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You Can't Handle the Heat: Bounding the White Cities Concept in Ahmedabad

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Introduction

In the spring and summer of 2026, India became the hottest country on Earth. Approximately 95 of the 100 hottest cities in the world were Indian. The generally high temperature of India is due to many reasons; the Thar Desert, pre-monsoon heat and cloudless skies, unique geography, climate change and the El Niño, and so on. India's geography and climate worsen when they encounter the physics of how heat operates in and around a city. Population density, urban sprawl, lack of tree cover, increased use of manufactured materials, high energy demands, and pavement structures of cities result in the Urban Heat Island Effect (UHIE). This refers to the phenomenon wherein urban areas suffer higher temperatures as compared to the surrounding countryside, and needs to be countered consciously [1]. However, simulation and model-based research for Indian urban areas is still in its infancy. This paper aims to participate in its growth.

A proposed solution to the UHIE problem is to achieve passive cooling via infrastructure changes in the white cities concept. This idea applies the concept of Albedo (also known as Solar Reflectance) to reflect heat instead of absorbing it (as most manufactured materials and pavement in cities do). The concept of replacing conductors with reflective materials is not novel; cities like Paris, Los Angeles, New York, Rotterdam, etc. already utilise a version [2]. Existing work such as [3] primarily applies this concept to American and European urban areas. Such work highlights the gap in urban climate modelling for Indian cities.

This brief asks multiple questions to begin the process: what are the upper and lower bounds to the benefits of the white cities concept? Inversely, what efforts would be required to achieve even the lower bounds of the benefits, and would the benefits be worth the effort? Lastly, what is the dampening effect of the atmosphere on the benefits? We will explore these questions through the example city of Ahmedabad, a city under frequent extreme heat stress.

Clarifications

A key concept in the Earth's energy budget is the Albedo Effect. Albedo is the measure of how much sunlight a surface reflects back into space. Light coloured surfaces reflect more light (these are therefore high albedo surfaces) while dark coloured surfaces reflect less light (i.e. low albedo). Ice and snow-covered regions across the globe have high albedo, meaning they reflect the solar radiation which would otherwise be absorbed, causing the planet to heat up. Hence, the proportion of ice and snow-covered regions on Earth has a lot to say about how much radiation is reflected or absorbed. Low albedo surfaces like concrete and asphalt lead to high uptake of radiation and hence warming. Additionally, when ice and snow melt, more dark surfaces (rocks and soil) are exposed, further increasing warming, leading to more snowmelt, and so on. This is therefore a positive feedback loop [7].

Urban Design

The Albedo effect can be observed at urban scale through the UHIE. Heat is trapped and absorbed by cities, which are largely made of concrete, asphalt, glass and steel. The consequences of urban heating are increasingly severe. Cities experience rising energy consumption due to increased cooling demands, worsening air quality through smog and pollution, and greater risks of heat stress, dehydration, and heat-related mortality, particularly among vulnerable populations living in dense neighbourhoods. Outdoor public spaces become less usable, and thermal discomfort begins to affect everyday life.

As awareness around these issues grows, urban designers, environmentalists, and city planners have begun actively exploring ways to mitigate urban heat. These mitigation efforts include usage of reflective surfaces [8], as in paint buildings white, installing solar-reflective roofs and light pavements, shaded streets; implementation of blue infrastructure like bioswales, wetlands, sponges; designing climate responsive urban forms which allow for ventilation and airflow along with permeable materials that do not absorb heat. These interventions operate at multiple scales of neighbourhood-planning and street geometry to material selection for public spaces.

At a larger scale, designers are now focusing on climate-responsive urban form. This involves designing streets, blocks, and building orientations that improve airflow and ventilation while reducing heat absorption. Urban designers increasingly rely on thermal comfort mapping and climatic simulations to study how solar radiation, shadows, materials, and wind movement affect the way people experience public spaces. These analyses help generate designs that consider factors such as shading, ventilation corridors, evaporative cooling, and outdoor thermal comfort indices like the UTCI (Universal Thermal Climate Index).

However, this also raises an important question regarding practicality. Retrofitting existing cities (as is called for in the white cities concept) often requires replacing roads, pavements, facades, and infrastructure systems. Does it truly make sense to demolish functioning urban systems in order to rebuild them using newer 'sustainable' materials? The process of demolition and reconstruction itself generates enormous amounts of waste and emissions, consumes energy, and contributes to pollution. Hence, as climate change intensifies, urban design is shifting from purely visual or functional design to environmental performance-based design where reducing heat stress, improving thermal equity and creating resilient urban microclimates are becoming central objectives of city-making. This process requires modelling and simulation, to predict which solutions would be more effective where, and such urban modelling is only beginning in India.

Process

Let us begin by estimating the upper bound of benefits. As per [6], roofs and pavements typically make up over 60% of an urban area, with roofs being 20% to 25% and pavements being approximately 40%. Therefore, we can conservatively estimate that 20% of the Ahmedabad area can be 'whitened' for our purposes. [4] notes that urban albedo is typically 0.2 on a scale of 0 to 1. In contrast, [5] states that white roofs have a solar reflectance of 0.8. Therefore, we ask that assuming 20% of Ahmedabad can be 'whitened' up to 0.8 albedo, what are the temperature change bounds?

Inversely, the UTCI heat stress guidelines [9] state that above 46°C is extreme heat stress, 38°C to 46°C is very strong heat stress, and 32°C to 28°C is strong heat stress. Ahmedabad summer temperatures frequently rise into the extreme category, implying that a 2°C temperature decrease is significant enough to merit a category change. Therefore we shall evaluate the necessary induced albedo to achieve 2°C to 5°C temperature change.

This brief utilises the Zero-Dimensional (0D) Equilibrium Temperature Equation in order to derive the upper bound on benefits stated by the white cities concept. This equation incorporates temperature and albedo in one line, but poses significant limitations. The equation is constructed considering planetary scale, not city-scale, and assumes that the surface is the only body determining temperature, whereas in reality, the atmosphere, climate, local weather, etc. play a major role. The 0D model assumes no lateral heat transport. For our purposes however, this model performs the required task of providing an upper bound.

The 0D Equilibrium Temperature Equation is as follows:

$$T = \left[\frac{S(1-\alpha)}{4\sigma}\right]^{1/4} \tag{1}$$

- T — equilibrium surface temperature (K)
- S — solar constant, 1361 W m^{-2}
- α — surface albedo (dimensionless, 0 to 1)
- σ — Stefan–Boltzmann constant, 5.67×10^{-8} W m^{-2} K^{-4}

If we differentiate this with respect to albedo, we get the required change in temperature due to albedo:

$$\frac{dT}{d\alpha} = -\frac{S}{16\sigma T^3} \tag{2}$$

Assuming 20% of Ahmedabad can be whitened up to 0.8 albedo (80% of the city remains at 0.2 albedo), we get a net city-wide albedo of 0.32 (see Appendix A for derivation). That is a difference of 0.12. By adding this difference into our differential result, we achieve the upper bound of temperature change. For our lower bound, a complex model that incorporates atmospheric dynamics and covers the caveats of the 0D model is required. This brief attempted to employ a CliMT single-atmospheric-column-with-slab model (see Appendix C) with the CliMT toolkit [10], incorporating Emanuel Convection and RRTMG radiation, in order to simulate complex dynamics. However, this attempt failed. Lack of cooling features like water bodies, clouds, and advection, required this model to run for years of simulated time to converge to a usable result. This was unfeasible due to computational limitations, and hence failed. In lieu of the complex model, this brief utilises existing research to provide a lower bound.

Results

After running the numbers through a python script for the 0D equation (see Appendix B for code), we get the following results:

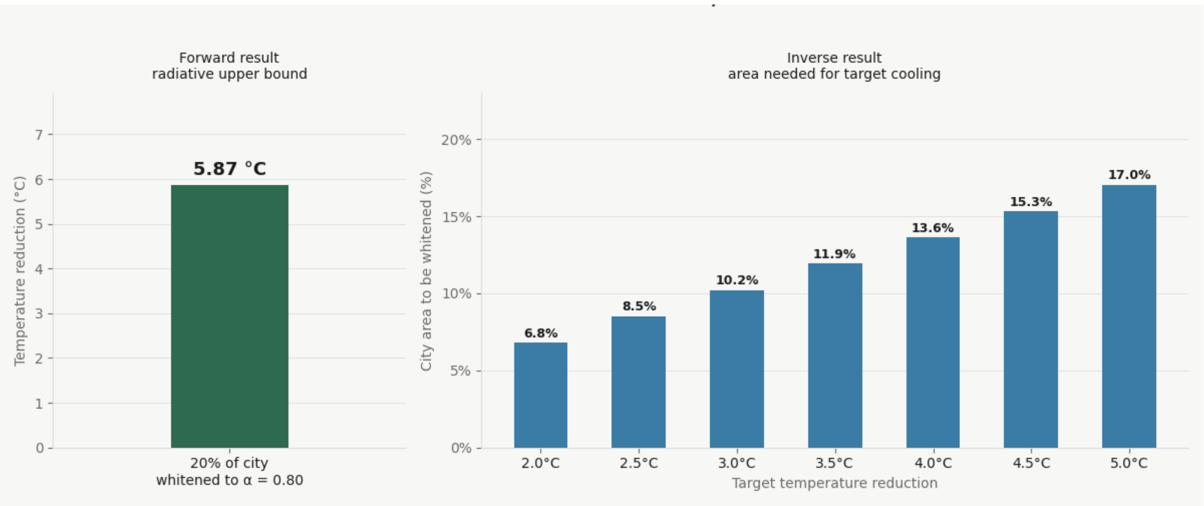

Figure 1: Forward and inverse results from the 0D radiative model. Left: theoretical upper bound on surface temperature reduction from whitening 20% of Ahmedabad to $\alpha = 0.80$. Right: city area required to be whitened to achieve target temperature reductions of 2°C to 5°C.

Whitening 20% of Ahmedabad to 0.8 albedo begets a temperature reduction of 5.87°C. Inversely, whitening 6.8% to 17% of the city buys our significant temperature change. These are highly optimistic results, but recall that these are our limited upper bounds.

To obtain our practical lower bound, we utilise [3], who apply several climate models to test climate change adaptation techniques. Cool roofs were tested (also on $\sim$20% of the total urban area, since they tested 100% roof area) in Arizona, USA, a location of comparable summer climate to Ahmedabad, and a temperature change of 0.47°C was discovered. This is a significant difference of two orders of magnitude from the 0D equation. Actual temperature change is likely to be near the lower bound than the 0D-acquired upper bound. Inversely, [3] dictates a requirement of 25% to 63% of Ahmedabad whitened to achieve 2°C to 5°C cooling.

Conclusion

The lower bound on cooling provided by [3] is 0.47°C, while the upper bound provided by our 0D model is 5.87°C. The true benefits of white cities lie somewhere in this domain, likely leaning towards the lower bound. This implies a cooling of less than equal to a single degree with the whitening of at least a quarter of the city area. The difference between the bounds provides the answer to our final question; the atmosphere's dampening effect is:

$$\beta = 1 - \frac{\Delta T_{\text{lower}}}{\Delta T_{\text{upper}}} = 1 - \frac{0.47}{5.87} = 0.920 \tag{3}$$

This suggests that 92% of upper bound benefits of white cities get dampened by atmospheric phenomena and urban processes.

The takeaway from these results is that even with focused deployment, the white cities concept alone has minor benefits. These benefits are certainly not sustainable or worth any required demolition and reconstruction. Policies can be employed for cool roofs application for new constructions or renovation already happening for other reasons, but dedicated deployment of white cities will not be sufficient for curbing the UHIE. This brief suggests dedicated efforts across multiple methods such as green corridors, vertical gardens, shading, water features, sustainable mobility, and architecture focused towards cooling and airflow optimisation will be required. To ensure the study, promotion, and employment of majorly beneficial methods to battle UHIE, further application of complex models dedicatedly for Indian urban areas is a necessary step for future research.

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Appendix A: Model Derivation

Disclaimer: AI tools were used to assist in formulating the mathematical structure of the model and in generating the initial Python code for calculations. All assumptions, parameter choices, interpretation of results, and written analysis are the authors'. AI was used as a computational aid, not for generating any written content.

City-wide albedo after partial whitening

Let f be the fraction of city area whitened, α_0 the original urban albedo, and α_1 the albedo of whitened surfaces. The city-wide effective albedo after intervention is:

$$\alpha_{\text{city}} = f \cdot \alpha_1 + (1 - f) \cdot \alpha_0 \tag{4}$$

The change in city-wide albedo is therefore:

$$\Delta\alpha = \alpha_{\text{city}} - \alpha_0 = f \cdot (\alpha_1 - \alpha_0) \tag{5}$$

For $f = 0.20$, $\alpha_0 = 0.20$, $\alpha_1 = 0.80$:

$$\Delta\alpha = 0.20 \times (0.80 - 0.20) = 0.20 \times 0.60 = 0.12 \tag{6}$$

The new city-wide albedo is $\alpha_0 + \Delta\alpha = 0.20 + 0.12 = 0.32$.

Derivation of the Planck sensitivity parameter

Beginning from the 0D equilibrium condition $T^4 = S(1 - \alpha)/(4\sigma)$, differentiating both sides with respect to α:

$$4T^3 \frac{dT}{d\alpha} = -\frac{S}{4\sigma} \tag{7}$$

$$\frac{dT}{d\alpha} = -\frac{S}{16\sigma T^3} \tag{8}$$

At Ahmedabad peak summer surface temperature $T = 313$ K:

$$\frac{dT}{d\alpha} = -\frac{1361}{16 \times 5.67 \times 10^{-8} \times 313^3} \approx -0.49 \text{ K per 0.01 albedo change} \tag{9}$$

The forward result is then:

$$\Delta T = \frac{dT}{d\alpha} \cdot \Delta\alpha = -48.92 \times 0.12 \approx -5.87°\text{C} \tag{10}$$

Appendix B: Upper Bound Code

The following is a summary of the Python script used to compute the 0D model results.

```
# Constants
S     = 1361        # solar constant, W/m²
sigma = 5.67e-8     # Stefan-Boltzmann constant
T_ahm = 313.0       # Ahmedabad peak summer temperature, K

alpha_original = 0.20   # urban albedo (Elgendy et al. 2025)
alpha_white    = 0.80   # white roof albedo (Heat Island Group, 2026)
f              = 0.20   # whitenable fraction (Akbari et al. 2009)

# Planck sensitivity: dT/dalpha = -S / (16 * sigma * T^3)
planck = -S / (16 * sigma * T_ahm**3)

# Forward calculation
delta_alpha = f * (alpha_white - alpha_original)   # = 0.12
delta_T     = planck * delta_alpha                 # = -5.87 °C

# Inverse calculation: fraction required for target cooling
for target in [2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0]:
    req_delta_alpha = target / abs(planck)
    req_fraction    = req_delta_alpha / (alpha_white - alpha_original)
    print(f"{target} °C -> {req_fraction * 100:.1f}% of city")
```

Appendix C: Lower Bound Code

This code is a modified version of [11]. It runs the radiative-convective equilibrium column model under two different albedo values in order to assess the effects of the white cities intervention under realistic atmospheric physics.

```
from sympl import DataArray, AdamsBashforth
import numpy as np
from datetime import timedelta
from climt import (EmanuelConvection, RRTMGShortwave, RRTMGLongwave,
    SlabSurface, SimplePhysics, get_default_state)

convection   = EmanuelConvection()
radiation_sw = RRTMGShortwave()
radiation_lw = RRTMGLongwave()
slab         = SlabSurface()

# Build default state and set Ahmedabad conditions
state = get_default_state([...components...])
state['air_temperature']     = 290.0 K  (initial profile)
state['surface_temperature'] = 303.0 K  (Ahmedabad JJA climatology)
state['zenith_angle']        = pi / 2.5  (approx. 72 deg, Ahmedabad JJA)
state['surface_albedo_*']    = albedo    (set all four components)

# timestep = 10 minutes, target = 60,000 steps (approx. 417 model days)
for i in range(n_steps):
    diagnostics, state = time_stepper(state, timestep)
    state.update(diagnostics)
    # apply simple physics and wind forcing at each step

# Run for alpha = 0.20 and alpha = 0.32 independently
# Report surface temperature at end of integration
# Delta T = T_eq(alpha=0.32) - T_eq(alpha=0.20)
```