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The effect of ceiling configurations on indoor air motion and ventilation flow rates

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ABSTRACT

The purpose of this paper is to evaluate the effects of a building parameter, namely ceiling configuration, on indoor natural ventilation. The computational fluid dynamics (CFD) code Phoenics was used with the RNG $k-\varepsilon$ turbulence model to study wind motion and ventilation flow rates inside the building. All the CFD boundary conditions were described. The simulation results were first validated by wind tunnel experiment results in detail, and then used to compare rooms with various ceiling configurations in different cases. The simulation results generated matched the experimental results confirming the accuracy of the RNG $k-\varepsilon$ turbulence model to successfully predict indoor wind motion for this study. Our main results reveal that ceiling configurations have certain effects on indoor airflow and ventilation flow rates although these effects are fairly minor.

1. Introduction

In architecture, natural ventilation is often used as a low-energy environmental solution to improve indoor microclimates and thermal comfort in buildings. In hot and humid tropical climates natural ventilation is particularly effective as it maintains the equilibrium of relative humidity inside and outside buildings, and prevents indoor humidity from condensing. Most folk and traditional architectures in many parts of the world have successfully applied natural ventilation solutions to solve various indoor environmental problems.

In the formation of an architectural space, the ceiling and floor are the two factors that are absolutely indispensable. In the indoor spaces of folk or traditional architecture, the ceilings are generally consistent with the roofs and therefore varied and often dependent on roof forms. A certain typical type of ceiling and roof in a specific region is often influenced by the natural environment, climate, culture, religion, local materials and construction technologies; creating a vernacular form of architecture (see Fig. 1).

Natural ventilation is the process of air exchange between an indoor and outdoor space by natural mechanisms. According to CIBSE [1], besides mechanically assisted ventilation, there are three types of natural ventilation in buildings: cross ventilation; single-side ventilation and stack ventilation. Cross ventilation and single-side ventilation, which are generally called wind driven ventilation, are caused by natural wind while stack ventilation is driven by the increased buoyancy of air as it warms up. The majority of buildings employing natural ventilation rely mainly on wind driven ventilation. However, stack ventilation has many advantages, especially in moderate and cold climates. Ideal designs for naturally ventilated buildings should take full advantage of both types of ventilation.

Khan et al. [2] made an extensive investigation and reported seven passive ventilation strategies, including:

(1) window openings,
(2) atria and courtyards,
(3) wing walls,
(4) chimney cowls/exhaust cowls,
(5) wind towers,
(6) wind catchers and
(7) wind floor – air inlet system.

We also assume

(8) solar chimneys and
(9) underground ventilation ducts

as two other ventilation strategies which were not mentioned by these authors.

Natural ventilation is obviously an important architectural feature in hot humid climates as wind motion removes heat concentration and humidity thereby improving thermal comfort.

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