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"THE IMPORTANCE OF TROMBE WALL–PV/T HYBRID SYSTEMS IN AIR PURIFICATION AND HEATING"

Abstract: *This thesis analyzes four main research studies on Trombe walls and PV-integrated Trombe walls (BIPV Trombe wall). In the future, parametric optimization will be conducted based on air flow rate, channel geometry, and wall mass, comparing winter heat gain, summer overheating, and PV power output.*

Keywords: *Trombe wall, solar PV/T system, air heating, air purification.*

Introduction

The building sector accounts for the largest share of energy consumption, with heating, ventilation, and air conditioning (HVAC) systems being major contributors to this demand [1]. Reviews of passive solar heating technologies indicate that properly designed passive solutions can significantly reduce the need for supplemental heating during winter, thereby improving the overall energy efficiency of buildings [2]. One of the classic passive strategies is the Trombe wall, which stands out for its structural simplicity, low operational cost, and broad applicability [3]. A Trombe wall absorbs solar radiation, stores heat in its massive structure, and gradually transfers it to the interior space, naturally supporting the process of indoor heating.

PV-integrated Trombe walls (PV-Trombe) build on the concept of simultaneously harnessing thermal and electrical energy. In these systems, the photovoltaic (PV) layer does not impose an extra load on the wall but rather becomes an active component of the building's energy system. As a result, the system can reduce annual heating demand while also generating electricity, enhancing the overall energy benefit [4].

Literature Review

Research on reducing energy consumption in buildings primarily emphasizes the “passive” approach: minimizing heat losses through the building envelope, managing useful solar heat gains, and efficiently utilizing natural heat transfer mechanisms [1]. In this context, Sadine et al. summarize how building envelope elements—walls, windows, insulation, and façade solutions—affect energy efficiency and directly influence heating and cooling loads [1]. Chan and colleagues classify passive solar technologies and highlight the importance of heat collection, storage, and transfer mechanisms, noting that practical performance depends strongly on proper selection of design parameters such as orientation, transparent coverings, air channels, and materials with high thermal capacity [2].

Saadatian et al. provide a comprehensive review of Trombe walls, discussing both their advantages—structural simplicity, heat storage capacity, and relatively low operating costs—and limitations, including seasonal adaptability, risk of overheating, reliance on natural convection, and design sensitivities [3]. Hu et al. compare the annual performance of three types of BIPV Trombe wall systems, demonstrating that PV integration can transform the wall into a multifunctional façade capable of generating electricity in addition to providing thermal comfort [4].

Research Methodology

The methodology of this thesis is grounded in a systematic review of the literature, focusing on passive building envelope solutions, particularly the evaluation of Trombe walls and their PV-integrated modifications. The approach was implemented through a four-step sequential framework. First, the study scope was defined within the concept of the “passive energy-efficient building envelope,” adopting a generalized approach to key factors affecting energy performance, including heat losses, useful solar gains, and structural solutions [1].

Next, a comparative analysis of design parameters and classifications of passive solar heating and cooling technologies was applied to clarify the role of Trombe walls within these systems and their practical application requirements [2]. The capabilities and limitations of Trombe walls were then examined using an “advantage–challenge–improvement” matrix, highlighting aspects such as heat storage, natural convection, seasonal adaptability, overheating risk, and potential optimization strategies through geometry, material selection, and airflow management [3].

For PV-integrated Trombe walls (BIPV Trombe walls), a comparative annual performance assessment approach was adopted, resulting in a conceptual framework that simultaneously considers thermal and electrical benefits. Within this framework, the methodological challenge of balancing the temperature sensitivity of PV modules with the heat storage function of the Trombe wall was explicitly addressed as a distinct evaluation criterion [4].

Discussion and Results

Analysis of the selected literature indicates that the most reliable strategy for enhancing building energy performance is to minimize heat losses through the envelope while effectively managing useful solar gains [1]. Reviews of passive solar heating and cooling technologies further suggest that energy efficiency outcomes are often determined more by the correct selection of design parameters—such as building orientation, transparent coverings, air channel configuration, high-thermal-capacity materials, and natural convection conditions—than by the specific device itself [2].

Within this context, the Trombe wall emerges as a practically viable platform among passive solutions; however, it is not without limitations. Seasonal adaptability, overheating risk, and the stability of airflow are factors that can constrain system performance [3]. Overall, the literature review presents Trombe walls and BIPV Trombe wall systems as energy-efficient building envelope technologies that align with the passive design concept but require careful optimization in both design and operational stages [1]–[4].

Conclusion and Recommendations

The review of selected studies demonstrates that the BIPV Trombe wall concept transforms a façade into a multifunctional system capable of providing both thermal comfort and electricity generation. However, due to the temperature sensitivity of PV modules, achieving a balance between heat collection and PV efficiency remains critical [4]. Future research should focus on climate-specific adaptation (e.g., hot or arid regions) and the assessment of system performance under real operational conditions. Additionally, façade solutions should be evaluated within a holistic building envelope energy efficiency framework to ensure integrated optimization [1]–[3].

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