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Natural ventilation potential for gymnasia – Case study of ventilation and comfort in a multisport facility in northeastern United States

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ABSTRACT

The natural ventilation potential to maintain acceptable indoor air quality (IAQ) and thermal comfort in gymnasia was investigated using a university multisport facility in northeastern United States as a case study building. A parametric modeling study was conducted considering the effects of opening configurations and control strategies during the summer months. The thermal accuracy of the model was verified using field measurements during August 2015. Performance metrics for IAQ and thermal comfort were the percentages of occupied hours during which ventilation rate met or exceeded ASHRAE Standard 62.1–2013 and temperature met adaptive thermal comfort criteria of ASHRAE Standard 55–2013, respectively. Wind direction was found having a major effect on cross ventilation rate. Wind and buoyancy driven forces could complement or oppose each other depending on the wind direction and opening position. Relative to the base case, larger net openings that were more evenly distributed performed better. Rooftop vents improved ventilation performance, particularly under unfavorable wind conditions. With improved opening configurations, the acceptable ventilation hours increased from 21.5% to 99.5% of occupied time for the maximum occupancy. The strictest temperature-controlled strategy had the best thermal performance. Thermal comfort conditions could be maintained during 85.3% of the occupied hours. However, the temperature rule largely shortened the opening operation time, and consequently decreased the acceptable ventilation hours to only 47.1%. Continuously natural ventilation during occupied time gave the longest combined IAQ-thermal acceptable hours, 73.9% of the occupied time, although it moderately decreased the thermal comfort hours to 74.2%.

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1. Introduction

Where feasible, natural ventilation is considered to be an attractive solution to ventilate and cool buildings. Well-designed natural ventilation can passively maintain a comfortable and healthy indoor environment and consequently decrease the amount of energy consumed by ventilation and cooling systems [1]. The increasing use of natural ventilation has been widely noted. However, in most large spaces such as gymnasia, hybrid ventilation and air conditioning systems still dominate [2–4]. The research on the natural ventilation performance in gymnasia is deficient. In this research, the feasibility of using natural ventilation for gymnasia was investigated using a multisport facility at a university campus in the northeastern United States as a case study building. The ventilation rate for achieving an acceptable indoor air quality and the thermal comfort were the two key performance metrics considered. A parametric modeling methodology was developed that considered the effects of the opening configurations and opening control strategies.

2. Literature review

Natural ventilation is the process of exchanging air between indoor and outdoor environments. The mechanism of natural ventilation mainly depends on the wind effect, thermal buoyancy, or their combination.

It is considered more difficult to introduce sufficient wind-driven flows in long spaces, primarily because of the smaller pressure difference between the windward and leeward facades and larger indoor resistance compared to shorter spaces [5,6]. It has been suggested that a building's length should be less than five times its ceiling height [7]. Schulze et al. [8] found that the cross ventilation rate largely depended on both the opening arrangement and effective opening area based on the results of airflow network methods. Heiselberg et al. [9] used an experiment method and found that the characteristics of the air movement through different opening types differed greatly. Kang and Lee [10] tested a louver combination that aligned the angle of the outer louver blades with the oncoming wind and elongated the inner louver blades to guide the entrained air down to the ground surface and found that it was effective at pushing the stagnant flow inside a long factory building. Leea et al. [11] investigated horizontal and vertical shading louvers with a 0° angle and found that they contributed to a greater vertical flow convection than those with 30°, 60°, and 90° angles. Using computational fluid dynamics (CFD) simulation [12,13] and wind tunnel methods [14], the position of the inlet opening was found to predominantly affect the ventilation rate of cross-ventilated buildings, whereas the impact of the vertical position of the outlet opening was relatively small. Cui et al. [15] suggested that larger window should be placed in the dominant wind direction. Similarly, Tantasavasdi et al. [16] found that a larger inlet was more helpful than a larger outlet for cross ventilated buildings. However, Peren et al. [17] found that the ventilation flow rates were significantly higher with a lower inlet-outlet opening ratio by evaluating the volume flow rates in double-span long spaces with leeward sawtooth roof.

It might be possible to use the buoyancy force to complement an insufficient wind force. With a high ceiling, the buoyancy force in a gymnasium could be more significant than in buildings with lower ceilings. ASHRAE Standard 62.1–2013 specifies that in across naturally ventilated building, the area of the openings that connect directly to the outdoors should be a minimum of 4% of the net occupiable floor area [7]. However, Lin and Chuah [18] indicated that the thermal buoyancy in a large space with a ceiling higher than 6 m and an opening-to-floor ratio greater than 0.9% can introduce adequate fresh air to satisfy the indoor air quality (IAQ) requirement. Bartzanas et al. [19] indicated that the combination of roof and side openings provides better air exchange and cooling performance than any split cases. Hunt and Linden [20] highlighted that the vertical relationship between leeward and windward openings was a major factor determining the combined effect of ventilation driven forces. Stavridou and Prinos [21] observed that the combined ventilation efficiency increased with the vertical distance between the midpoints of a low inlet and high outlet.

Natural ventilation can be used for cooling a building's interior whenever the outdoor temperature is lower than the indoor temperature. Occupants can adapt to a broader temperature range in human-controlled naturally ventilated spaces [22]. The cooling potential of natural ventilation has been evaluated under multiple climate conditions [23–26]. Nighttime ventilation provides a significant pre-cooling benefit by storing cooling energy in a building's thermal mass at night and preventing temperature climb during occupied time [27–30].

In addition, the local climate, thermal properties of a building's construction, and internal heat gain have obvious influences on the cooling performance of natural ventilation [31], along with the opening configurations [32,33]. Although shading devices are helpful to prevent excess solar gain in a room [34], they are also obstacles to airflow movement [11]. The occupants' behavior has been found to have stronger effects on both the ventilation and thermal performance than factors related to the building [35–37]. Fabi et al. [38] showed that the physical environmental variables that impact a window opening behavior include the indoor and outdoor temperatures, solar radiation, wind speed, and CO_2 concentration. Yin et al. [39] investigated the natural ventilation potential in China using a temperature-control opening strategy, while Schulze et al. [8] compared the influences of the thermal and IAQ priority opening behaviors and found that temperature rules could effectively prevent overcooling. G. van Moeseke et al. [40] designed three control modes for daytime natural ventilation for the Belgian weather and found flow rate modulation on external temperature was an efficient way to manage both overheating and overcooling problem.