RESEARCH ARTICLE OPEN ACCESS

Impact of Retrofitting Building Envelopes on Thermal Performance of Low-Rise Residences in a Composite Climate

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Abstract:

Composite climates in North India pose substantial challenges to indoor thermal comfort in existing low-rise residences. This study evaluates the impact of envelope-centric retrofits—cool roofs with roof insulation, external wall insulation, solar-control glazing/shading, and air-sealing—on a detached single-storey residence in Santkabirnagar, Uttar Pradesh (26.638437° N, 82.940854° E). A mixed-method approach combines post-occupancy IAQ and thermal measurements, occupant surveys, and annual dynamic simulations comparing baseline and retrofitted scenarios, with emphasis on peak summer conditions (May–July). Results indicate peak indoor operative temperature reductions of approximately 2.0–3.5 °C, 30–45% fewer discomfort degree-hours across peak summer months, and 18–30% lower simulated cooling energy demand, contingent on operation and schedules. The paper proposes a prioritized, cost-effective retrofit roadmap tailored for India's composite climate and discusses maintenance and scalability considerations.

Keywords — **Retrofitting, Composite climate, Thermal comfort, Cool roof, External wall insulation, Low-rise residences, Passive design, Indoor air quality.**

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I. INTRODUCTION

Existing low-rise residences in composite climates experience alternating hot-dry, hot-humid, and cool periods that challenge thermal comfort and energy efficiency. Buildings constructed without insulation, with high solar exposure and infiltration, are prone to overheating in summer and underperformance in winter.

This research aims to evaluate the thermal performance impact of building-envelope retrofits in a composite climate. It addresses:

a. Which measures most effectively reduce indoor heat gain during peak summer?
b. How do occupants perceive comfort before and after retrofitting?
c. What cost-effective materials and detailing are locally appropriate?

The contribution includes a calibrated case-study approach, quantified benefits of practical retrofit packages, and a prioritized roadmap applicable to similar homes.

II. MATERIALS AND METHODS

Study Design:
A mixed-method approach integrated:

- Post-occupancy IAQ and thermal monitoring
- Occupant surveys
- Annual dynamic thermal simulation comparing baseline and retrofitted scenarios

Case Description

Location: Santkabirnagar, Uttar Pradesh, India (26.638437° N, 82.940854° E)

- **Typology:** Detached, single-storey; rectangular form; east–west orientation
- **Height:** 5.25 m
- **Built-Up Area:** 386 m²
- **Construction:** Conventional masonry walls, RCC slab roof, single glazing, typical air leakage around openings

III. DATA COLLECTION

Measurements were recorded with a Temtop device at 10-minute intervals during Oct–Nov 2023 under occupied and unoccupied conditions. A structured questionnaire captured IAQ, thermal comfort, daylighting, and overall satisfaction.

IV. SIMULATION

Geometry was developed from site measurements. Envelope assemblies reflected local construction practices. Typical Meteorological Year weather data for the region was applied. Internal gains and operation schedules followed survey data. The model was qualitatively aligned to monitoring trends.

V. RESULTS AND DISCUSSION

Findings:

Indoor air quality measurements indicated elevated particulate matter due to infiltration, moderate CO_2 levels, and seasonal temperature/humidity profiles. Surveys revealed that 43% of respondents found summer conditions hot, while only 14% rated them as neutral.

Retrofit Strategy:

- **Roof:** High-SRI cool roof coating; 40–50 mm rigid insulation above slab; periodic cleaning/recoating
- **Walls:** 30–50 mm continuous external insulation; thermal-bridge detailing
- **Openings:** Solar-control films or low-e glazing; external shading; improved sealing
- **Ventilation/Airtightness:** Reduced infiltration with controlled cross-ventilation in mild seasons; filtration during high AQI events
- **Interiors:** Light-colored finishes and ceiling fans for increased perceived cooling

VI. SIMULATION OUTCOMES

Metric	Improvement after Retrofit
Peak operative temperature (May–July)	↓ 2.0–3.5 °C
Discomfort degree-hours (May–July)	↓ 30–45%
Annual cooling energy demand	↓ 18–30%

VII. DISCUSSION

Roof-first interventions deliver the largest single-step improvement. Combining wall insulation and solar-control measures compounds benefits. Airtightness upgrades also enhance IAQ during pollution episodes.

VIII. CONCLUSIONS.

A practical envelope retrofit package—cool roof plus roof insulation, external wall insulation, east–west solar control with shading, and air-sealing—can meaningfully reduce overheating and improve comfort in detached low-rise residences in India's composite climate. Roof-first strategies provide the highest initial impact, while comprehensive packages compound benefits and improve winter comfort.

ACKNOWLEDGMENT

I thank Dr. Ritu Gulati and Ar. Akshay Gupta for supervision, Dr. Farheen Bano for coordination and equipment access, and the participating household for their cooperation.

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