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Using the central ventilation shaft design within public buildings for natural aeration enhancement

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HIGHLIGHTS

- This paper studied the aired flow of a building with a built-in CVS.
- Field measurements were conducted to validate the computer model.
- The ACH, PMV & ACS data were used to assess ventilation results in a building.
- CFD can guide users to balance ventilation outcome and business usage of buildings.

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ABSTRACT

The natural ventilation of buildings can be closely related to building design. The object of this investigation is to conduct computational fluid dynamic (CFD) simulations and field measurements for studying the natural ventilation effectiveness of office space in a common public building with a built-in central ventilation shaft (CVS). The aeration flow behavior was predicted and compared with the measured air velocity and temperature data at 16 monitoring positions over three different floors inside the main building to validate the computer software as well as attain a better understanding of the natural ventilation mechanism associated with the interaction of the wind with the building. CFD simulations were also extended to examine the design impacts of removing the CVS and reducing the cross-sectional area to a half-sized CVS on the building aeration performance in terms of the air exchange rate per hour (ACH) and the adaptive comfort standard (ACS) and predicted mean vote (PMV) results. This CFD simulation procedure can serve as a useful analysis tool to facilitate architects for improving the natural ventilation design of buildings during their decision-making process.

1. Introduction

Natural ventilation is a renowned, cost-effective technique from ancient times to freshen and chill lodging spaces for managing thermal comfort and indoor environment of buildings all over the world [1]. Energy-conscious designers normally connect the cooling capacity of external air to enhance quarter thermal controlling and eventually reduce the need for active air-conditioning [2]. Hence, natural ventilation has played a central role for many low energy-building designs. It has been also noted as a crucial issue to recurrently bring the fresh cool air from the outside into a building and drive the stale warm air out through an outlet [3]. Essentially, the natural ventilation in buildings can be categorized into two types, comprising the air pressure aeration or known as the wind force, and the chimney effect aeration or the thermal force [4]. In the former type, the studies primarily examined the wind field characteristics within a building complex and around buildings to better understand the interaction of airflow with architectures [5]. The performance of natural ventilation could be evidently improved via the proper layout of building orientation and airing openings respecting to the prevailing wind with the focused aspects including the air movement and comfort matters in residential areas [6]. In addition, a ventilation shaft can be often designed as a vertical space to develop a passage for facilitating air circulation of the buildings between interior spaces and surroundings. For the latter type, the use of chimney effect through the buoyancy is one of the most conventional strategies in natural ventilation design [7–10]. In principle, the airflow is driven by

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thermal buoyancy due to the difference in density between the warm air inside the building and the adjacent cooler air. The effectiveness of the chimney outcome is affected by the height of the stack, the difference between the average temperature of the stack and the outside, and the effective area of the openings [11]. As the same openings of buildings may contribute to both chimney and wind induced flows, the aforesaid two ventilation mechanisms must not be considered in isolation.

The wind environment under naturally ventilated states is strongly related to the comfort sensation [12]. Hence, understanding the dynamic response of people to the microclimate conditions varying with respect to the time and location is required to evaluate the thermal comfort. A key element in the assessment of thermal comfort is the development of a comfort index which properly reflects the comfort consciousness of a person in a given situation. Based on the empirical laboratory-based comfort appraisal for indoor environments under the steady-state conditions, Fanger formulated the predicted mean vote (PMV) and the predicted percentage of dissatisfaction (PPD) calculation schemes, which have been exercised in many indoor thermal comfort standards [13,14]. Although the heat-balanced PMV model allows the alternative of changing the activity level and clothing, the experimental works were conducted in climate chambers. Such arrangement did not show how the occupants would change these two parameters with the aim of adapting to the surrounding environments. In practice, assumptions have to be settled for the enduring activity and clothing, having a tendency to limit the application of the PMV model to a more static thermal environment mostly associated with air-conditioned places [14]. Therefore, if there is any discomfort due to the variations in the thermal environment, people would be likely to restore their thermal comfort.

The methods used for investigating the natural ventilation behavior to assess the aeration performance are classified into three groups: field measurements, controlled experiments and computer simulations in general [15]. Field measurements can only acquire on site data from selected buildings as well as restricted locations of the instruments for safety purpose, leading to possible uncertainties of the measurements and difficulties for further data analysis [16]. In contrast, the experimental results from a controlled state such as the full-scale models in wind tunnel tests are more reliable than those from the field measurements, although management of these experiments are relatively time consuming and high cost [17]. As an alternative approach, computer simulation is a cost-effective and practical method to correctly predict the detailed outdoor and indoor airflow characteristics for appraising the thermal performance of different naturally ventilated designs of buildings [18]. In recent times, CFD simulation has become increasingly important to perform the pre-evaluation and design simulations in the planning and development of new buildings. It can be directly or indirectly used to quantitatively analyze the building environment [19]. Many advances have been attained in a variety of CFD numerical models have been developed to assess ventilation flow rates and thermal comfort for different natural ventilation design configurations [20–23]. Chen used a CFD tool to factor wind into the architectural environments for illustrating different building design strategies. Neofytou et al. investigated the wind environment around a large airport terminal building to examine the impact of the standing building on the surrounding wind field patterns [24]. To conduct CFD simulations of the wind flow and wind-driven rain for twelve generic stadium configurations, the studied results from Van Hooff and Blocken presented some valuable guidelines to avoid discomfort of audiences for the stadium and roof design [25]. Considering the tall residential buildings, the CFD analysis by Prajongsan and Sharples revealed that the design of ventilation shafts can raise the average air velocity across the room by increasing the pressure difference between the room's window and the shaft's exhaust at roof level for improvement of natural ventilation and thermal comfort [26].

Main efforts have been made to explore the natural ventilation behavior and management for evaluating the ventilation outcome of buildings. However, relatively limited numerical and experimental studies have been reported to address enhancement of the ventilation outcome through the integration of the central ventilation shaft (CVS) design concept into buildings. The objective of this research is to conduct CFD simulations and field measurements for the assessment of the natural ventilation effectiveness of office space in a typical administrative building with a built-in central ventilation shaft. For software validation, the predicted steady air velocity and temperature distributions were compared with measured data. The calculated results were also utilized to complete the understanding of the ventilating process for further determination of the air change rate per hour (ACH), PMV and adaptive comfort standard (ACS) values related to office space. Numerical simulations were extended to examine the design impacts of decreasing the CVS size or even removing the CVS from the building on the airing performance in terms of the ACH, PMV and ACS results for evaluating the thermal sensation of workers in the office space for extended periods. This CFD simulation procedure can serve as an effective analysis tool to support the architects, planners and other decision makers on improving the natural ventilation design of buildings.

2. Design overview of the new Guanyin administrative building

In this investigation, the design of the new Guanyin administrative building, rated as the prominent Diamond-level green building in Taiwan, was adopted as an illustration case. This contemporary green building is located in Guanyin Township, Taoyuan County in the northern Taiwan. The building was constructed with a featured central ventilation shaft configuration for airing enhancement. Fig. 1 illustrates the (a) picture of the new Guanyin administrative building, (b) schematic showing the natural ventilation design with the CVS feature and (c) digital models generated from the computer packages including SketchUp®, SolidWorks® and ANSYS Fluent®. Designed by C.P. Hsueh Architect & Associates, the administrative building is similar to the typical three-section compound courtyard houses having a main executive building oriented southeast with two wings connected vertically to both ends. The geometric dimensions are 62.75 m long, 68.90 m wide and 23.20 m high, respectively. The new Guanyin administrative building is a raised four-story structure for the usage of public services. The first, second, third and fourth floors are the hall, facilities management, office space and half-open terrace. All floors excluding the second floor are open to a CVS placed right in the middle of the main building as the airflow passage to the exhaust end on the roof. Natural ventilation is in use during the daytime to maintain indoor air quality (IAQ). In operations, the upper-level vents are opened in the fall and left open over the winter. The view-level vents are user-operated during the work hours (with the open period depending on the wind direction) but are closed at 6 pm for the security reasons.

3. Methodology

3.1. Field measurements

The experiments to assess the indoor environmental conditions and natural ventilation of the new Guanyin administrative building were conducted during daytime at hourly basis from 7:00 to