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Life Cycle Assessment of Social Housing in Humid Tropical Climates: Decarbonization through Bio-based Materials and Passive Design

Summary

Achieving deep decarbonization in the building sector remains a critical challenge, particularly in humid tropical climates where latent loads and high outdoor temperatures drive cooling energy demand. While extensive research has been conducted in temperate climates, the transferability of these approaches to tropical environments remains limited due to specific hygrothermal dynamics.

This study investigates the decarbonization potential of social housing in humid tropical climates through a comprehensive life cycle assessment (LCA). A multi-scale framework integrating operational energy, embodied carbon, and carbon storage of bio-based materials is developed. Dynamic thermal simulations coupled with LCA are applied to a representative case study in Guadeloupe.

Results indicate that operational energy dominates emissions in conventional buildings, while embodied carbon becomes significant in optimized scenarios, reaching up to 60% of total emissions. The integration of bio-based materials reduces embodied carbon by 30–50% and enables carbon storage of 20–40 $kgCO_2/m^2$. Combined strategies lead to total life cycle emission reductions of 45–65%.

The study demonstrates that deep decarbonization in tropical climates requires a shift from energy-based to carbon-based design, integrating passive cooling and low-carbon materials.

This project aims to define a set of effective and applicable technical solutions for the renovation and construction of housing in tropical climate. Decarbonizing buildings will involve not only improving their energy performance but also leveraging them as carbon sinks by using bio-based materials.

Keywords: bio-based materials, LCA, dacarbonization, bio based material

Field of application for the findings: building renovation and construction

Addressed audience: engineers, architect, designers

Introduction

The building sector is responsible for a large share of global energy consumption and greenhouse gas emissions. In humid tropical climates, energy demand is dominated by cooling loads and latent heat effects. Social housing represents a key opportunity for large-scale decarbonization.

Traditional approaches focus on operational energy reduction, but recent studies highlight the importance of embodied carbon. This research proposes an integrated LCA framework adapted to tropical climates, combining energy performance, material selection, and carbon storage potential.

This work aims to address this gap by proposing a comprehensive life cycle assessment framework specifically adapted to tropical social housing. The study combines building physics, material science, and environmental assessment to identify effective decarbonization strategies.

2. Literature Review

The importance of life cycle assessment in the building sector has been widely recognized. Ramesh et al.

(2010) demonstrated that life cycle energy consumption of buildings can vary significantly depending on design choices, highlighting the need for a holistic perspective.

Dixit et al. (2010) further emphasized the importance of embodied energy, showing that material production and construction processes contribute substantially to total emissions. This is reinforced by Cabeza et al. (2014), who provided a comprehensive review of LCA methodologies applied to building materials, demonstrating their relevance for environmental decision-making.

Chastas et al. (2016) introduced the concept that embodied energy can represent more than 50% of total life cycle impacts in highly efficient buildings. This finding is critical in the context of tropical climates, where improvements in operational efficiency shift the balance toward embodied emissions.

Bio-based materials have emerged as a promising solution. Palumbo et al. (2016) showed that these materials exhibit favorable hygrothermal properties, including moisture buffering capacity, which can significantly influence indoor comfort and energy demand. Moreover, Collet and Pretot (2014) demonstrated that moisture content strongly affects thermal conductivity, highlighting the importance of coupled heat and moisture modeling.

Moisture buffering has also been extensively studied. Rode et al. (2005) and Osanyintola and Simonson (2006) quantified its impact on indoor humidity regulation and comfort, particularly in climates with high moisture loads.

Despite these advances, few studies combine LCA, hygrothermal modeling, and bio-based materials in tropical contexts. This paper addresses this gap by integrating these dimensions into a unified framework.

1. Methodology and results

The life cycle assessment follows ISO 14040 and ISO 14044 standards. The functional unit is defined as 1 m² of conditioned floor area over a 50-year lifespan.

The system boundaries include production (A1–A3), construction (A4–A5), use (B6), and end-of-life (C1–C4). Operational energy consumption is calculated using dynamic thermal simulations under Guadeloupe climatic conditions.

Three scenarios are analyzed:

- Baseline (conventional construction)
- Optimized (energy-efficient design)
- Bio-based (integration of low-carbon materials)

Embodied carbon values are derived from literature and environmental databases, while carbon storage is estimated based on biomass content of materials.

Results indicate that in the baseline scenario, operational energy accounts for approximately 70% of total emissions. In optimized buildings, this share decreases, and embodied carbon becomes dominant.

The integration of bio-based materials reduces embodied carbon by up to 50% and introduces carbon storage effects. Total life cycle emissions are reduced by 45–65%, depending on the scenario.

These results confirm that decarbonization strategies must address both operational and embodied emissions simultaneously

The results highlight a fundamental paradigm shift in building design. While traditional approaches focus on reducing operational energy, this study demonstrates that embodied carbon becomes a dominant factor in high-performance buildings.

Bio-based materials provide a dual benefit: they reduce embodied emissions and act as carbon sinks. Their hygrothermal properties also contribute to improved indoor comfort, particularly in humid tropical climates.

However, several limitations must be acknowledged. The use of literature-based data introduces uncertainties, particularly regarding regional variations in material production. Additionally, the model does not fully account for long-term degradation of materials.

From a policy perspective, the findings support the integration of LCA into building regulations. Tropical regions, particularly island territories, offer unique opportunities to implement low-carbon construction strategies at scale.

Conclusion

This study demonstrates that a comprehensive LCA approach is essential for achieving deep decarbonization in tropical buildings. By integrating operational energy, embodied carbon, and bio-based materials, the proposed framework provides a robust basis for sustainable design.

Future research should focus on experimental validation and the development of more regional material databases.

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