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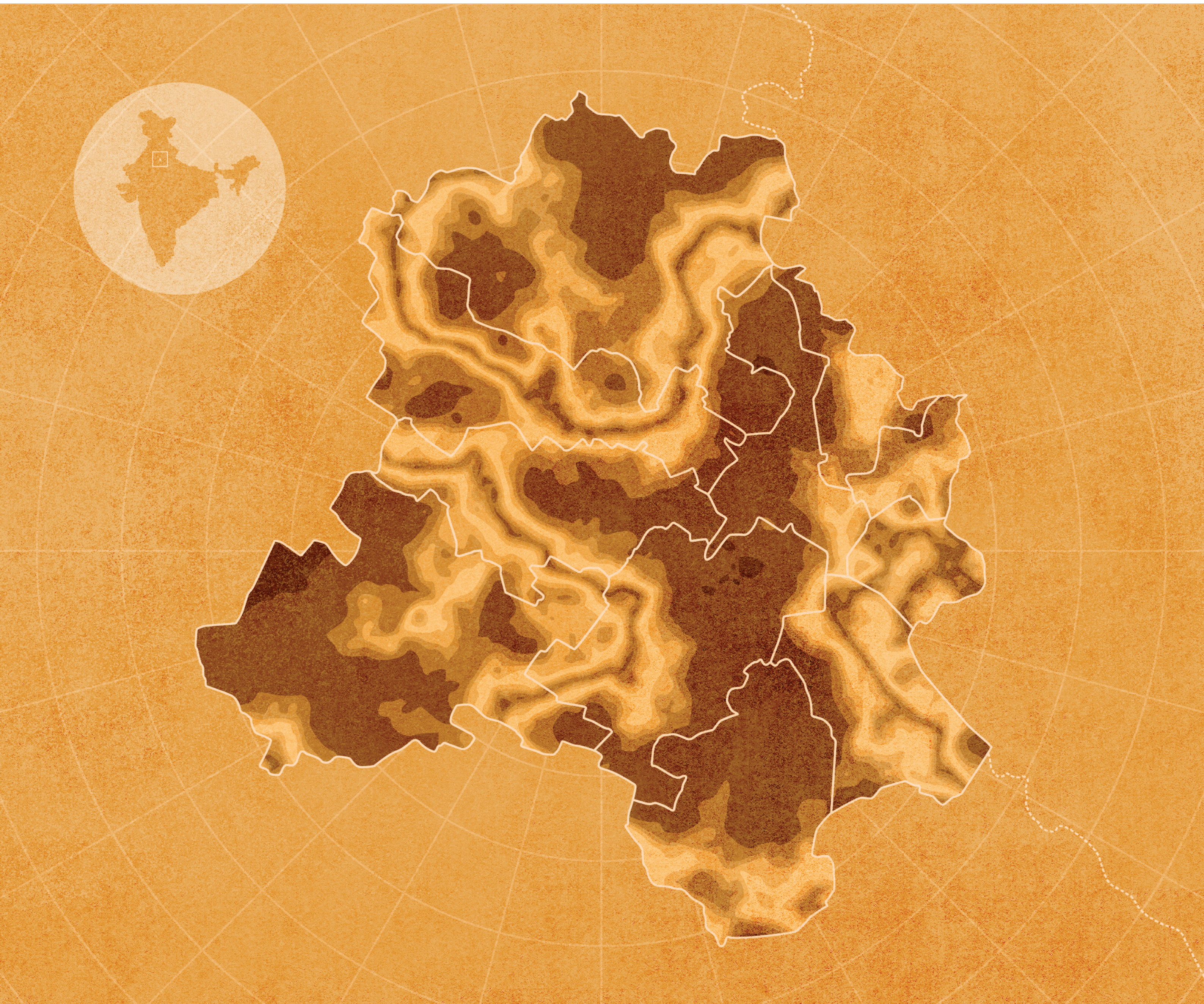
WHITE PAPER

Mapping Heat Inequality Across Neighbourhoods in Delhi

Integrating Geospatial and Citizen Data for Climate Resilience



Credits

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ABOUT

Artha Global

Artha Global is a globally networked policy consulting organisation that partners with governments, multilateral agencies, philanthropies, and the private sector to address systemic challenges that hinder people’s aspirations for shared prosperity and opportunity.

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Executive Summary

Extreme heat has become a defining urban challenge in India, with Delhi illustrating how rising temperatures interact with dense built environments and unequal access to cooling. While Heat Action Plans (HAPs) set out a broad response framework, they do not yet incorporate granular evidence on how people's ability to cope differs across neighbourhoods. This study addresses that gap by integrating high-resolution climate and remote-sensing data with a large sample of household surveys to understand the spatial, social and behavioural dimensions of heat vulnerability in Delhi.

The distinctive contribution of this study is the spatial layering of citizen experience over micro-climate and built-form data. By combining how hot people feel with objective measures of the built environment and atmospheric conditions, the analysis identifies not only where heat is most intense but also the greatest constraints in coping. The study shows that heat exposure, coping behaviour and health outcomes cannot be explained through temperature averages alone; they emerge from the interaction between urban form, socio-economic conditions and household adaptation choices.

Our methodology integrates three high-resolution geospatial layers with household survey data to construct a detailed picture of micro-climatic variation and lived heat exposure across Delhi. Built-up area was mapped using the Global Built-Up Surface dataset (by the Global Human Settlement Layer - GHSL) at 100-metre resolution, where each pixel captures the square metres of constructed surface within that cell. This allowed us to identify neighbourhoods with dense, concretised forms and limited ventilation, which tend to retain heat for longer periods. Vegetation was mapped using MODIS Vegetation Continuous Fields at 250-metre resolution, with each pixel indicating the percentage of tree canopy, non-tree vegetation and non-vegetated ground cover. This enabled us to locate areas where insufficient shade and low green cover intensify local heat stress. To capture experienced heat, we combined ERA5-Land data on surface temperature and dew point (originally at 10-kilometre resolution) with VIIRS land-surface temperature at 1 kilometre. ERA5 data were resampled to 1 kilometre, corrected for bias, and used to compute relative humidity and a heat index using the Rothfusz regression. Together, these layers provided a consistent spatial grid from which to derive neighbourhood-level micro-climate conditions.

The framework guiding this work views heat vulnerability as the interaction of three dimensions. Micro-climate conditions determine the baseline level of heat and humidity that residents experience. Built-environment characteristics, including density, tree cover and other factors, shape how heat accumulates and dissipates. Socio-economic conditions, such as income, occupation, appliance ownership and time spent outdoors, determine whether households can buffer themselves or are forced to absorb the effects of rising heat. Vulnerability accumulates across these dimensions: neighbourhoods with high built-up area and low vegetation face higher temperatures; households with limited cooling face greater exposure; and individuals with prolonged daily heat exposure face higher risks of both illness and productivity loss.

The findings show that even small differences in built-up form and vegetation correspond to meaningful differences in experienced heat. Increasing built-up area from roughly 25% to 55% raises experienced temperature by about 0.6°C. In contrast, increasing tree cover from around 3% to 11% lowers experienced heat by approximately 1°C. This asymmetry suggests that even modest improvements in green cover have a stronger cooling effect than the warming effect associated with similar increases in built-up area. The result reinforces the role of neighbourhood-scale greening as a practical lever for reducing heat exposure in dense urban settings.

Differences in coping capacity also emerge clearly. Sleep disruption rises by 5–6 percentage points with a 3°C increase in experienced heat, but households with air conditioners report substantially better sleep outcomes. AC-owning households spend nearly twice as much on electricity during extreme heat, while non-AC households face constraints in increasing cooling hours. Appliance-usage data indicates that wealthier households already cool their homes for 12–14 hours a day, leaving little scope for further adjustment as temperatures rise. Additionally, in terms of cooling hours almost all respondents also report using the AC during the night, while 50% report using it in the afternoon. By contrast, lower-asset households lack both cooling appliances and the financial room to increase energy use, exposing them to persistent heat strain.

These inequalities extend into health outcomes. A 3°C rise in experienced heat corresponds with a 15 percentage point increase in respondents reporting illness for more than five days in the previous month. Illness prevalence is highest in the 42.5–47°C heat range, where nearly 30% report prolonged ill health, and over 80% of all respondents who reported illness fall within these higher heat categories. AC ownership is associated with an 11.6% lower incidence of heat-related illness, suggesting that even intermittent access to cooling reduces physiological burden. Analysis of chronic conditions shows clear clustering of hypertension, diabetes, obesity, thyroid conditions and respiratory issues in the hotter heat-index bands.

Heat also has a measurable impact on productivity. The share of households missing work due to heat rises from around 18% to nearly 28% with a 3°C rise in experienced heat. AC-owning households report an 18% lower incidence of heat-related work loss compared to non-AC households. Workers with long commutes or significant time spent outdoors face the greatest disruptions. In the highest heat-index band, almost half of respondents work in the sun for more than two hours a day, and a third for more than six hours, compounding exposure at both home and work.

Impact on mental state shows a similarly clear pattern. The share of respondents reporting noticeable changes in mental state rises from about 15% to 30% as experienced heat moves from roughly 42°C to 45°C. These findings are consistent with global evidence linking elevated temperatures to increased stress and mental-state-related morbidity.

Taken together, the results indicate that extreme heat operates as a structural stressor that exacerbates existing inequalities. Households with limited physical, financial and infrastructural buffers face higher levels of exposure, greater illness and more frequent productivity losses. These disparities are likely to sharpen as temperatures continue to rise, making a strong case for policy interventions that combine spatial precision with citizen-centric data systems.

> **Taken together, the results indicate that extreme heat operates as a structural stressor that exacerbates existing inequalities. Households with limited physical, financial and infrastructural buffers face higher levels of exposure, greater illness and more frequent productivity losses. These disparities are likely to sharpen as temperatures continue to rise, making a strong case for policy interventions that combine spatial precision with citizen-centric data systems.**

The study identifies three areas for policy action. The first is the development of micro-level heat action plans supported by routine, citizen-centred data. Institutionalising short, rapid surveys within state systems would create a low-cost, continuous feedback loop on lived experience. When combined with ward-level and settlement-scale mapping, this approach allows authorities to locate high-risk clusters and direct measures—such as cool roofs, shading and targeted outreach—to the communities most affected. State Disaster Management Authorities, working with urban local bodies, are well placed to coordinate this model. For these state heat action plans to be effective, there is also a need to focus on developing the relevant data literacy within government bodies, including the ability to interpret charts, indicators and spatial data to enable evidence-based planning and effective heat risk management.

The second priority is to embed heat resilience within urban planning. The study shows that modest increases in vegetation yield larger cooling effects than equivalent increases in built-up areas generate warming. Urban design therefore has a central role in moderating exposure. Neighbourhood-level greening, improved airflow, reflective materials, shaded pedestrian routes and climate-responsive housing standards can reduce heat accumulation. Integrating blue–green infrastructure into zoning and redevelopment decisions strengthens longer-term resilience, while low-cost retrofits in informal settlements—such as reflective coatings and improved roofing—can reduce indoor heat without imposing significant costs.

The third priority concerns energy systems and appliance design. Rising urban heat is rapidly reshaping electricity demand in India, with cooling loads emerging as a major source of peak grid stress during heatwaves. Integrating heatwave forecasting, hourly cooling demand and neighbourhood level exposure into energy planning is critical to avoid outages and unequal access to reliable power. Appliance efficiency (particularly for air conditioners) offers a cost effective pathway to reduce peak demand, emissions and long-term grid investment needs. Targeted financing, smarter energy labels and context specific appliance design can accelerate adoption among low income households while strengthening urban resilience.

> Together, these three priorities—citizen-centred micro-planning, heat-responsive urban design and energy systems aligned to rising cooling needs—provide a coherent basis for strengthening heat resilience in Delhi and other cities facing similar climatic pressures, while building the institutional and technical capacity required for effective implementation.

Spatial Heat Baseline: Built Area & Tree Cover

25% to **55%**

Increase in built-up area

↓

Raises felt temperature by about

0.6°C ▲

3% to **11%**

Increase in tree cover

↓

Lowers experienced heat by approximately

1°C ▼

This demonstrates the cooling effect of green cover.

Coping Capacity

3×

(31.2% vs. 13.0%)

better sleep in households that own AC

Underscores the role of cooling in restoring rest during high night-time temperatures.

₹1,155

(₹2,560 vs. ₹1,405)

higher monthly electricity spend for households with AC

Reveals that AC owning households incur substantially higher electricity spending during heat periods.

Impact of Heat

30%

of respondents

report prolonged ill health in the **42.5–47°C** heat range,

with over

80%

of all reported illness

occurring at these higher temperatures, revealing the impact of heat on health.

18% to **28%**

Increase in the share of households missing work due to heat

↓

Due to an **increase** in experienced heat by

3°C ▲

Shows the impact of heat on productivity.

Sleep disruption rises by

5-6 percentage points

with a **3°C increase** in experienced heat.

15% to 30%

of respondents

report noticeable changes in mental state as experienced heat rises from roughly **42°C to 45°C.**

02

Introduction

1 Heat Stress in India

In April 2025, Delhi recorded its warmest night[1] temperature in six years. In a period of slightly over 2 months, from March to May of 2022, India experienced more than 280[2] heatwave days. As extreme heat is occurring more frequently in India, its effects are evident across areas – from overwhelmed health systems and soaring power demand to damaged crops, shrinking water resources, and declining productivity in both people and agriculture.

The effects of extreme heat on health are severe. Vulnerability to the health effects of heat stress is not uniform, with certain groups being disproportionately affected. By occupation, outdoor workers such as agricultural labourers, construction workers, police personnel, etc face the highest risk. By age, the elderly or individuals with chronic health conditions are most vulnerable. Additionally, high overnight temperatures[3] make it challenging to adequately rest and recover from heat exposure in the day. Between 1 March – 18 June 2024 India logged >40,000 suspected heat-stroke cases and at least 110 confirmed deaths, a figure experts still call a large under-count[4].

Economic productivity losses also occur as a consequence of high heat stress. It is estimated that heat stress in India could lead to the loss of 35 million jobs[5] and a 4.5% reduction in GDP by 2030. Economic productivity is reliant on consistent power supply and a resilient power grid, which are threatened by extreme heat. An immediate consequence of increasing temperatures is the pressure on power consumption. Record temperatures have pushed peak power demand to new highs (250 GW nationally[6]).

Urban and semi-urban areas are often the sites of extreme heat events. In light of the rapid urbanisation[7] underway in India, understanding heat stress in urban environments becomes increasingly critical.

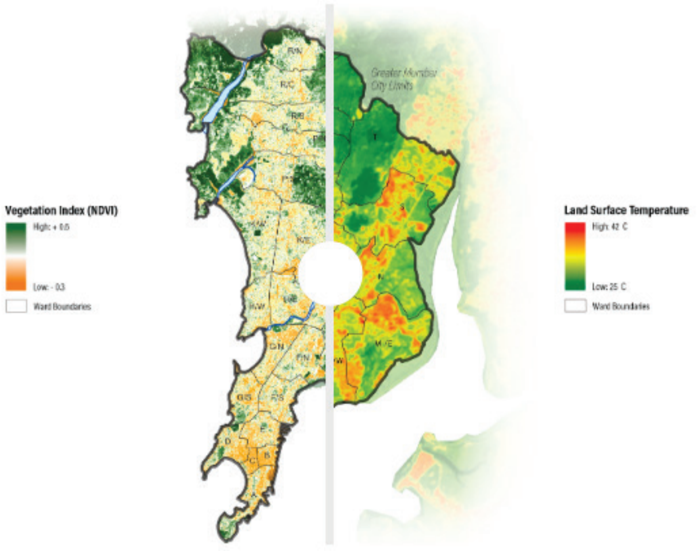
2 Urban Heat Island Effect

Indian cities are experiencing extreme temperatures and are often significantly warmer than the surrounding rural areas. In some cases, this difference can be as high as 6°C[8] (10.8°F) in terms of measured air temperature. Even within cities, temperatures vary considerably, with certain neighbourhoods facing much higher heat levels than nearby areas due to differences in the built environment. This phenomenon, known as the Urban Heat Island Effect[9], occurs because of high concentrations of concrete, asphalt, and dense populations. Rapid urbanisation, shrinking green spaces, and unplanned construction further contribute to this effect.

A study by the World Resources Institute highlighted the substantial variation in temperature linked to the extent of green cover in Mumbai[10]. The study found a 5.5°C difference in land temperature between the hottest and coolest neighbourhoods. Areas with greater green cover recorded substantially lower temperatures, while neighbourhoods with a high concentration of metal roofs (commonly found in informal settlements and low-income housing) experienced much hotter surface temperatures. With around 37% of Mumbai households living under metal roofs, a large share of the population is disproportionately exposed to elevated heat risk. This gap also reflects how socio-economic inequalities are embedded in the types of housing people occupy, reinforcing disparities in vulnerability.

Mumbai shows a strong relationship between vegetation cover and lower land surface temperature

Left: Vegetation index. *Right:* Land surface temperature



Sources: *Land surface temperature:* WRI India using LandSat 8 (USGS) of October 2017-2019; Google Earth Imagery.
Vegetation index: WRI India; Contains Modified Copernicus Sentinel Data [2015-2020] & LandSat 8 (USGS).

WORLD RESOURCES INSTITUTE

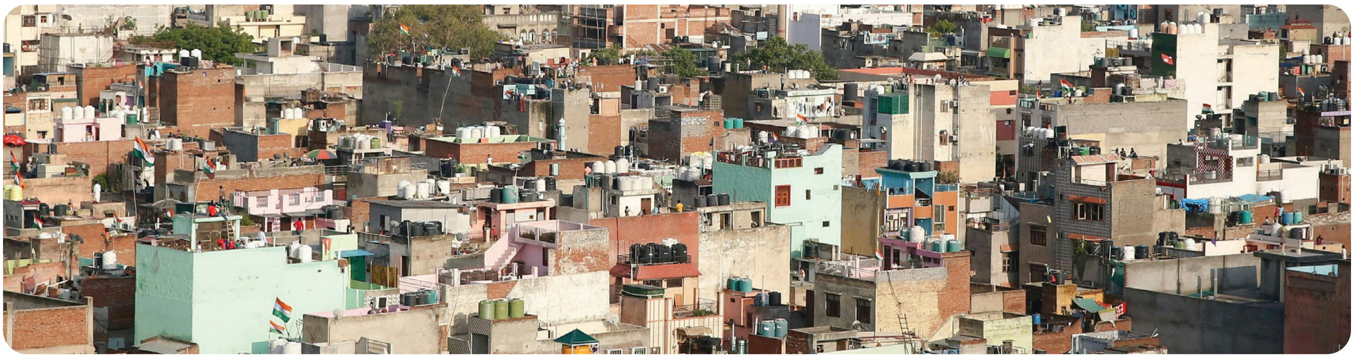
Figure 1: Relationship between vegetation cover and lower land surface temperature in Mumbai
World Resources Institute[11], 2024

3 The Need for Spatially Targeted Policy Response

India's primary approach to addressing extreme heat is through Heat Action Plans (HAPs). An HAP[12] outlines a coordinated framework to implement and evaluate extreme heat response measures, with the goal of reducing heat-related health risks. Its core objective is to warn high-risk populations when dangerous heat conditions are present or expected and support timely protective actions.

However, these plans, produced at the state, city and sometimes even district level, require significant strengthening. 95 per cent[13] of HAPs currently lack detailed assessments of heat risks and vulnerabilities (Pillai and Dalal, 2023). This gap hampers authorities' ability to identify and prioritise high-risk areas and to allocate financial resources effectively.

> **While most state/city-specific Heat Action Plans in India focus on broad strategies for coping (such as early awareness alerts, ensuring health sector preparedness, water availability, electricity access and more), there is a need for understanding the micro-level spatial variation in not just the heat temperature, but in people's lived experience and ability to cope.**



People's experiences vary widely and are shaped by multiple factors. Within cities, features such as tree cover, water bodies, street width, and building materials can shift local air temperatures by 2–5°C, directly affecting how much heat citizens experience.

However, current Heat Action Plans do not adequately account for local differences in heat exposure or in people's ability to cope. Existing strategies overlook the substantial variation that can arise due to the urban heat island effect, as mentioned in the section above. The differences in the built environment, access to cooling appliances, and other contextual conditions affect people's ability to cope. To address extreme heat effectively, it is essential to capture citizen experiences at a more granular, micro level, enabling responses that are tailored to local needs and realities. A granular picture[14] of the variation in heat risk and ability to cope would be crucial in developing responsive strategies for building resilience to climate change.

The National Disaster Management Authority (NDMA)'s Heat Action Plan framework recommends mapping vulnerabilities to heat at the city and municipal ward levels, using ward-wise land surface temperatures, air temperatures, and socio-economic indicators to identify priority areas for intervention. Some HAPs have begun implementing this approach. For example, Rajkot[15] and Varanasi[16] conduct ward-level heat hotspot and vulnerability analyses and then identify priority wards for targeted measures such as cool roofs, shading infrastructure, health camps, and focused communication efforts. A 2023 assessment of 37 HAPs[17] by the Centre for Policy Research (CPR) reaches a similar conclusion, noting that city-level plans often overlook spatial variation in exposure and vulnerability and recommending ward-level identification of hotspots, particularly informal settlements and low-income pockets.

The NDMA[18] also recommends a two-step approach: use the district or city as the primary governance unit for coordination, and use the ward as the minimum unit for hotspot and vulnerability mapping. Within high-risk wards, agencies are further advised to identify "micro hot pockets," such as specific settlements, industrial clusters, or corridors, to enable targeted interventions. A 2025 study[19] of heat risk in Nagpur, which integrated ward-level socio-economic variables, found that 68 of the 136 wards were susceptible to high heat risk, highlighting the need for ward-level heat-risk mapping.

Earlier all-India work on heat-wave vulnerability mapping at the district scale concludes that the next step should be sub-district analyses[20]. A study of intra-urban heat-stress risk in Delhi[21] develops a ward-scale Heat Stress Risk Index using land-surface temperature, built-form, and demographic indicators, and shows that high-risk pockets are concentrated in specific wards with dense, low-income housing, patterns that would be invisible at a city-average scale. Overall, studies consistently recommend that risk assessments and interventions be planned at least at the ward scale, with further zoom-ins to specific local climate zones[22] or settlements for implementation.

03

Our Unique Contribution

A key contribution of our study is overlaying citizen experience with high resolution climate and remote sensing data.

> By combining what people feel with environment data, we move beyond broad assumptions about heat to uncover the real factors and vulnerability at a neighbourhood level. This integrated approach allows us to pinpoint not only where extreme heat is experienced most, but also why certain communities face more struggles to cope.

a **Hypothesis:**

People's ability to cope with extreme heat is shaped by the interaction of three core factors:

i. **Who you are:** Household demographics like income, occupation, age, gender, social group and religion, appliance ownership, household size, commute patterns and daily routines that influence both how individuals experience heat as well as cope with it.

ii. **How the city is built:** Dense, concretised areas trap and retain heat while tree cover and open spaces provide cooling. Housing quality and building materials determine how long heat lingers indoors. Planned neighbourhoods typically have regulated building layouts and ventilation, reducing heat accumulation while unplanned informal settlements usually tightly packed with limited green cover, intensifying heat exposure.

iii. **Where you live:** Even within the same city, temperature, humidity and airflow differ across neighbourhoods creating smaller micro-climates of discomfort. Increased humidity limits the body's ability to cool itself through sweating, making heat feel more intense and prolonging discomfort even at lower temperatures. Poor airflow prevents heat from dissipating, trapping hot stagnant air and amplifying discomfort.

b **Testing our Hypothesis:**
Modelling variables across 3 dimensions:

i. **Household level variables (to determine a person’s baseline vulnerability):** Income and occupation, appliance ownership (to cope with heat – AC, coolers, fans, etc), household routines (time spent indoors vs outdoors) collected during peak summer months of May and June (2025)

ii. **Built environment variables (to see how heat accumulates):** Building density and material type, green cover and open spaces, housing quality (formal vs informal)

iii. **Micro-climate and environment variables (to include temperature and other atmospheric conditions):** Land and air temperature, humidity, wind

By modelling all these variables together, we can quantify which factors matter most, identify high-risk communities and generate insights for targeted heat resilience interventions at more granular, neighbourhood and household, levels.

04

Methodology

Our methodology involves triangulating satellite-based micro climate data with neighbourhood built-form and environmental characteristics, as well as household surveys, to understand the true drivers of heat vulnerability in Delhi.

Table 1: Overview of the data we used

Variable Type	Details/ Components	Source	How we processed it
Household-level variables	Income, occupation, appliance ownership (AC, cooler, fan), time spent indoors/ outdoors, electricity bill amounts	Household surveys (Surveyed 2368 HH across Delhi)	Collected through structured questionnaires; cleaned, coded, and converted into categorical/ continuous variables for modelling baseline vulnerability
Built-environment variables (used as a reference to cross check our environmental heat index values)	Building density, surface material, settlement type, green cover, open spaces, housing quality (formal vs informal)	Remote sensing datasets (e.g., GHSL Built-up 100m, MODIS VCF), field observations	Downloaded spatial layers, clipped to study area, resampled and normalised, extracted pixel-level indicators for each neighbourhood
Micro-climate and environmental variables	Land and air temperature, humidity, derived heat index	ERA5-Land (2m temperature & dew point), VIIRS (land surface temperature)	Resampled ERA5 to 1 km, aligned with VIIRS, applied correction offsets, computed relative humidity and heat index using Rothfusz regression for each grid cell and time period

Step 1:

Integrating three high resolution geospatial layers to understand the spatial landscape in Delhi. These layers include:

i. Built Up Area (GHSL: Global built-up surface 100m):

Using remote sensing data on built-up surface area, we mapped how the city’s physical form traps and retains heat. Each 100m x 100m pixel shows the built-up surface area as a percentage of the pixel’s total area. Dense, concretised neighbourhoods with low ventilation were identified as higher-risk zones, where heat is retained for longer periods.

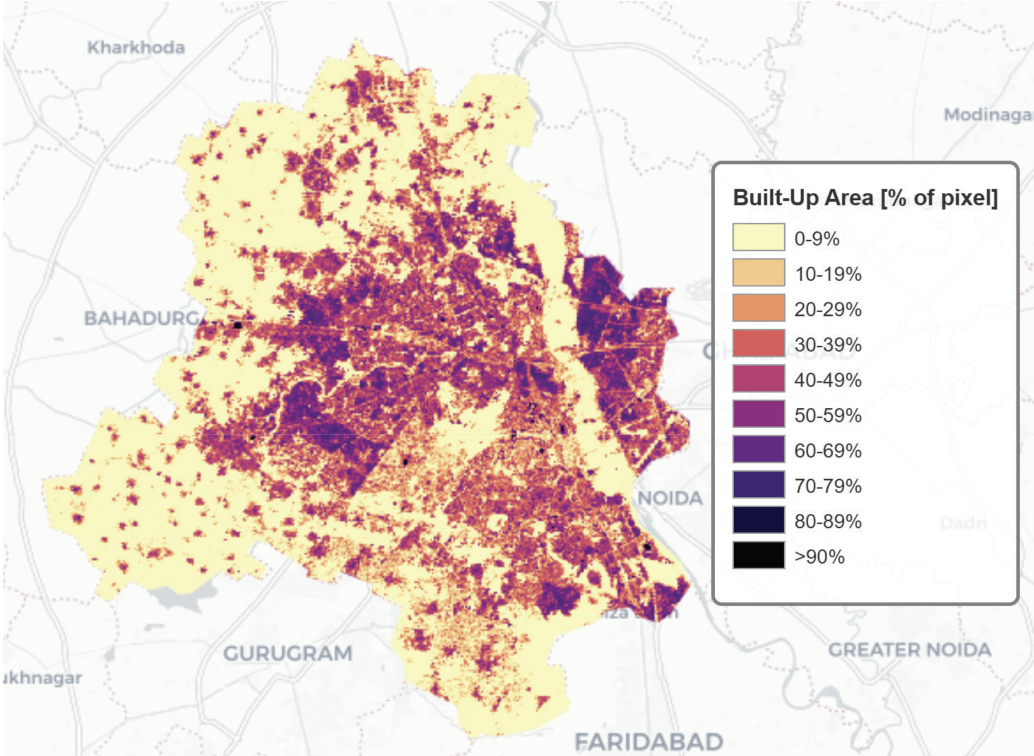


Figure 2: Built-Up Area from GHSL Global Built-Up Surface Dataset - 100m×100m pixels

ii. Tree Cover (MOD44B.061 Terra Vegetation Continuous Fields Yearly Global 250m):

Satellite data was used to map vegetation and canopy cover to assess the scope of natural cooling. Each 250m by 250m pixel represents the percentage of that area covered by different ground-cover types. Specifically, one band gives percent tree canopy cover (0–100%) per pixel, along with bands for non-tree vegetation and non-vegetated surface. This helped us identify zones where lack of shade and green intensifies heat stress.

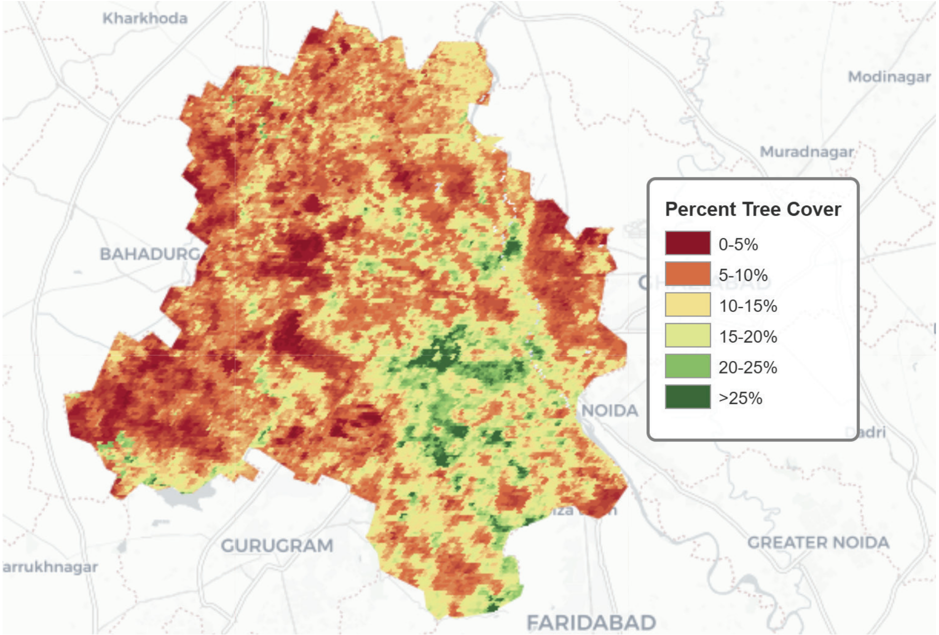


Figure 3: Tree Canopy Cover from MOD44B VCF - 250m x 250m pixels

iii. Experienced Heat (ERA5 and VIIRS):

The ERA5 Land data set provides surface temperature and dew point values at a 10km resolution, while VIIRS provides surface temperature at a 1km resolution. We resampled ERA5 to 1km resolution, applied a correction offset, and computed relative humidity and the heat index at 1km resolution using the Rothfusz regression.

Together these three geospatial layers allowed us to build a micro-climate profile for different neighbourhoods.

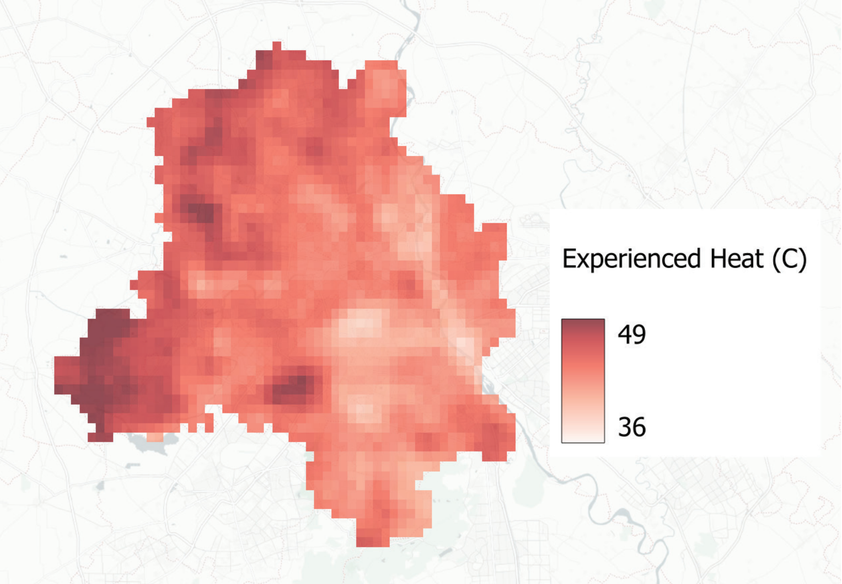


Figure 4: Experienced Computation Using ERA5-Land and VIIRS- 1km x 1km Resolution

Step 2:

Integrating a rapid citizen layer, through on-ground surveys

To complement spatial data, we collected high frequency, on ground citizen data through surveys from households across several assembly constituencies in Delhi: For our sampling strategy: We wanted to capture maximum spatial variation in our data to capture neighbour-hood level variation in experienced heat. We picked 200 polling booths to capture a diverse range of neighbourhoods across all 70 Assembly Constituencies, with ~12 households per PB (total: 2368 households).

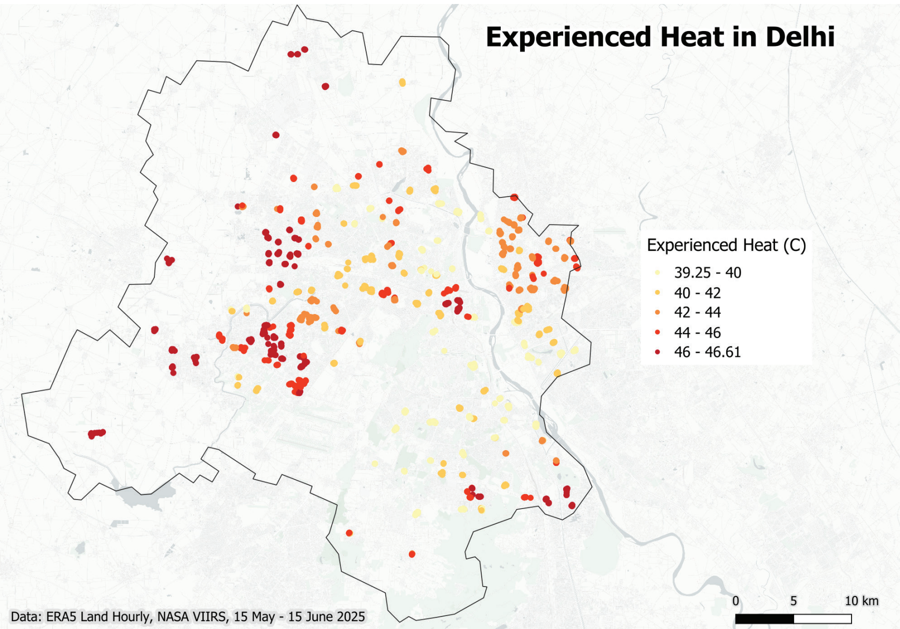


Figure 5: Spatial distribution of 2368 HH surveys across Delhi

Step 3:

Survey implementation and data collection, broad areas of data collected

Primary in-person household surveys (See Appendix 1 for the Questionnaire) were administered from 17th June to 2nd July 2025 (asking for responses pertaining to the past month which characterised peak summer), to capture multiple ways in which heat affects health, productivity, behaviour, household expenditure on electricity and coping. The survey recorded:

- **Socio-economic profiles:** Demographics (age, gender, etc), household size and structure, employment details, commute behaviour
- **Energy consumption and appliance usage (AC, fan, cooler, geysers, refrigerators):** Ownership, number of appliances, star rating, usage pattern, bill amount and variation
- **Climate change and awareness:** Self-assessed impact and sources of climate change
- **Heat-related health and productivity impacts:** Heat-related illnesses (fever, vomiting etc), days of work missed, number of days sick, change in mental state

- **Household context:** Presence of green cover, floor level residence, house accessibility, polling booth, assembly constituency and energy account number for spatial tagging

This data not only helps capture how citizens experience heat, but also how they face constraints and adapt in the face of it.

Table 2: Sample Characteristics

Age: 68% of our respondents are below the age of 45.

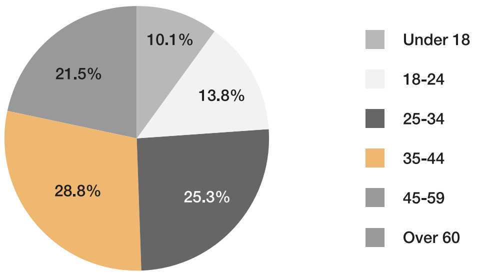


Figure 6: Age Distribution (Count) -
Under 18: 13, 18-24: 327, 25-34: 599,
35-44: 682, 45-59: 508, Over 60: 239

Social category:

Among our respondents, the distribution was:

45%
General category

25%
OBC category

AC Ownership: Only a little over 30% of the households surveyed own an AC.

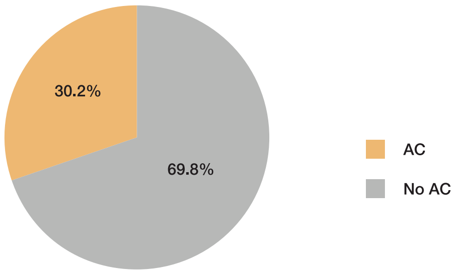


Figure 8: AC Ownership (Count):
AC users: 714, Non-AC users: 1654

Gender:

53% of our respondents are female and 47% are male

1258
Female

1110
Male

Asset Distribution:

96% of our respondents own a fan, ~80% own a TV and Fridge

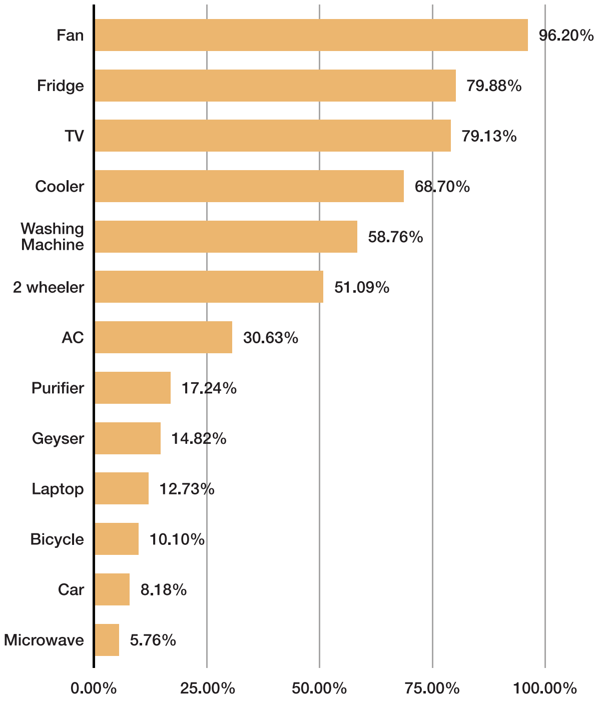


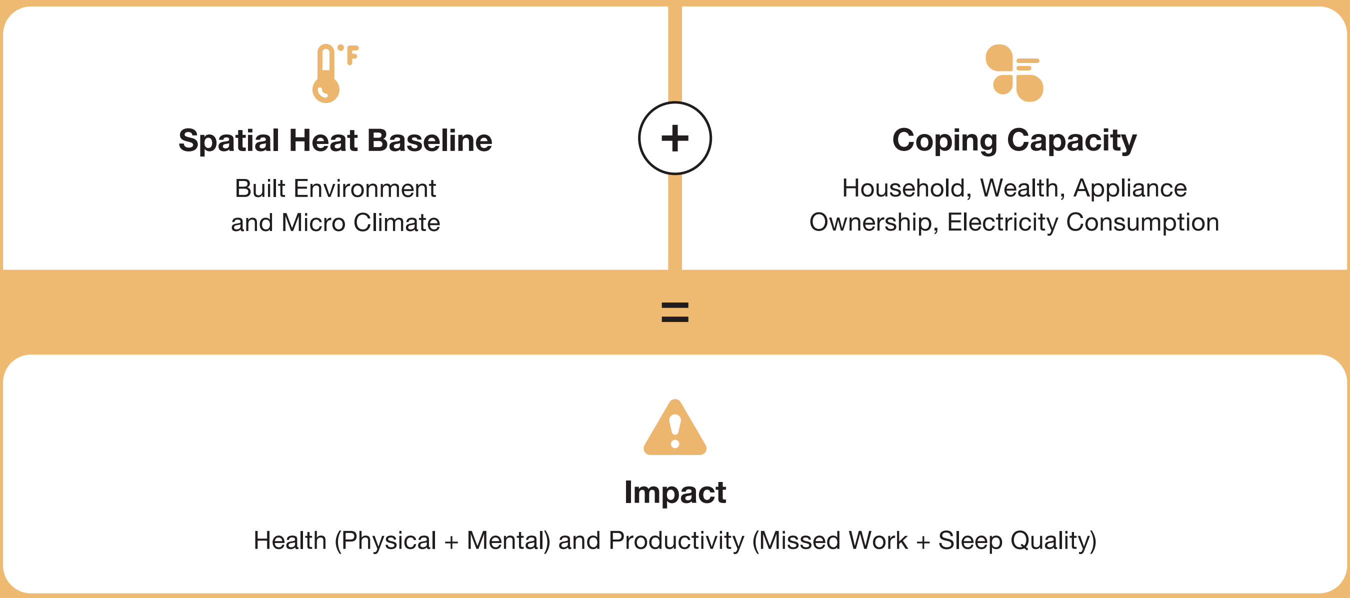
Figure 7: Asset Distribution (Count) -
Total: 2368; Fan: 2305; Fridge: 1914; TV: 1896;
Cooler: 1646; Washing machine: 1408; 2-wheeler: 1224

These layers of geospatial analysis, structured household sampling and citizen reported data allow us to build an unusually granular and integrated picture of heat vulnerability in Delhi.

05

Our Framework

> Heat vulnerability is not the result of a single factor. It emerges from the interaction of micro-climate, built environment, and household socio-economic capacity, which together shape how much heat people experience, how long they remain exposed, and how well, or poorly, they can buffer themselves. Our findings reveal a clear and systematic pathway through which vulnerability accumulates.



Spatial Heat Baseline

Built Environment
and Micro Climate

\+

Coping Capacity

Household, Wealth, Appliance
Ownership, Electricity Consumption

=

Impact

Health (Physical + Mental) and Productivity (Missed Work + Sleep Quality)

OUR FRAMEWORK:
Linking Spatial Variation & Exposure, Coping Capacity, and Impact

Neighbourhood-level heat sets the environmental baseline; exposure adds individual-level load; and socio-economic capacity determines whether households can shield themselves. The interaction of these layers produces concentrated pockets of high heat stress, higher illness, productivity loss, and energy burden.

Figure 9: Our framework for linking spatial variation, exposure, coping capacity and impact

06

Key Findings

Urban heat is reshaping everyday life, influencing how much heat people feel, how they cope and the toll it takes on their health and productivity.

> **92% of our respondents stated that they experienced the effects of climate change in their daily lives. Our findings show that heat exposure is deeply uneven, shaped by neighbourhood characteristics, socio-economic factors, and access to adaptive resources like cooling.**

As temperatures rise, the ability to cope becomes increasingly unequal, translating into widening health risks and economic losses. The concentration of illness in the hottest zones points to spatial inequalities in exposure, where neighbourhoods already facing infrastructural and socioeconomic disadvantages bear a disproportionate health/ economic burden.

As we show below, the difference observed between AC and non-AC households reinforces how access to cooling functions as a form of health protection, creating a divide between those who can buffer heat and those who must absorb its load. However, this inequity extends beyond health to directly impact livelihoods: rising temperatures correspond with significant productivity losses, as households increasingly miss work due to heat, disrupting income and economic security. A 3°C rise leads to a clear increase in work days lost, and those without cooling experience face the most severe disruptions.

These dynamics also spill over to the energy system: heat-driven spikes in cooling demand raise peak electricity loads, increasing grid stress and the likelihood of power disruptions that can further compound health and productivity challenges.

Ultimately, these patterns highlight that urban heat is functioning as a structural stressor, intensifying inequities, undermining economic resilience and increasing pressure on public health, labour systems and energy grids in ways that are likely to worsen as experienced heat continues to rise.

Table 3: Overview of our Findings

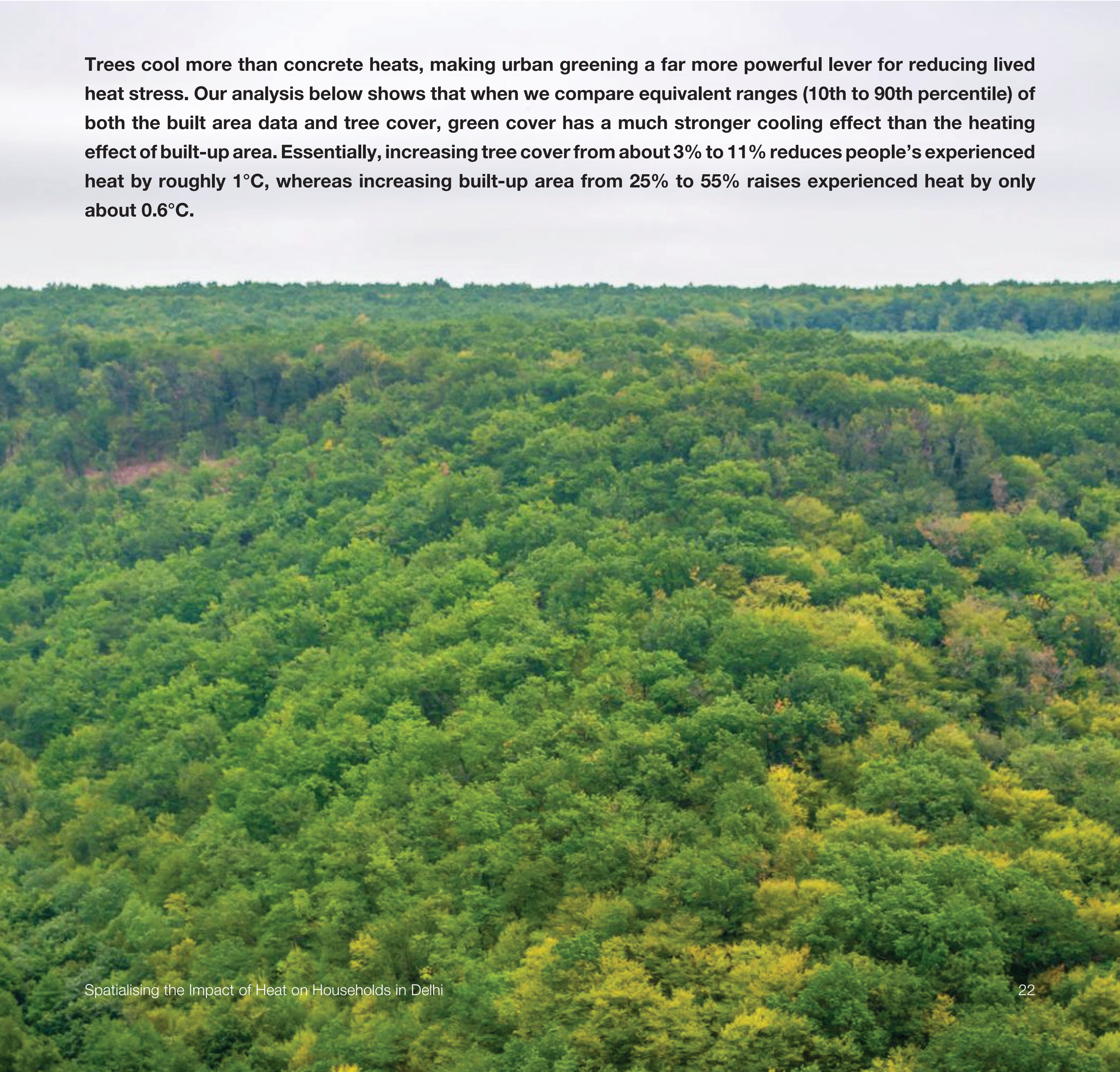
1.	**Spatial Heat Baseline**
1.1	When built-up surface area increases from about 25% to 55%, experienced temperatures rise by roughly 0.6°C
1.2	A rise in green cover from 3% to 11% lowers experienced heat by ~1°C
2.	**Coping Capacity/ Adaptation**
2.1	Sleep disruption rises by 5–6 percentage points with a 3°C heat increase, but AC access helps mitigate it
2.2	Households that own an AC spend nearly 2x during extreme heat
3.	**Impact**
3.1	A 3°C increase in temperature corresponded with a 15 percentage point rise in reported illness. Further, AC ownership is associated with about an 11.6% lower incidence of heat-induced illness
3.2	A 3°C increase in experienced heat shows a 10% jump in households missing work due, from about 18% to nearly 28%. Further, AC owners report 18% lesser incidence of work loss compared to non-ac owners
3.3	Respondents reporting heat-related changes in mental state jump from 15% to 30% as heat increases by 3°C.

1 Spatial Heat Baseline: Factors Shaping Experienced Heat

India's primary approach to addressing extreme heat is through Heat Action Plans (HAPs). An HAP outlines a coordinated framework to implement and evaluate extreme heat response measures, with the goal of reducing heat-related health risks. Its core objective is to warn high-risk populations when dangerous heat conditions are present or expected and support timely protective actions.

However, these plans, produced at the state, city and sometimes even district level, require significant strengthening. 95 per cent of HAPs currently lack detailed assessments of heat risks and vulnerabilities (Pillai and Dalal, 2023). This gap hampers authorities' ability to identify and prioritise high-risk areas and to allocate financial resources effectively.

Trees cool more than concrete heats, making urban greening a far more powerful lever for reducing lived heat stress. Our analysis below shows that when we compare equivalent ranges (10th to 90th percentile) of both the built area data and tree cover, green cover has a much stronger cooling effect than the heating effect of built-up area. Essentially, increasing tree cover from about 3% to 11% reduces people's experienced heat by roughly 1°C, whereas increasing built-up area from 25% to 55% raises experienced heat by only about 0.6°C.



1.1 When built-up surface area increases from about 25% to 55%, experienced temperatures rise by roughly 0.6°C

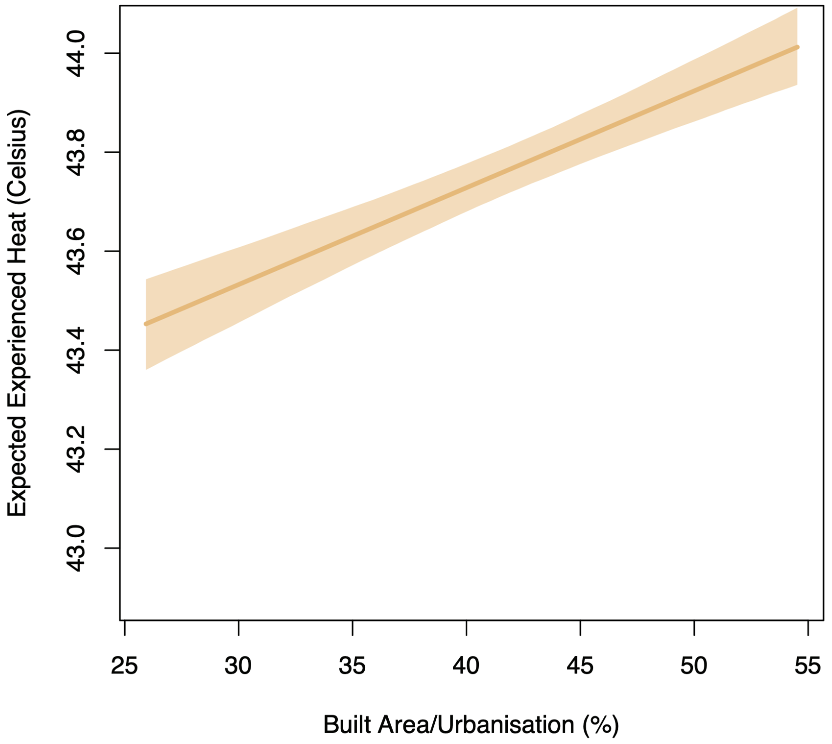


Figure 10: Relationship between built-up area and experienced heat

The chart above shows us that moving from areas with around 25% built-up area to those with 55% built-up area corresponds to roughly a 0.6°C rise in experienced temperature, demonstrating how the Urban Heat Island effect can vary dramatically across short distances due to small differences in built area.

Building form[23], density, and material used can all intensify the Urban Heat Island effect. Dense, tall, and closely packed buildings made with low-reflectance materials[24] trap heat and slow night-time cooling.

The Urban Heat Island effect is especially relevant as urban areas are essentially labour markets[25]. A well functioning labour market is essential for the growth of cities and hence the overall economic growth of a country. It is estimated that urban populations contribute 63% to India's GDP[26], and this is expected to grow to 75% in 2030. While we discuss productivity effects later in the paper, this section focuses on how urban form influences people's experiences of heat.

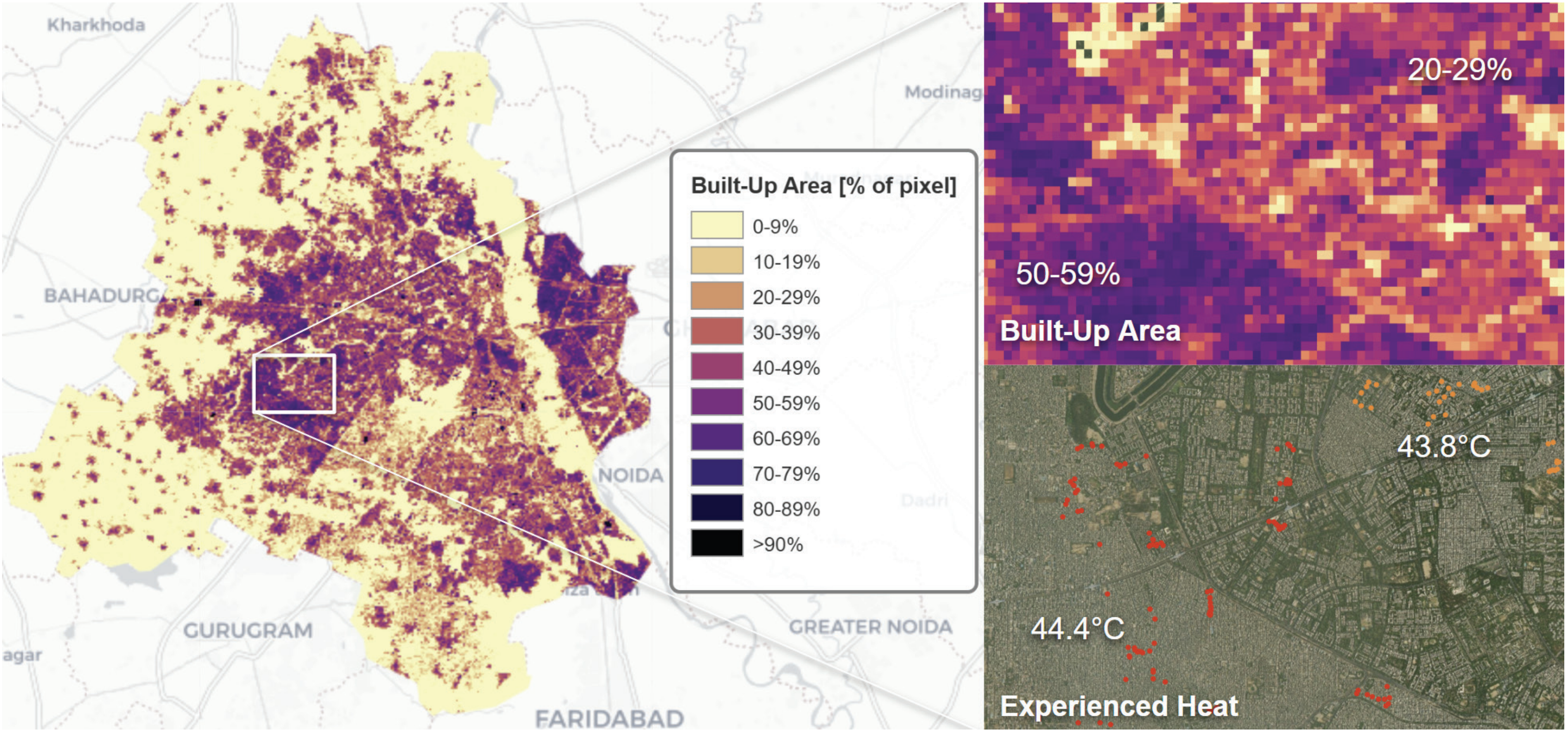


Figure 11: Detail of Delhi showing contrast in experienced heat between neighbourhoods with variable built-up area (image on the right shows the zoomed in version of the map highlighted by the box)

1.2 A rise in green cover from 3% to 11% lowers experienced heat by ~1°C

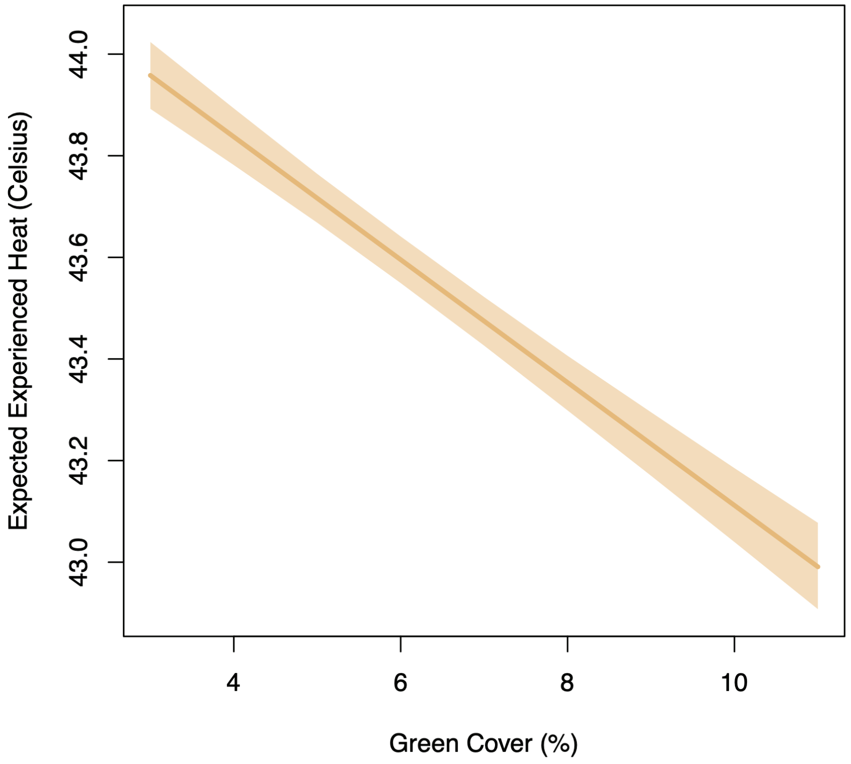


Figure 12: Relationship between green cover and experienced heat

> **We found that a rise in green cover from about 3% to 11% is associated with roughly a 1°C drop in experienced heat, showing that even modest increases in greenery can substantially reduce local heat stress.**

Green spaces can help mitigate[27] the urban heat island effect through evaporation, shading, and increased surface reflection. Tree cover reduces heat absorption in densely built environments by providing shade, while green roofs add insulation that limits heat gain. Evidence shows that the design of vegetation, including its layout and arrangement, plays a direct role[28] in determining the cooling effectiveness of urban landscapes.

Urban greenery can reduce local ambient temperatures by a few degrees by providing shade and enhancing 'evapotranspiration[29]'. Adding vegetation such as trees, rooftop gardens, and other green spaces into cities, has been found to reduce surface warming by 0.13 degrees[30] celsius per decade in European cities.

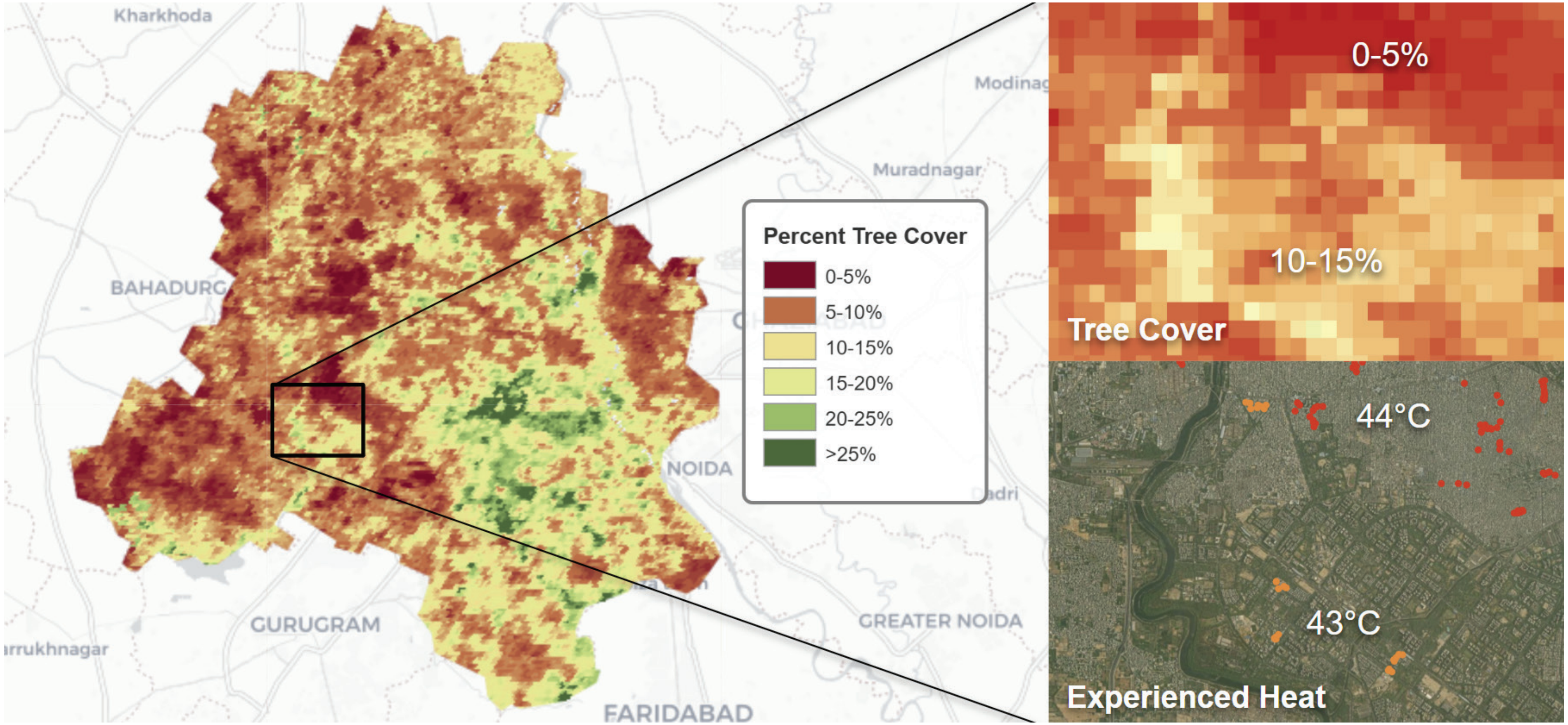


Figure 13: Detail of Delhi showing contrast in experienced heat between neighbourhoods with variable tree cover (image on the right shows the zoomed in version of the map highlighted by the box)

2 Coping Capacity/ Adaptation: Household Appliances, Occupation and Commute

After establishing what drives uneven heat exposure, we turn to how households attempt to cope. Access to adaptive tools such as air conditioners, quality housing and commute flexibility determines who can buffer the effects of extreme heat and who cannot. Examining adaptation helps illustrate the growing divide between those who can protect themselves and those forced to absorb rising heat stress.

Extreme heat sharply worsens sleep, and the ability to mitigate this impact is deeply unequal and closely tied to household wealth.

> **Our findings show that rising heat sharply worsens sleep: with the worst sleep concentrated in the 42.5–47°C range. Access to cooling dramatically reduces this burden, however this is unequal as AC-owning households spend nearly twice as much on electricity, while lower-asset households lack both appliances and the financial flexibility to increase cooling as temperatures rise.**

2.1 Sleep disruption rises by 5–6 percentage points with a 3°C heat increase, but AC access helps mitigate it

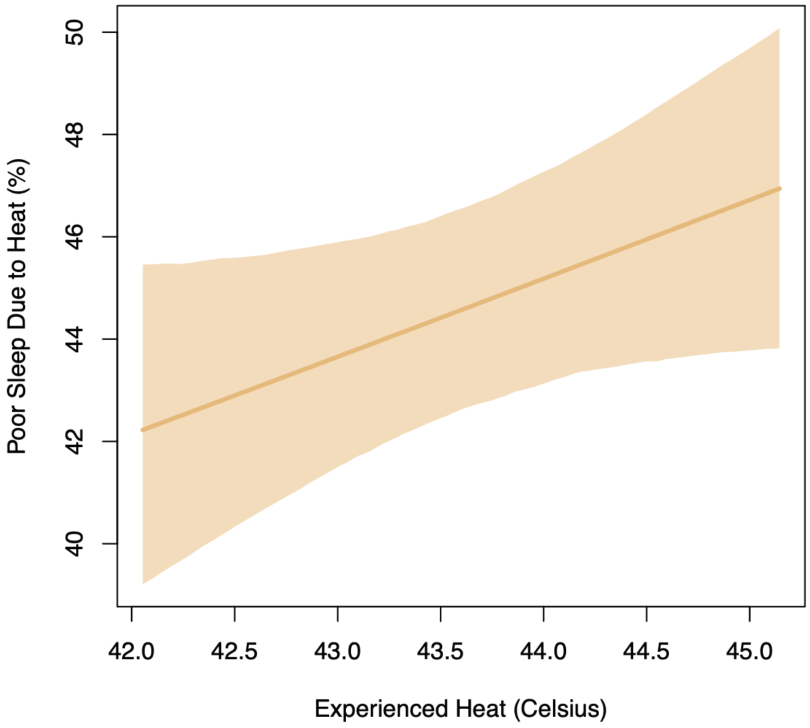


Figure 14: Relationship between sleep quality and experienced heat

Our study shows how respondents reporting poor or very poor sleep are concentrated in the higher heat index ranges. We observe a 5-6 percentage point increase in respondents reporting they experience poor sleep over just a 3°C rise, a clear indication that even relatively small increases in experienced heat significantly worsen sleep quality.

Sleep is fundamental to physical and mental health[31], enabling the body to repair and the brain to recover for daily functioning and wellbeing. As climate change drives sharp increases in daytime and nighttime temperatures[32], the ability to maintain restful sleep is increasingly challenged. Disturbed sleep has emerged as a critical pathway through which rising heat triggers a range of adverse health and behavioural outcomes.

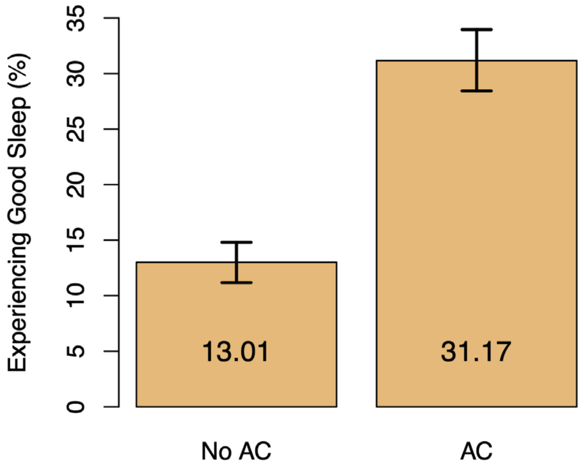


Figure 15: Percentage of AC and non AC owners experiencing good sleep

Our data shows a strong and consistent relationship between AC ownership and improved sleep during extreme heat. Households with an air conditioner report three times higher levels of good sleep (31.2% vs. 13.0%), underscoring the role of cooling in restoring rest during high night-time temperatures.

2.2 Households that own an AC spend nearly 2x during extreme heat

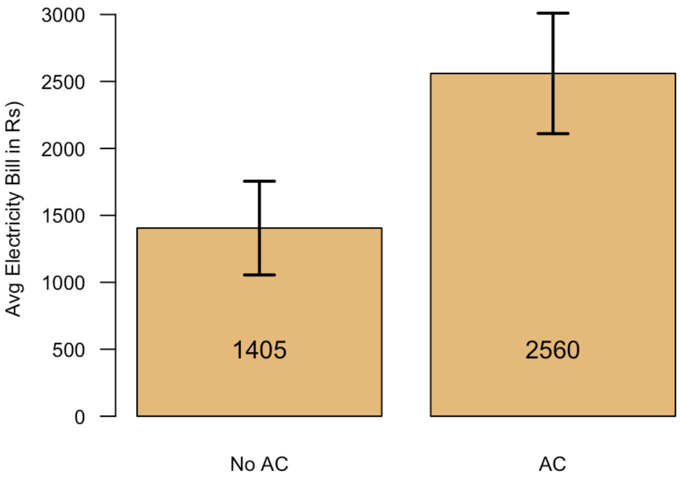


Figure 16: Average household monthly electricity bill for AC and non AC users -
Sample size: 250 electricity bills captured

Our analysis shows that households with greater financial resources are able to spend substantially more on power during periods of extreme heat (nearly twice as much as households without an AC). On average, non-AC households report monthly electricity bills of around ₹1405, while AC owning households spend approximately ₹2560, which shows that AC owning households incur substantially higher electricity spending during heat periods. Among households that own an AC, 35% have a 5-star rated unit, while another 40% own ACs rated 3 or 4 stars.

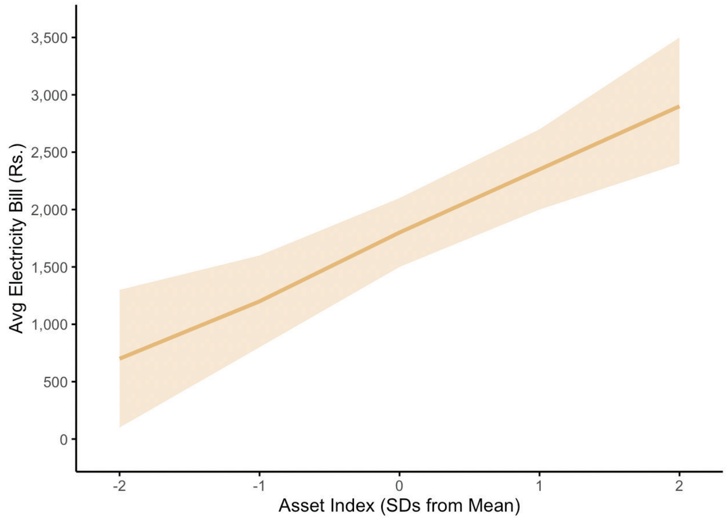


Figure 17: Relationship between the asset index scores and average household monthly electricity bill - Sample size: 250 electricity bills captured

This pattern is further reinforced using our asset-based wealth index. As asset scores increase, electricity expenditure rises significantly, indicating that wealthier households not only own more appliances but also use them more intensively to buffer themselves from heat. In contrast, lower-asset households have both less access to cooling and less flexibility to increase energy use as temperatures rise.

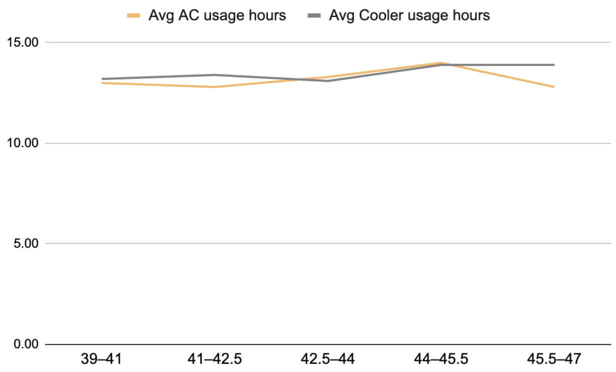


Figure 18: Average AC and cooler usage hours across heat ranges

If we look at AC or cooler usage hours, these households are already wealthier, already cooling for 12–14 hours a day, and have both the financial means and the behavioural habit of running cooling appliances nearly continuously during peak summer. As a result, even when temperatures rise sharply (from 39°C to 47°C), usage barely increases — it is essentially flat — because these households are already operating close to the maximum they are willing or able to run.

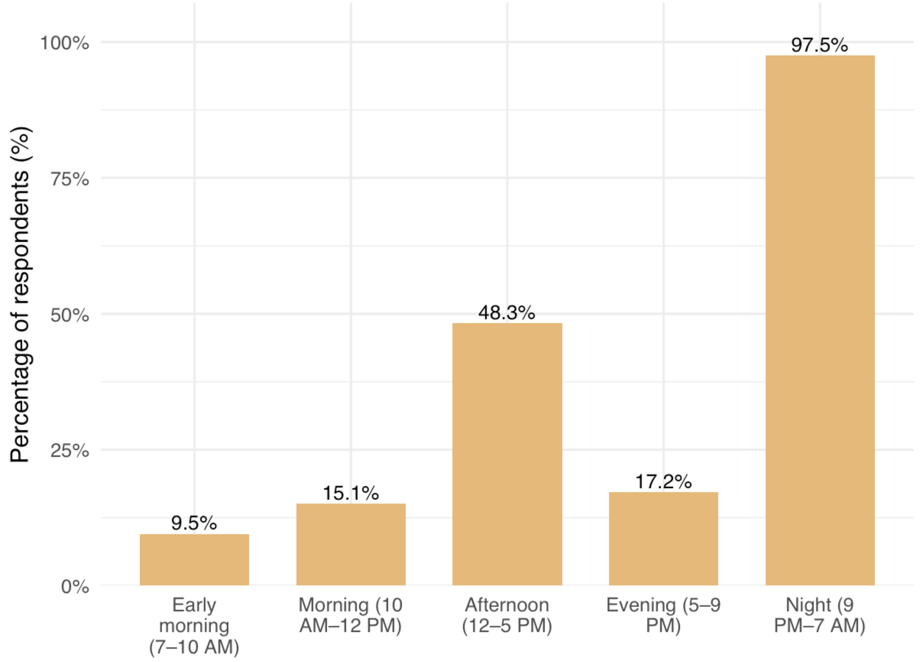


Figure 19: AC hourly usage patterns - Sample size: 714 AC owners

In terms of hourly usage, almost all respondents owning an AC report using the AC during night time (9PM to 7AM) and 50% report using it in the afternoon.

These findings highlight a critical affordability divide: coping with extreme heat is costly and the ability to adapt through increased energy consumption remains heavily constrained by household wealth. This has direct implications for equity, as poorer households bear the brunt of heat exposure while having the least financial capacity to protect themselves.

Although over 30% of the households in Delhi own an AC (NSS 2021) and 61% of households in Delhi own some sort of a cooling appliance (NFHS 2019-21), this alone is neither sufficient nor equitable as a cooling strategy. A set of broader more structural interventions can play a critical role in helping citizens cope with extreme temperatures. At a household level, these include use of improved roofing materials, cool or reflective roof coatings and insulated construction techniques such as sandwich walls while at a neighbourhood level, these include shaded networks and arcaded walkways for relief. These have been further elaborated in our policy recommendations section.

3 Outcomes: Impact on Health and Productivity

Finally, we analyse what these differences in exposure and coping capacity mean for people’s health and livelihoods. Rising temperatures correspond with increases in physical illness, mental state effects, and lost work days, demonstrating that heat is not only a discomfort but a significant public health and economic concern. The most severe impacts fall on those already facing disadvantages, highlighting heat as a structural driver of inequality with growing implications for both wellbeing and economic stability.

3.1 A 3°C increase in temperature corresponded with a 15 percentage point rise in reported illness. Further, AC ownership is associated with about an 11.6% lower incidence of heat-induced illness

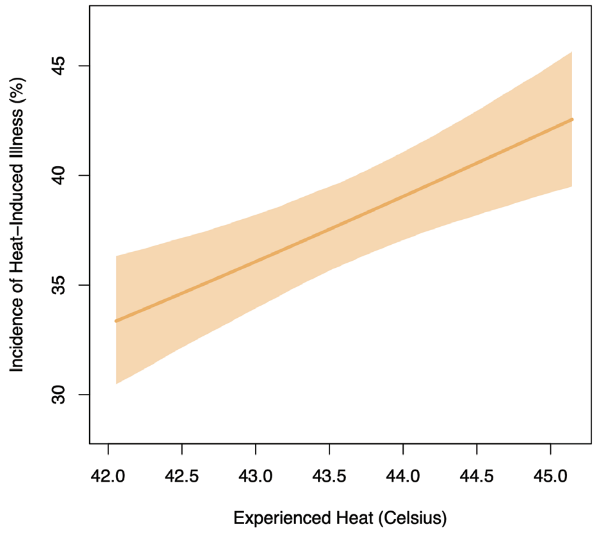


Figure 20: Relationship between self-reported days of illness and experienced heat

We observed a strong positive correlation between rising temperatures and an increased number of individuals reporting that they were ill for more than 5 days in the past month, underscoring the significant strain that heat places on overall wellbeing.

This pattern is further reflected in distributional outcomes: nearly 30% of individuals belonging to the highest heat index range reported being sick for more than five days in the last month, and over 80% of all respondents who reported illness fell within the higher heat categories (42.5 - 47°C).

Increased heat stress has direct consequences for both physical and mental health. Research[33] shows that even moderate temperature rises place significant strain on the body's physiological systems, increasing the likelihood of multiple illnesses over an extended number of days.

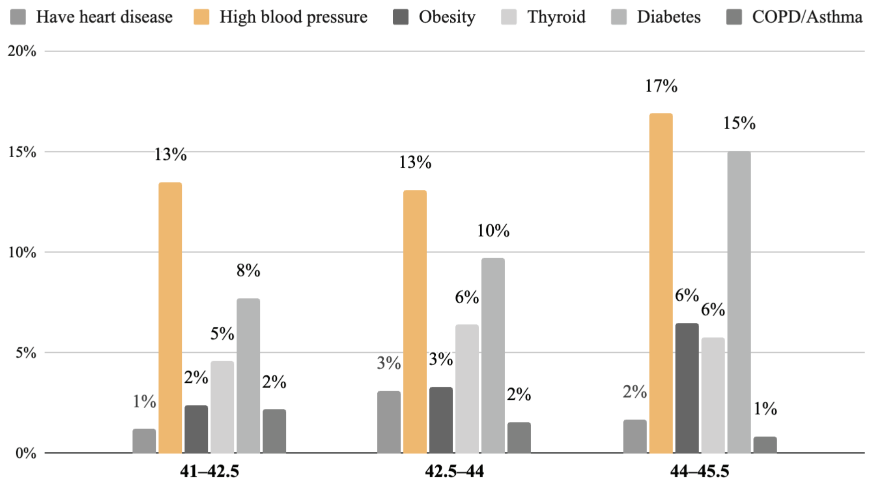


Figure 21: Medical conditions experienced across heat ranges –
41-42.5: 415, 42.5-44: 1031, 44-45.5: 710

To analyse medical conditions by heat range, we focused on the middle bands (41–45.5°C), as the lowest and highest ranges had small and non-comparable sample sizes. Our findings reveal that the prevalence of medical conditions is highest in the mid-to-high ranges (42.5 - 45.5°C), with heart disease, thyroid issues and COPD peaking in 42.5°C - 44°C and high blood pressure, obesity, and diabetes peaking in 44°C - 45.5°C. Together, these findings point to a clear concentration of heat related morbidity in hotter zones.

Failure to dissipate heat effectively disrupts the body's thermal balance, substantially elevating the likelihood of heat exhaustion and heatstroke. The physiological load of cooling the body stresses the heart and kidneys. Consequently, extreme heat aggravates chronic health[34] conditions and can trigger acute kidney injury.

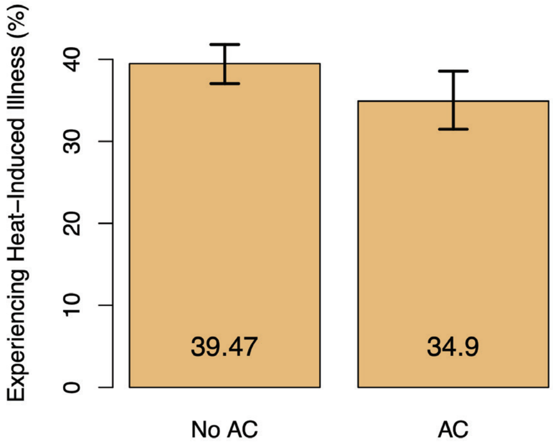


Figure 22: Incidence of self-reported illness between AC and non AC users

Coping with heat stress varies by socio-economic class, with lower-income groups unable to access[35] strategies like air conditioning and green infrastructure to better manage heat strain. AC access is also associated with lower incidence of heat-induced illness. While heat-related symptoms remain substantial for both groups, those without ACs report a noticeably higher burden (39.5% vs. 34.9%). Those owning AC report a 11.6% lower incidence of heat-induced illness. This indicates that even partial cooling or occasional use helps reduce strain during periods of high heat stress.

3.2 A 3°C increase in experienced heat shows a 10 percentage point jump in households missing work, from about 18% to nearly 28%. Further, AC owners report 18% lesser incidence of work loss compared to non-ac owners

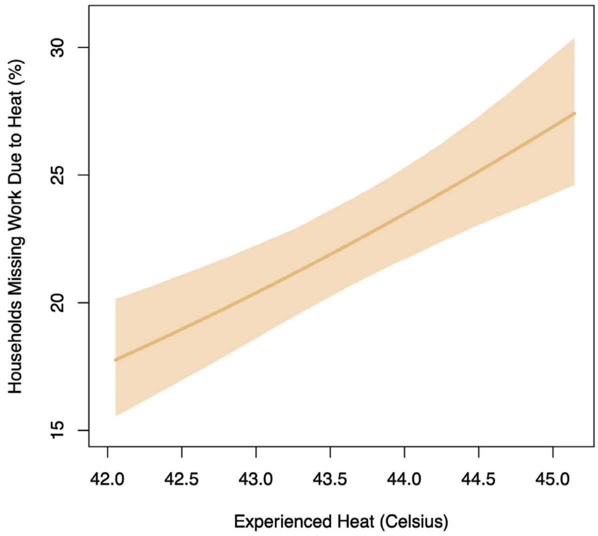


Figure 23: Relationship between households missing work due to heat and experienced heat

Our findings confirm that rising heat levels are strongly associated with higher productivity losses across households, with the number of households missing work due to heat jumping from 18% to 28% with a 3 degree rise in temperature.

More frequent and intense heat stress events linked to climate change threaten the global economy by significantly reducing worker productivity. A paper by OECD[36] shows that heat stress substantially reduces labour productivity, with ten extra days above 35°C causing around a 0.3% annual reduction in firm productivity. This impact is especially pronounced in smaller firms with lower output per worker and worsened by longer heat waves.

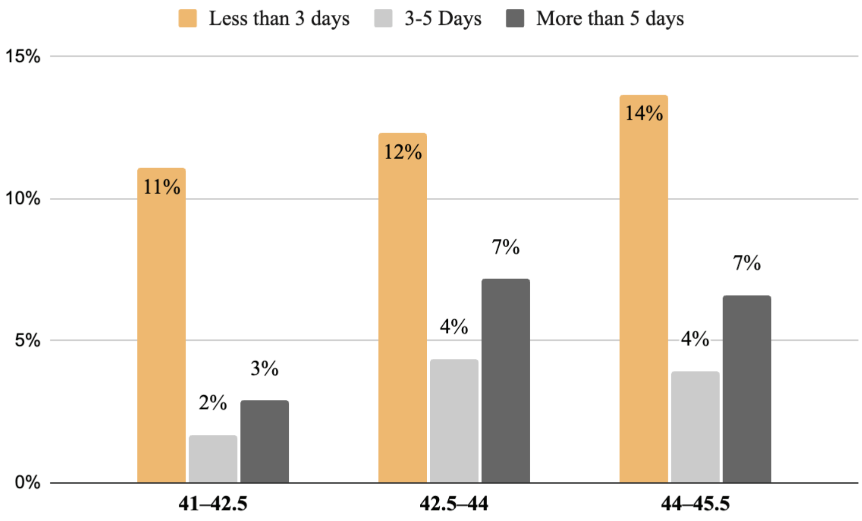
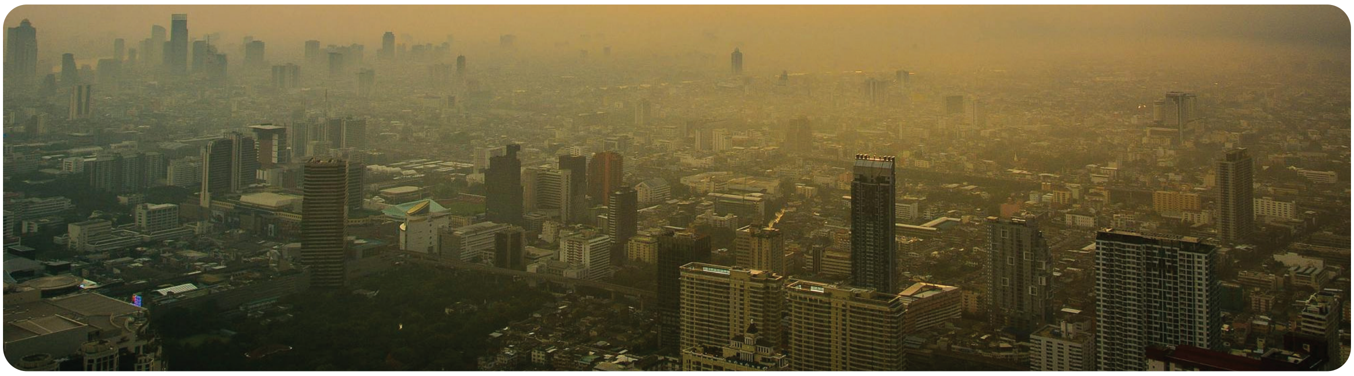


Figure 24: Days of work missed across heat ranges



Although our dataset spans temperatures from 39–47°C, we have only presented descriptive results for the middle 3 ranges as they together constitute a majority of our sample (2156) since the upper and lower heat bands have non-comparable sample sizes. Across these middle bands (41-45.5°C), we observe a clear pattern: the share of respondents reporting heat-related illness steadily rises as temperature rises. This reinforces our regression findings that experienced heat is significantly associated with reported illness.

Additionally, our survey also looked at the occupation, commute patterns and daily heat exposure levels of those reporting missed work due to extreme heat. Heat exposure is a major challenge for India's workforce with an estimated 231 million people working outdoors[37] and linked to a 10% decline in productivity[38]. Commuting patterns during peak hours[39] also significantly compound this burden.

Our findings further show that in the 45.5-47°C, a higher number of regular wage earners (31.6%) and self-employed workers (26.3%) report missing work as compared to casual labourers (18.4%), with a similar pattern in the 44–45.5°C range. In addition to that, nearly half of the respondents (47%) in the highest heat category 45.5-47°C work in the sun for over 2 hours daily and 1/3rd for over 6 hours daily. This pattern is consistent with the nature of informal[40] and self-employed work, which often involves prolonged outdoor tasks and offers limited flexibility to reduce exposure during extreme temperatures.

Again, commute duration adds to this strain. In the two highest heat bands, 52% and 68% of respondents had commutes over 30 minutes, and at 45.5–47°C, half travelled for over an hour.

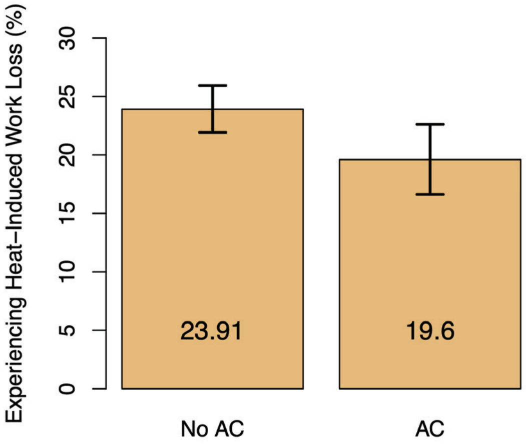


Figure 25: Incidence of heat-induced work loss between AC and non AC users

AC users experience reduced productivity losses, with heat induced work disruption falling from 23.9% among non-users to 19.6% among AC users, reporting 18% less work loss. This suggests that cooling access not only improves comfort, but also improves productivity by reducing work days lost to heat.

3.3 Respondents reporting heat-related changes in mental state jump from 15% to 30% as heat increases by 3°C.

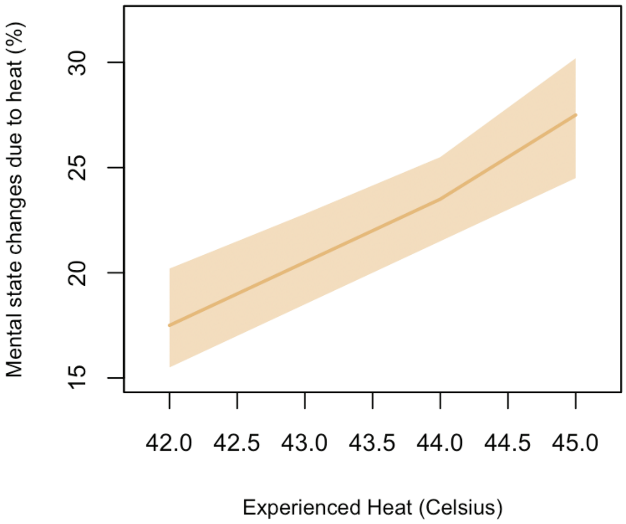


Figure 26: Relationship between noticed changes in mental state and experienced heat

Our survey asked respondents whether they had noticed a change in their mental state or mood over the past month, and the regression below shows a clear positive relationship: as experienced heat rises from about 42°C to 45°C, the share of people reporting a change in mental state increases from roughly 15% to 30%, indicating that higher heat is closely linked to worsening mental state.

Higher experienced heat is strongly associated with a rise in self-reported mental statehealth impacts. Several studies[41] have found a potential link between higher ambient temperatures and increased mental state-related morbidity in adults.

07

Policy Recommendations

Strengthening heat resilience in Indian cities requires an approach that goes beyond disaster response. As climate extremes intensify, cities like Delhi must pair scientific and spatial data with real time insights into how people experience and cope with heat.

> **Effective policy must therefore be grounded in citizen experience as well as supported by urban planning, housing design and energy systems that are responsive to extreme climate conditions.**

State heat action plans should also prioritise building basic data literacy within government teams, including the ability to interpret charts, indicators and spatial data to enable evidence-based planning and effective heat risk management. This must be supported by targeted investments in capacity building, along with improved access to relevant datasets, tools and sustained engagement with the broader climate and urban data ecosystem.

The following recommendations outline considerations for embedding heat resilience into long-term urban development and governance.

1 Micro-level heat action planning grounded in citizen-centred data

- **Micro-level Heat Action Plans backed by data on citizen experiences are needed.** India's current Heat Action Plans provide a foundation for responding to extreme heat, but their effectiveness is limited by the lack of granular, context-specific information. A micro-level approach, anchored at the ward level and extending to settlement-scale "hot pockets"- is therefore essential. Evidence from Rajkot, Varanasi, Nagpur and Delhi shows that ward-level and intra-urban mapping can reveal high-risk clusters that would otherwise remain invisible in city-level averages. These granular insights enable targeted interventions such as cool roofs, shading infrastructure, heat-health outreach, and tailored communication strategies for vulnerable communities. National guidance from the NDMA already recognises this need, recommending ward-wise mapping supported by socio-economic indicators, and further micro-targeting within high-risk areas.

- **A mechanism for rapid and routine data collection on citizen experiences and perspectives of climate change must be institutionalised:** Existing data collection mechanisms within states must be strengthened in order to collect detailed information on citizen experiences of climate change. A routine mechanism for states to monitor citizen experiences of climate change would be a critical step toward strengthening climate resilience. It is important to build capacities to institutionalise such a mechanism at the state level, and in doing so, it is crucial that the cognitive burden upon citizens, as well as the cost and time burden on states remains low. Conducting rapid surveys, which are cost-effective and quick to administer, is an effective measure that could be institutionalised to supplement existing state data systems. Shorter response times make it easier to garner citizen participation and minimise respondent fatigue. Such surveys would not only capture citizens' lived experiences but also gather valuable feedback. This could help create an essential feedback loop, enabling climate action plans to be more responsive to citizen concerns and the challenges they face.

Institutionalising rapid citizen data collection will require sustained capacity building within state statistical units, disaster management authorities and urban departments. Apart from improving familiarity with data, it includes training officials in survey design, digital data collection, data interpretation and feedback integration, as well as establishing standard operating procedures to ensure continuity across political and administrative cycles. Partnerships with academic institutions and civil society organisations can help states build these capabilities without significantly increasing costs or administrative burden.

- **Using high-resolution spatial datasets, governments can identify settlement types at a granular level and design more targeted Heat Action Plans.** Various initiatives are combining remote sensing data with machine learning algorithms to accurately detect informal settlements and guide climate-smart planning and resource allocation. These include the ESA-funded IDEAtlas[42], which is co-developing AI-based methods with municipal stakeholders, and academic research studies that map Mumbai's informal settlements[43] using Sentinel-2 imagery and whose methods can be replicated to other Indian cities.

  However, the effective use of high resolution spatial and machine learning based tools depends on building technical capacity within state and municipal governments. Dedicated training in geospatial analysis, data governance and ethical use of AI, along with institutional access to interoperable datasets, is essential to ensure these tools translate into actionable planning decisions rather than remaining pilot projects or external consultancies.

- **State Disaster Management Authorities (SDMAs), as the nodal authority, supported by Urban Local Bodies for on-ground implementation, could serve as an effective model that ensures central coordination while enabling granular reach.** In most Indian states, the SDMA is responsible for the creation of the Heat Action Plan (HAP), in collaboration with the National Disaster Management Authority and the Indian Meteorological Department, and around 120 cities and districts across 14 states[44] have prepared HAPs. A review of 37 Heat Action Plans[45] (city (9), district (13) and state (15) levels) across 18 states shows that although most plans reference State Disaster Management Authorities (SDMAs) and local bodies, the depth of local-level engagement and the clarity of institutional roles vary significantly. Assessments of city-level HAPs echo this pattern. While some cities have begun to establish intersectoral, city-wide[46] heat governance structures, such as the model seen in Delhi, this approach is not yet standard practice across the country. Strengthening Heat Action Plans will require targeted capacity building at both the SDMA and Urban Local Body levels with a particular focus on cross sector coordination.

  In Delhi[47], the SDMA plays a key role in the implementation of the Heat Action Plan, but there is a high level of interdepartmental coordination. A point of contact is designated in each relevant department to coordinate heat-response activities. Key stakeholders include the Delhi State Disaster Management Authority, Delhi State Surveillance Unit, local nongovernment organisations, community health groups, media, the health department and hospitals, and the departments responsible for labour, water and sanitation, transportation, and power supply and distribution, along with private institutions and religious organisations.

  While some states have established such a system, implementation of this model remains uneven[48], particularly with respect to coordination with ULBs. Inter-departmental coordination is often limited[49], and the flow of funds and responsibilities[50] from SDMAs to municipal bodies continues to be a major challenge, leading to fragmented or inconsistently executed heat-response actions. Strengthening this coordination, especially ensuring predictable funding, clear mandates, and accountability frameworks, is essential if HAPs are to reach vulnerable settlements effectively and act at a micro-level.

Additionally, capacity building must focus on implementation readiness, ensuring departments and ULBs have trained personnel, predictable funding flows and monitoring frameworks to translate plans into on ground action. As a first step, practical tools such as data.org's Data Maturity Assessment[51] can support key stakeholders in identifying strengths, gaps and areas of opportunities to drive action.

2 Urban planning as a core strategy for heat resilience

Delhi's urban development trajectory has been characterised by rapid densification. The challenge is not density itself, but the way density has manifested on ground. A climate sensitive approach to compact growth must incorporate multiple design considerations, including appropriate building materials, street widths that support natural airflow, continuous shading networks and balanced green cover, ensuring that dense neighbourhoods remain comfortable and liveable.

- **Balancing density with green cover and ecology considerations:** One of the findings from our analysis shows that the cooling effect of vegetation significantly outweighs the heating effect of built-up area, suggesting that strategically increasing tree cover can offset thermal impacts even in high-density environments. Planned densification that embeds vegetation as essential infrastructure is critical to reversing the intensifying urban heat island effect in Delhi.

  Additionally, the neglect of blue green infrastructure (BGI) systems has aggravated multiple urban vulnerabilities, including surface heat retention, waterlogging and declining groundwater recharge. The recent *Suitability Analysis for Blue-Green Infrastructure in Urban Area: Delhi (2025)*[52] highlights a spatially informed planning framework that identifies high potential zones across the city for targeted BGI interventions and states that the integration of wetlands, water bodies, shaded corridors and vegetation networks is essential to heat mitigation and climate adaptation.

  Although BGI principles feature in the Master Plan for Delhi 2041[53], implementation remains fragmented. Integrating the BGISM (Blue Green Infrastructure and Service Model) into zoning and redevelopment decisions offers a replicable tool for strengthening ecological resilience while supporting climate comfort. In parallel, sustained maintenance of Delhi's extensive park network is necessary to ensure continued cooling benefits rather than lost assets.

- **Urban form, materials and street design:** Regulations for urban form, including building height controls, street widths, land use distribution and material used, all contribute directly to the Urban Heat Island Effect.

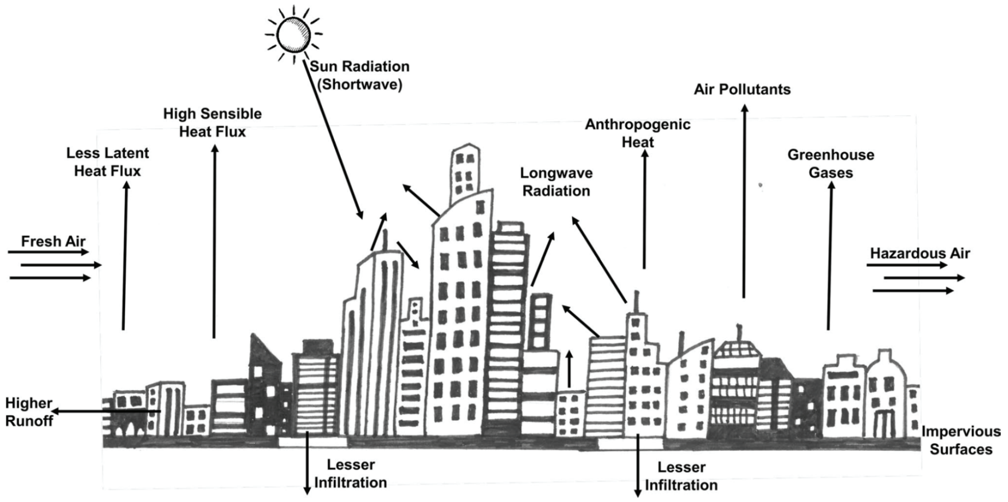


Figure 27: Urban form contributing to the heat island effect[54]
Source: Discover cities - Urban eat island effect in India

Wider, well-oriented road networks improve airflow, reduce canyoning effects[55] and reduce trapped heat, while the adoption of permeable and reflective paving[56] reduces surface heat absorption and supports stormwater management under increasingly variable rainfall conditions (essential for the increasing rainfall now experienced in Delhi[57]). Compact urban development[58] must incorporate mixed-use zoning allowing residential, commercial and institutional uses to coexist, thereby reducing commuting distances and heat exposure.

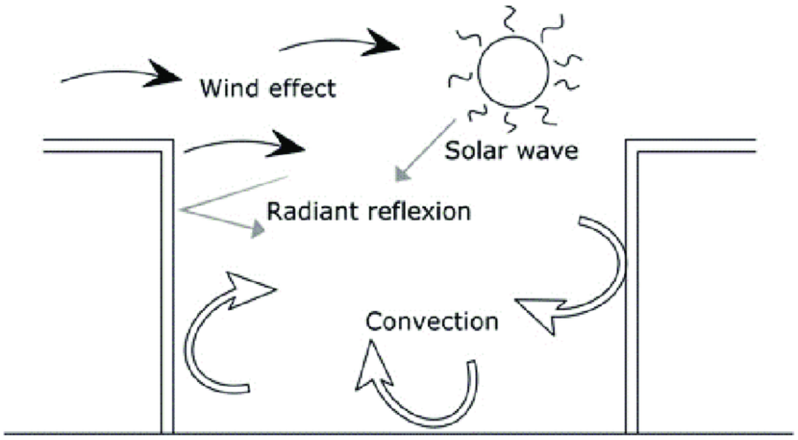


Figure 28: Heat transfer in an urban canyon: between two buildings[59]
Source: Cuadernos de Investigación Urbanística

- **Neighbourhood level interventions:** Neighbourhood scale interventions offer immediate and scalable pathways to reduce heat exposure especially for pedestrian and transit users. Designing continuous shade networks across sidewalks, bus corridors and metro routes significantly lowers direct heat stress and supports mobility during peak heat hours. Similar models have been implemented in high-temperature cities globally, where intersection shading structures[60] and transit cooling zones[61] reduce street level exposure. Another potential key intervention is arcaded walkways[62] (covered pedestrian paths built into building frontages that provide continuous shade along commercial and transit corridors). By reducing direct sun exposure, they enable comfortable movement even during peak heat.

Figure 29: Canopy installed at the traffic signal[63]/ junction at Puthur Road in Tiruchi, Tamil Nadu

Source: The Hindu

- **Housing and Architectural Typologies:** Housing form and material choice are central to shaping indoor heat exposure. Climate-responsive architecture[64], including passive ventilation, reflective coatings, insulated wall assemblies, cool roofs, vertical gardens and terrace vegetation, must become standard practice in both formal and informal settings. For informal settlements, low-cost retrofits such as layered roofing, reflective paints and modular shading[65] offer substantial cooling benefits without the socio-economic costs associated with relocation. There is an urgent need to promote innovation in building technologies (like 3D printing[66]) and affordable materials (like fiber reinforced cement[67]) that enable heat-resilient construction at scale, alongside government-led guidance and public awareness to support adoption of these solutions. Formulating typology based guidelines can ensure that heat-resilient design is implemented across varying built forms, including high-rise, mid-rise, plotted housing and informal clusters.

3 Energy management and appliance design

Rising urban temperatures are reshaping electricity demand patterns, particularly through increased and more concentrated and unpredictable cooling loads during extreme heat events. Managing this shift requires integrating appliance efficiency with heatwave scenarios, hourly cooling demand and spatial patterns of exposure into energy system planning.

- **Heatwaves, hourly cooling demand and grid stress:** As temperatures rise and cooling becomes a necessity rather than a luxury, India's electricity grid[68], especially in cities like Delhi, are facing unprecedented stress. The rapid expansion of AC ownership[69] is already reshaping peak demand curves. Without proactive planning, heatwaves could trigger frequent outages and widen existing inequalities in access to reliable electricity.

  Smarter, data-driven energy management is therefore critical. The hourly cooling appliance usage patterns captured in our survey provide valuable insight into when and how households consume electricity during hot periods. These data points can help DISCOMs model peak demand more accurately, design time-of-use tariffs that shift consumption away from critical hours and assess how heatwaves amplify short-term load relative to average conditions.

  Importantly, India already has a foundation for integrating heatwave scenarios into energy planning. Current forecasting systems developed by the India Meteorological Department (IMD) incorporate heatwave prediction through numerical weather prediction models, multi-model ensembles and extended-range forecasts[70] of up to two weeks. These forecasts assess not only daytime temperatures, but also nighttime heat, humidity, duration and regional vulnerability, inputs that are already used in Heat Action Plans to anticipate impacts across health, power and agriculture sectors. IMD's growing focus on compound and recurring events, such as back to back or "double" heatwaves in north-western India, provides a basis for linking meteorological forecasts with short-term electricity demand surges during extreme heat.

  Equally important is recognising that informal and formal neighbourhoods experience and respond to heat very differently. Integrating and researching geospatial datasets into load forecasting[71] would allow utilities to plan infrastructure where need is greatest, rather than simply where consumption is already high.

  From a renewable energy perspective, this opens the opportunity to build local solar generation capacity to meet the cooling requirements of underserved settlements (supported by targeted incentives). When designed well, such systems can even generate surplus energy that feeds back into the grid, strengthening resilience city wide. In this way, energy policy becomes not only a technical exercise but a pathway towards more climate responsive and socially equitable urban planning.

- **Appliance efficiency and design:** The design of appliances, as well as the regulations that govern their use, can be an effective tool for managing energy consumption and management. The India Cooling Action Plan[72] identifies improved air conditioner (AC) efficiency as a key strategy for limiting future cooling demand. Larger cooling systems can be made significantly less carbon intensive too through their design. Singapore's largest district cooling system[73] yet will also be its most energy efficient, with the potential to reduce emissions by 120,000 tonnes per year.

- **Increasing the default temperature setting of air conditioners can significantly reduce energy use.** The Bureau of Energy Efficiency (BEE) estimates that increasing an AC's set temperature by 1°C[74] can reduce electricity consumption by about 6 percent. Adjusting default temperatures also helps reduce evening peak loads[75], which eases pressure on the grid and limits the need for additional generation capacity as AC penetration rises. Along with reducing default AC settings—such as the BEE mandate to 24°C in 2020[76]), raising the minimum temperature at which an AC can operate can further reduce energy consumption. A new temperature band of 20–28°C[77] is currently under discussion as the proposed minimum and maximum setting for air conditioners. A higher minimum temperature also reduces the risk of refrigerant leakage[78], preventing the release of greenhouse gases. Policies can use the star-rating system to reward AC models that support higher temperature settings.

  The BEE periodically revises[79] energy efficiency ratings, to progressively improve efficiency levels. This means that what would correspond to one star efficiency today might be deemed to be below the minimum standard at a later date. To incentivise higher efficiency, it would be useful to pre-announce future star bands, ensuring that a present day 5-star rating becomes a 3-star rating in the future.

- **Financing Efficiency:** A study found that 70 to 75[80] per cent of households are aware of the star label and express a preference for efficient air conditioners, but only about 14 per cent ultimately purchase 4 or 5 star models because of their higher cost. To address this, star ratings can be used as the basis for concessional finance and targeted subsidies that enable low-income and lower-middle-income households to adopt efficient AC units. Governments can also introduce incentives for first-time AC buyers in hot, low-income urban areas, tied to the purchase of higher efficiency ACs.

  A "super-efficient[81]" tier could potentially be introduced, above the existing 5-star rating, by creating a voluntary band, such as 5+, for air conditioners that achieve very high Indian Seasonal Energy Efficiency Ratio (ISEER) and use low global-warming-potential (GWP) refrigerants. This tier should be supported through industrial incentives, including tax benefits or Production Linked Incentive (PLI) schemes, to encourage manufacturers to produce and promote the most efficient and environmentally friendly models.

In addition, any public or multilateral utility demand-side management programme, including DISCOM-run AC replacement schemes, should phase out support for 1 and 2 star models and provide larger rebates for higher star levels, with incentives front-loaded where potential grid relief is greatest.

- **Research[82] on label preferences in India shows that energy labels strongly influence purchase decisions when consumers trust them and find them easy to interpret.** Current star labels display an annual kWh estimate based on assumed average usage hours, but actual consumption varies widely across cities and climates. Providing clearer and more contextual information on the label can help guide better consumer choices.

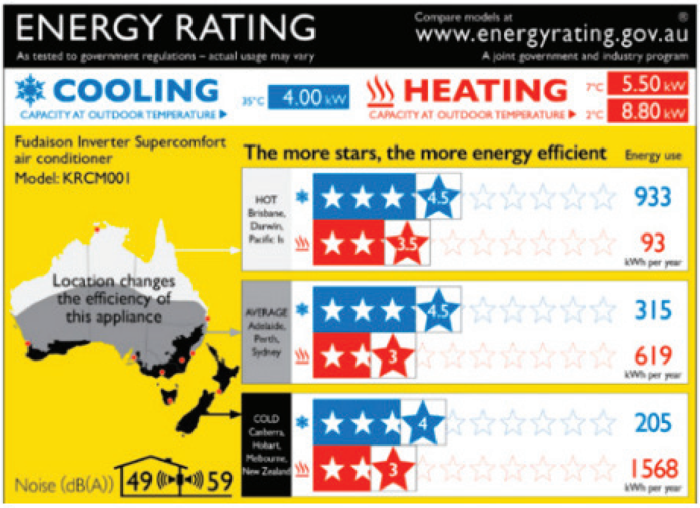


Figure 30: Energy efficiency labels in Australia

In Australia[83], for instance, labels display estimated energy consumptions for various regions, allowing consumers to have a more realistic understanding of their estimated energy use. A study of energy efficiency labels in the United States too found that state-specific[84] labels lead to a decrease in the lifetime cost of air conditioning.

- **Designing cooling solutions for Indian conditions:** Designing air conditioners for greater energy efficiency in India primarily involves improving the internal hardware[85], optimising systems for Indian weather, and incorporating smarter controls.

High-efficiency[86], variable-speed (inverter) compressors, larger and better-designed heat exchangers, and electronic expansion valves can substantially reduce electricity use while maintaining or enhancing comfort. Optimizing ACs[87] for the Indian Seasonal Energy Efficiency Ratio (ISEER) and for very high outdoor temperatures (40–45°C) would ensure efficient performance under real Indian conditions rather than only under mild laboratory test points.

Switching to low GWP refrigerants[88] and redesigning the refrigerant circuits around them can enable improvements in efficiency and reduced climate impact. Features such as adaptive “eco/comfort” modes that maintain temperatures around 24–26°C, improved sensors and algorithms to prevent over-cooling, and user interfaces that indicate approximate energy use or cost at different set-points could help consumers operate ACs more efficiently in everyday use. These measures have been combined to create ‘super efficient ACs’ which have been shown to achieve

30–40 percent or more efficiency improvements[90], often at costs lower than generating the same energy from new capacity.

As cooling demand diversifies, efficiency policies must extend beyond room ACs to include chillers, Variant Refrigerant Flow (VRF[91]) systems, ducted and packaged units and rooftop systems. This will require standardised test procedures, expanded testing capacity, new efficiency metrics and closer integration of appliance standards with building codes and urban energy planning.

- **Grid investment and international context:** Rising cooling demand also has major implications for grid investment and finance. An IEA analysis finds that digitalisation and flexible-load strategies could reduce peak demand by around 13% by 2030[92], but achieving this requires substantial investment in modernising distribution networks. Indian cities are projected to need $2.4 trillion by 2050[93] for resilient infrastructure, including heat mitigation measures that could boost GDP and save lives.

  India's position in international climate negotiations reflects these realities. Citing low current AC penetration and the need to protect cooling access, India declined the COP28 pledge[94] and continues to emphasise its Cooling Action Plan, which targets a 20–25 percent reduction in cooling demand by 2038 through context-specific solutions. At COP30[95], India has also highlighted the need for adaptation finance, particularly grant-based funding, to support grid upgrades and manage heat driven peak demand without worsening inequality.

  Capacity building for energy management should focus on equipping DISCOMs, urban planners and state energy departments with the interdisciplinary skills to integrate heatwave forecasts, cooling demand data and appliance efficiency insights into grid planning, tariff design and demand-side interventions with specific targeted investments to do the same.

08

Road Ahead

The next stage of this work is to scale the approach across cities with differing micro-climates, built forms and patterns of citizen experience.

> **Applying the same integrated methodology—combining geospatial data with rapid household surveys—in cities with varied densities, vegetation profiles and exposure patterns will allow a clearer understanding of how heat risk manifests differently across contexts.**

This will help inform a broader strategy for heat resilience that is comparable across India and, over time, across global cities facing similar conditions.

To support this, the study will develop a replicable survey instrument and field protocol for collecting data on heat exposure, energy use and coping behaviour. In parallel, anonymised microdata, geospatial layers, model code and a full replication package will be made publicly available to enable adaptation in other South Asian cities. Together, these steps aim to build a consistent evidence base that supports comparative analysis, informs policy design and strengthens the capacity of cities to respond to rising heat. Alongside developing tools and datasets, targeted capacity building initiatives will equip municipal authorities, disaster management teams and local stakeholders with the skills to interpret data, implement heat-response actions and institutionalise best practices.

09

Appendix

Survey Instrument

A. Demographics

What is your age? Select one	☐ Under 18 years ☐ 18–24 years ☐ 25–34 years ☐ 35–44 years ☐ 45–59 years ☐ Over 60 years
What is your gender? Select one	☐ Male ☐ Female ☐ Non-binary (Other) ☐ Prefer not to say
What is your religion? Select one	☐ Muslim ☐ Hindu ☐ Christian ☐ Buddhist ☐ Sikh ☐ Jain ☐ No Religion ☐ Prefer not to answer ☐ Other
Which social category do you belong to? Select one	☐ SC ☐ ST ☐ OBC ☐ General ☐ No caste ☐ Prefer not to answer

Including yourself, how many people live in your household? Insert number	
What kind of work are you engaged in? Select one	☐ Regular wage/salary earning ☐ Self-employed ☐ Casual labour ☐ Housewife ☐ Unemployed ☐ Retired ☐ Others
NSS/ PLFS (1 digit code) Insert number	
If you work outside the home, how long is your commute to work? Select one	☐ Don't work outside the house ☐ Less than 30 mins ☐ 30-60 mins ☐ Over 60 mins
If you work outside the home, what conveyance(s) do you use to get to work? Select multiple	☐ Walk ☐ Bus ☐ Train ☐ Metro ☐ Auto Rickshaw ☐ Taxi/ Ride share ☐ Two-wheeler (Cycle, scooter) ☐ Private car
On an average, how many hours in a day do you spend working outdoors in the heat (direct heat)? Select one	☐ Don't work in direct heat ☐ Less than 2 ☐ 2-4 hours ☐ 4-6 hours ☐ Over 6 hours

B. Energy Consumption

Which of the following does your household own? Select multiple	☐ Television ☐ Electric Fan ☐ Air Conditioner ☐ Cooler ☐ Microwave/ Oven ☐ Water purifier ☐ Refrigerator ☐ Geyser ☐ Bicycle ☐ Motorised Two-wheeler ☐ Washing Machine ☐ Laptop/Computer ☐ Car/Four-wheeler/Six or Eight wheeler

Electric Fan

Do you own an electric fan? Select one	☐ Yes ☐ No
***If yes:* How many electric fans do you have in your household?** Select one	☐ One ☐ Two ☐ Three ☐ More than 4
***If yes:* What is the star rating of your electric fan/s?** Select one	☐ Under 3 stars ☐ 3 stars ☐ 4 stars ☐ 5 stars ☐ Don't know
***If yes:* During which part of the day do you keep your electric fan on?** Select multiple	☐ Early morning (7 AM to 10AM) ☐ Morning (10 AM to 12 PM) ☐ Afternoon (12 PM to 5 PM) ☐ Evening (5 PM to 9 PM) ☐ Night (9 PM to 7 AM)

Air Conditioner

Do you own an air conditioner (AC)? Select one	☐ Yes ☐ No
***If yes:* How many air conditioners (ACs) do you have in your household?** Select one	☐ One ☐ Two ☐ Three ☐ More than 4
***If yes:* What is the star rating of your air conditioner/s (AC)?** Select one	☐ Under 3 stars ☐ 3 stars ☐ 4 stars ☐ 5 stars ☐ Don’t know
***If yes:* During which part of the day do you keep your air conditioner/s (ACs) on?** Select multiple	☐ Early morning (7 AM to 10AM) ☐ Morning (10 AM to 12 PM) ☐ Afternoon (12 PM to 5 PM) ☐ Evening (5 PM to 9 PM) ☐ Night (9 PM to 7 AM)

Air Conditioner

Do you own a cooler? Select one	☐ Yes ☐ No
***If yes:* How many coolers do you have in your household?** Select one	☐ One ☐ Two ☐ Three ☐ More than 4
***If yes:* During which part of the day do you keep your electric fan on?** Select multiple	☐ Early morning (7 AM to 10AM) ☐ Morning (10 AM to 12 PM) ☐ Afternoon (12 PM to 5 PM) ☐ Evening (5 PM to 9 PM) ☐ Night (9 PM to 7 AM)

Geyser

Do you own a geyser? Select one	☐ Yes ☐ No
***If yes:* How many geysers do you have in your household?** Select one	☐ One ☐ Two ☐ Three ☐ More than 4
***If yes:* What is the star rating of your geyser/s?** Select one	☐ Under 3 stars ☐ 3 stars ☐ 4 stars ☐ 5 stars ☐ Don’t know

Refrigerator

Do you own a refrigerator? Select one	☐ Yes ☐ No
***If yes:* What is the star rating of your refrigerator/s?** Select one	☐ One ☐ Two ☐ Three ☐ More than 4
Do you switch off your fridge at any point in the day? Select one	☐ Yes ☐ No

C. Climate Change Awareness

Is climate change impacting you? Select one	☐ Significantly ☐ Moderately ☐ Slightly ☐ Not at all
Which specific aspect of climate change is having the greatest impact on you? Select multiple	☐ Rising temperatures ☐ Erratic rainfall patters ☐ Water shortage ☐ Poor air quality ☐ Flooding ☐ Droughts ☐ Depleting soil quality ☐ Others (no need to please specify) ☐ No significant impact

D. Heat Impact

In the past month, have you or anyone in your household experienced illness, such fever, vomiting, headache, or dizziness, due to extreme heat? Select one	☐ Yes, more than 5 days in the last month ☐ Yes, but fewer than 5 days in the last month ☐ No, not at all
Do you have any of these medical conditions? Select multiple	☐ Heart disease ☐ High blood pressure ☐ Obesity ☐ Thyroid ☐ Diabetes ☐ COPD/Asthma ☐ Arthritis/ bone or joint pain ☐ Other
Do you notice any changes to your mental state or mood during extreme heat? Select one	☐ Yes ☐ No ☐ Have not noticed

Does excess heat make it harder for you to do your work/ complete your tasks? Select one	☐ Yes ☐ No
In the past month, how many days of work did you miss due to extreme heat? Select one	☐ Did not miss work ☐ Less than 3 days ☐ 3-5 Days ☐ More than 5 days
Is there an increase in your energy bills during excess heat? Select one	☐ Yes ☐ No ☐ Don’t know
How would you rate your sleep quality at night during conditions of excess heat? Select one	☐ Very poor - struggle to sleep ☐ Poor - feel unrested ☐ Fair - slightly disturbed but manageable ☐ Good - get disturbed sometimes but mostly restful ☐ Very good - no impact on sleep quality

E. Questions for the enumerator

Assembly constituency number Insert number	
Polling booth number Insert number	
CA number Insert number	
Is there green cover on the house? Select one	☐ None ☐ Partial ☐ Significant
Is the person living on the top floor? Select one	☐ Yes ☐ No
Is the approach road to the house motorable? Select one	☐ Yes ☐ No

Endnotes

1. Burning point: Increasing heatwaves threaten lives across India. (n.d.). TERI. https://www.teriin.org/article/burning-point-increasing-heatwaves-threaten-lives-across-india
2. Burning point: Increasing heatwaves threaten lives across India. (n.d.). TERI. https://www.teriin.org/article/burning-point-increasing-heatwaves-threaten-lives-across-india
3. Shah, A., Sugathan, A., Malghan, D., Kim, R., & Subramanian, S. V. (2025). Spatiotemporal changes in heat stress exposure in India, 1981-2023. Nature Communications, 16(1), 9496. https://doi.org/10.1038/s41467-025-64840-x
4. India reports over 40,000 suspected heatstroke cases over summer. (2024, June 19). Reuters. https://www.reuters.com/world/india/un-relenting-heatwave-kills-five-indian-capital-2024-06-19/?utm_source=chatgpt.com
5. Council on Energy, Environment and Water. (n.d.). How extreme heat is impacting India: Assessing District-level Heat Risk. In CEEW. https://www.ceew.in/publications/mapping-climate-risks-and-impacts-of-extreme-heatwave-disaster-in-indian-districts
6. Dutta, S. (2024, May 30). India's power demand hits new peak at 250 gigawatts. The Times of India. https://timesofindia.indiatimes.com/india/indias-power-demand-hits-new-peak-at-250-gigawatts/articleshow/110572267.cms?utm_source=chatgpt.com
7. Kouamé, A. T. (2024, January 30). Gearing up for India's Rapid Urban Transformation. World Bank. https://www.worldbank.org/en/news/opinion/2024/01/30/gearing-up-for-india-s-rapid-urban-transformation
8. Jairaj, B. (n.d.). Buildings are a hidden source of Indian cities' extreme heat. World Resources Institute. https://www.wri.org/insights/buildings-are-hidden-source-indian-cities-extreme-heat
9. Prabhu, S., Anthikat Suresh, K., Mandal, S., Sharma, D., Chitale, V., & Council on Energy, Environment and Water. (2025). How Extreme Heat is Impacting India: Assessing District-level Heat Risk [Report]. Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/ceew-how-extreme-heat-is-impacting-india-final-web-file.pdf
10. Mackres, E. (n.d.). As the Earth Gets Hotter, Can Our Cities Get Cooler? World Resources Institute. https://www.wri.org/insights/earth-gets-hotter-cool-cities-infrastructure-solutions
11. Mackres, E. (n.d.-a). As the Earth Gets Hotter, Can Our Cities Get Cooler? World Resources Institute. https://www.wri.org/insights/earth-gets-hotter-cool-cities-infrastructure-solutions
12. Delhi Disaster Management Authority & Govt. of NCT of Delhi. (n.d.). Delhi Heat Action Plan 2024-25. In Guidelines U/S 18 (2) (H) of Disaster Management Act, 2005 for Prevention, Mitigation, Capacity Building and Preparedness to Combat the Adverse Impact of Heat Waves in Delhi (p. 2) [Report]. https://ddma.delhi.gov.in/sites/default/files/ddma/generic_multiple_files/final_hap_12.04.2024.pdf
13. Prabhu, S., Anthikat Suresh, K., Mandal, S., Sharma, D., Chitale, V., & Council on Energy, Environment and Water. (2025). How Extreme Heat is Impacting India: Assessing District-level Heat Risk [Report]. Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/ceew-how-extreme-heat-is-impacting-india-final-web-file.pdf
14. Prabhu, S., Anthikat Suresh, K., Mandal, S., Sharma, D., Chitale, V., & Council on Energy, Environment and Water. (2025). How Extreme Heat is Impacting India: Assessing District-level Heat Risk [Report]. Council on Energy, Environment and Water. https://www.ceew.in/sites/default/files/ceew-how-extreme-heat-is-impacting-india-final-web-file.pdf
15. Integrated Research and Action for Development & International Development Research Centre, Government of Canada (IDRC). (2020). Heat wave Action Plan- Rajkot City. Integrated Research and Action for Development (IRADe). https://irade.org/Rajkot-Heat-Action-Plan.pdf
16. Department of Medical Health & Family Welfare Government of Uttar Pradesh, Varanasi Nagar Nigam, NRDC, Indian Institute of Public Health, & Mahila Housing Trust. (n.d.). Varanasi Heat Action Plan.
17. Pillai, A. V., Dalal, T., & Centre for Policy Research. (2023). An Assessment of Heat Action Plans With Insights for Transformative Climate Action https://cprindia.org/wp-content/uploads/2023/03/Heat-Report_27March-23_Updated-Table.pdf
18. National Disaster Management Authority, Ministry of Home Affairs, Government of India. (n.d.). Beating the Heat: How India Successfully Reduced Mortality Due to Heat Waves.
19. Kotharkar, R., Ghosh, A., & Keskar, R. (2025). Fine-scale mapping of heat-hazard risk and vulnerability using geo-spatial techniques: Insights from a tropical Indian city. Geographica Pannonica, 29(2), 84–107. https://doi.org/10.5937/gp29-56164
20. Azhar, G., Saha, S., Ganguly, P., Mavalankar, D., & Madrigano, J. (2017). Heat wave vulnerability mapping for India. International Journal of Environmental Research and Public Health, 14(4), 357. https://doi.org/10.3390/ijerph14040357
21. Heat stress risk at an intra-urban level: A case study of Delhi, India. (2024). Building and Environment, 264. https://doi.org/10.1016/j.buildenv.2024.111897
22. Kotharkar, R., Ghosh, A., & Keskar, R. (2025). Fine-scale mapping of heat-hazard risk and vulnerability using geo-spatial techniques: Insights from a tropical Indian city. Geographica Pannonica, 29(2), 84–107. https://doi.org/10.5937/gp29-56164
23. Jairaj, B. (n.d.). Buildings are a hidden source of Indian cities' extreme heat. World Resources Institute. https://www.wri.org/insights/buildings-are-hidden-source-indian-cities-extreme-heat
24. Jairaj, B. (n.d.). Buildings are a hidden source of Indian cities' extreme heat. World Resources Institute. https://www.wri.org/insights/buildings-are-hidden-source-indian-cities-extreme-heat

25. Bertaud, A. (2014). Cities as Labour Markets. In Working Paper #2 / FEBRUARY 19, 2014.

26. Boston Consulting Group. (2023). Cities of the Future: Reimagining and Rejuvenating India's Top 50 Urban Ecosystems. https://www.bcg.com/publications/2023/india-cities-of-the-future

27. The role of urban green spaces in Mitigating the urban heat island Effect: A Systematic review from the perspective of types and mechanisms. (n.d.). Department of Life Sciences, Beijing Normal-Hong Kong Baptist University, Zhuhai 519087, China. https://www.mdpi.com/2071-1050/17/13/6132

28. The role of urban green spaces in Mitigating the urban heat island Effect: A Systematic review from the perspective of types and mechanisms. (n.d.). Department of Life Sciences, Beijing Normal-Hong Kong Baptist University, Zhuhai 519087, China. https://www.mdpi.com/2071-1050/17/13/6132

29. Urban greenery distribution and its heat mitigation effect on outdoor jogging activities. (2025). Urban Forestry & Urban Greening, 104. https://doi.org/10.1016/j.ufug.2024.128655

30. Cities are warming 29% faster than rural areas. Could urban greening fix this? (2022). World Economic Forum. Retrieved November 10, 2025, from https://www.weforum.org/stories/2022/10/cities-heat-urban-greening/

31. The impact of sleep on health and well-being. (n.d.). Mental Health Foundation. https://www.mentalhealth.org.uk/explore-mental-health/publications/sleep-matters-impact-sleep-health-and-wellbeing

32. A systematic review of ambient heat and sleep in a warming climate. (2024). Sleep Medicine Reviews, 75. https://www.sciencedirect.com/science/article/pii/S1087079224000194

33. Oppermann, E., Kjellstrom, T., Lemke, B., Otto, M., & Lee, J. K. W. (2021). Establishing intensifying chronic exposure to extreme heat as a slow onset event with implications for health, wellbeing, productivity, society and economy. Current Opinion in Environmental Sustainability, 50, 225–235. https://doi.org/10.1016/j.cosust.2021.04.006

34. World Health Organization: WHO. (2024, May 28). Heat and health. https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health

35. Berger, T., Chundeli, F. A., Pandey, R. U., Jain, M., Tarafdar, A. K., & Ramamurthy, A. (2022). Low-income residents' strategies to cope with urban heat. Land Use Policy, 119, 106192. https://doi.org/10.1016/j.landusepol.2022.106192

36. Costa, H., Franco, G., Unsal, F., Mudigonda, S., Caldas, M. P., & OECD Economics Department. (2024). The heat is on: Heat stress, productivity and adaptation among firms (No. 1828). https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/12/the-heat-is-on-heat-stress-productivity-and-adaptation-among-firms_07b86e8b/19d94638-en.pdf

37. Jha, A., & Kishore, R. (2024, May 29). 49% of Indian workers are employed outdoors in scorching heat | India News. Hindustan Times. https://www.hindustantimes.com/india-news/49-of-indian-workers-are-employed-outdoors-in-scorching-heat-101651514183004.html

38. Pti. (2025, October 31). India's migrant workers face 10% productivity loss due to heat stress over past 4 decades: Study. The Economic Times. https://economictimes.indiatimes.com/news/india/indias-migrant-workers-face-10-productivity-loss-due-to-heat-stress-over-past-4-decades-study/articleshow/124989473.cms?from=mdr

39. Impact of heat stress on labor productivity and decent work - Perry World House. (2025, February 18). Perry World House. https://perryworldhouse.upenn.edu/news-and-insight/impact-of-heat-stress-on-labor-productivity-and-decent-work/#:~:text=For%20workers%2C%20exposure%20to%20extreme%20heat%20can,hours.%20For%20economies%2C%20it%20threatens%20their%20productivity.

40. Costa, H., Franco, G., Unsal, F., Mudigonda, S., Caldas, M. P., & OECD Economics Department. (2024b). The heat is on: Heat stress, productivity and adaptation among firms (No. 1828). https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/12/the-heat-is-on-heat-stress-productivity-and-adaptation-among-firms_07b86e8b/19d94638-en.pdf

41. Liu, J., Varghese, B. M., Hansen, A., Xiang, J., Zhang, Y., Dear, K., Gourley, M., Driscoll, T., Morgan, G., Capon, A., & Bi, P. (2021). Is there an association between hot weather and poor mental health outcomes? A systematic review and meta-analysis. Environment International, 153, 106533. https://doi.org/10.1016/j.envint.2021.106533

42. Ideatlas.eu. (2025, June 18). Home - ideatlas.eu. https://ideatlas.eu/

43. Peng, F., Lu, W., Hu, Y., & Jiang, L. (2023). Mapping slums in Mumbai, India, using Sentinel-2 imagery: Evaluating Composite Slum Spectral indices (CSSIs). Remote Sensing, 15(19), 4671. https://doi.org/10.3390/rs15194671

44. National Disaster Management Authority, Ministry of Home Affairs, Government of India. (n.d.). Beating the Heat: How India Successfully Reduced Mortality Due to Heat Waves.

45. Pillai, A. V., Dalal, T., & Centre for Policy Research. (2023b). An Assessment of Heat Action Plans With Insights for Transformative Climate Action. https://cprindia.org/wp-content/uploads/2023/03/Heat-Report_27March-23_Updated-Table.pdf

46. https://ijmr.org.in/heat-action-plans-in-eight-indian-cities-knowledge-gaps-opportunities-for-intersectoral-heat-governance/

47. Delhi Disaster Management Authority & Govt. of NCT of Delhi. (n.d.-c). Delhi Heat Action Plan 2024-25. In Guidelines U/S 18 (2) (H) of Disaster Management Act, 2005 for Prevention, Mitigation, Capacity Building and Preparedness to Combat the Adverse Impact of Heat Waves in Delhi (p. 2) [Report]. https://ddma.delhi.gov.in/sites/default/files/ddma/generic_multiple_files/final_hap_12.04.2024.pdf

48. Pillai, A. V., Dalal, T., & Centre for Policy Research. (2023c). An Assessment of Heat Action Plans With Insights for Transformative Climate Action. https://cprindia.org/wp-content/uploads/2023/03/Heat-Report_27March-23_Updated-Table.pdf

49. Singh, C., Vyas, D., Patil, S., Ranjit, N., Poonacha, P., & Surampally, S. (2024). How are Indian cities adapting to extreme heat? Insights on heat risk governance and incremental adaptation from ten urban Heat Action Plans. PLOS Climate, 3(11), e0000484. https://doi.org/10.1371/journal.pclm.0000484

50. Pillai, A. V., Dalal, T., & Centre for Policy Research. (2023d). An Assessment of Heat Action Plans With Insights for Transformative Climate Action. https://cprindia.org/wp-content/uploads/2023/03/Heat-Report_27March-23_Updated-Table.pdf

51. https://data.org/dma/
52. Goyal, K., & Biswas, R. (2025). Suitability analysis for Blue Green Infrastructure in urban area: Delhi. Innovative Infrastructure Solutions, 10(11). https://doi.org/10.1007/s41062-025-02334-x
53. Master Plan for Delhi - 2041 (Draft) | DDA. (n.d.). https://dda.gov.in/master-plan-delhi-2041-draft
54. Islam, S., Karipot, A., Bhawar, R., Sinha, P., Kedia, S., & Khare, M. (2024). Urban heat island effect in India: a review of current status, impact and mitigation strategies. Discover Cities, 1(1). https://doi.org/10.1007/s44327-024-00033-3
55. Kanakiya, R. S., Singh, S. K., Mehta, P. M., & International Science Congress Association. (2015). Urban Canyon modelling: A need for the design of future Indian cities. In International Research Journal of Environment Sciences (Vols. 4–7, pp. 86–95) [Journal-article]. International Science Congress Association. https://www.isca.me/IJENS/Archive/v4/i7/14.ISCA-IRJEvS-2015-109.pdf
56. The use of permeable and reflective pavements as a potential strategy for urban heat island mitigation. (2019). Urban Climate, 31. https://doi.org/10.1016/j.uclim.2019.100534
57. Bhattacharya, A. (2025, June 1). How Delhi's summer is changing: 3-fold rise in May rainfall in 75 years. The Times of India. https://timesofindia.indiatimes.com/city/delhi/how-delhis-summer-is-changing-3-fold-rise-in-may-rainfall-in-75-years/articleshow/121544756.cms
58. Compact city planning and development: Emerging practices and strategies for achieving the goals of sustainability. (2020). Developments in the Built Environment, 4. https://doi.org/10.1016/j.dibe.2020.100021
59. Tumini, I. (2015). The urban microclimate in open space. Case studies in Madrid. Cuadernos De Investigación Urbanística, 96. https://doi.org/10.20868/ciur.2014.96.3022
60. The Hindu Bureau. (n.d.). Traffic police puts up canopies at key junctions in the city. The Hindu. https://www.thehindu.com/news/cities/Tiruchirapalli/traffic-police-puts-up-canopies-at-key-junctions-in-the-city/article69412805.ece
61. A design workflow for effective solar shading of pedestrian paths. (2024). Building and Environment, 261. https://doi.org/10.1016/j.buildenv.2024.111718
62. A design workflow for effective solar shading of pedestrian paths. (2024). Building and Environment, 261. https://doi.org/10.1016/j.buildenv.2024.111718
63. The Hindu Bureau. (2025, April 5). Traffic police puts up canopies at key junctions in the city. The Hindu. https://www.thehindu.com/news/cities/Tiruchirapalli/traffic-police-puts-up-canopies-at-key-junctions-in-the-city/article69412805.ece
64. PwC. (2023). Climate responsive and sustainable buildings.
65. Cool roofs can mitigate cooling energy demand for informal settlement dwellers. (2022). Renewable and Sustainable Energy Reviews, 159. https://doi.org/10.1016/j.rser.2022.112183
66. Susheel, T. (2025, October 2). India's first 3D-printed rural home comes up in Roorkee. The Times of India. https://timesofindia.indiatimes.com/city/dehradun/indias-first-3d-printed-rural-home-comes-up-in-roorkee/articleshow/124263767.cms
67. Building Materials & Technology Promotion Council, Ministry of Housing & Urban Affairs, Government of India. (2025). Innovative building materials & construction technologies. https://bmtpc.org/DataFiles/CMS/file/PDF_Files/National_Conference_Proceeding_book_2025_S.pdf
68. How Delhi is losing its Cool: Heat and rising demand for cooling and electricity consumption. (n.d.). https://www.cseindia.org/sharp-rise-in-summer-heat-and-humidity-in-delhi-jacks-up-cooling-demand-and-electricity-consumption-cse-12857
69. Biswas, S. (2024, June 27). India heat: What record air conditioner sales reveal about heatwave. https://www.bbc.com/news/articles/cw555ny3q9xo
70. Council on Energy, Environment and Water. (n.d.). How extreme heat is impacting India: Assessing District-level Heat Risk. In CEEW. https://www.ceew.in/publications/mapping-climate-risks-and-impacts-of-extreme-heatwave-disaster-in-indian-districts
71. Geospatial Forecasting of Electric Energy in Distribution Systems Using Segmentation and Machine Learning with Convolutional Methods. (2025). Energies. https://doi.org/10.3390/en18020424
72. Ozone Cell, Ministry of Environment, Forest & Climate Change Government of India. (2019). India Cooling Action Plan. https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf
73. Qing, A. (2022, May 18). Largest industrial district cooling system to be built in Ang Mo Kio by 2025. The Straits Times. https://www.straitstimes.com/singapore/largest-industrial-district-cooling-system-to-be-built-in-ang-mo-kio-by-2025
74. BEE: Raising AC setting by 1° can save 6% power – Urja Dakshata Information Tool. (n.d.). https://udit.beeindia.gov.in/bee-raising-ac-setting-by-1-can-save-6-power/
75. India's New AC Set Point Rule: A Small Tweak with Big Implications. (n.d.). TERI. https://www.teriin.org/article/indias-new-ac-set-point-rule-small-tweak-big-implications
76. BEE notifies new energy performance standards for air conditioners. (n.d.). https://www.pib.gov.in/PressReleasePage.aspx?PRID=1598508®=3&lang=2
77. Bhirani, G. (2025, June 12). Government may soon freeze AC limits: Cooling below 20°C and heating above 28°C could be barred. Mint. https://www.livemint.com/news/india/government-may-soon-freeze-ac-limits-cooling-below-20-c-and-heating-above-28-c-could-be-barred-11749624202278.html
78. India's New AC Set Point Rule: A Small Tweak with Big Implications. (n.d.). TERI. https://www.teriin.org/article/indias-new-ac-set-point-rule-small-tweak-big-implications
79. BEE announces new star rating methodology for Air conditioners. (n.d.). https://www.pib.gov.in/newsite/PrintRelease.aspx?relid=149154®=3&lang=2

80. Council on Energy, Environment and Water. (2020). Do Residential AC Buyers Prioritise Energy Efficiency? In CEEW. https://www.ceew.in/publications/do-residential-ac-buyers-prioritise-energy-efficiency
81. Accelerating room air conditioner efficiency in India: Grid, economic, and policy implications through 2035. (n.d.). The Electricity Journal, 38(3). https://doi.org/10.1016/j.tej.2025.107493
82. Consumer preference for labels in the purchase decisions of air conditioners in India. (2017). Energy for Sustainable Development, 42. https://doi.org/10.1016/j.esd.2017.09.008
83. International Energy Agency (IEA). (2024b). Energy rating labels and potential for energy savings across the Global South. In ISSUE BRIEF Energy. https://files.unsdsn.org/CEET%20Brief_Energy%20Rating%20Labels%20and%20Potential%20for%20Energy%20Savings%20Across%20the%20Global%20South.pdf
84. International Energy Agency (IEA). (2024b). Energy rating labels and potential for energy savings across the Global South. In ISSUE BRIEF Energy. https://files.unsdsn.org/CEET%20Brief_Energy%20Rating%20Labels%20and%20Potential%20for%20Energy%20Savings%20Across%20the%20Global%20South.pdf
85. Ernest Orlando Lawrence Berkeley National Laboratory. (2013). Avoiding 100 new power plants by increasing efficiency of room air conditioners in India: opportunities and challenges.
86. Ernest Orlando Lawrence Berkeley National Laboratory. (2013). Avoiding 100 new power plants by increasing efficiency of room air conditioners in India: opportunities and challenges.
87. Accelerating room air conditioner efficiency in India: Grid, economic, and policy implications through 2035. (n.d.). The Electricity Journal, 38(3). https://doi.org/10.1016/j.tej.2025.107493
88. Ozone Cell, Ministry of Environment, Forest & Climate Change Government of India. (2019). India Cooling Action Plan. https://ozonecell.nic.in/wp-content/uploads/2019/03/INDIA-COOLING-ACTION-PLAN-e-circulation-version080319.pdf
89. Ernest Orlando Lawrence Berkeley National Laboratory. (2013). Avoiding 100 new power plants by increasing efficiency of room air conditioners in India: opportunities and challenges.
90. Kalanki, A., McGavisk, I., & Center for Advanced Research in Building Science and Energy, CRDF, CEPT University. (2025). Super-efficient room Air conditioner Performance specification Guideline for Indian market (C. Ding, W. Y. Park, Clean Cooling Collaborative, & N. Shah, Eds.). Global Cooling Efficiency Accelerator. https://www.cleancoolingcollaborative.org/wp-content/uploads/2025/03/Super-efficient-AC-Performance-Specification_Final_March-2025.pdf
91. Accelerating room air conditioner efficiency in India: Grid, economic, and policy implications through 2035. (n.d.). The Electricity Journal, 38(3). https://doi.org/10.1016/j.tej.2025.107493
92. Singh, A. (2024, May 23). Surging use of air conditioners to strain India’s power grids: IEA. Mercomindia.com. https://www.mercomindia.com/air-conditioners-strain-india-grid-iea
93. Indian cities need $2.4 trillion for climate infrastructure by 2050, World Bank says. (2025). Reuters. https://www.reuters.com/sustainability/cop/indian-cities-need-24-trillion-climate-infrastructure-by-2050-world-bank-says-2025-07-22/
94. India unlikely to join global cooling pledge at COP28 - govt sources. (2023). Reuters. https://www.reuters.com/world/india/india-unlikely-join-global-cooling-pledge-cop28-govt-sources-2023-10-27/
95. India reaffirms commitment to equity, climate justice and multilateralism at COP30, in Belém, Brazil. (n.d.). https://www.pib.gov.in/PressReleasePage.aspx?PRID=2189018®=3&lang=2

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