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Research on the Outdoor Climate Distribution and Effect for the Air-conditioning Load of a Thousand-meter Scale Skyscraper

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Abstract This paper investigates the outdoor climate vertical distribution and its impact of height on the air-conditioning (A/C) load for a hypothetical thousand-meter scale megatall building in Dalian by both the energy simulation software TRNSYS16 (Transient System Simulation Program) and the mesoscale meteorological model WRFV3.4.1 (Weather Research and Forecasting Model). We assumed that the building would be a office building according to the investigation on the use of the supertalls and megatalls that had been constructed. According to the vertical distribution of the atmospheric parameters used in the calculation of building A/C load, we modified the database of TRNASYS16 according to the result from WRF and calculated the A/C load of each room at different heights. The result shows that the A/C load gradually decreased as the height increases. The room A/C load at the height of 1000m above the ground was 30% less than that close to the ground.

Keywords：megatall building, mesoscale meteorological model,WRF,TRNSYS, air-conditioning load

1 Introduction

The tall building boom of the past decades has been unprecedented in that it has taken place across virtually the entire globe simultaneously. By the end of 2012, the statistic shows that 58 0f 100 tallest buildings in the world have been completed in the past seven years. According to CTBUH (Council on Tall Buildings and Urban Habitat), the supertall is defined as a building over 300 meters, and the megatall as a building over 600 meters. Fig.1 shows the total number of buildings over 200 meters in existence globally, it has been more than doubled in the last ten years, more interesting than the number and height is the function of the tallest building have been changing, but the office buildings are still in a large proportion (see Fig.2).With the increase of the number and the height, the cooling load calculation of the tall buildings has brought the designers new problems. The heights of megatalls have gone far beyond the ordinary buildings, the parameter of the design code could not meet the needs of the megatallls yet. In this study we used the mesoscale meteorological model WRFV3.4.1 to simulate the air temperature values along the vertical direction in Dalian ,which was widely used in meteorology, then we got the variation of the parameters along the vertical direction，and calculated the air-conditioning load of rooms at different heights in a hypothetical thousand meter scale megatall building in Dalian by the software of TRNSYS16.

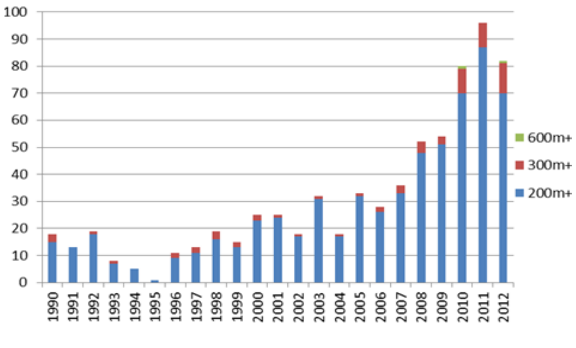


Fig.1 *Numbe of Tall Buildings*

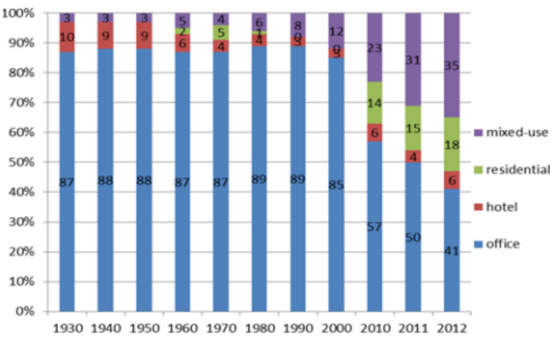


Fig.2 *Use of Tall Buildings*

2 Method of Research

2.1 Combination of WRF and TRNSYS

WRF model is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications. The development of WRF has been a multi-agency effort to build a next-generation mesoscale forecast model and data assimilation system to advance the understanding and prediction of mesoscale weather and accelerate the transfer of research advances into operations .WRF reflects flexible, state-of-the-art, portable code that is efficient in computing environments ranging from massively-parallel supercomputers to laptops. It is suitable for a broad span of applications across scales ranging from large-eddy to global simulations.

We simulated the distribution of the air temperature by WRF, and got the variation of the parameters along the vertical direction. According to the previous results, we modified the weather database of TRNSYS16 with the height. Finally the cooling load were calculated with the modified parameters Fig.3 shows the concise information of this research.

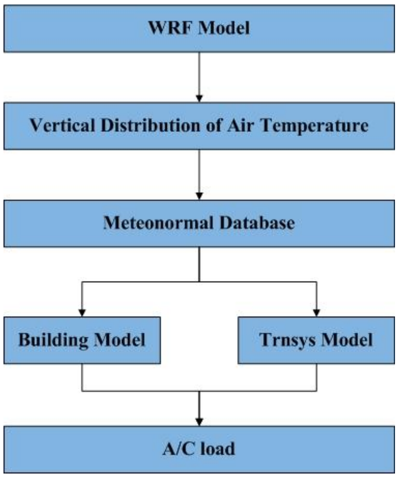


Fig.3 *Concise Information of Research*

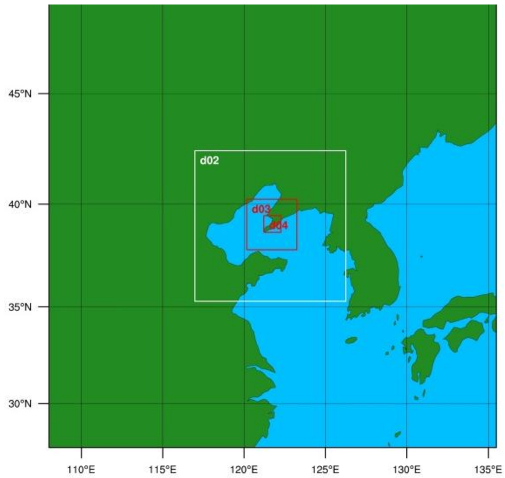


Fig.4 *Domains of Simulation*

2.2 Calculation Conditions

2.2.1 Atmospheric Conditions

In our study, the model was designed as follows: We used WRFV3.4.1 and made the simulation area quadruple nested with 37 levels in vertical direction (default levels). The simulation domains are shown in Fig.4. The WRF model is built over a parent domain (1) with 120km of spatial resolution, covering all of Beijng area. The first nested domain (2) , with a spatial resolution of 70km, comprise the main city center of Dalian. The second domain (3) has a spatial resolution of 3.7km. The innermost domain (4) has a spatial resolution of 0.4km and it is focused on the chosen area to simulate. All domains are centered in a point with the coordinates: Latitude=39°24′24 ″, longitude=123°35′19″, and they interact with each other through a two-way nesting strategy.

2.2.2 Building Model

There is no such a standard building that can represent all the actual situations. In this study we selected a normal rectangle office building model in Dalian that has normal typical floor (see Fig.5), which is consisted of office rooms with the same area. We calculated the cooling loads of the rooms of each orientation by the software of TRNSYS16 with the design conditions that the office hours is from 8:00 to 18:00 and one computer is for each person. The building envelope parameters and calculation conditions are shown in the table1:

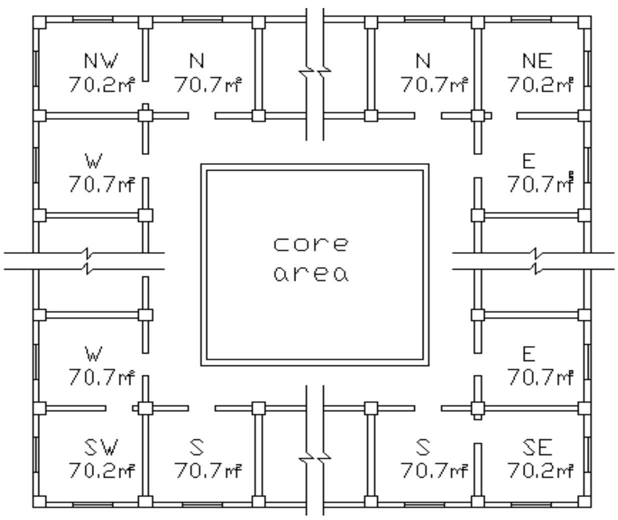


Fig.5 *Model for Simulation*

***Table1** Parameters of the Load Calculation*

Parameter	Value
Heat transfer coefficient of exterior wall	0.6W/(㎡·K)
Window-wall ratio	0.4
Heat transfer coefficient of exterior window	2.7W/(㎡·K)
Effective area/total area of window	0.85
Shading coefficient of exterior window	0.86
Tn (design temperature)	25℃
ψn (design relative humidity)	60%
Occupant density	4 ㎡/person
Equipment power	56w/㎡
Lights	12w/㎡
Air-change of ventilation	2.2/h
Activity	Very light

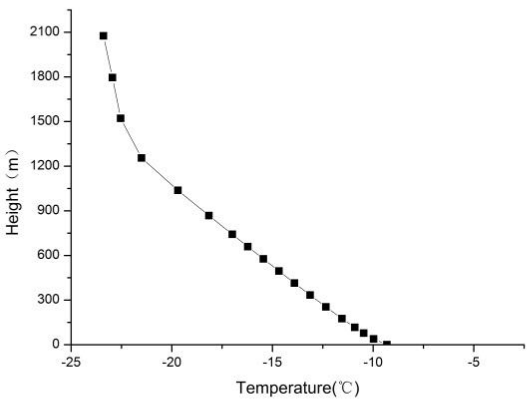
3 Results and Analysis

3.1 Atmospheric Parameters Calculated by WRF

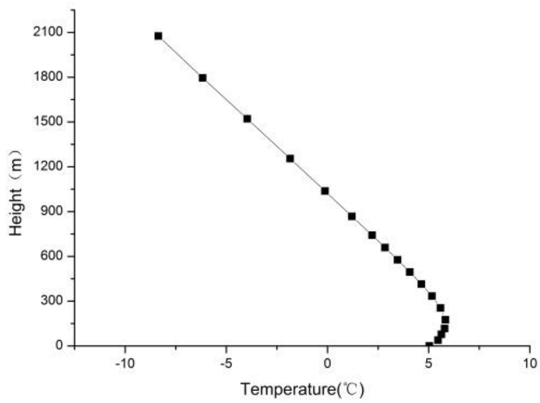
In order to obtain the distribution of air temperature and wind velocity profile, The case studies selected for simulation correspond to the occurrences of seasonally continuous sunny days in the year of 2012.a total of four simulations are considered which are defined in Table2. Each simulation is for 7 days period. The National Centers for Environmental Prediction (NCEP) Final Analysis data available at 6 h interval on a 1°X1° resolution are used to supply initial and boundary conditions. The model integration was performed with two way nesting.

Table3 Period of the simulation

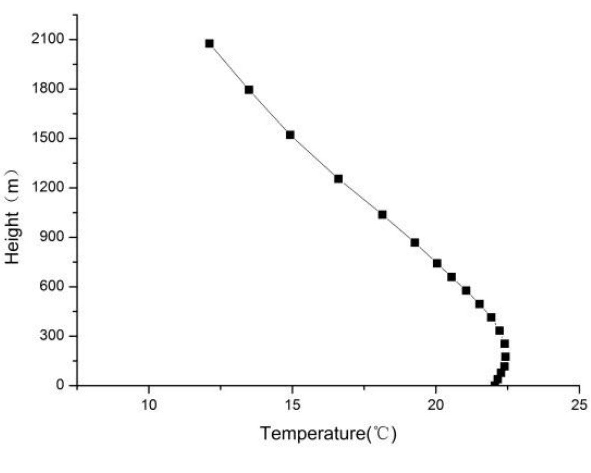
Simulation	Season	Month	From	To
1	Spring	January	1	7
4	Summer	April	4	10
8	Autumn	August	17	23
10	Winter	October	12	18



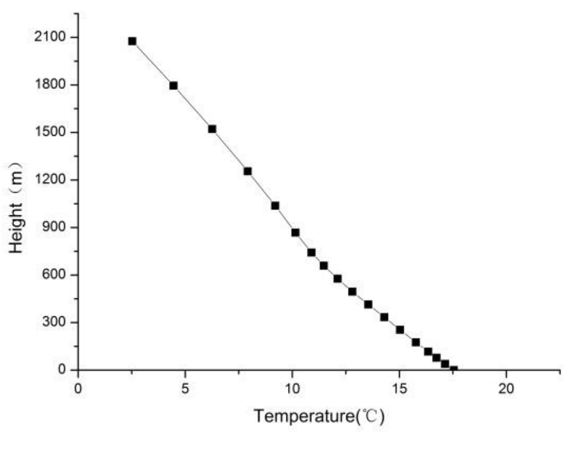
(a) January



(b) February



(c) July



(d) October

Fig8 variation of temperature

The results from the innermost domain at 3km resolution are analyzed and presented here（see Fig.6 and Fig.7）. The simulations carried out corresponding to the case studies described in Table 2 and vertical profile plots for air temperature and wind velocity. Also, we define the average value of the same height as the statistical indices which are indicators of local meteorology.

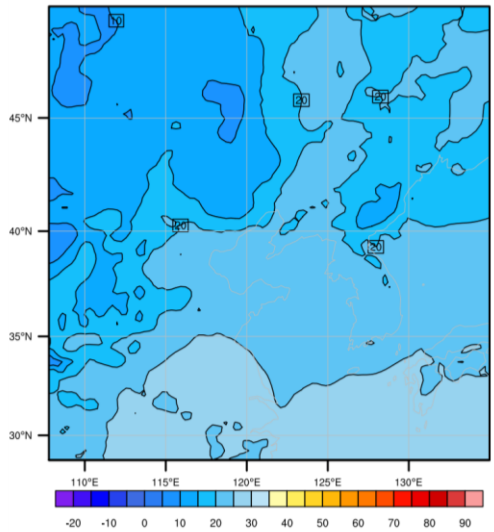


Fig6 Contour of air temperature 2m above the ground

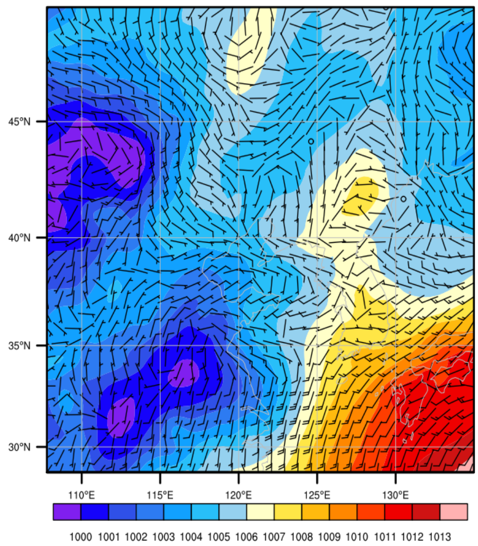


Fig7 Wind direction 2m above the ground

Each simulation is for 7 days, and we extract one set of data every 3 hour in one day. So each simulation provides 56 data sets(7X24/3). For better clarify the distribution of air temperature, we compute the average value of the air temperature at the same heights. Fig 8 presents the average temperature value in the simulation, the temperature decreases with the increase of the height. The air temperature and the height are in linear relationship on the whole. It should be noted that, such as April and May, the air temperature increases with the height under the heights of 300m. This could be mainly because of the complexity of the sea climate. Up to the height higher than 300m, the air temperature reduces about 0. 57℃ every 100m on the average.

In order to illustrate the air temperature with height variation better, we defined the temperature difference T_x (see Formula(1)~(4))， In view of the space consideration and also to avoid repetitive discussion, the results on the temperature difference T_x are given only for the typical months，namely January，April，August and December.

$$T_{x,1} = T_b - 0.0056x - 0.3149 \quad (R^2=0.95) \qquad (1)$$

$$T_{x,4} = T_b - 0.0057x - 0.1074 \quad (R^2=0.92) \qquad (2)$$

$$T_{x,8} = T_b - 0.0058x - 0.3837 \quad (R^2=0.96) \qquad (3)$$

$$T_{x,10} = T_b - 0.0057x - 0.3013 \quad (R^2=0.94) \qquad (4)$$

T_x——The air temperature at the height of x meters above the ground（℃）,the subscript means the month;
T_b——The air temperature at the bottom of atmosphere（℃）.
x——the height of room above the ground (m).

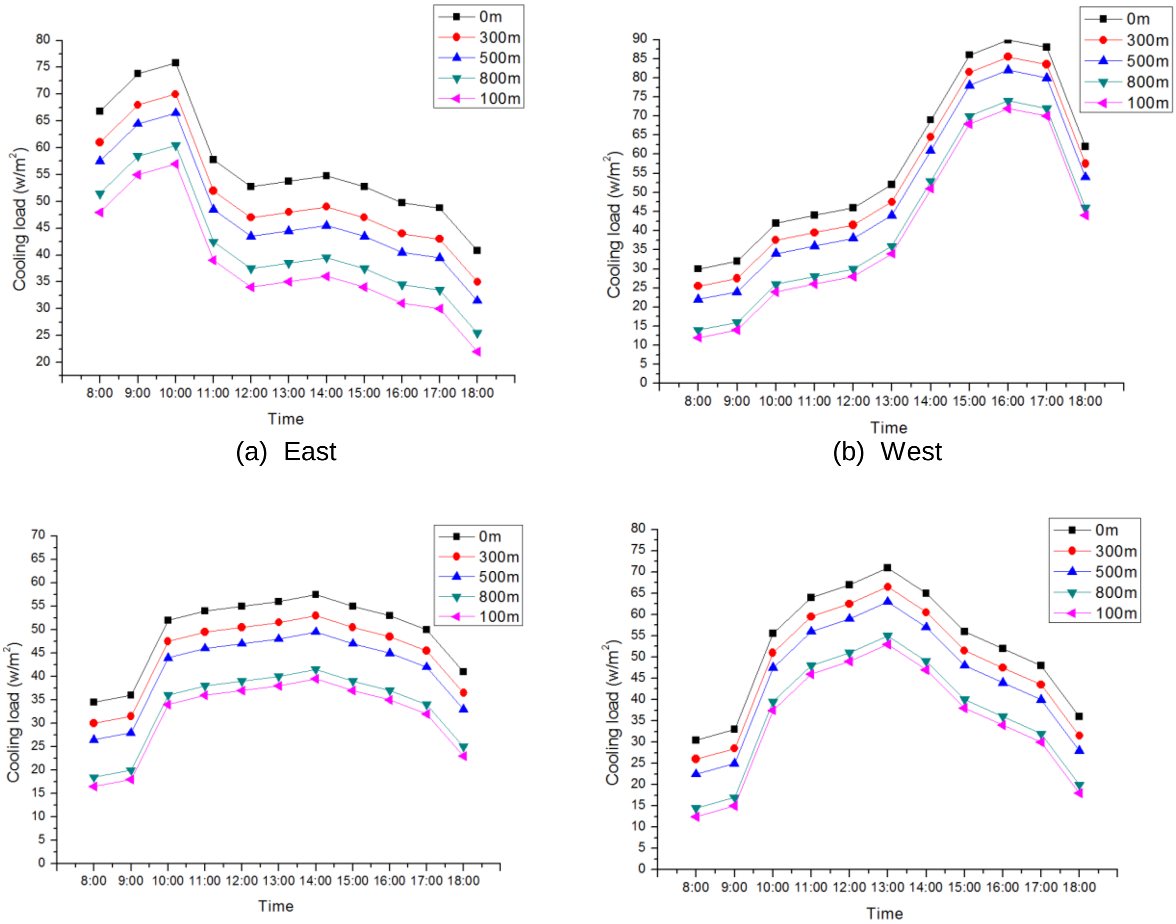
Considering that the formulas have little difference, we select $T_{x,4}$ as the representative vertical distribution of air temperature in the city of Dalian. The summer outdoor dry bulb temperature for air conditioning calculation and the winter outdoor temperature for heating calculation from 《Design code for heating ventilation and air conditioning of civil buildings》(GB 50736-2012)are used to compute the air temperature of different heights, which are shown in the Table 3.

Table3 Temperatures of Different Heights

	Height	0m	300m	500m	800m	1000m
Sumer	Temperature（℃）	29	27	26	24	23
Winter	Temperature（℃）	-9.8	-11.8	-13	-14.6	-15.7

3.2 Cooling Load Calculation

In this section, we calculate the A/C load of the building model that has been built in section 2. The TRNSYS model for A/C load calculation is set up with a modified meteonormal database,(contained in the pack of TRNSYS16)according to the distribution of air temperature. The hourly cooling load is from July 1st to August 31th, the average A/C cooling loads of the rooms with different orientations above the ground 0 meter, 300 meters, 500 meters, 800 meters and 1000 meters are presented in Fig.12. The heating A/C loads are from calculated by Trnbuild, which are shown in Fig13.



(a) East (b) West

(c) South (d) North

Fig12 Variation of hourly cooling load with height

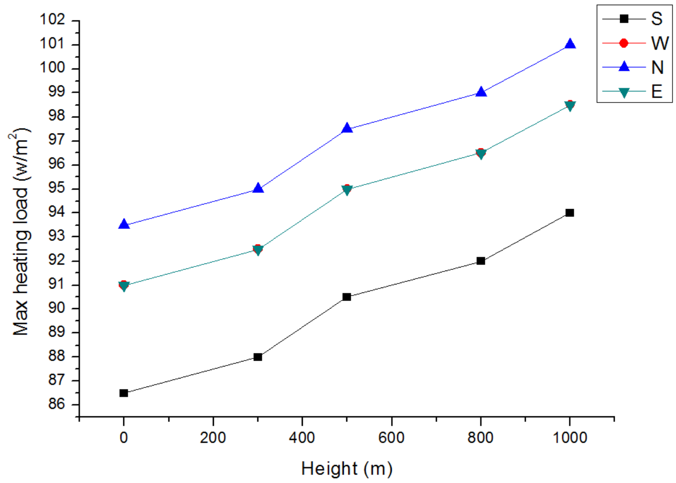


Fig13 variation of design heating load with height

The days of A/C cooling load calculation are 61, to better illustrate the variation of A/C load with the height, Fig. 12 shows the average A/C load of the same time each day during the calculation period. To avoid the repetitiveness, we take the room of east orientation for example to discuss the vertical regularity of the hourly A/C load. For the room of east orientation, the heat transfer from the equipment and occupants is fixed, the maximum solar radiation appears around 10:00, the hourly A/C cooling load has the maximum value at the same time. With the same building envelope, the hourly cooling loads of different orientations gradually decrease with the increase of the height. The A/C load difference between the rooms of different heights just relate to the heat transferred from the glass curtain wall, it can be seen that the hourly cooling load decreases 2w/㎡ every 100m under the design condition. In terms of the heating load, it increases about 1.2w/㎡ for every 100m increasing of the height. Generally speaking, the heating loads of east and west orientations have the same orientation correction coefficient, so the rooms have the same heating load.

4 Conclusions

Simulations were carried out with the Weather Research and Forecasting (WRF) model Version 3.4.1 for Dalian site. It is seen that the temperature decreases linearly with the rising height, the temperature increases about 0.57℃ every 100m. In case of the wind profile, the CHTC increases 3.3% with a 6m/s increase of the wind velocity, the influence is so little that it can be ignored. As to the A/C load, the hourly cooling load decreases 2w/㎡ for every 100m under the design condition in summer, and the heating load increases 1.2 w/㎡for every 100m in winter.

Through the large number of simulation case studies carried out covering selected days in all 12 months of the year, we have been able to identify the distribution of air temperature and wind velocity in the city of Dalian. with the modified database of TRNSYS16, the A/C load is calculated. The vertical variation of air temperature plays an important role in the A/C load in a megatall building, the influence of wind profile on the CHTC can be ignored. Such studies on the coupled system, like WRF/TRNSYS, for the vertical distribution of air parameters and A/C system design are useful when the megatall height is far beyond the ordinary buildings.

4 Acknowledgment

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