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Facade design optimization for naturally ventilated residential buildings in Singapore

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Abstract

Parametric studies of facade designs for naturally ventilated residential buildings in Singapore were carried out to optimize facade designs for better indoor thermal comfort and energy saving. Two criteria regarding indoor thermal comfort for naturally ventilated residential buildings are used in this study. To avoid the perception of thermal asymmetry, temperature difference between mean radiant temperature and indoor ambient air temperature should be less than 2 °C [F.A. Chrenko, Heated ceilings and comfort. J. Inst. Heat. Ventilating Eng. 20 (1953) 375–396; F.A. Chrenko, Heated ceilings and comfort. J. Inst. Heat. Ventilating Eng. 21 (1953) 145–154]. Thermal comfort regression model for naturally ventilated residential buildings in Singapore was used to evaluate various facade designs either. Facade design parameters: *U*-values, orientations, WWR (window to wall ratio) and shading device lengths are considered in the investigation. The building simulation results for a typical residential building in Singapore indicated that the *U*-value of facade materials for north and south orientations should be less than 2.5 W/m^2 K and the *U*-value of facade materials for north and south orientations should be less than 2 W/m^2 K. From the coupled simulation results, it was found that the optimum window to wall ratio is equal to 0.24. Optimum facade designs and thermal comfort indexes are summarized for naturally ventilated residential buildings in Singapore.

Keywords: Natural ventilation; Facade design; Thermal comfort; Simulation

1. Introduction

There is a growing interest in the application of natural ventilation in buildings due to the energy, indoor air quality and environmental problems associated with mechanically ventilated buildings. Various mechanical systems including heating, ventilation and air-conditioning (HVAC) systems in residential and office buildings contribute substantially to the energy consumption.

As the benefits of natural ventilation, including reducing operation costs, improving indoor air quality and providing satisfactory thermal comfort in certain climates, are recognized, passive cooling of houses using natural ventilation has become an attractive alternative to alleviate the associated problems with air-conditioned buildings. The concept of natural ventilation is well accepted and welcomed by people and designers in the world. Even in places with hot-humid climates, where air-conditioners are ordinary in both residential and commercial buildings, naturally ventilated buildings are not uncommon. For example, 86% of the people in Singapore live in HDB (Housing and Development Board) residential buildings, which are designed to be naturally ventilated.

Natural ventilation is difficult to design and control although the principle itself is not difficult to understand. The excessive amount of moisture in the air and intensive solar radiation makes many passive cooling design strategies difficult to implement in hot and humid regions. The success of a naturally ventilated building is decided by a good indoor climate, which influences its sustainability. The thermal performance of facade components plays an important role in determining heat gains into buildings which can determine the indoor environment, especially for buildings with low internal heat source such as residential buildings or schools. For this reason, naturally ventilated building design in hot-humid climates needs to pay more attention to orientations, shading devices, material selections, and window sizes. The study of heat gains through facade for naturally ventilated buildings is more critical than that for air-conditioned buildings since the amount of heat gain

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is a significant factor influencing the indoor thermal comfort for naturally ventilated buildings. Ventilation is considered to be one of the effective means to achieve thermal comfort in naturally ventilated buildings. With the increase of air velocity, neutral temperature for thermal comfort can be increased. Another important factor that affects thermal comfort in naturally ventilated buildings is solar heat gain, which can be controlled by shading devices. Increasing window to wall ratios can improve ventilation and indoor air quality but increase solar heat gain as well and therefore, external shading devices become an important component to reduce solar heat gain, especially for large windows. The evaluation of thermal performance of facade designs in naturally ventilated buildings should been conducted in a comprehensive way and arbitrarily exaggerating the effects of one particular component and neglecting the effects of others would be biased. Thermal comfort is an effective criterion to integrate the various impacts of all these facade components on indoor thermal environment.

The significant effects of dynamic outdoor climate on indoor environment increase the complexity of natural ventilation. Although there are many research works carrying out on the impacts of facade components on energy consumptions in sealed mechanically ventilated buildings (e.g. [1–3]), the knowledge of facade designs in naturally ventilated building is deficient, especially for the hot-humid climate. Therefore, the optimization and comprehensive evaluation of the facade systems for naturally ventilated buildings are carried out for hot-humid climate based on thermal comfort criteria. This paper is based on the previous studies [4] to further investigate facade optimization with two facade design criteria and develop facade design guidelines for naturally ventilated residential buildings in Singapore.

2. *U*-value determination with building simulations

Thermal resistance of facade plays an important role in reducing solar heat gain and maintaining a good indoor thermal environment. The criteria that temperature difference between mean radiant temperature (MRT) and indoor ambient air temperature should be less than 2 °C [5] to avoid the perception of thermal asymmetry by occupants is adopted to evaluate the thermal performance of external wall with various *U*-values. The thermal impacts of *U*-value are mainly on indoor location nearby openings and the impacts of facade material properties on indoor averaged thermal environment (centre of the room) are relatively small. Actually, thermal impacts of *U*-values are most significant in indoor locations near the openings (within 200 mm distance from openings) and thus demands further investigation.

2.1. The simulated building

High rise residential building HDB274C model (Fig. 1) was built for the parametric studies on *U*-values by a series of TAS simulations (EDSL, UK [6]). TAS is a suite of software products, including TAS Building Designer, TAS system and TAS Ambiens to simulate the dynamic thermal performance of buildings and HVAC systems and trace the thermal state of the building through a series of hourly snapshots, with integrated zonal simulation of natural and forced airflow. A bedroom with one external wall at the 10th floor in the buildings is selected for the study.

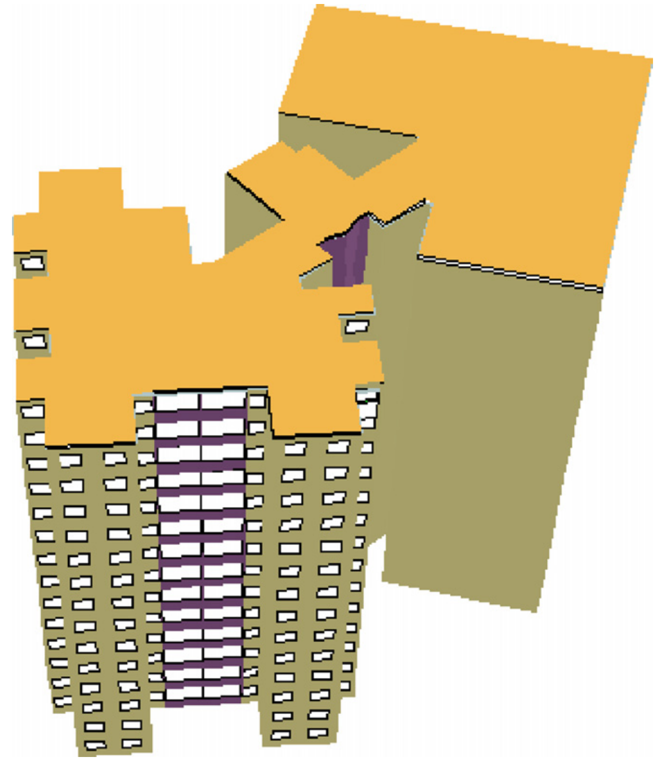

Fig. 1. HDB274C model in TAS simulation.

In this study, *U*-values ranged from 1.5 to 3.5 W/K m^2 at 0.5 intervals. The window size was made to vary from WWR = 0.1 to WWR = 0.4. Three orientations: north, east, west are investigated. The indoor ambient temperature and mean radiant temperature near the openings are affected by changing the *U*-value. In the simulation, the weather file 2001 was adopted. The hottest day in typical year 2001 for Singapore was selected for this study. The highest solar radiation was 979 W/m^2 and outdoor ambient temperature was 33.8 °C.

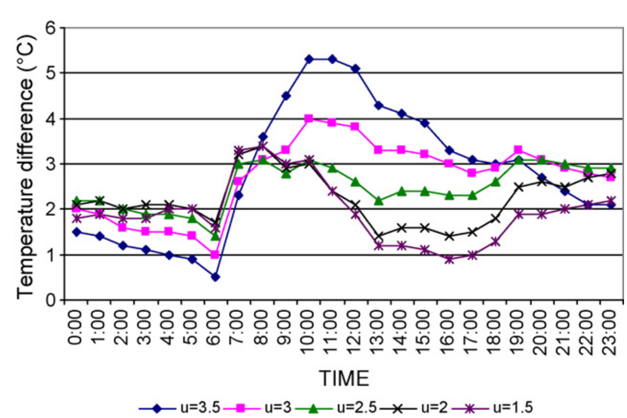

Fig. 2. Difference between mean radiant temperature and indoor ambient temperature (WWR = 0.1).