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Research Paper

A united WRF/TRNSYS method for estimating the heating/cooling load for the thousand-meter scale megatall buildings

Junliang Cao [a], Jing Liu [a,b,*], Xiaoxin Man [a,c]

[a] School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin, China
[b] State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, Harbin, China
[c] China Construction Engineering Design Group Corporation Limited, Beijing, China

HIGHLIGHTS

- Vertical weather condition is explored by mesoscale meteorological model WRFv3.4.
- Weather database of TRNSYS16 is corrected in terms of height by the WRF results.
- A method is developed to calculate the heating/cooling load for megatall buildings.
- Effect of room height on heating/cooling load is investigated for megatall buildings.
- Height correction factor of heating/cooling load is defined and analyzed.

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ABSTRACT

A united WRF/TRNSYS method is developed to calculate the heating/cooling load for the plan of constructing the thousand-meter scale megatall building in this study. The core of the united WRF/TRNSYS method consists of three parts: (1) utilizing mesoscale meteorological model WRFv3.4 (Weather Research & Forecasting Model) to obtain the vertical distribution of atmospheric temperature and wind velocity in a particular region, (2) correcting weather database of TRNSYS16 (Transient Systems Simulation Program) based on results from (1), (3) calculating the heating/cooling load using the corrected weather database for a megatall building. To better illustrate the utilization of the very method, the heating/cooling load is calculated for a hypothetical thousand-meter scale megatall building in the site of Dalian, China. We assumed the building would be used primarily for commercial office purposes. The results show that the building cooling load gradient with height is approximately −2 to $-2.5\ \mathrm{W\,m^{-2}{\cdot}100\,m^{-1}}$, while the heating load gradient with height is approximately +1.2 to $+2.5\ \mathrm{W\,m^{-2}{\cdot}100\,m^{-1}}$. Compared with the heating/cooling load close to the ground, the cooling load of rooms at 1000 ms (m) above the ground decreases by about 25%, while the heating load increases by about 10%, under the design conditions.

1. Introduction

1.1. Background

With the rapid progress of urbanization, together with the development of new, light-weight materials and advanced construction techniques, the tall-buildings boom of the past decades has been unprecedented in that it has occurred across virtually the entire globe, simultaneously.

Fig. 1 shows that, globally, the total number of existing buildings over 200 ms (m) has more than doubled in the last ten years [1]. According to the Council on Tall Buildings and Urban Habitat (CTBUH), a supertall building is defined as a building taller than 300 m, and a megatall building is defined as a building over 600 m [2]. Burj Khalifa, is presently the tallest building in the world at a height of 828 m. Furthermore, the world's first thousand-meter scale building, Kingdom-Tower, in Jeddah, Saudi Arabia, is set to be constructed in this decade, with a designed building height of 1000 m. This means that the world is expected to enter the era of the thousand-meter scale megatall building in the foreseeable future.

* Corresponding author at: School of Municipal and Environmental Engineering, Harbin Institute of Technology, Harbin, China.
E-mail address: liujinghit0@163.com (J. Liu).

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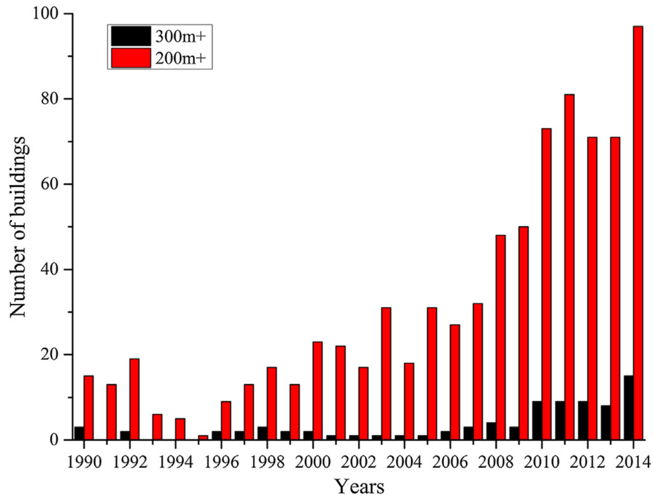

Fig. 1. Number of tall buildings over 200 m and 300 m [1].

Additionally, what is more interesting than the number of buildings and their heights is that the function of the tall buildings has been changing, as shown in Fig. 2. The ratio of residential and mixed-use functions has increased, from 12% at the turn of this century, to 53% currently; office space is still a large proportion of the total use.

With the increase in the number of buildings and their heights, the heating/cooling load calculation for megatall buildings has created new challenges for designers. Conventionally, the evaluation of the heating/cooling load uses values from atmospheric temperatures and wind velocities at the meteorological station level (at approximately 2 m or 10 m above the ground). For example, the Ref. outdoor atmospheric temperature for a heating/cooling load calculation, given by the ASHRAE standard, is a constant for the particular site, and the ASHRAE 'standard' value for the convective heat transfer coefficient (CHTC) at the building's external surface is about 31 W/(m^2 K) at a wind velocity of 6.7 m/s [3]. In past years, standard practice worldwide did not consider the potential variation in this coefficient in the vertical direction. However, it is obvious that this practice is adaptable only for relatively 'low' buildings, namely those where the variation of atmospheric parameters around the building in the vertical direction is minor enough to be ignorable.

In terms of the megatall buildings, the prominent feature of building height, has gone far beyond most existing buildings, even exceeding the top of the atmospheric boundary layer. The vertical variation of atmospheric temperatures and wind velocities surrounding the building may exhibit noticeable variability, and the corresponding heating/cooling load cannot be predicted accurately if this is not taken into consideration. Incorrect predictions will lead to the decreased comfort of occupants or an increase in building energy consumption.

In recent years, some researches have been carried out on vertical wind environment in urban regions. For example, Liu et al. [4]. conducted computational fluid dynamics simulation of the wind flow over an airport terminal building. Draxl et al. [5]. conducted a simulation of wind profile in urban region to evaluate the vertical wind shear using weather research and forecasting model. Mattar and Borvarán [6] represented a simulation of wind velocities at 5 specific heights by mesoscale meteorological model near the central coast of Chile to estimate the wind power. Sakakubara and Nakagawa [7] described the vertical temperature profile with light breeze at night in urban and rural area. However, these studies mentioned before concerned much on the drag effect of buildings on the air flow characteristics in building or building cluster scale, which are, in general, conducted based on existing typical wind profiles through wind tunnel test or computational fluid dynamics (CFD) techniques. The typical wind profiles expressed in empirical power law are basically applied within atmospheric boundary layer, tops out between about 250 and 500 m [8]. It is obvious this height is not applicable to thousand-meter scale megatall building.

In fact, only two megatall buildings exist worldwide, there is a lack of research on the vertical variation of atmospheric parameters to inform accurate prediction of heating/cooling load. In light of the potential construction trend for the megatall buildings, it is therefore an imperative to put forward proper methods for heating/cooling load calculations.

Actually, the building heating/cooling load can be divided into two parts: the heat generation from the internal equipment and occupants, and the heat transfer through the external building surfaces. The first part is governed by the building function. The second part is influenced by a number of factors, such as the thermal physical properties of the building envelope, the wind

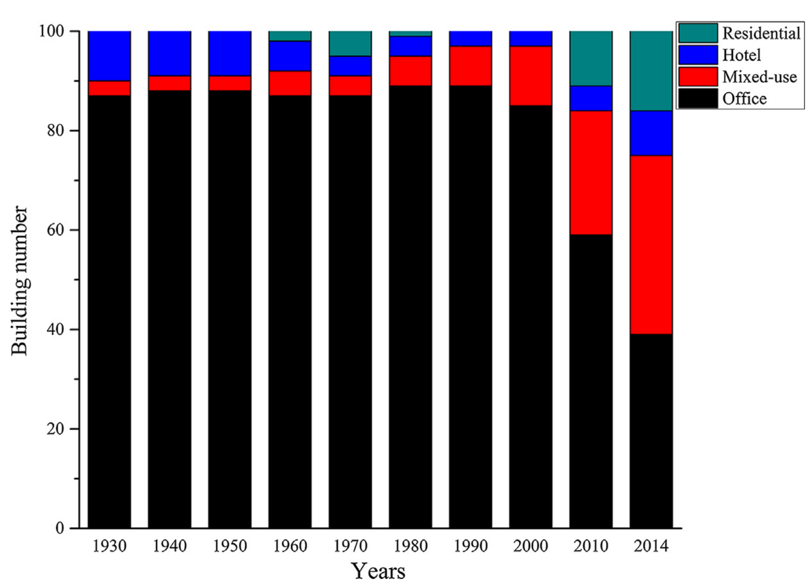

Fig. 2. 100 tallest buildings by function [1].