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Too Hot to Stay at Home: Residential Heat Vulnerability in Urban India

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Abstract. Rising temperatures may lead to deadly heat waves in India. Combined with a growing urban population and mass production of affordable housing, this can sharply accelerate the demand for space cooling. India's voluntary Energy Conservation Building Code - Residential (ECBC-R) or Eco Niwas Samhita 2018 limits thermal transmittance of the envelope. This research considers and critiques this approach through building simulation and an analysis of indoor comfort and severity of overheating during the summer months (April-May-June), in hot-dry and warm-humid climate zones. Code requirements neither vary with climate zones, nor is it adapted to future climate conditions. Our building simulations and analysis show that soon (2030s) parts of the country are likely to suffer from overheating 74% of time in summer. A minimally code compliant building would need air conditioning 90% of summer while a highly efficient iteration could reduce this by a third, in the hot-dry climate zone. Further, commonly used envelope assemblies are uncomfortably hot 77% (in the hot-dry zone) and 23% (in the hot-humid zone) of time in summer, on average. This analysis illustrates 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.

1. Introduction

Temperature surges due to global warming severely affect the most vulnerable populations, making access to comfort cooling critical to surviving heatwaves. However, the direct and indirect emissions from entry-level room air conditioners (RACs) alone could contribute to as much as a 0.5°C increase by 2100 [1]. The projected climate for India, in the year 2050, follows the global trends of rising temperatures. Simultaneously, the country's population is expected to continue to grow, peaking by mid-century, particularly in urban centers. A recent analysis of climate trends found that by the end of this century, climate change could lead to summer heat waves with levels of heat and humidity that exceed what humans can survive without protection [2]. The average temperature over India is projected to rise by approximately 4.4°C, relative to the recent past (1976–2005 average) [3].

1.1. Residential cooling demand in India

Driven by economic and population growth, space cooling is the leading driver of new electricity demand in residential buildings [4]. India's affordable housing policy - *Pradhan Mantri Awas Yojana* (Urban) (PMAY-U) aims to provide Housing for All (HFA) [5] by year 2022. This vital goal will accelerate demand for cooling. The built-up area is projected to increase five times by 2030, dominated by residential use [6]. Therefore, the housing sector can be instrumental in shaping the



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building stock's climate resilience, particularly against the effects of heat stress. India's Cooling Action Plan (ICAP) outlines the goal of thermal comfort for all through the adoption of adaptive comfort standards [7]. While the household ownership of ACs in India was a mere 7% in 2019, the demand for comfort cooling is expected to drive the total stock of room ACs to over 1 billion by 2050 – a 40-fold growth from 2016 [8]. Thermally efficient buildings can improve comfort and effectively reduce the requirement for space cooling, overcoming the limitations of access to electricity and cooling technologies in the affordable sector. Large scale construction presents a valuable opportunity for the building industry to emphasize energy efficiency and resource optimization, through policy frameworks like mandatory building standards.

1.2. Current policy framework

India's national energy code, Energy Conservation Building Code Residential (ECBC-R) or *Eco Niwas Samhita* 2018, is voluntary. It currently quantifies thermal transmittance of the envelope in two parts - the roof and the rest (opaque and non-opaque). A Residential Envelope heat Transmittance Value (RETV) is defined as the net (mean) heat gain rate (over the cooling period) through the building envelope (excluding roof) of the dwelling units divided by the area of the building envelope [9]. The code does not address thermal comfort directly. Further, it does not set different envelope requirements for different climate zones, which is an unusual approach among international building codes. The need for air conditioning is a direct outcome of envelope material choices. Focus is needed on the long-term impact and future performance of the code-compliant buildings designed today.

2. Method

The goal is to determine how current building envelopes protect inhabitants from extreme heat conditions. This study focuses on the two climate zones that have the highest vulnerability to rising temperatures, with one city chosen as a representative large urban center in each: Hot-Dry climate zone – Ahmedabad, Gujarat, and Warm-Humid climate zone – Kolkata, West Bengal. One representative floor of a typical multi story residential tower is studied. Dwelling units are laid out on either side of a linear double-loaded corridor on the top floor (most susceptible) of a north-south facing building [10,11]. The building envelope is modified in various scenarios to investigate the impact on indoor occupant comfort and subsequent need for air conditioning. Two climate scenarios are considered in this study: Current – Typical Meteorological Year (TMYx) 2004-2018 and Future - Representative Concentration Pathway (RCP) 4.5 (50th percentile) 2026-2045.

2.1. Comfort Analysis

In the Indian context, there is little consensus on an optimum comfort range for different climate zones [12]. Therefore, this study defines its own adaptive thermal comfort range, based on the prevailing outdoor temperature computed from a weighted running mean of the last week. The acceptable comfort range roughly corresponds to a 90% acceptance (as defined in ASHRAE 55 2013) and accommodates a variation of $\pm 3^{\circ}\text{C}$, described as “comfort class 2” in the European standards for indoor comfort for free running buildings. The comfort range computed in this manner aligns closely with the acceptable adaptive thermal comfort (ATC) set-points, identified in an extensive literature review [12]. This study focuses on the hottest period of the year, i.e., the months of April, May, and June (AMJ) - most susceptible to heat waves. The comfort range for this season is determined to be 25.7 to 31.7 $^{\circ}\text{C}$, as the maximum possible value in both current and future climate scenarios.

2.2. Exceedance Hours

It is insufficient to consider whether the indoor operative temperature exceeds the target comfort range. The severity and frequency of this exceedance is crucial in understanding the real impact of the discomfort and health risk posed on occupants. Therefore, this study uses the criteria for overheating as defined in CIBSE TM52 [13] and CIBSE TM59 [14], for buildings in free-running mode. Hours of exceedance (He) is a measure of number of hours for which the indoor operative temperature exceeds

the threshold comfort temperature during a typical cooling season, as a percentage of the total occupied hours. Daily weighted exceedance (We) deals with the severity of overheating within a typical cooling design day. This can be as important as its frequency; a function of both temperature rise and duration.

2.3. Base Case

A large part of the current housing shortage is seen in affordable housing. Thus, the layout includes two dwelling units targeted towards the low-income group (LIG), with a “carpet area”, or net usable floor area, of 60sqm. The other two units are intended for the economically weaker section (EWS), with a carpet area of 30sqm [15] (figure 2). Unit sizes and income groups are determined by the PMAY-U scheme guidelines [16]. The north-south facades have a continuous sunshade of 0.6m depth and a window to wall ratio (WWR) of 30%. Operable outdoor shutters are installed over the windows. In summer, they are closed during the day when outdoor temperatures are high (9am to 9pm) and open at night to allow purging. The east-west facades have no windows and are modelled to be adiabatic, assuming there will be additional apartments on either side. Since the number of people in each unit is typically high, they are always occupied. Ceiling fans are used to induce a wind speed of 1m/s.

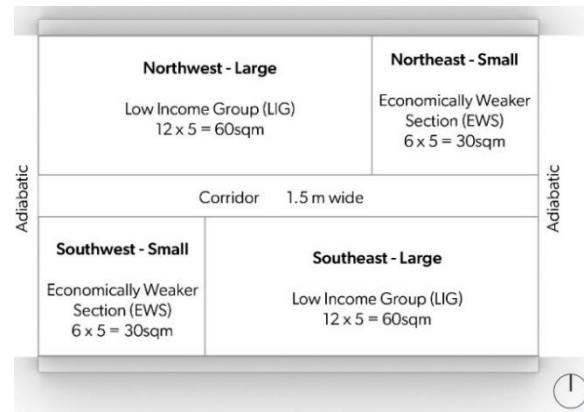


Figure 1. Representative layout (partial plan).

2.4. Construction assembly and materials

The study is divided into two parts, the first considers common examples, across a spectrum of thermal performance (table 1), typically seen in high rise residential development. The second part analyses commonly used wall assemblies [15] (table 2), in combination with a moderate performance roof and windows. All other factors about the design and construction remain constant.

Table 1. Cases of analysis in Part 1.

Metrics	Maximum allowable	Worst case	Moderate case	Best case
U_{roof} (W/m ² K)	1.2	1.16	0.45	0.21
RET _V (W/m ²)	15	14.67	6.35	4.86

Table 2. Walls - thermal properties.

Case	Name	U value (W/m ² K)	RET _V (Hot-dry)	RET _V (Hot-humid)
1	Compressed stabilized earth blocks (CSEB)	2.48	16.18	13.84
2	Fly-ash blocks (150 mm thick)	2.45	16.04	13.72
3	230mm Brick wall with cement plaster	2.15	14.31	12.25
4	200mm AAC blocks with cement plaster	0.76	6.35	5.49
5	200mm Porotherm blocks with lime plaster	0.53	5.00	4.34
6	Emmedue (Rapid panels)	0.45	4.59	3.99
7	Insulating concrete form	0.32	3.81	3.33

Table 3. Roofs and windows - thermal properties.

Roofs	U_{roof} (W/m ² K)	Windows	U value (W/m ² K)	SHGC	VLT
Worst case: 150mm RCC slab with 10mm polyurethan foam (PUF) insulation	1.16	Worst case: Clear double glazing	2.66	0.7	0.79
Moderate case (all cases in Part 2): 150mm RCC slab with 40mm PUF insulation	0.46	Moderate case (all cases in Part 2): Double glazing with low e coating	1.36	0.27	0.69
Best case: 150mm RCC slab with 100mm PUF insulation	0.21	Best case: Triple glazing with low e coating	0.85	0.26	0.45

2.5. Indoor comfort

Using adaptive comfort standards, spaces are analyzed for indoor comfort. This study simulates natural ventilation in Energy Plus's airflow network. In future work, one could couple the simulation with computational fluid dynamics (CFD) to get a more accurate natural cooling potential.

3. Results

A total of 40 cases were studied in both climate zones - part 1 (12 cases), part 2 (28 cases).

3.1. Indoor Comfort Analysis

Plotted as prevailing indoor operative temperature and the adaptive comfort chart. In all cases, solar radiation is the largest source of heat gain, while natural ventilation of heat loss. Under the current climate scenario, 89% of the time a minimally code compliant case (worst case) is too hot without active cooling. The adaptive comfort chart shows that large time periods exceed the upper limit of the comfort range i.e., 31.7°C (figure 2). In the future, the same assembly is uncomfortably hot 94% of the time. In comparison, the best case scenario is uncomfortable 62% of the time, in current climate and 75% of time in the future. In the warm-humid climate zone, the same minimally code compliant layout is uncomfortably hot 43% of the time (current) and 54% of time (future). This large discrepancy between the two climate zones is important to note, particularly since the energy code (ECBC-R) is the same across all climate zones in the country.

The analysis in part 2 yielded similar results across all cases, despite a wide range of resultant RETV. All the cases were uncomfortably hot 77% of the time (on average) in the current climate, and 84% of the time (on average) in the future scenario. This implies that none of the current materials respond well to this climate, making active cooling a necessity, albeit an unaffordable one, as described below. In the warm-humid climate zone, all cases are too hot for comfort 23% of the time (on average) in the current climate and 28% of the time in the future. Again, a difference of almost 54% (current climate) is seen between the two climate zones. It suggests that despite following climate zone specific construction material and design guidelines, the same assembly behaves differently.

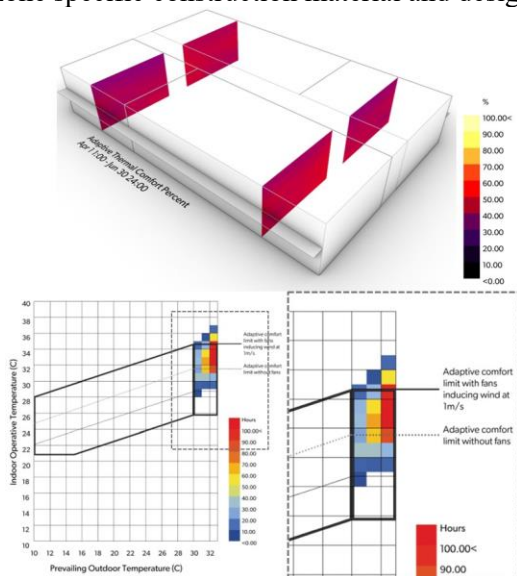


Figure 2. Worst case, current climate.

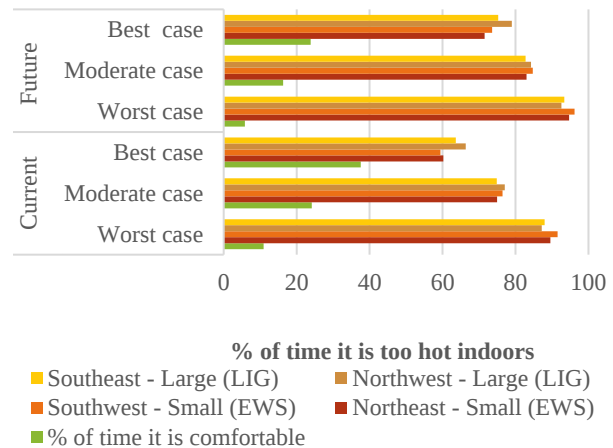


Figure 3. Comparison of indoor comfort.

3.1.1. Need for air conditioning

Using the hours of discomfort, the approximate cost for air conditioning is calculated. In both unit sizes, it is assumed that 50% of the volume would be air conditioned with a 1.5 ton highly energy efficient (4.73 ISEER value; BEE 5-star rating) split AC unit. The approximate resultant monthly

electricity expense in the city of Ahmedabad [17] can be seen in figure 4. Under current conditions, the best case needs air conditioning for almost 24 days (average) fewer than the worst case i.e., almost a third of the three-month summer season. Resulting in a potential cost saving of ₹1,000 (49%) and ₹2,000 (38%) in the EWS and LIG units, respectively. It should be noted that the monthly income for the EWS is up to ₹25,000 (USD 340) and that for the LIG is ₹25,000 to ₹50,000 (USD 340 to 680). Thus, in the worst case under current climate conditions, residents would need to spend 15% of their monthly income on air conditioning, a huge burden on an economically challenged group. This expense is only expected to increase in the future scenario.

3.2. Exceedance hours

3.2.1. Hours of exceedance (H_e)

Over the summer months, the daily indoor operative temperature seldom falls within the comfort range, most often it is much higher. In the hot-dry zone, worst case, only nights are comfortable in April while May-June have daytime temperatures between 35 to 38°C (current climate). While the best case is comfortable in April with slightly lower temperatures in May-June. In part 2, nighttime temperatures fall within the comfort range only in April, ranging from 32 to 36°C in May-June. Thus, the unit does not cool down even at night when outdoor temperatures fall within the comfort range (figure 5). This situation is expected to get exacerbated with higher outdoor temperatures in the future.

In the hot-dry climate zone, the indoor operative temperature exceeds comfort conditions 70% of the time, with a maximum exceedance of up to 6°C in the minimally code-compliant case (worst case) in the future. Part 2 cases exceed by 1 to 2°C, 40% of the time. In the warm-humid climate zone, the worst case exceeds comfort conditions by 1 to 2°C, 30% of the time, while the best case for under 4%. Part 2 cases are all comfortable with a 1°C exceedance, 10% of the time.

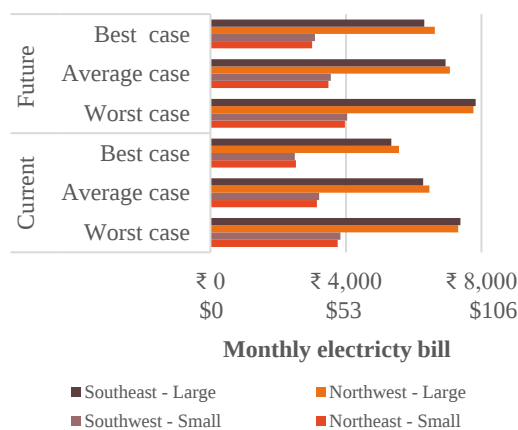


Figure 4. Estimated monthly electricity bill.

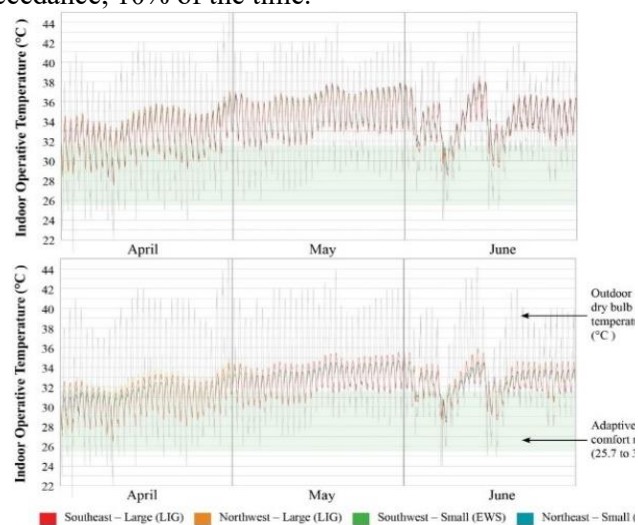


Figure 5. Exceedance of indoor operative temperature from the adaptive comfort range (°C).

3.2.2. Daily weighted exceedance (W_e)

On a typical cooling day (June 21st) the indoor operative temperature by far exceeds the comfort range in all cases (part 1 and 2) in the hot-dry climate zone (figure 6). This implies that thermal mass is playing an integral role in transferring solar heat gain to the interiors. Even though nighttime outdoor temperatures fall within the comfort range, indoor temperatures remain much higher. In the warm-humid climate, the same assemblies are much more comfortable. This can be attributed to the low diurnal variation in the outdoor dry-bulb temperature. Part 2 cases exceed at all times of the day in current and future conditions, in the hot-dry climate zone.

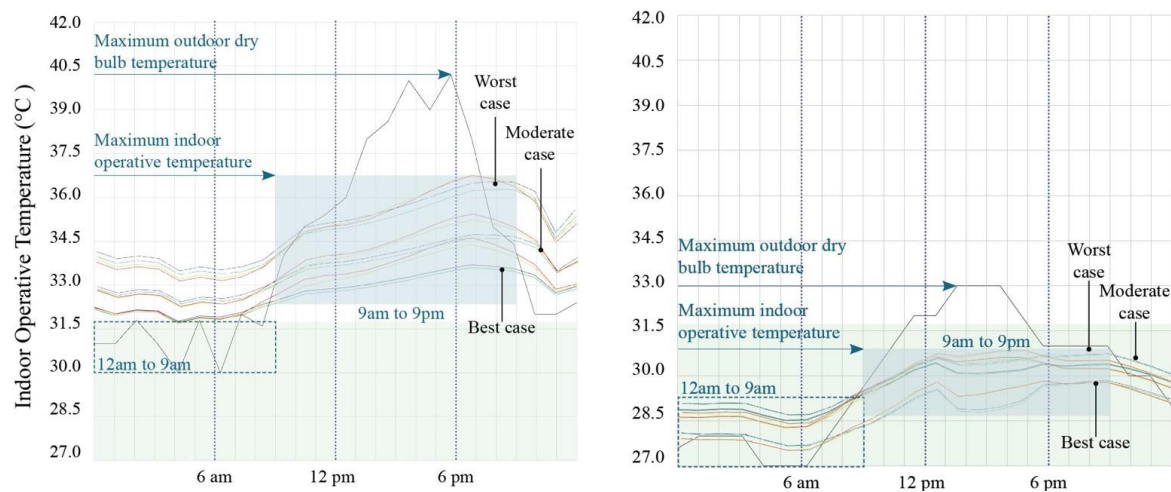


Figure 6. Exceedance on a cooling design day, in hot-dry (left) and warm-humid climate (right).

4. Discussion

A common rule of thumb is that the indoors should be at least as comfortable as the outdoors, if not more. However, a poorly designed building envelope can amplify the effect of discomfort. We have seen that with existing building practices, not only does the envelope heat up during the peak day time hours, but it also retains heat even when outdoor temperatures dip after midnight. Extreme heat at night can disrupt sleep patterns and have a negative impact on the occupants' health.

4.1. Limited role of RETV

Through a simple indoor comfort analysis, it was seen that a minimally code-compliant envelope creates uncomfortable conditions for almost 90% of the summer months while a higher performing one can be comfortable for a third of the time – a difference of 26%, in the hot dry climate zone. At the same time, all the commonly used wall assemblies provide poor thermal comfort, despite their thermal transmittance (U values). This implies that maybe RETV is not the only metric to be considered for evaluating thermal performance. The code should include a way to consider impact on comfort during the day (peak) and nighttime.

4.2. Climate zone specific

Moreover, the same assemblies behave very differently in different climate zones. Thus, the energy code should be climate zone specific and account for readily available (i.e., affordable) construction materials. In the warm-humid zone, nighttime indoor operative temperature has a big difference between current and future climate scenarios. Therefore, the often-overlooked impacts of overheating on sleep patterns are likely to be more pronounced in the future. In the hot-dry climate zone, an almost identical thermal performance by the different wall assemblies suggests that the roof assembly is a more dominant factor. RETV should be calculated separately for units that are directly exposed to the sun (i.e., top floor) and those that are not.

4.3. Severity of overheating

The severity and frequency of exposure to higher temperatures is not clearly addressed in the current form of the energy code. Not only does the indoor temperature exceed the comfort range for prolonged periods of time, but it also exceeds by several degrees, in the hot-dry climate zone. In the minimally code compliant design (worst case), under current climate conditions, a maximum exceedance of up to 4°C is observed, however, in the future this rises up 5 to 6°C. In terms of our ability to adapt, it is more harmful to be exposed to a higher temperature differential for prolonged periods. Thus, it is important for the code to set a maximum limit of exceedance within a typical summer day, as a factor

of the time and duration. Admittedly, this study's approach has some shortcomings, namely, that other variables of comfort, such as humidity and wind speed are not fully explored. The current code does not explicitly capture the potential of cross ventilation. It only sets a minimum requirement for the openable portion of the envelope, but the design and location of openings are not considered.

4.4. Cost implications

A recent study observed that the incremental cost for complying with the requirements of the ECBC-R entails only a small (+1.2%) increase in the construction cost. After 2030 the code is projected to become more stringent (RETV 8 W/m², U_{roof} 0.5 W/m²K), in a deep emission cut scenario. Only then is the construction cost projected to be significantly higher (+9.2%), at current prices [18]. While thermally efficient construction techniques may come at a higher cost, when compared to the projected requirement for air conditioning it is likely to translate into much larger direct and indirect, cost and health savings. It would be extremely difficult for the occupants of affordable housing units to spend 15% of their monthly income only on air conditioning for one season (hot-dry climate zone). Providing thermally inefficient housing could expose inhabitants to extreme heat wave conditions if they cannot ensure active cooling mechanisms.

4.5. Long term lock-in

Residential multi-story buildings have a typical lifespan of 30 to 50 years. Within the next two decades, summertime temperatures are expected to rise for sustained periods of time. As a result, the same envelope assembly that is minimally code compliant today, gets much more uncomfortable in the future, 94% of the time in the hot dry climate zone and 54% in the warm-humid zone. Thus, the need for air conditioning will rise steadily. Not only does this impact the livability of the dwelling units, but it also has a sustained negative impact on human health.

5. Conclusion

There is a greater need to understand the impacts of policy decisions and climate trends in the Indian context. Heat vulnerability is a major concern in housing projects, particularly for those that cannot afford active cooling mechanisms. Higher performing envelope assemblies have the potential to not only reduce the extent of discomfort but also lead to a direct savings in the electricity demand for air conditioning. In the hot-dry climate, upgrading the envelope construction can reduce the need for air conditioning by up to 24 days (in the current climate) – a significant portion in a three-month summer season. Through the analysis of different envelope assemblies, this study illustrates that buildings designed as per the current ECBC-R guidelines will severely overheat and require active cooling mechanisms to be used extensively. It is expensive to run air conditioning for extended periods and the added costs of purchase, installation and maintenance make it further out of reach. Further, this study indicates that current building practices are not suitable for future climate scenarios with respect to health and thermal comfort. Using inefficient building codes can result in a long-term lock in of an underperforming housing stock of massive scale.

Acknowledgements

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