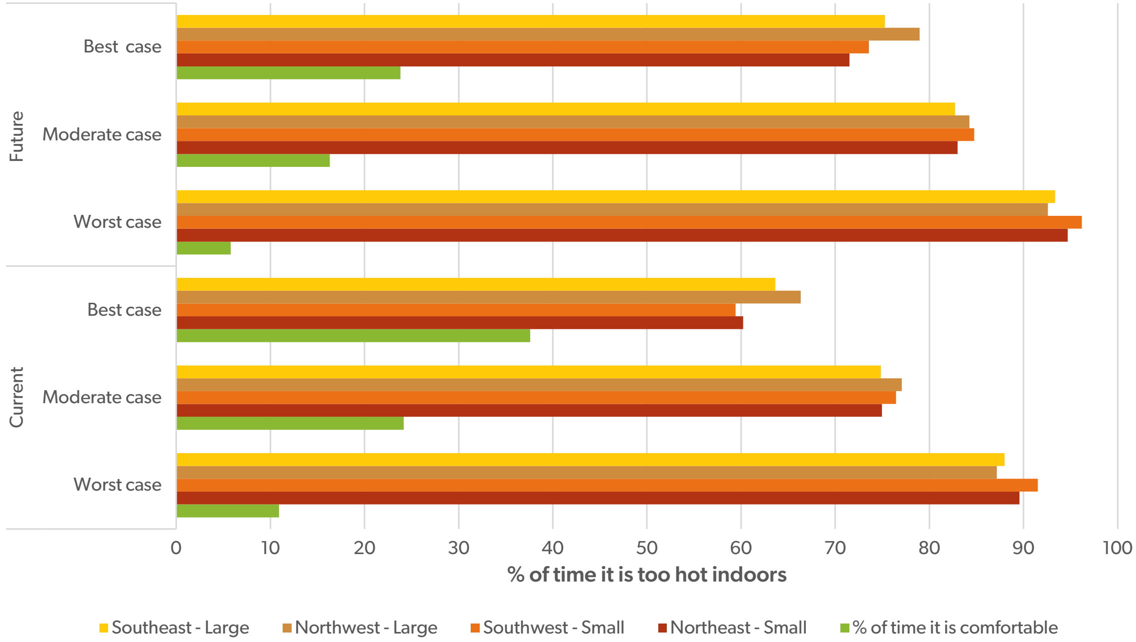
Adaptive comfort - Current climate

Adaptive thermal comfort standards suggest that humans are not inert, instead we can adapt to—and even prefer—a wider range of thermal conditions than is generally considered comfortable; particularly in free running or naturally ventilated buildings.

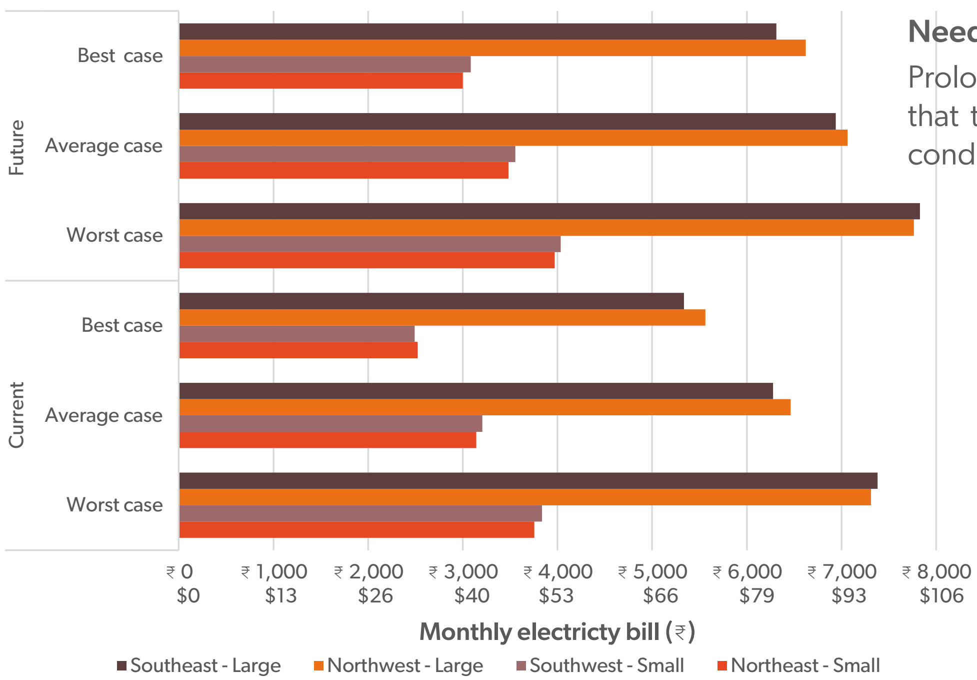
Climate conditions	Current (TMYx 2004 – 2018)		
Dwelling Unit	Worst case	Moderate case	Best case
	% of time comfortable		
	11	24	38
	% of time too hot		
Northeast - Small	90	75	60
Southwest - Small	92	76	59
Northwest - Large	87	77	66
Southeast - Large	88	75	64

Climate conditions	Future (RCP 4.5 2026 – 2045)		
Dwelling Unit	Worst case	Moderate case	Best case
	% of time comfortable		
	6	16	24
	% of time too hot		
Northeast - Small	95	83	72
Southwest - Small	96	85	74
Northwest - Large	93	84	79
Southeast - Large	93	83	75

Under current climate conditions, a minimally code compliant building is **uncomfortably hot ~90% of the time.**



Under current climate conditions – the **best case** needs air conditioning for almost 24 days **(1/3 of summertime)** fewer than the worst case, resulting in a potential **cost saving of 40%** (on average).



Need for air conditioning

Prolonged periods of discomfort mean that the occupants will need to use air conditioning.

Even if only 50% of the volume is cooled with a highly efficient split AC unit, based on typical income levels, the electricity expense could come close to **15% of the monthly income** for both groups.

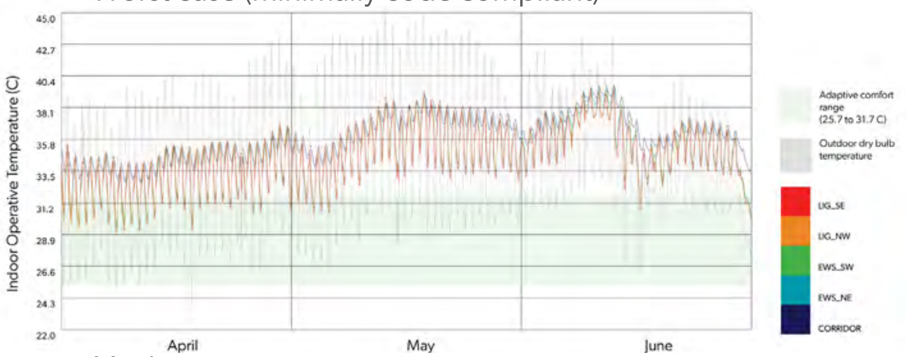
**Monthly income for the Economically Weaker Section (EWS) is up to ₹25,000 (USD 330)*

**Monthly income for the Lower Income Group (LIG) is between ₹25,000 to ₹50,000 (USD 330 TO 660)*

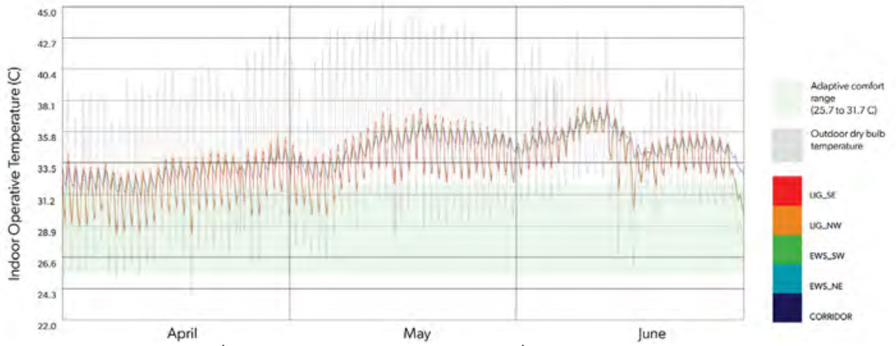
** The average cost of electricity is ₹4/unit (5.3 cents/kWh)*

Image source: "India Heatwave Temperatures Pass 50 Celsius," June 2, 2019. https://phys.org/news/2019-06-india-heatwave-temperatures-celsius.html.

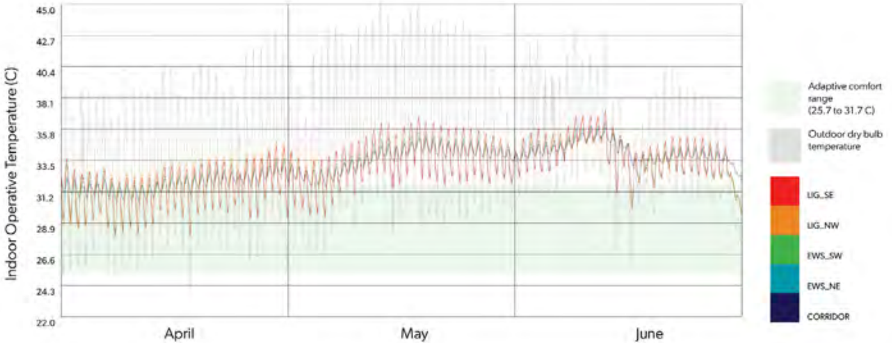
Worst case (minimally code compliant)



Moderate case



Best case (highly efficient version)

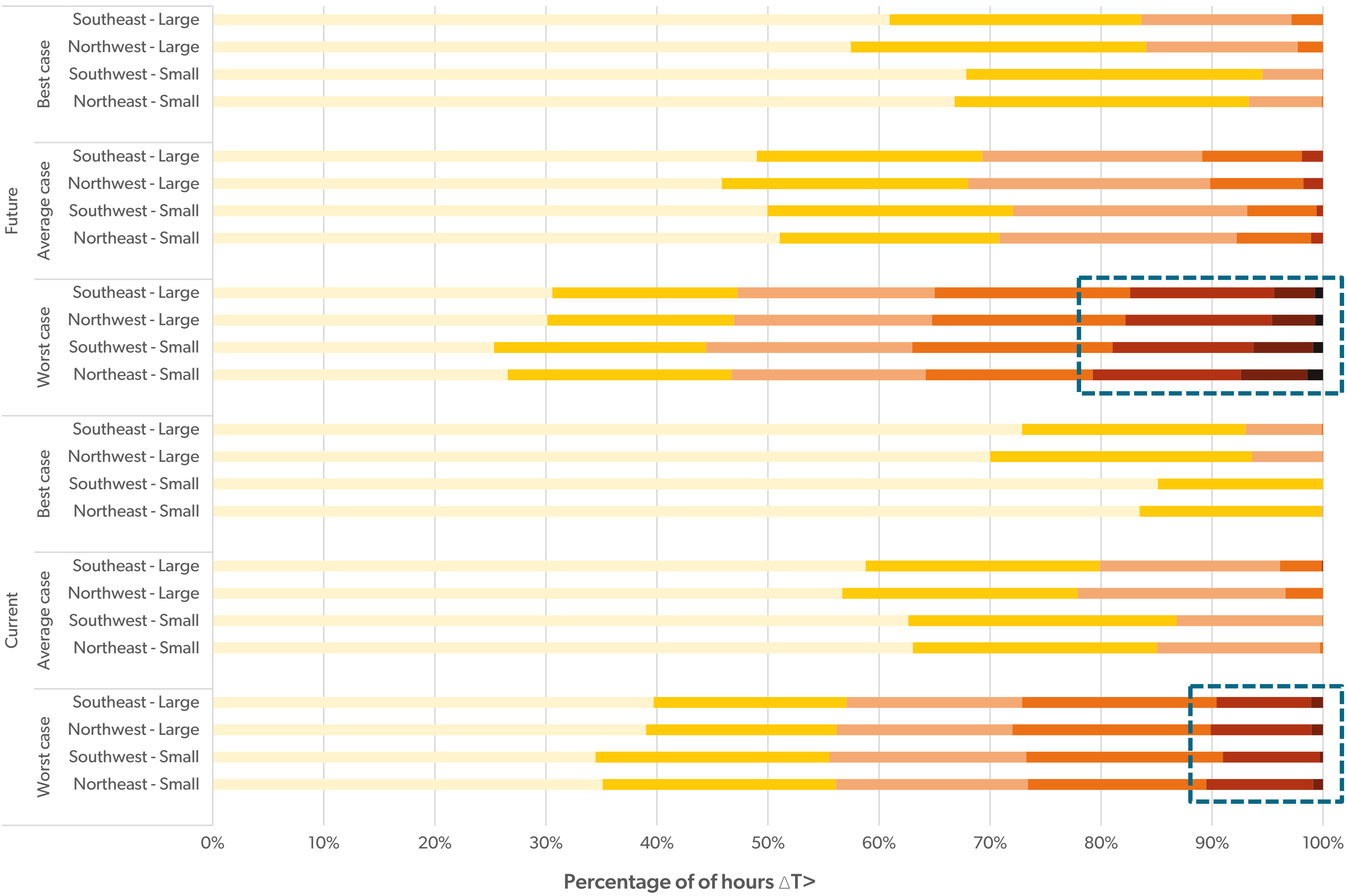


Hours of exceedance - Future climate

A measure of the number of hours for which the indoor operative temperature exceeds the threshold comfort temperature.

Under current climate conditions, the indoor operative temperature exceeds the comfort range almost all the time during the day and at night in the months of May and June.

In the future too, not only are the daytime temperatures higher, even the **nights are much warmer** than the current conditions.



Severity of exceedance

In the future, maximum exceedance jumps to 5°C (9 F) with even a few times **exceeding by 6°C (10.8 F)** (worst case or minimally code compliant version).

Weighted exceedance - Future climate

Deals with the severity of overheating within any one day. This study considers a typical cooling design day, i.e. June 21st.

Between 12-9am outdoor temperatures fall within the comfort zone. However, **indoor temperatures remain uncomfortably high even at night**.

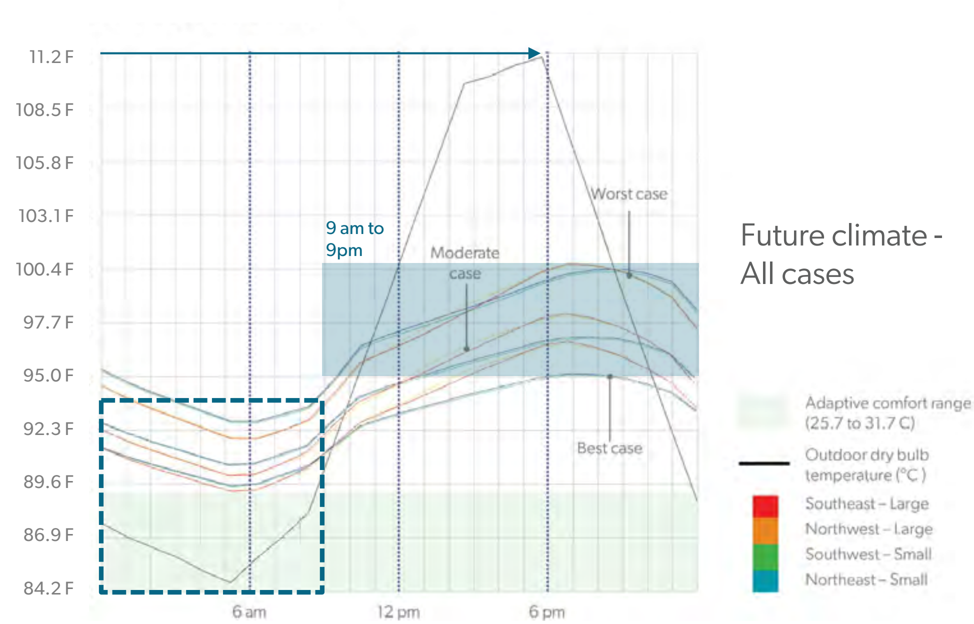


Image Source: [illegible] McKenna, "Fast-Rising Demand for Air Conditioning Is Adding to Global Warming. The Numbers Are Striking." [illegible] Climate News (blog), [illegible]ber 12, 2018, https://insideclimatenews.org/ne[illegible]air-conditioning-half-degree-global-warming-by-2100.

EXISTING BUILDING STOCK
Code compliant + Current weather

Uncomfortable 90% of the time in summer (current)
Extreme discomfort + very high energy generation footprint

Existing code might be too weak to provide more comfortable and energy-efficient performance for this climate zone.

Not only does the envelope heat up during the peak day time hours, it also retains the heat even when the outdoor temperatures dip after midnight. Extreme heat at night can disrupt sleep patterns and have negative impact on the occupants' health. Furthermore, the severity and frequency of exposure to higher temperatures is not clearly addressed. Also, it also does not account for the effectiveness of cross ventilation.

VOLUNTARY ENERGY CODE
Highly efficient + Current weather

Uncomfortable 62% of the time in summer (current)
Reduced cooling bill + close to 30% reduction in energy generation footprint

Potential for significant improvement from a minimally code compliant to highly efficient design alternative

Addition of more insulation on the roof and thermally efficient blocks in the walls can make the same design comfortable for at least a third of the time more. Although these changes may come at a higher cost, when compared to the projected requirement for air conditioning it could still translate into much larger direct and indirect, cost and energy savings.

STRICTER FUTURE CODE
Highly efficient + Future weather

Uncomfortable 76% of the time in summer (future)
Potential to rethink avoidable cooling bill + energy generation footprint

Need for much stricter, mandatory energy code that is revised every few years to address changing climate

Rising temperatures in the future mean that the same envelope assembly will need air conditioning for longer periods. Thus, in the future, a much stricter, mandatory code is required which is revised every few years. Buildings have a longer life span and by using inefficient building codes we run the risk of maladaptation.