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Estimating natural-ventilation potential considering both thermal comfort and IAQ issues

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Abstract

Natural-ventilation potential (NVP) value can provide the designers significant information to properly design and arrange natural ventilation strategy at the preliminary or conceptual stage of ventilation and building design. Based on the previous study by Yang et al. [Investigation potential of natural driving forces for ventillation in four major cities in China. Building and Environment 2005;40:739–46], we developed a revised model to estimate the potential for natural ventilation considering both thermal comfort and IAQ issues for buildings in China. It differs from the previous one by Yang et al. in two predominant aspects: (1) indoor air temperature varies synchronously with the outdoor air temperature rather than staying at a constant value as assumed by Yang et al. This would recover the real characteristic of natural ventilation, (2) thermal comfort evaluation index is integrated into the model and thus the NVP can be more reasonably predicted. By adopting the same input parameters, the NVP values are obtained and compared with the early work of Yang et al. for a single building in four representative cities which are located in different climates, i.e., Urumqi in severe cold regions, Beijing in cold regions, Shanghai in hot summer and cold winter regions and Guangzhou in hot summer and warm winter regions of China. Our outcome shows that Guangzhou has the highest and best yearly natural-ventilation potential, followed by Shanghai, Beijing and Urumqi, which is quite distinct from that of Yang et al. From the analysis, it is clear that our model evaluates the NVP values more consistently with the outdoor climate data and thus reveals the true value of NVP.

Keywords: NVP; Thermal comfort; IAQ

1. Introduction

As one of passive-cooling strategies, natural ventilation has enjoyed a profoundly historic root and been welcomed by architects. Many famous architectures like RWE Headquarters in Germany, Tjibaou Cultural Center in New Caledonia and Inland Revenue Centre in UK all reveal to us the beauty and fancy of natural ventilation [1]. After suffering the IAQ problems in air-tightened buildings, more and more people turn their eyes to this energy-efficient and environment-friendly ventilation strategy. It is believed that we are stepping into the century of the revival of natural ventilation and it will march on to at least another couple of decades.

A good natural ventilation design does contribute a significant part to achieving satisfying indoor air environment. During the early stages of design, it is necessary for the designers to recognize how the potential for natural ventilation utilization is. The concept of potential for natural ventilation (NVP) is defined as the possibility, or probability, to ensure an acceptable indoor air quality by natural ventilation [2]. However, we expand the definition here to ensure both acceptable indoor air quality and thermal comfort by natural ventilation only, for we consider the thermal-comfort issue in naturally ventilated buildings is, if not more than, but atleast as important as IAQ.

The evaluation of NVP depends on many criteria. They are divided into three general parts: outdoor meteorological

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criteria (including macroscale wind speed distribution and orientation, macroscale temperature distribution, solar radiation, outside air moisture), urban criteria (including outdoor air quality, outdoor noise levels, outdoor environment and urban topology) and building criteria (including building layout, building height, indoor pollutant sources, indoor heat sources, indoor air quality requirement, etc) [2,3]. In this paper, we narrow our interests in the first part, to investigate how the NVP for a simplified model of buildings is influenced by outdoor climate, i.e., to what degree the natural ventilation air flow rate due to combined thermal buoyancy and wind forces can secure thermal comfort and IAQ indoors under different outdoor climates. In other words, it aims at providing the architects information on the issue of "where to build" more than on "how to build". China is a country with a vast territory, complex topography and diverse climates, it is meaningful and necessary to estimate NVP in different climates for the buildings before carrying on a practical natural ventilation design. Here, based on the early work of Yang et al., we develop a revised model considering both thermal comfort and IAQ issues to estimate NVP for Chinese buildings and then choose four representative cities located in four different climates, i.e., Urumqi in severe cold regions, Beijing in cold regions, Shanghai in hot summer and cold winter regions and Guangzhou in hot summer and warm winter regions of China, to apply and verify our model.

2. Previous studies

Theoretical and experimental studies of natural ventilation is extensively investigated in literature, but few are found to be related to NVP evaluation. Germano et al. [2] proposed a multicriteria method to assess NVP in urban context using GIS (Geographical Information Systems) information. One of the main drawbacks of this methodology is the lack of GIS data for the entire world, another is that it did not take the real driving force effects induced by thermal buoyancy and wind into account and thus lost the precise picture. Aynsley [4] focused on the summer wind-driven NVP for thermal comfort in a specified location and time. It is not easy and reasonable to expand to other time and cities. Axley assessed the suitability of a climate for natural ventilation of commercial buildings [5]. The climate suitability for natural ventilation is different from the potential for natural ventilation. NVP mentioned here is closer to the concept of potential for natural-ventilation-driving forces which depicts the real ability of natural ventilation induced by stack effect or wind effect [3]. The most recent model to estimate NVP was developed by Yang et al. [3]. The effective pressure difference induced by combined stack and wind forces was calculated and compared with the required pressure difference for IAQ issue in residential buildings. If the effective pressure was larger than the required pressure, it indicated the positive potential for natural-ventilation-driving forces. When the hourly positive differences between hourly effective pressure and required pressure were accumulated, the pressure difference Pascal hours (PDPH) was obtained. PDPH can provide guidance on the availability of natural driving forces. However, there is a very important assumption before building the model, i.e., the indoor air temperature should be constant and equal to 22 °C, which greatly weakens its precision. One of typical features for natural ventilation is that the indoor temperature will vary with the outdoor climate (both outdoor temperature and wind profiles), so it is unreasonable to keep a constant value of indoor temperature without altering the other parameters when the building is ventilated only naturally. Moreover, the constant indoor air temperature may produce absolutely different thermal stack effect compared with the varying indoor air temperature, and thus lose the true value of the potential of natural ventilation.

The purpose of this paper is to present a revised analytical model for natural ventilation potential evaluation based on the early work of Yang et al. Compared with the existing model, the newly developed model no longer sets the indoor temperature to a constant value but calculate it according to the heat balance and combined effects of thermal buoyancy and wind forces. In addition, it incorporates the thermal-comfort issue into the evaluation of NVP. Consequently, this model is more capable of reflecting both the basic mechanism of natural ventilation and real conception of NVP.

3. Revised model for NVP evaluation

3.1. A simple building model for natural ventilation

To avoid the influence of the surroundings (streets, other buildings, etc.) to our building studied, the model building is assumed to be far away from the crowd and noisy city but in an open area in suburbs. To make a convenient and reasonable comparison, some basic suggestions in [3] are also adopted: south oriented, uniform opening distribution and same opening areas in both south and north walls and uniform indoor air distribution.

Consider a simple building with porous openings on two opposite walls (south and north), as shown in Fig. 1. Occupants are considered as indoor heat sources, E_i, and solar radiation acts on the building via a sol–air temperature [6] from the walls and solar heat gain directly through the openings, E_d. We also assume that there is no thermal mass in the buildings, for if thermal mass is included in the analysis, no analytical solution exists [6]. Applying the heat balance equation on the building yields

$$\rho C_\mathrm{p} q(t_\mathrm{in} - t_\mathrm{out}) + \sum U_j A_j (t_\mathrm{in} - t_{\mathrm{sol\text{-}air},j}) = E_\mathrm{i} + E_\mathrm{d}, \quad (1)$$

$$t_\mathrm{sol\text{-}air} = t_\mathrm{out} + \frac{\lambda I}{h}, \quad (2)$$

where t_in is the indoor air temperature, t_out the outdoor air temperature, q the natural ventilation flow rate, I the solar radiation intensity, h and λ the convective heat transfer