Bio-retrofit: Potential of Mycelium-based Composites to Future-proof India and Australia's Residential Buildings against Extreme Climate Events post-2040

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Abstract

In India and Australia, many residential buildings lack adequate thermal comfort, particularly during extreme heat events, such as heat waves. This results in indoor overheating and increased air conditioning (A/C) use, leading to higher energy demand for cooling. Most existing and newly built residential buildings will remain operational post-2040, necessitating retrofitting for extreme climate events in a warming world. While lower-carbon retrofitting technologies are emerging, many remain carbon-intensive in their manufacture and disposal, hindering the achievement of net-zero goals. The emphasis on maximising the build-up area complicates external retrofitting. This study examines mycelium-based composites (MBC), an innovative bio-based material, to enhance resilience against extreme climate events in these regions after 2040. Our bio-retrofitting solution, MBC insulation, was tested using simulated models from living labs in Sydney and Vadodara under various climate scenarios via Designbuilder and EnergyPlus. Our business-as-usual projections indicate a 5-21% rise in indoor temperatures in both countries, with cooling energy demands increasing by 1.9 to 3 times due to higher outdoor temperatures. Bio-retrofits could reduce this demand by approximately 0.4—3.2%. In addition, this study investigated the use of carbon-negative MBC, derived from local biomass waste, which provided a mitigation impact without its own embodied carbon, on a larger scale to enhance the resilience of residential buildings against future climate challenges. Further investigations are required to reduce the anticipated cooling energy demand through passive building skin designs.

Key Innovations

- This study presents an integrated approach using mycelium-based composites (MBC), future climate projections, and dynamic simulation to assess passive cooling retrofits across residential buildings in India and Australia.
- It provides a rare cross-regional comparison of retrofit performance under future mid- and late-century climate scenarios.
- The impact of building typology on retrofit effectiveness is analysed, highlighting context-specific design implications.
- Results show MBC can reduce indoor temperature rise and cooling energy demand, supporting climate-resilient retrofitting.
- The research promotes MBC as a scalable, biodegradable solution for sustainable building upgrades in hot climates.

Practical Implications

A simulation practitioner should always evaluate existing and new building designs against future climate scenarios to prevent performance failures in a warming world. Buildings will operate for 50—70 years, during which time the climate is expected to differ significantly from current conditions. Nevertheless, it is crucial also to consider reliable future projections and the limitations of the forecasted climate data.

Introduction

Extreme heatwaves are becoming increasingly frequent and intense due to climate change, especially in South Asia, where they have become an annual phenomenon affecting billions of urban residents (IPCC, 2022; Debnath K. B., Jenkins, Patidar, Peacock, & Bridgens, 2023). Australia is also projected to face 90+ days annually above 35°C by 2050 (Climate Council, 2024), with rising urban heat compounding the challenge of decarbonising a rapidly growing building sector. An estimated 5.4 million new buildings will be required in Australia by 2050, while 10.9 million existing homes need to be retrofitted to meet net-zero targets (Armstrong, Pears, Delafoulhouze, & Moore, 2022; Sayce, Wilkinson, & Armstrong, 2022). In both countries, exposure to extreme heat poses serious health risks, including heatstroke and death (NIH, 2022) while increasing reliance on air conditioning raises concerns about electricity demand and carbon emissions (Debnath K. B., Jenkins, Patidar, & Peacock, 2020).

In India alone, air conditioning units are expected to increase from 21.8 million in 2017 to 240 million by 2030 and 1.14 billion by 2050 (IEA, 2019; GoI, 2015). As most of the current building stock is expected to remain in use beyond 2050, retrofitting existing homes to improve their thermal performance is critical. Passive cooling strategies offer a lower-carbon solution; however, conventional retrofitting materials often have high embodied energy and are non-biodegradable, which limits their sustainability and scalability.

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To address these gaps, this study explores the potential of mycelium-based composites (MBC)—a bio-based, biodegradable, and low-carbon material—for building envelope retrofits in hot climate zones. The research focuses on two representative urban centres: Vadodara in western India and Sydney in eastern Australia. Vadodara, located in Gujarat's hot semi-arid climate zone (BSh), experiences extended periods of extremely high summer temperatures, often exceeding 44°C. It typifies the mid-rise multifamily housing stock common in rapidly urbanising Tier-2 Indian cities, making it a relevant case for climate-resilient retrofitting. Sydney, meanwhile, is Australia's most populous city and a prototypical urban area within a humid subtropical climate (Cfa), increasingly vulnerable to heatwaves and urban heat island effects. Its low-rise detached residential buildings are widely representative of the Australian suburban housing stock.

These cities were selected not only for their climate vulnerability and regional representativeness but also due to the availability of long-term weather projection data, access to typical residential building archetypes, and active collaboration with local partners through academic and policy-focused living labs. Using dynamic thermal simulation (DesignBuilder with EnergyPlus) and open-source future climate scenarios (HadCM3 A2, RCP2.6, RCP4.5, RCP8.5), the study assesses the effectiveness of MBC insulation in reducing indoor temperatures and cooling energy demand under mid-century (2050s) and late-century (2090s) climate conditions. Preliminary findings from these simulations offer cross-regional insights into the viability of MBC retrofitting as a scalable strategy for enhancing thermal comfort, reducing cooling loads, and improving climate resilience in residential buildings.

Methodology

As a climatic context, we focused on the tropical savanna (Köppen: Aw) climate in Vadodara, India and the humid subtropical (Köppen: Cfa) climate in Sydney, Australia. The study consisted of two major parts: building a thermal model and developing case studies, as well as additional bio-retrofit scenario testing and analysis under current and future climate scenarios.

Building physics modelling

We developed the building physics models of a 9-storey mixed-use apartment building in India and a two-storey residential building in Australia using Designbuilder (Version v7.3.0.029) with EnergyPlus as the simulation engine. DesignBuilder has been widely used in thermal comfort and building energy studies (Xu, Taylor, & Pisello, 2014; Yoon, Baldick, & Novoselac, 2014; Al-janabi, Kavgic, Mohammadzadeh, & Azzouz, 2019; Huang & Wu, 2019; Debnath & Jenkins, 2020).

To reduce computational time while maintaining representative modelling detail in the Indian case study, we simulated two edge apartments (south-east and south-west facing) on the 2nd, 6th, and 9th floors. Each apartment included one bedroom, a kitchen, a living-dining area, a bathroom, and a balcony (Figure 1A&D). The 2nd floor was chosen as the bottom reference instead of the ground floor, as commercial spaces occupied the latter.

The Australian case featured a four-bedroom single-family home with a living room, a kitchen-dining area, and three bathrooms, spread across two floors, representative of a detached suburban dwelling typical of Sydney's Fairwater precinct (Figure 1B&C).

In the second stage, both models were simulated under multiple climate scenarios to assess current and future thermal performance and cooling energy demand. These included:

- **Vadodara (India):** 2050 and 2080 under the HadCM3 A2 scenario
- **Sydney (Australia):** 2050, 2070, and 2090 under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios

We assessed the performance of existing units as well as the impact of MBC insulation retrofits, applied both inside and outside the exterior wall.

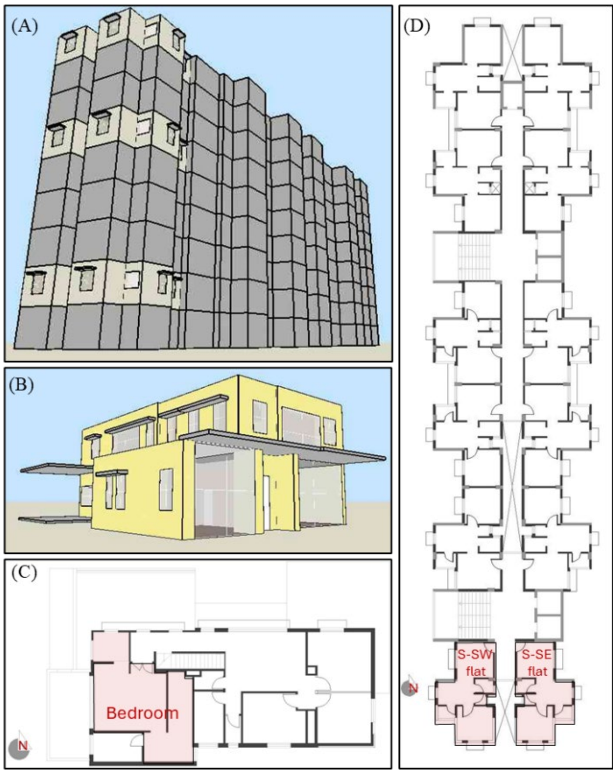

Figure 1: Building physics model of (A) Apartment building in Vadodara (India) and (B) Single-family home in Fairwater (Sydney, Australia), developed in Designbuilder. (C) The 2nd floor plan (not to scale) of the Australian case study, where the red area is the selected main bedroom for analysis. (D) The typical floor plan (not to scale) of the Indian case study, where the red area is the selected S-SW and S-SE flats for analysis.

For the Indian case study, we modelled naturally ventilated multi-zone apartments (area: 35.35 m² each) on floors 2, 6, and 9 using envelope constructions and materials described in Table 1. Domestic schedule templates were used for occupancy and equipment loads, including: 0.0229 persons/m² occupancy in the main bedroom, and Schedules such as, Dwell_DomBed_Occ, Dwell_DomKitchen_Occ, and Dwell_DomLounge_Occ

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A Unitary Heat Cool system was added to the bedroom zone only, using the schedule Dwell_DomBed_Cool, with a cooling setpoint of 25°C and setback to 28°C to simulate typical occupant behaviour under extreme heat.

For the Sydney case, a naturally ventilated, multi-zone, two-storey single-family house (area: 166.09 m² on the ground floor, 138.73 m² on the first floor) was modelled using constructions as described in Table 1. Similarly, domestic templates were applied for all zones with tailored schedules. A GSHP Unitary Water-to-Air Heat Pump was modelled for cooling in the master bedroom only, with the same temperature settings and cooling schedule.

Table 1: Construction name, thickness, and materials; for the material properties, we used a Designbuilder software database

Name	**Thickness** (m)	**Materials**	**U-Value** (W/m^2-K)
Exterior walls (India)	0.220	Brickwork and Gypsum plastering on both sides	2.309
Exterior walls (Australia)	0.352	Timber frame construction with two layers of glass wool, separated by a 25mm air gap. The weatherboard is on the exterior, and the cement plaster is on the interior surface.	0.102
Floor and roof (India)	0.100	Cast concrete (dense)	2.929
Ground floor (Australia)	0.333	Cast concrete with Urea Formaldehyde Foam, Floor Screed and timber flooring	0.250
Flat roof (Australia)	0.368	Glass wool with asphalt on the outer layer, air gap (25mm) and then Plasterboard in the interior	0.250
Window (India)	0.019	Double-layer 3mm Glass windows with an air gap and wooden frames	1.960
Window (Australia)	0.025	Double-layer 6mm Glass windows with 13mm air gap	2.665

To evaluate the impact of climate change on indoor conditions and cooling energy use: (a) Annual simulations were conducted to assess overall cooling demand, and (b) Peak summer periods were selected to analyse indoor operative temperatures under critical heat exposure for Vadodara: 1–2 June, and Sydney: 1–2 January. Thermal comfort was assessed using:

- **India:** India Model for Adaptive Comfort (IMAC), indicating a neutral temperature range of 19.6°C to 28.5°C for naturally ventilated spaces (Manu, Shukla, Rawal, Thomas, & De Dear, 2016).
- **Australia:** Optimal comfort temperature range of 20°C to 26°C for sedentary indoor activity (Australia Government, 2025).

Scenario development

In the base case, the case study models were simulated with and without air conditioning (A/C) units under future climate conditions. For the study, the following scenarios are described below (and illustrated in Figure 2) were selected to test the effect of climate change on existing buildings and the impact of the proposed Bio-Retrofit on the indoor operative temperature and cooling energy demand due to the use of A/C:

- **Base case:** No change in the existing building skin for the Indian (Figure 2A) and Australian (Figure 2D) case study.
- **Bio-Retrofit_in**: 50mm MBC panels, interior of the external wall for the Indian (Figure 2B) and Australian (Figure 2E) case study.
- **Bio-Retrofit_out**: 50mm MBC panels exterior of the external wall with 100mm air gap for Indian (Figure 2C) and Australian (Figure 2F) case study.

The MBC used in the Bio-Retrofit panels was modelled in EnergyPlus using thermal conductivity (0.069 W/m·K), density (599 kg/m³), and specific heat (6894 J/kg·K), based on empirical measurements by (Zhang, Hu, Fan, & Yu, 2022).

The fungal species used was *Pleurotus ostreatus*, a fast-growing edible fungus, as reported by Zhang et al. (2022). Sterilised (454 g per batch at 121°C for 2.5 hours) rye berries were inoculated with the fungal spores, containing vegetative hyphae and spores. The colonisation was visually observable within three days, with complete incubation achieved in seven days. The substrate mixture was manually homogenised and transferred to sterilised silicone moulds in quantities of 40–45 g. Growth occurred for four days on one side, followed by flipping and an additional four days to ensure uniform colonisation. The incubation conditions were maintained at 25°C and 65% relative humidity. The composite was then oven-dried at 65°C for 24 hours to deactivate microbial activity and stabilise the material (Zhang, Hu, Fan, & Yu, 2022).

This growth process yielded a fibrous internal matrix and a naturally formed outer 'fungal skin'—a denser surface layer which contributes to mechanical strength and basic moisture resistance. However, MBC remains a hygroscopic material, and prolonged exposure to ambient humidity, precipitation, or vapour ingress requires additional protective strategies.

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In the current study, external weather protection layers such as vapour barriers or cladding systems were not modelled, as these remain under experimental development as part of the ongoing 'Data-driven Bio-Fabricated Carbon-Negative Building Skin for Passive Cooling (BioCOOL)' project. Future work will incorporate these protective layers once their thermal and moisture performance has been fully characterised and validated. Thus, the present simulation results represent a proof-of-concept thermal performance analysis, which in the absence of other protective linings comprises a conservative model with the understanding that real-world implementation of exterior MBC systems will necessitate additional moisture-resilient detailing.

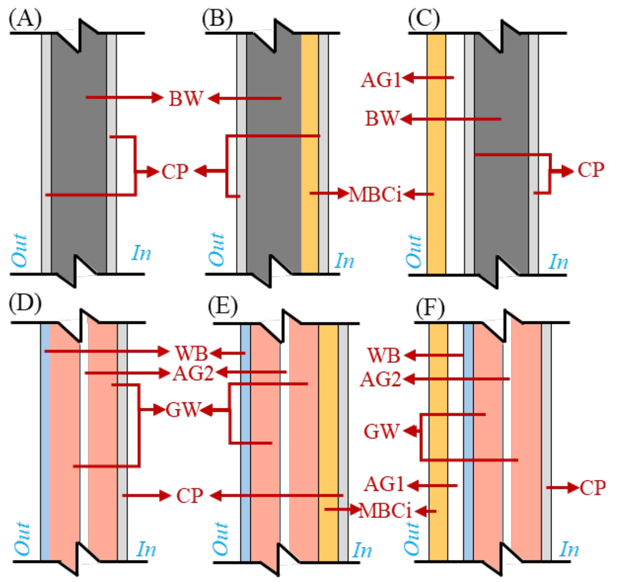

Figure 2: Building wall sections of different scenarios for Indian (A-C) and Australian (D-F) case studies. Here, BW: Brick wall, CP: Cement plaster (sand aggregate), MBCi: MBC insulation, AG1: 100mm Air gap, AG2: 25 mm Air gap, WB: Weatherboard, GW: MW Glass wool, In: Indoor and Out: Outdoor.

Future climate scenarios

In the case of Sydney, Australia, we utilised Nathers climate zone: 17 —Location: Sydney RO (Observatory Hill), longitude: 151.2, latitude: -33.9— file from the datasets titled 'Projected Weather Files for Building Energy Modelling,' which include 996 text files, each containing hourly weather data for 83 Australian locations (CSIRO, 2025). The projections consider three future climate scenarios—RCP2.6, RCP4.5, and RCP8.5—and four future timeframes: 2030, 2050, 2070, and 2090. In the RCP2.6 scenario, greenhouse gas (GHG) emissions peak around 2020 and decline rapidly due to strict reductions. In contrast, RCP4.5 sees emissions peak in 2040, while RCP8.5 involves minimal constraints on emissions. These datasets are formatted to ensure compatibility with various simulation software, including EnergyPlus, ESP-r, IESVE, and non-regulatory modes of NatHERS tools such as AccuRate, BERSPro, FirstRate5, and HERO. This resource is instrumental in evaluating the potential impacts of climate change on the performance of building energy consumption.

For Vadodara, India, the CCWorldWeatherGen tool (Jentsch, James, Bourikas, & Bahaj, 2013) was utilised to create climate change weather files for building performance simulations. This Microsoft Excel-based application employs the 'morphing' methodology to convert current EPW weather files into future climate scenarios, utilising HadCM3 A2 data from the Intergovernmental Panel on Climate Change (IPCC). The tool generates climate-adjusted EPW or TMY2 files that are compatible with Energyplus. We separately obtain baseline weather files for Vadodara's current climate —IND_GJ_Baroda.AP.427480_TMYx.2009-2023—from (Climate.OneBuilding.Org, 2025) to use in CCWorldWeatherGen tool. Furthermore, since CCWorldWeatherGen operates based on coarse General Circulation Model data, the limitations and uncertainties associated with the generated climate change weather data can be found in IPCC assessment reports (IPCC, 2022).

Results

Outdoor temperature

Under the current climate (2009–2023), the average outdoor temperature in Vadodara, India, was 27.94°C, with maximum and minimum recorded temperatures of 41.98°C and 13.03°C, respectively. Simulation projections indicate that by 2050, the average outdoor temperature could rise to 29.80°C and further increase to 31.23°C by 2080. Correspondingly, peak temperatures are expected to reach 43.48°C in 2050 and 44.68°C in 2080 (Figure 3A).

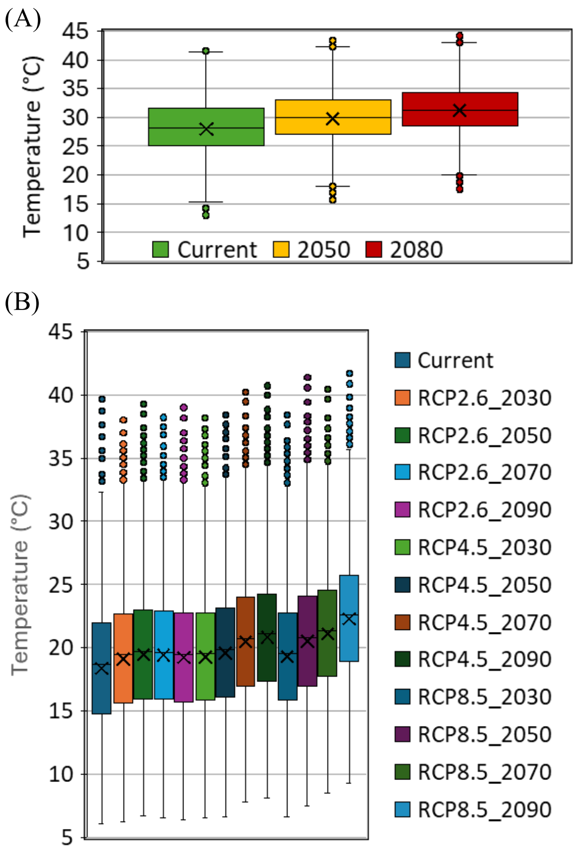

Figure 3: (A) Hourly annual outdoor temperature in Vadodara, India: Current (2009-2023), 2050 and 2080; (B)

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Hourly annual outdoor temperature under RCP 2.6, 4.5 and 8.5 scenarios in Sydney, Australia: Current (2009-2023),2030, 2050, 2070 and 2090.

For Sydney, Australia, the current average outdoor temperature (2009–2023) was 18.35°C, with extremes ranging from 39.68°C to 6.10°C (Figure 3B). Future projections under different Representative Concentration Pathways (RCPs) indicate varying degrees of warming:

- **RCP2.6**: Average temperatures are expected to increase slightly to 19.12°C in 2030, 19.47°C in 2050, 19.41°C in 2070, and 19.23°C in 2090. Maximum and minimum temperatures remain relatively stable, fluctuating between 38.03 °C and 39.30 °C, and 6.20 °C and 6.70 °C.
- **RCP4.5**: A more moderate warming trend is projected, with average temperatures rising to 19.28°C (2030), 19.60°C (2050), 20.47°C (2070), and 20.82°C (2090). Peak temperatures could increase to 40.73°C by 2070–2090, while minimums may rise to 8.10°C.
- **RCP8.5**: The most extreme scenario shows the highest projected averages, up to 22.27°C by 2090. Maximum temperatures are expected to reach 41.70°C, with minimums increasing to 9.30°C.

Indoor operative temperature

Vadodara, India: In the India case study, indoor operative temperatures were monitored in the main bedroom of two flats—South-Southwest (S-SW) and South-Southeast (S-SE)—on three floors (2nd, 6th, and 9th), under natural ventilation and without air conditioning (Figure 4A). For the S-SW flat, the annual average indoor operative temperature was:

- **2nd floor:** 23.55°C (max: 28.84°C, min: 13.40°C)
- **6th floor:** 23.47°C (max: 28.77°C, min: 13.32°C)
- **9th floor:** 23.41°C (max: 28.71°C, min: 13.26°C)

For the S-SE flat:

- **2nd floor**: 23.50°C (max: 28.91°C, min: 13.26°C)
- **6th floor**: 23.43°C (max: 28.84°C, min: 13.18°C)
- **9th floor**: 23.37°C (max: 28.78°C, min: 13.12°C)

Under the Bio-retrofit_in scenario (passive design interventions), the average indoor operative temperatures across floors slightly increased:

- **Current climate:** 25.74°C, 25.67°C, and 25.61°C for floors 2, 6, and 9, respectively (max: ~30.3°C; min: ~17.2°C).
- **Future climate (2080):** 28.91°C, 28.84°C, and 28.78°C for floors 2, 6, and 9, respectively (max: ~33.9°C; min: ~21.4°C).

Figure 5A illustrates rising peak temperatures during summer (1–2 June) in both Bio-retrofit_in and Bio-retrofit_out scenarios under future climate conditions.

Sydney, Australia: In the Sydney case study, the main bedroom (located on the first floor) had an annual average indoor operative temperature of 18.35°C (maximum: 39.68°C, minimum: 6.10°C) under current climate conditions. Future projections are (Figure 4B):

- **RCP 2.6:** 24.43°C (2030), 24.60°C (2050), 24.63°C (2070), 24.45°C (2090) (max range: 38.42–38.75°C; min: 13.93–14.47°C)
- **RCP 4.5:** 24.53°C (2030), 24.74°C (2050), 25.43°C (2070), 25.67°C (2090) (max: up to 39.85°C; min: up to 15.70°C)
- **RCP 8.5:** 24.51°C (2030), 25.42°C (2050), 25.91°C (2070), 26.74°C (2090) (max: up to 41.04°C; min: up to 16.85°C)

Under Bio-retrofit_in scenario, the average indoor operative temperature was 23.28°C (max: 34.51°C, min: 15.12°C). The Bio-retrofit_out scenario produced a similar average but a higher peak of 35.79°C. Compared to the base case, Bio-retrofit_in reduced peak temperature by 1.1°C (Figure 5B).

Figure 5C shows that, under all RCP scenarios (2.6, 4.5, 8.5) in both 2050 and 2090, the Bio-retrofit_in configuration consistently outperformed the base case and Bio-retrofit_out, maintaining lower indoor operative temperatures despite warming trends.

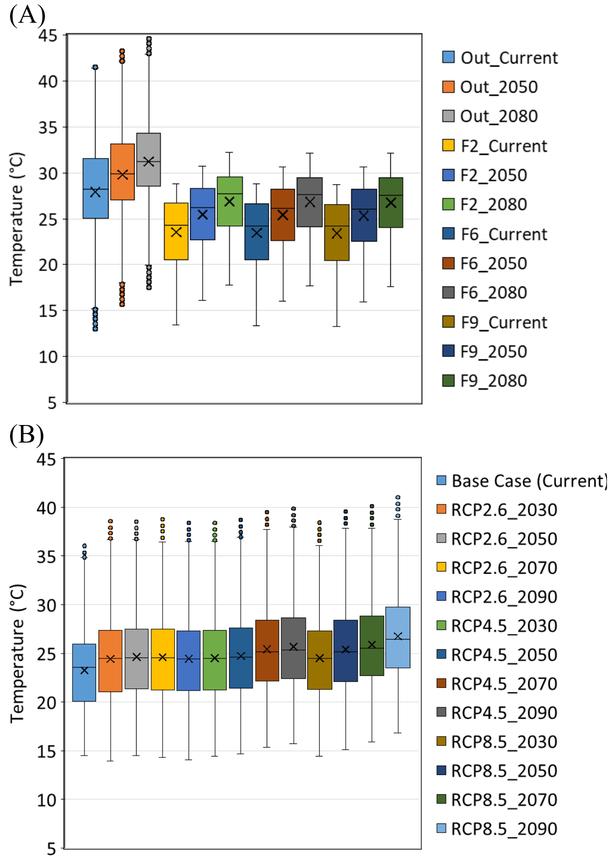

Figure 4: Indoor temperature in the case study in (A) Vadodara, India, and (B) Sydney, Australia.

Cooling energy demand

In the Indian case study, total cooling energy demand (for S-SW and S-SE flats with A/C in bedrooms) under the base case was 0.96 MWh on floors 2 and 6, and 0.90 MWh on floor 9 in the current climate. By 2050, demand nearly doubled to 1.91, 1.87, and 1.84 MWh, respectively.

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By 2080, it had tripled to 2.79, 2.75, and 2.71 MWh—an almost 190% increase from current values (Figure 6A).

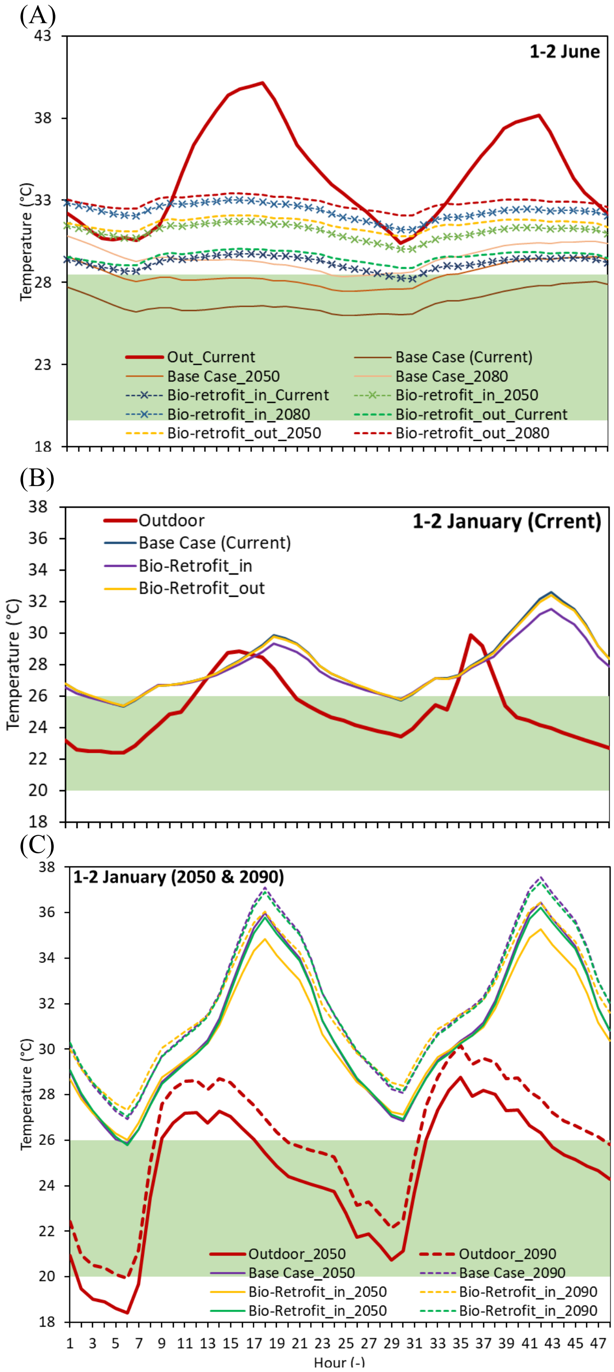

Figure 5: Indoor operative temperature in (A) India case study's S-SW flat's bedroom on 1-2 June, and in Sydney, Australia on (B) 1-2 January (current) and (C) 1-2 January (2050 & 2090).

Under the Bio-retrofit_in scenario, current demand was higher than the base case (1.38, 1.35, and 1.33 MWh) and rose to 2.32, 2.29, and 2.26 MWh in 2050, then to 3.22, 3.17, and 3.14 MWh in 2080—a 133% increase over the starting point. The Bio-retrofit_out scenario followed a similar trend, with slightly lower values in 2080 (3.20, 3.16, 3.13 MWh), suggesting marginally better thermal performance.

Therefore, in India, cooling demand increases significantly across all scenarios. Although retrofits increase current demand, they reduce the growth rate under future climate scenarios, with external retrofits performing slightly better.

In the Australian case study, the base case demand in the main bedroom was 1.15 MWh under the current climate, dropping slightly with retrofits (1.11 MWh for Bio-retrofit_in and 1.12 MWh for Bio-retrofit_out).

Under RCP2.6, demand in the base case ranged from 1.71 MWh (in 2030) to 1.66 MWh (in 2090), with minor reductions (1–2%) under retrofit scenarios. In RCP4.5, demand peaked at 2.59 MWh by 2090 (base case), rising ~125% from current levels. Bio-retrofit_out reduced this to 2.54 MWh. Under RCP8.5, demand reached 3.48 MWh by 2090—a nearly 200% increase—with Bio-retrofit_out slightly lowering it to 3.41 MWh (Figure 6B).

Therefore, in the Australian case study, cooling demand increases with warming, especially under the RCP8.5 scenario. Retrofits provide modest reductions, with external strategies offering slightly better performance.

Discussion

This study examined the projected impacts of climate change on indoor thermal comfort and cooling energy demand in two contrasting climate zones: Vadodara, India, and Sydney, Australia, through building performance simulations under current and future climate scenarios (RCP2.6, RCP4.5, and RCP8.5). The results indicate significant warming trends: in Vadodara, average annual outdoor temperatures are projected to rise from 27.94°C to 31.23°C by 2080 (an 11.78% increase), with peak summer temperatures approaching 45°C. In Sydney, although current outdoor temperatures are lower, the relative increase is potentially greater, particularly under the RCP8.5 scenario, where average temperatures are projected to rise by 21.33% by 2090.

These temperature increases have direct implications for naturally ventilated indoor environments. Rising outdoor temperatures compromise thermal comfort and increase the energy required for cooling to maintain habitable indoor conditions. In Vadodara, for instance, bedroom cooling demand could nearly triple by 2080 under the base case. In Sydney, similar trends are observed, though the increases are more gradual.

Bio-retrofit strategies—targeting internal and external surfaces—were tested to evaluate their ability to mitigate these impacts. While they improved indoor temperatures and reduced cooling demand compared to the base case, their performance was limited under extreme climate projections. For example, despite retrofits, cooling energy demand in India and Australia is still expected to show significant growth by 2080 and 2090, respectively.

Crucially, this study does not aim to provide a comprehensive retrofit solution, but rather to define the baseline performance of typical mid-rise housing under future climate conditions. The models developed here are part of a broader research initiative, BioCOOL, which aims to create a next-generation building envelope using

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mycelium-based composites (MBC). The BioCOOL project also addresses weather protection challenges by developing bio-based protective treatments for MBCs, ensuring the building skin remains durable and practical in real-world conditions.

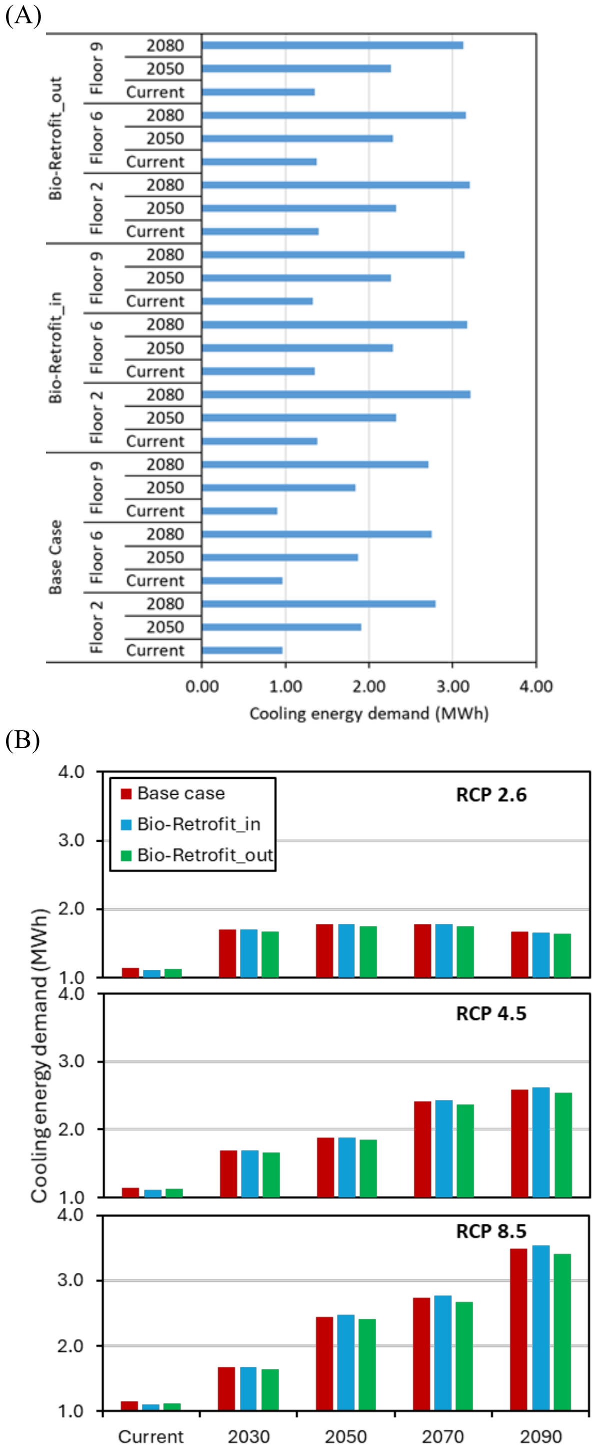

Figure 6: Cooling energy demand under base case, Bio-Retrofit_in and Bio-Retrofit_out scenarios in (A) Indian case study's floors 2, 6 and 9 in current (2009-2023), 2050 and 2080, (B) Australian case study in Current (2009-2023), 2030, 2050, 2070, and 2090 under RCP 2.6, 4.5 and 8.5.

Previous studies with shoebox models under the present climate scenario of New Delhi, India, showed that perforated exterior MBC screens (Bio-Jaali) could reduce daily average indoor operative temperatures by 3.95-14.01% in summer (Debnath, Pynirtzi, Scott, Davie, & Bridgens, 2023). The Indian and Australian case studies offer a more realistic framework for testing and validating MBC-based systems across diverse climates and future scenarios.

Overall, bio-retrofit solutions offer partial mitigation but are insufficient on their own. Long-term climate resilience in buildings will require integrated passive strategies, such as shading, natural ventilation, and renewable energy sources, tailored to local climatic conditions. The differences between RCP2.6 and RCP8.5 highlight the crucial role of climate policy in shaping future building performance and energy demand. While Vadodara may require more aggressive heat adaptation, Sydney can focus on energy efficiency and phased retrofitting.

Conclusion

This study highlights the pressing need to reassess building design strategies in response to rising ambient temperatures and growing energy demands for cooling. Bio-retrofitting measures, utilising MBC, show potential in reducing peak indoor temperatures and lowering energy consumption. As suggested in existing literature, MBC also offers environmental advantages: it is biodegradable at the end of its lifecycle. It can incorporate agricultural and industrial biomass waste, thereby supporting circular economy principles and reducing both the environmental footprint and embodied carbon of building materials. These attributes highlight the need for further research into MBC's thermal performance, long-term durability, and its practical application in building envelopes. Nevertheless, MBC and similar materials alone are unlikely to fully mitigate the projected impacts of climate change. A comprehensive, climate-responsive design strategy—integrating advanced passive cooling techniques, adaptive ventilation systems, renewable energy technologies, and policy-driven low-emission frameworks—is essential. Such integrated approaches are crucial for ensuring indoor thermal comfort and sustainable energy performance across diverse urban climates, ranging from hot regions like Vadodara to temperate cities like Sydney.

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