Solar Chimney Applications in Buildings

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A solar chimney is a renewable energy system used to enhance the natural ventilation in a building based on solar and wind energy. It is one of the most representative solar-assisted passive ventilation systems attached to the building envelope. It performs exceptionally in enhancing natural ventilation and improving thermal comfort under certain climate conditions. The ventilation enhancement of solar chimneys has been widely studied numerically and experimentally. The assessment of solar chimney systems based on buoyancy ventilation relies heavily on the natural environment, experimental environment, and performance prediction methods, bringing great difficulties to quantitative analysis and parameterization research. With the increase in volume and complexity of modern building structures, current studies of solar chimneys have not yet obtained a unified design strategy and corresponding guidance. Meanwhile, combining a solar chimney with other passive ventilation systems has attracted much attention. The solar chimney-based integrated passive-assisted ventilation systems prolong the service life of an independent system and strengthen the ventilation ability for indoor cooling and heating. However, the progress is still slow regarding expanded applications and related research of solar chimneys in large volume and multi-layer buildings, and contradictory conclusions appear due to the inherent complexity of the system.

Keywords: natural ventilation ; solar chimney ; Trombe wall ; renewable energy ; passive ventilation ; building application

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Due to the potential benefits of passive ventilation systems in economic and energy conservation and resistance against noise and carbon dioxide emission [1][2][3], more research has focused on exploring and improving passive ventilation in the past 20 years. Passive ventilation strategies have been extensively studied over the years. According to local climate conditions and building characteristics, passive ventilation systems show different airflow characteristics and temperature distributions. Simultaneously, some passive ventilation systems also have heat dissipation and heat acquisition functions for space cooling and heating apart from providing adequate ventilation [3][4][5][6][7][8][9]. Most modern buildings rely entirely on mechanical ventilation, i.e., active ventilation systems, to satisfy indoor comfort. The majority of the energy supply is used for those active ventilation systems, occupying usable space due to its relatively large volume and structural complexity. Additionally, buildings with mechanical ventilation are often highly airtight to minimize energy consumption and heat loss, resulting in an inadequate fresh air supply [2].

Passive ventilation systems are increasingly being advocated as low-energy alternatives and low-cost solutions for energy conservation buildings. According to the pressure difference sources, typical modes of passive ventilation are referred to as wind-induced, buoyancy-driven, and hybrid ventilation [10][11]. Corresponding air movement is caused by wind pressure, temperature difference, or both of the above, and humidity difference [12]. It has been found that natural ventilation has the potential to provide adequate capacity for thermal regulation and satisfying indoor air quality in available climatic conditions without reliance on mechanical systems [10][13][14].

Passive ventilation systems rely on natural physical mechanisms, which make many uncertainties occur during operation. Wind-induced ventilation systems are solely dependent on prevailing wind speed and incident angle. The stochastics of wind direction and wind intensity bring significant challenges to system performance evaluation and design [15]. Buoyancy-driven ventilation builds upon the air intensity difference caused by the internal and external temperature difference, ventilating the space even in windless conditions. However, under extremely hot and humid climatic conditions (the temperature difference is insignificant), the system is probably not working properly. Not every passive ventilation system has the dual function of heating and cooling space driven by natural forces. The natural ventilation system can remove the stale warm airflow indoors by accelerating the air movement to provide a space cooling effect. Achieving heating usually requires collecting and storing heat gain and releasing heat when needed to increase the indoor temperature. As the most representative buoyancy ventilation system, the solar chimney has attracted researchers' attention because of its simultaneous ventilation, heating, and cooling functions.

A typical solar chimney is presented in Figure 1. It consists of an absorption wall, a glazing wall, tuyeres/vents, and heat-insulating materials. Airflow is affected by the air density difference between the internal and external environment and the external wind [16][17][18][19]. Stale air escapes from the purpose-built openings by the thermo-siphoning effect. The solar chimney components can employ direct or indirect solar energy to drive the airflow in the space. Quesada et al. [20][21] comprehensively reviewed the research on transparent and translucent solar facades in the past ten years based on theory and experiment and explored its development and applicability. The solar façade absorbs and reflects incident solar radiation and converts direct or indirect solar energy into usable heat. Jiménez-Xamán et al. [22] verified that a roof-top solar chimney applied to a single room for cooling purposes could increase the ventilation rate by 1.16–45.0%. The numerical code was generated to solve the conjugate turbulent heat transfer in a single room equipped with a solar chimney based on the coupling of CFD and global energy balances.

Solar chimneys stand out among many natural ventilation systems not only because of the convenience of their structural features when they are integrated into buildings or in conjunction with other ventilation systems but also because the solar chimney has heating and cooling modes through the cooperation of damping and openings, which makes the structure more sustainable. Figure 2 presents two modes that a solar chimney can achieve in the cooling season and heating season. In order to improve thermal comfort and enhance the applicability of natural ventilation, Monghasemi et al. [6] summarized the existing combined passive ventilation system based on solar chimneys and investigated the thermal regulation of the selected systems and their ability to improve ventilation efficiency.

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