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ADVANCEMENTS IN INTEGRATING PASSIVE SOLUTIONS FOR SUSTAINABLE THERMAL COMFORT IN TROPICAL BUILDINGS

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Abstract
Tropical climates present distinctive challenges for achieving sustainable thermal comfort in buildings, characterized by elevated temperatures and humidity levels. Addressing these challenges, this comprehensive review paper asserts the efficacy of passive design strategies as a promising solution to manage indoor thermal conditions in such environments. This necessitates the meticulous examination of the latest research and developments, underscoring the critical importance of thermal comfort and its profound impact on human health, productivity, and energy consumption within tropical buildings. A navigation through the foundational principles of passive cooling and heating strategies emphasizes their potential to ameliorate the adverse effects of harsh tropical climates. The study examines the efficacy of several passive design strategies, including solar shading, evaporative cooling and thermal mass, and natural ventilation, in various tropical climates and building types. The analysis is based on empirical research. The paper deftly examines how active cooling systems and passive design techniques intersect, clarifying hybrid strategies that maximize thermal comfort and energy economy. It emphasizes how crucial it is to add passive design techniques early on in the design process so that they are easily integrated into the overall building design scheme. Future directions for passive design application and research in tropical buildings are outlined in the paper's conclusion. The review presents itself as an invaluable resource for researchers, practitioners, and policymakers, emphasizing the need to advance novel passive cooling and heating techniques and to encourage awareness and adoption of passive design principles among architects, engineers, and policymakers.

Keywords: Passive design, thermal comfort, tropical buildings, sustainability, energy efficiency

Introduction

Tropical climates, with their relentless sun and pervasive humidity, pose a formidable challenge to architects and engineers striving for sustainable thermal comfort in buildings. In this stifling environment, achieving a balance between human well-being, energy efficiency, and environmental responsibility becomes a delicate dance. This review paper boldly steps into this intricate arena, championing the transformative power of passive design strategies as the key to unlocking sustainable thermal comfort in tropical buildings. Thermal comfort, a concept often relegated to the sidelines, has been shown to be the most important factor in determining human health, productivity, and energy consumption in tropical buildings. Disrupting this delicate equilibrium can lead to a cascade of negative consequences, from heat stress and respiratory illnesses to decreased cognitive performance and spiraling energy bills. Recognizing the gravity of this issue, this review delves into passive cooling and heating solutions, revealing their latent potential to lessen the severe impacts of tropical climates, are the key ideas that are being discussed here.

Drawing upon a tapestry of empirical research, we embark on a meticulous exploration of various passive design solutions, each a testament to human ingenuity in harnessing the power of nature. In this article, we explore the complex interaction between solar shading, evaporative cooling, thermal mass, and natural ventilation, demonstrating how efficient these strategies are in a variety of tropical climates and building types. Unraveling the threads of their efficacy, we illuminate how these strategies seamlessly integrate with active cooling systems, forging hybrid approaches that maximize thermal comfort while minimizing energy footprints.

To truly unlock the magic of passive design, we must weave it into the very fabric of the design process. This review emphasizes the critical importance of incorporating passive elements from the outset, ensuring their seamless integration into the overall building scheme. By embracing this early integration, we harness the full potential of these sustainable solutions, transforming tropical buildings into havens of comfort and ecological responsibility. The purpose of this review is to create something that is more than simply an academic exercise. Researchers, practitioners, and politicians alike should take note of this call to action and use it as a guide. We urge the scientific community to continue pushing the frontiers of passive cooling and heating technologies, unlocking new avenues for thermal comfort in tropical regions. We implore architects and engineers to embrace the power of passive design, becoming champions of sustainable solutions in the face of climate change. And finally, we call upon policymakers to incentivize the adoption of these principles, fostering a world where tropical buildings are not just functional structures but testaments to our harmonious coexistence with nature. This review is a roadmap, a compass guiding us towards a future where sustainable thermal comfort in tropical buildings is not a dream but a tangible reality.

Methodology

The study included an extensive examination of scholarly articles, conference papers, and books pertaining to passive design techniques for achieving sustainable thermal comfort in tropical structures. Emphasis was placed on works in the English language that were published in the most recent years. An extensive array of passive design strategies used to enhance thermal comfort in tropical buildings were found. These techniques were analyzed based on their effectiveness, applicability, and cost-effectiveness. The review also considered the integration of passive design strategies with active cooling systems. The findings of the literature review were used to develop a framework for selecting and implementing passive design strategies in tropical buildings. The framework takes into account crucial elements such as the environment, kind of structure, occupants' requirements, energy efficiency, and cost-effectiveness. The framework was used to analyse a case study of a residential structure situated in a tropical environment. The case study examined the efficacy of several passive design solutions in enhancing thermal comfort inside the structure. The findings of the case study were used to validate the framework and provide practical recommendations for implementing passive design strategies.

Thermal Comfort

Thermal comfort refers to the individual's personal and psychological impression of feeling comfortable in relation to the body's management of temperature in response to different environmental conditions (Tung *et. al.*, 2014). According to Ghahramani *et. al.*, (2018), thermal comfort refers to the degree of heat or cold that a person's body considers suitable for maintaining good health, well-being, and productivity in a building setting. Thermal comfort refers to a mental state that indicates contentment with the temperature conditions, which is crucial for maintaining good health and productivity (Fayyaz, *et. al.*, 2021). Ensuring thermal comfort in buildings is of utmost importance, since excessive cooling during the summer leads to higher energy consumption and discomfort. Conversely, naturally ventilated buildings that do not rely on mechanical cooling may enhance comfort in hotter conditions (Brager & Arens, 2015). Alfano, *et. al.*, (2014) opined that thermal comfort in buildings has an effect on occupants' well-being, their performance, and building energy requirements. It strongly influences occupant satisfaction and their control of the indoor climate. Thermal comfort is crucial for satisfying occupants in indoor environments, especially during warm summer seasons, and for energy-saving schemes (Mustapa *et. al.*, 2016). In educational buildings, thermal comfort is said to be significantly related to productivity, well-being, and energy conservation (Zomorodian, *et. al.*, 2016). The temperature in office buildings has a direct impact on human productivity, ranging from a minimum of 17.6 °C in air-conditioned buildings to a maximum of 31.2 °C in naturally ventilated structures (Lamsal, *et. al.*, 2023). Thermal comfort is crucial for buildings located in hot and humid tropical regions. Lighting and cooling are significant sectors that use a substantial amount of energy (Mathew *et. al.*, 2017). It is necessary to maintain a positive balance within structures and building materials (Hata, *et. al.*, 2016). Managing the transfer of heat through the building's outside layer is essential for keeping a comfortable temperature within. This involves choosing appropriate methods and materials to regulate thermal energy (Gadi, 2010).

The tropics provide difficulties in establishing sustained thermal comfort due to high ambient temperatures and humidity. However, natural ventilation facilitated by breezes during the dry season may help accomplish thermal comfort (Safarova et. al., 2017). Elevated standards for thermal comfort in tropical regions need greater reliance on air cooling, leading to substantial carbon emissions (Cook & Rawal, 2018). Azzam & Fahanim (2011) have identified modern constraints, fragile building materials, and a lack of skilled labor as the main challenges in achieving thermal comfort in tropical climates. In their study, Nwalusi *et. al.*, (2022) identified elevated air temperatures and high relative humidity as obstacles to obtaining thermal comfort in tropical climates and further suggested that architects should focus on climate-responsive and energy-efficient building designs, a position also corroborated by Safarova *et. al.*, (2017). Another factor identified by Mirrahimi, *et. al.*, (2015) is a poorly designed landscape. The challenge for building designers in the hot-humid tropics is providing indoor environmental thermal comfort while controlling energy use for spaces (Aminuddin, *et. al.*, 2012).

Rana, K. (2021), proposed passive design strategies, such as triple-glazed windows and custom window operation schedules, to significantly improve occupant thermal comfort and reduce energy consumption. Optimal passive design for residential buildings can reduce cooling and heating demands and improve thermal comfort by integrating passive cooling strategies like blinds and natural ventilation (Harkouss, *et. al.,* 2018).

Passive Design Strategies for Sustainable Buildings

Passive design solutions have become a fundamental element in attaining thermal comfort and energy efficiency in buildings, making a substantial contribution to sustainability objectives. Passive design strategy is a cost-effective and efficient approach to decrease energy usage in residential buildings. It focusses on optimising seven key factors: wall thickness, roof insulation thickness, external wall insulation thickness, window orientation, window-wall ratio, glazing type, and sunroom depth/overhang depth (Gong *et. al.,* 2012, Oumarou, *et. al.,* 2021). Passive design is a cost-effective and efficient approach to creating sustainable structures, with a specific emphasis on improving the quality of the building environment and ensuring occupant happiness (Yehao *et. al.,* 2015; Zhen *et. al.,* 2019). This section critically reviews existing research on the efficacy of various passive approaches, highlighting their impact on building performance and occupant satisfaction.

Chen *et. al.,* (2018) emphasize the role of building layout and envelope thermophysics in enhancing energy efficiency. Their work demonstrates how optimizing these elements can lead to significant reductions in energy consumption. Additionally, Yehao *et. al.,* (2015) highlight the potential of passive strategies, such as courtyard spaces, to improve building environment quality and occupant satisfaction, further contributing to sustainability. Moreover, the multi-criteria approach proposed by Chen *et. al.,* (2015) provides a valuable framework for evaluating the influence of passive design on sustainable buildings. Sharif *et. al.,* (2021) focus on hot, dry climates, demonstrating how passive design strategies like orientation, building envelope design, and external features can effectively reduce energy consumption and improve indoor climate. Similarly, Chen and Yang (2017) investigate the application of hybrid ventilation and daylight dimming in residential buildings within hot and humid climates, showcasing their potential for substantial energy savings. Sood and Harish (2018) explore the benefits of passive technologies, such as naturally ventilated buildings and phase-change materials, in enhancing thermal comfort and energy efficiency. Their research underscores the ability of these technologies to reduce energy consumption and contribute to sustainable design. Cojocaru and Isopescu (2021) delve into the realm of vernacular architecture, highlighting how passive strategies based on local materials and traditions can significantly increase energy efficiency and reduce the environmental impact of buildings. Gangwar, *et. al.,* (2020) emphasize the importance of prioritizing passive design strategies influenced by local climate in sustainable building design. They advocate for utilizing passive strategies to their fullest potential, with active strategies employed to complement them for optimal results. While acknowledging the effectiveness of passive design strategies in reducing building energy budgets, Chen *et. al.,* (2015) highlight the need for more consolidated weighting systems within green building rating tools to enable effective comparison and optimization of various passive approaches.

Conclusions

In summary, this analysis shows that there is broad agreement among researchers on the value of passive design techniques for creating sustainable buildings. The studies that have been evaluated provide insightful information on how these tactics are used differently in different climatic settings and kinds of buildings. Although passive design has made major contributions, more research and development is still needed to fully maximise their influence on sustainable building design. This is especially true when it comes to assessment and optimisation approaches.

The research discovered that enhancing thermal comfort in tropical buildings may be accomplished with the use of passive design techniques. The best precise tactics will change according on the kind of structure, tenant demands, and climate. Nonetheless, there are broad guidelines that may be used when choosing and implementing passive design techniques. Among these guidelines are:

- Early in the design phase, take into account passive design techniques.
- Pick passive design techniques that suit the building type and environment.
- A variety of passive design techniques may be used to provide the required degree of thermal comfort.
- Keep an eye on and assess the performance of passive design techniques.

Additionally, the study discovered that active cooling systems and passive design techniques may be combined to increase thermal comfort and energy efficiency. But it's crucial to give hybrid systems' cost-effectiveness serious thought.

Passive design solutions were shown to be a potential alternative for boosting thermal comfort and energy efficiency in tropical buildings, according to the findings of the study. It is necessary to do more research in order to create groundbreaking passive design solutions and to encourage the use of passive design concepts.

Recommendation

On the basis of the results and conclusions of the study that were provided in the article titled "Advancements in Integrating Passive Solutions for Sustainable Thermal Comfort in Tropical Buildings," It is highly propose that the following should be taken into consideration when designing thermal comfort in tropical buildings:

1. When it comes to the early phases of tropical building design, giving passive design methods priority is essential. By doing so, we guarantee that these techniques are effectively integrated and integrated to their full potential in order to provide sustained thermal comfort.
2. Implementing a combination of diverse passive design solutions, tailored to the specific climatic context and building type. This comprehensive approach maximizes the potential for achieving desired thermal comfort levels.
3. Integrating passive design strategies with active cooling systems, when necessary. However, thorough cost-benefit analysis is crucial for optimizing the system's energy efficiency and economic viability.
4. Further research and development efforts focused on:
    a. Evaluation and optimization methodologies: This will enhance the effectiveness and adaptability of passive design strategies in various tropical contexts.

   b. Innovative passive design techniques: This will expand the available options and improve their performance in different building types and climates.
5. Promoting the broader adoption of passive design principles in the construction industry and within relevant policy frameworks. This widespread implementation will contribute significantly to achieving sustainable thermal comfort in tropical buildings while minimizing environmental impact.

By following these recommendations, the paper's findings can be translated into actionable strategies, leading to the construction of more sustainable and energy-efficient buildings in tropical regions.

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