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CFD Investigation of Heat Recovery Ventilation Systems with Integrated Thermal Energy Storage for Energy-Efficient Homes

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ABSTRACT

Energy efficiency in residential buildings is a growing concern, particularly in cold climates where heating demands are high. Heat Recovery Ventilation (HRV) systems play a crucial role in reducing energy loss by exchanging heat between outgoing and incoming air while maintaining indoor air quality. However, conventional HRV systems have limitations in effectively storing and utilizing excess heat. Integrating Thermal Energy Storage (TES) with HRV systems can enhance energy efficiency by capturing waste heat and releasing it when needed, reducing reliance on external heating sources. This study employs Computational Fluid Dynamics (CFD) to investigate the performance of an HRV system combined with a Phase Change Material (PCM)-based TES unit.

The research aims to analyze airflow distribution, heat transfer efficiency, and thermal storage effectiveness under various environmental and operational conditions. A CFD model of a residential space equipped with an HRV-TES system is developed using ANSYS Fluent. The TES unit, integrated into the HRV system, contains PCM materials capable of storing excess thermal energy during ventilation and releasing it during periods of peak heating demand. The simulation examines critical parameters such as air velocity, temperature distribution, PCM melting and solidification cycles, and overall system efficiency.

A parametric study is conducted to evaluate the impact of different PCM materials, ventilation rates, and outdoor temperatures on heat recovery efficiency. The study explores optimal PCM selection based on thermal properties such as latent heat capacity, melting point, and thermal conductivity. Additionally, the effect of varying HRV operation modes, including intermittent and continuous airflow, is examined to determine the most effective strategy for maintaining indoor thermal comfort while minimizing energy consumption.

Preliminary results indicate that integrating TES into HRV systems can significantly improve heat retention and energy efficiency in residential buildings. The use of PCM allows for better temperature stabilization, reducing the need for auxiliary heating and lowering overall energy costs. The study also identifies key design parameters that influence the effectiveness of HRV-TES integration, providing recommendations for system optimization in different climatic conditions.

This research contributes to the advancement of energy-efficient building technologies by demonstrating the potential of HRV-TES systems in sustainable home heating. The findings can guide future residential HVAC system designs, promoting lower energy consumption and reduced carbon footprints. Future work will explore experimental validation of CFD simulations and practical implementation of optimized HRV-TES configurations in real-world applications.