Vertical Distribution of Air-conditioning (AC) Load in a Thousand-meter Scale Megatall Building

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Introduction

CTBUH (Council on Tall Buildings and Urban Habitat)

Surpertall: Buildings over 300m

Megatall: Buildings over 600m
Introduction

Tall buildings completed in each year

100 tallest buildings by function
Introduction

Top 9 tallest buildings (completed)
Top 9 tallest buildings by 2020
Introduction

Troposphere

Atmospheric Boundary Layer

Ground

Air Temperature

Wind Velocity

Heat Transfer

AC load

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Methodology

Integrated WRF/TRNSYS system

WRF (Weather Research & Forecasting Model)

TRNSYS16 (Transient System Simulation Program)

Concise information of WRF/TRNSYS system
Methodology

- Building Location: Dalian, China;
- Building Height: 1000m;
- Building Function: office.
Methodology

- WRF model
- TRNSYS Model

- Period: 2012.01-2012.12
Results

Contour of temperature from WRF

0701_00:00

0701_06:00

0701_03:00

0701_09:00
Results

Wind vector from WRF

0701_00:00

0701_03:00

0701_06:00

0701_09:00
Results

Monthly Average Temperature Profile

January

February

March

April

May

June

July

August

September

October

November

December
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Results

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

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

\[ T_{x,8} = T_b - 0.0058x - 0.3837 \quad (R^2=0.96) \]

\[ T_{x,10} = T_b - 0.0057x - 0.3013 \quad (R^2=0.94) \]

\( T_x \)—— The air temperature at the height of \( x \) meters above the ground (°C), the subscript means the month;

\( T_b \)—— The air temperature at the bottom of atmosphere (°C).

\( x \)—— the height of room above the ground (m).

**Modified temperature of the AC design code**

<table>
<thead>
<tr>
<th></th>
<th>Height</th>
<th>2m(Design code)</th>
<th>300m</th>
<th>500m</th>
<th>800m</th>
<th>1000m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Summer</strong></td>
<td>Temperature (°C)</td>
<td>29</td>
<td>26.9</td>
<td>25.7</td>
<td>24.0</td>
<td>22.8</td>
</tr>
<tr>
<td><strong>Winter</strong></td>
<td>Temperature (°C)</td>
<td>-9.8</td>
<td>-11.8</td>
<td>-13</td>
<td>-14.6</td>
<td>-15.7</td>
</tr>
</tbody>
</table>
Results

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Monthly Average Wind Profile

January
February
March
April
May
June
July
August
September
October
November
December
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Results

Relationship between wind velocity, outdoor convective heat transfer coefficient (CHTC) and heat transfer coefficient (HTC)

\[ \alpha_w = 4.21v_s + 6.01 \]

\[ k = \frac{1}{\frac{1}{\alpha_w} + R_0 + \frac{1}{\alpha_n}} \]

\( \alpha_w \) — convective heat transfer coefficient (CHTC) of outdoor surface (w/k·m²);
\( v_s \) — the wind velocity (m/s);
\( k \) — heat transfer coefficient (HTC) (w/k·m²);
\( \alpha_w \) — convective heat transfer coefficient (CHTC) of indoor surface (w/k·m²);
\( R_0 \) — heat resistance of glass curtain wall.

CHTC profile ranging from 0m to 1000m

HTC profile ranging from 0m to 1000m

Wind velocity: 5m/s------11m/s
HTC: 2.1 w/k·m²----2.17w/k·m²
Increase: 3.3%
Results

Model of building

Function: office

Area: 70 m²
## Results

Parameters setting for AC Load calculation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat transfer coefficient of glass curtain wall</td>
<td>2.1 W/(m²·K)</td>
</tr>
<tr>
<td>Window-wall ratio</td>
<td>0.7</td>
</tr>
<tr>
<td>Indoor air set temperature</td>
<td>25°C</td>
</tr>
<tr>
<td>Indoor air set relative humidity</td>
<td>60%</td>
</tr>
<tr>
<td>Occupant density</td>
<td>5 m²/person</td>
</tr>
<tr>
<td>Equipment power</td>
<td>40 W/m²</td>
</tr>
<tr>
<td>Activity</td>
<td>Very light</td>
</tr>
</tbody>
</table>
Results

Hourly cooling load
Results

Heating load

- South
- West
- North
- East
- Southwest
- Northwest
- Southeast
- Northeast

Heating Load (W/m²)

Height (m)
Conclusions

- The air temperature decreases linearly with increasing height; When the building height increases 100m, the ambient air temperature decreases about 0.57 °C in Dalian site.

- The influence of wind velocity for CHTC can be ignored when the AC system design is concerned.

- The cooling load decreases about 2w/m², and the heating load increases 1.2w/m² with the height increasing 100m in Dalian site under the previous condition.
Conclusions

● Under the design condition, the cooling load of rooms at the height of 1000m decreased about 30%~40%. The heating load increased about 10%~15%.

● When the AC system design of megatall building is concerned, the vertical variation of meteorological condition should be taken into consideration.

● The coupled systems, such as WRF/TRNSYS system, are in a unique position for cross-scale study.
Conclusions

● Further researches on the use of wind profile for the energy conservation and emission reduction would be carried out in the future.

● Considering that the air temperature decreases linearly with the increasing height, we can make full use the upper cold air as fresh air for the AC system.
Question Time
Thank You!

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