

A Strategic Review and Framework for Quantifying Building Thermal Resilience in Response to Climate Change

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Problem Statement

- **Challenges posed by climate change:** Increasing extreme weather events threaten building thermal stability, affecting energy efficiency and occupant comfort.
- **Need for resilience:** There is a critical requirement to enhance the thermal resilience of the built environment through informed design and retrofiting.
- This study reviews modeling techniques for a framework that strengthens building resilience against climate-induced thermal stressors.

Introduction

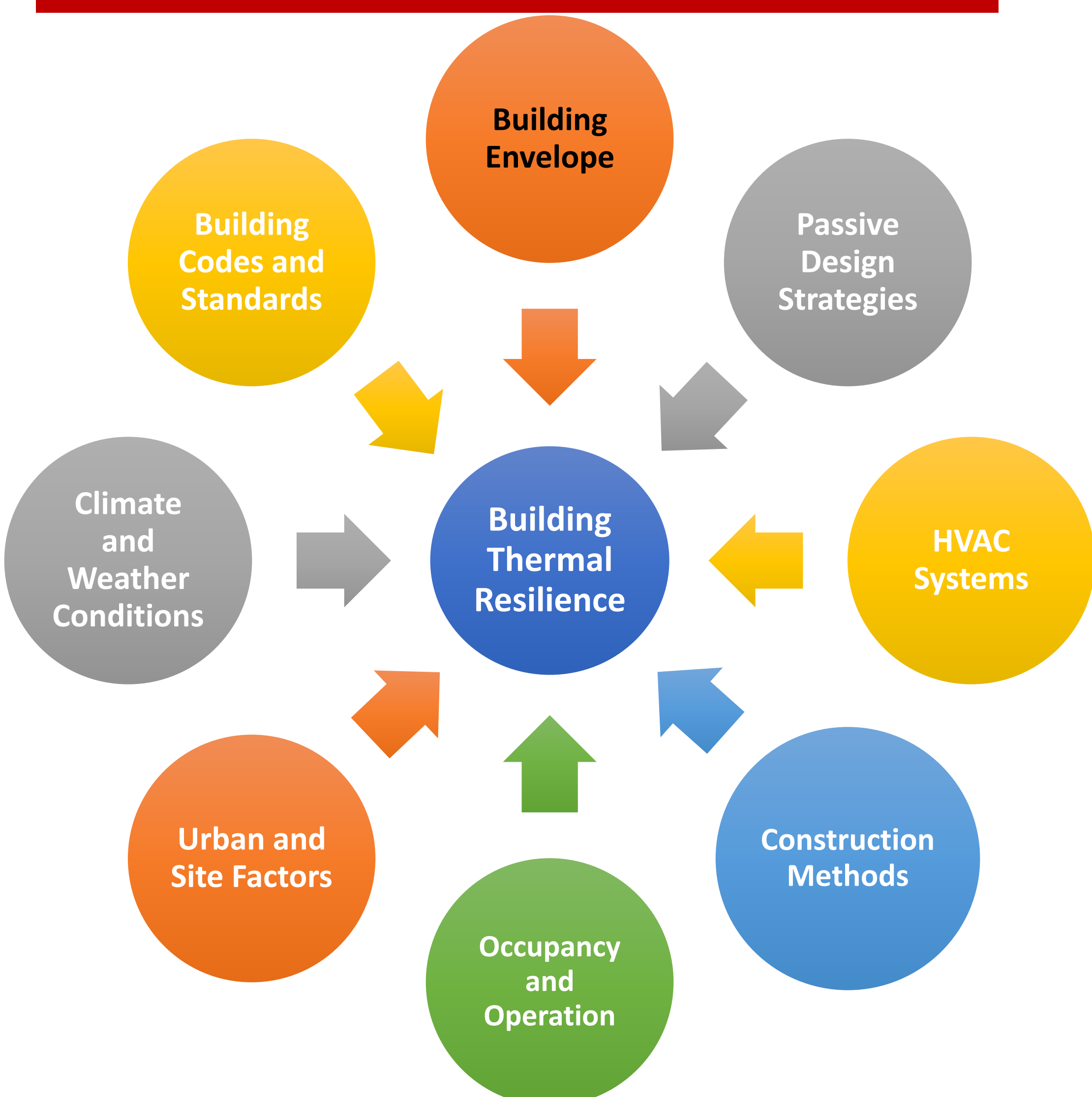


Fig. 1. Components Influencing the Thermal Resilience of Buildings.

- Stakeholder reports from organizations, researchers, and policymakers underscore the necessity for quantitative methods in evaluating building resilience;
- The concept of thermal resilience, though not widely defined, relates to a building's capacity to adapt and recover from temperature fluctuations in changing climates;
- The application of quantitative and qualitative evaluation approaches, particularly simulation methods such as fluid dynamics modeling, EnergyPlus, MATLAB, and CFD, is pivotal in evaluating building thermal performance;
- This paper presents a strategic review of modeling and simulation methods for thermal resilience, seeking to reinforce building sustainability and durability against climate uncertainties.

Evaluation Metrics

Quantifying Building Thermal Resilience

- **Classification of Approaches:**
 - General modeling: Broader conceptual understanding of resilience.
 - Structural-based modeling: Detailed simulations capturing dynamic system behavior.
- **Literature Highlights:**
 - Key studies review resilience definitions, metrics, and modeling approaches.
 - Focus on ventilation strategies, resilient cooling, and simulation metrics for design.
 - Address integration of resilience and sustainability in building assessment.

Table 1 Highlights of Previously Reviewed Articles on Building Resilience

Authors	Highlights	Academic Journals
Hong et al. 2023	Examination of key questions regarding the thermal resilience of buildings for occupants in the context of climate change.	Building and Environment
Jia et al. 2023	A comprehensive review of the quantification indicators and assessment methods for the resilience and sustainability of individual buildings across various dimensions.	Structures
Siu et al. 2023	A systematic summary of existing practices and simulation metrics for thermal resilience in building design process.	Building and Environment
Elnagar et al. 2023	A comprehensive review of various integrated active cooling systems for buildings, highlighting their advantages, limitations, and potential for integration with renewable energy sources.	Renewable and Sustainable Energy Reviews
Tavakoli et al. 2022	Review of definitions, metrics and approaches available to quantify indoor thermal resilience in relation to cooling strategies	Building and Environment
Attia et al. 2022	A literature review leading to a novel definition for resilient cooling in buildings, informed by extensive analysis and expert consultations.	REHVA 14 th HVAC World Congress
Zhang et al. 2021	A critical review of the qualitative assessment and cooling strategies for building resilience in the design phase of a building or during the planning of retrofits.	Energy and Buildings

- **Current Trends:**
 - Thermal resilience has emerged as a critical aspect of building performance.
 - Advanced simulations can quantify resilience, informing strategies for design and retrofit.
- **Research Framework:**
 - Proposes a comprehensive approach to study thermal resilience.
 - From defining metrics to implementing strategies across building scales.
 - Emphasizes a multi-faceted perspective, integrating energy use and sustainability considerations.

Fig. 2 Research diagram for building thermal resilience.

Discussion

Towards a Resilient Built Environment

- **Quantitative Exploration:**
 - Quantitative methods and structural-based modeling are pivotal for a detailed evaluation of resilience at both building and urban scales.
- **Defining Resilience Metrics:**
 - Thermal resilience is measured by a building's response to extreme weather, with indices such as structural, human, and environmental factors.
- **Simulation as a Tool for Resilience:**
 - Simulations cover building specifics, including type, systems, and construction features.
 - Calls for industry-wide collaboration to standardize resilience modeling practices.
- **Scaling Up Simulations:**
 - Highlights the expansion of simulations from single structures to the urban scale to grasp the complex dynamics of thermal resilience.
- **Integration of Design and Strategy:**
 - Urges the integration of preventive strategies in early design.
 - Highlights the use of green and sustainable design principles for resilient construction.
- **Technological Advancements:**
 - Smart technologies and control systems are crucial for augmenting building adaptability and managing emergencies at all scales.

Conclusion

Towards a Resilient Built Environment

- **Progress and Challenges:** Building thermal resilience is advancing with a focus on sustainability, yet integration across scales and technology adoption remain key challenges.
- **Research Diagram:** Proposes a structured approach to unify and enhance resilience studies.
- **Future Direction:** Aims to provide a guiding framework to inform and direct future investigations into building and urban resilience.