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Optimization of wind tower cooling performance: A wind tunnel study of indoor air movement and thermal comfort

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Abstract

Wind tunnel testing and thermal comfort simulations were conducted to explore the performance of a wind-tower in a typical, medium-density apartment building located in subtropical Sydney. The research design consisted of three phases; first, wind tunnel experiments measured pressure distributions over the surface of a four-storey apartment building model scaled at 1:100. Secondly, hourly indoor air velocities were predicted for the six warmest months in Sydney using the Typical Meteorological Year 2013. Finally, thermal comfort simulations evaluated the comfort cooling potential of the wind towers. Results indicate that, during Sydney's warm hours (≥23°C), elevated air speeds resulting from the wind-tower improved in indoor comfort by 1725.8 degree hours (SET*) compared to the default design relying on through-window cross ventilation under the same conditions.

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Keywords: Natural ventilation; wind tower; wind tunnel; indoor air speed; thermal comfort

1. Introduction

Heating and cooling account for 40% of household electricity end-use in the Australian household sector, and within that 40% a large share is attributed to comfort cooling which is dramatically increasing [1]. Australia's National Climate Change Adaptation Research Facility reports that Australian cities would encounter more heat and radiation and less rain over the next fifteen years [2]. Since the building sector is responsible for 40-50% of the

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carbon emissions around the world, natural ventilation systems have become the focus of attention to mitigate the hazards resulting from fossil fuel consumptions [3]. During the past decades, studies on the effects of ventilation on the occupants' thermal comfort have reported that increased air movement can offset elevated indoor operative temperature by removal of heat of human body tissue through evaporative and convective transfers [4-8].

The wind tower, as a vernacular natural ventilation technique, has been applied in Persia and Persian Gulf region since 1300 BC [9, 10]. The wind tower or "wind catcher" is a tower mounted on the construction roofline where it captures air flowing at high speeds within the urban canopy layer and channels it down into the living room or the basement of the building for comfort cooling during the warmer months of the climatic year. The wind tower's openings are exposed to the free-stream wind with higher speed, which generates a large pressure distribution over the wind tower. The internal partitions of the tower channel the flow into the occupied interior spaces downstairs [11].

Nomenclature

Cp	mean pressure coefficient
Pm	mean surface pressure
Ps	mean static pressure
Pd	dynamic pressure
ρ	air density
V	exterior mean wind speed
Q	mean mass flow rate
A	area
ΔCp	pressure coefficient differential
Vi	indoor air speed
L	room volume
k	surface roughness
ν	kinematic viscosity
P	perimeter of conduit

1.1. Background of the research

Numerous earlier studies have attempted to evaluate the function and the cooling performance of wind towers. Bahadori [12,13] analyzed the function of wind tower and suggested two new designs of evaporative wind towers. Karakatsanis et al. [14] assessed the wind tower cooling performance with an adjoining courtyard in the building. They concluded that the courtyard could increase the cooling efficiency of the tower. They also noted that the wind direction and the tower's opening configurations play a significant role on the overall efficiency of the wind tower. Roaf [9] carried out field studies in the hot and arid climate in Yadzd, Iran on the thermal performance and the potential of temperature reduction of wind towers. Elmualim [15] reported that the efficiency of wind tower would reduce by increasing the wind direction from normal to tower's opening. Montazeri and Azizian [16] found that the number of wind tower openings was a significant factor in generating the airflow rate inside the duct. They reported that the higher number of openings would lead to less airflow rate. Similarly, Khan et al. [17] presented that one-sided wind tower preformed higher ventilation rate than a multi-sided tower under the optimum direction of a dominating wind. Conversely, in another research on the evaporative wind tower, Hosseinnia et al. [18] concluded that the higher number of internal wet partitions inside the tower could increase the thermal performance of the tower by increasing the evaporation process. The impact of pressure difference between inlet and outlet air on the wind tower efficiency has been noted in Montazeri et al. [19] research.

In a numerical modeling exercise using CFD, MacCabe and Roaf [20] evaluated the effects of height and cross-sectional area of the tower on the adaptive comfort and the thermal environmental performance of simulated vernacular wind towers. The geometry of the wind tower's roof was assessed in a wind tunnel study by Dehghan et al. [21] using three detached models and the results showed that the incline roof could preform more efficiently