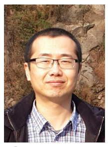
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Natural Ventilation Performance in a High Density Urban Area Based on CFD Numerical Simulations in Dalian

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dated : 15 June 2015

Abstract

The urban expansion of Dalian city over the past 60 years from approximately 50 km^2 to 500 km^2 has been characterized by a high-density downtown morphological pattern, while the urban wind speed per year has trended downward. To evaluate natural ventilation performance in the high-density downtown area of Dalian, an in situ wind environmental survey was performed, and the results were used as a reference to configure CFD numerical simulation boundary conditions. The results indicate that urban edifices, such as enclosed city blocks, strip apartments in rows and, especially, high-rise buildings with large podium bulk, were unfavorable to natural ventilation and could reduce the mean wind speed by up to 78% relative to the approaching speed. The natural ventilation performance of different building morphologies were further evaluated via CFD simulations, which indicated such strategies as using ventilation paths, hybrid buildings with different heights, and increasing building height while decreasing their land coverage could improve the urban ventilation performance. Increasing the building height and reducing land coverage was one of the most efficient strategies and increased wind velocities up to 2.4 times the real case. Green land significantly cooled and humidified its surroundings, particularly the downwind spaces.

Keywords: numerical simulation, CFD, Dalian, natural ventilation performance

1. Introduction

Urbanization has led to sharp increase in china’s city size and the high-rise buildings. With the increase in impervious land cover and decrease in green space, the air circulation is hindered, and heated island, rainstorm waterlogging, harmful air pollution and other climate phenomena occur. The study on the improvement in high density urban environment and enhancing the quality of urban life, has become a key issued in many disciplines such as environmental, meteorological, geographic, urban planning, etc.. Many researchers carried out in-depth analysis in the air flow, heat exchange and steam transportation and other physical phenomena using CFD model, to investigate the rules of influence of urban morphology on the physical environment and to propose optimization strategy, and to gain the experiences for creating a livable city.

Dalian, surrounded by the sea, with more than 2,200 kilometers of coastline, has a high average annual wind speed and rich land sea breeze resource. If fully utilized in urban design phase, it will be of great importance for improving the high-density urban thermal comfort. In this paper, by using a typical urban area as the research object, the comparative and simulative analysis on the wind environment was performed before and after optimization through CFD simulation. The study areas include Zhongshan Square, Democracy Plaza, Harbor Plaza, Erqi Plaza and other famous landmarks. It is about 1100 meters from north to south, and about 1400 meters from east to west. The total geographical area is approximately 1.54km² (Figure 1).

Figure 1 Schematic of Study Regions

2. Urban Morphology Optimization Strategy

Through field investigation and morphological analysis, we proposed the design strategy of adjusting the building morphology to build the city's ventilation path under the premise of ensuring the total area of building unchanged(Figure 2).

The strip apartments in rows, high-rise buildings with large podium bulk and slab high-rise buildings have high hindrance on wind. It needs to carefully adjust the planning layout and optimize the building morphology design. Our strategy is to arrange them of different heights of buildings, appropriately increase the building height, reduce the occupation area and frontal area, to control the distance between different high buildings.

City ventilation path is a low surface roughness space with certain length and width such as rivers, valleys, green belts, and low-density urban area. We designed an open space along the city leading wind direction as the ventilation path to lead the land-sea breeze and mountain-valley wind to the core area of the city.

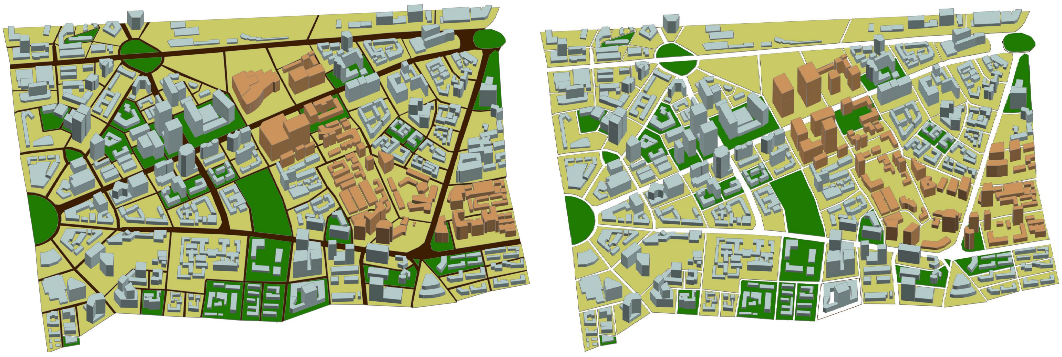

Figure 2 Schematic of Comparison of Morphology Optimization Strategy

3. CFD Simulation Analysis

3.1 Simulation configurations

In order to evaluate the effect of the optimization strategies, simulation analysis was performed on the wind environment before and after optimization using PHOENICS. Since complex topography and the urban environment exist around the simulation domain, a five-day continuous site observation was carried out on the thermal environment in the testing domain before simulation, and the measurement results were used as the reference for setting the boundary condition. The corresponding heat conduct coefficient and emissivity were set for the buildings, roads, paving and greenery in the region, respectively. The initial temperature, solar radiation, wind speed and other boundary conditions were set as shown in Table 1. The size in the domain was 5000m × 4000m × 500m, and the number of grids was 48 million.

Table 1 Simulation Condition Setting

Simulation Boundary Condition	
Incoming flow direction	South East
Incoming flow speed	1.8m/s
Air temperature	28.3℃
Solar radiation	direct solar radiation580w/㎡
	diffuse radiation130w/㎡
Simulation time	July 7, 2013 14:00
Building	surface temperature 36℃
	convective heat transfer coefficient 10 w/㎡
	solar radiation absorption coefficient 0.65
Green space	surface temperature 25℃
	convective heat transfer coefficient 100 w/㎡
	solar radiation absorption coefficient 0.65
Road	surface temperature 42℃
	convective heat transfer coefficient 30 w/㎡
	solar radiation absorption coefficient 0.5
Paving	surface temperature 40℃
	convective heat transfer coefficient 30 w/㎡
	solar radiation absorption coefficient 0.5

3.2 Simulation Results

(1) Wind field

It can be found from the wind field simulation results before optimization that, the buildings in A and B zones are dense, and the air is difficult to pass through smoothly. The frontal area of large volume of high-rise buildings in A zone is large, which has great hindrance on the wind. In the B Zone, the distance between buildings is small, with high density, and there is a number enclosed city blocks, which would reduce the air speed in the whole area and downstream. The average wind speed in A, B zones is lower than 0.4m · s-1, only 22% of the incoming flow speed. In zone C, there is a great area of green space, which will not only reduce the building density of the entire zone, but also provide urban cold island and improve the overall downstream ventilation.

The optimized wind field simulation results showed that when the city ventilation path is set, the building height is appropriately increased, the low-level large podium bulk is reduced and the frontal area of the building is reduced, it will have obvious effect on the overall ventilation effect of the city. In the B zone, the average wind speed increases to 0.95m / s, 2.4 times of that before improvement. The large plot with the speed close to zero in A zone basically disappeared. The ventilation in A, B zones are significantly improved (Figure 3, Figure 4).

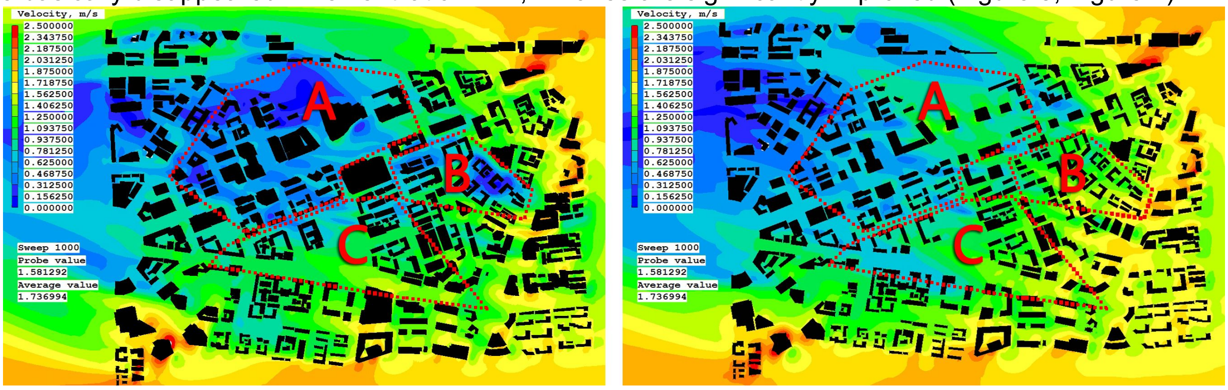

Figure 3 Comparison of high wind field plane at 10 m before and after optimization (left: before optimization right : after optimization)

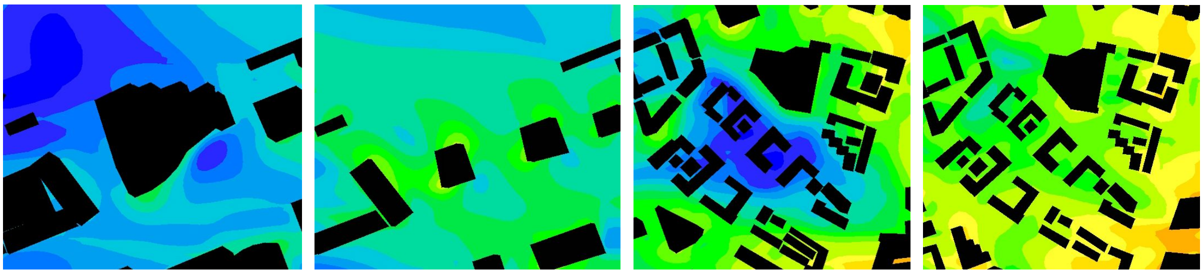

Figure 4 Comparison of high wind field plane at 10 m before and after optimization in zones A, B (left: before optimization right : after optimization)

(2) Temperature field

The temperature field simulation results before optimization showed that, the temperature in zones A and B is high and the isotherm is dense, with great temperature difference and obvious heat island regions (Figure 5, Figure 6). The reason is that there is a large building area in zones A and B, less green space, and the heat capacity of the building body is high and the ventilation is poor. The average temperature of zones A and B is up to 30.5 ℃, higher than the incoming flow temperature by about 2℃, which is very unfavorable to the pedestrians in the public space. In zone C, the temperature is low, and the isotherm is sparse, with small temperature difference. The reason is that the green space in zone C can alleviate the thermal environment pressure in a great range.

The temperature field simulation results after optimization showed that, the ventilation path along the city formed an obvious cold corridor, and several contiguous heat island spaces were divided and the spread was alleviated. The ventilation in zones A, B was enhanced, which effectively reduced the air temperature and surface temperature of various land surfaces in the zones. The surface temperature of green space in zone C was low, which provided a wide range of cold source for the surrounding space, especially remarkable cooling effect on the downstream(Figure 5, Figure 6).

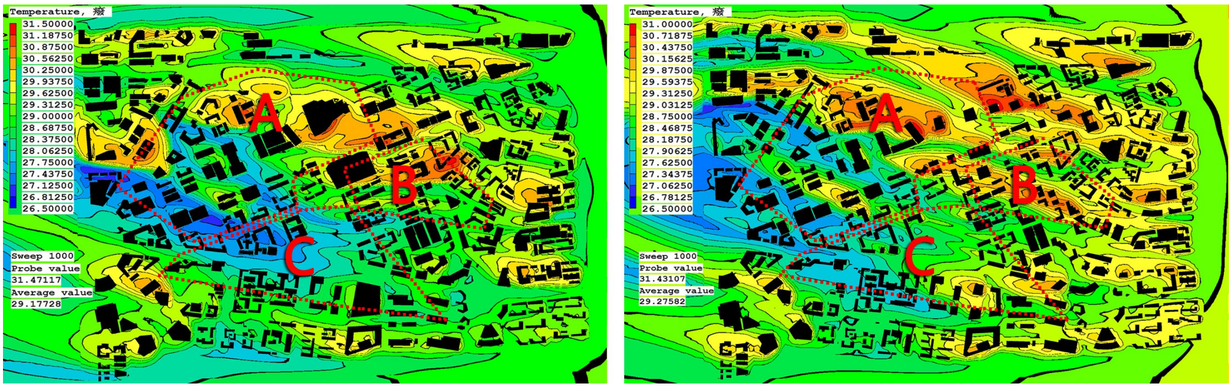

Figure 5 Comparison of high temperature field plane at 10 m before and after optimization (left: before optimization right : after optimization)

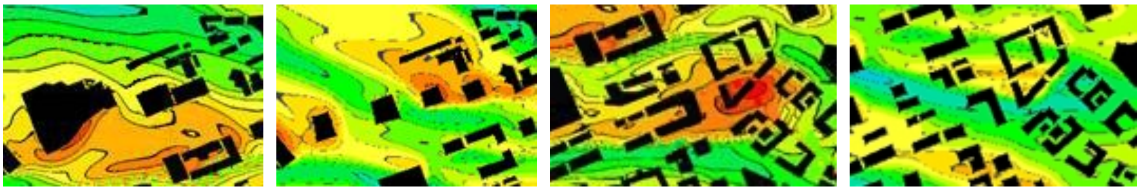

Figure 6 Comparison of high temperature field plane at 10 m before and after optimization in zones A, B (left: before optimization right : after optimization)

4. Summary

High-density urban wind environment, on one hand, is strongly influenced by the surrounding complex topography, and the relationship of land and water spatial location, and on the other hand, the intensive internal layout of the buildings makes unique characteristics of wind and thermal environment. The study result showed that it is feasible to improve the wind and thermal environment and the urban thermal comfort to ease the heated island by careful optimization of urban morphology. By giving full considerations to the wind, water, greenery and urban morphology and other factors, the suggestions on the planning of urban wind and thermal environment are summarized as follows:

(1) The wall effect formed by high-rise buildings with large podium bulk is very unfavorable to the ventilation and thermal environment. It is required to strictly control the bulk and appropriately increase the height, to guarantee unchanged land use intensity.

(2) Strip apartments in rows and enclosed city blocks are extremely unfavorable to the ventilation, which should be avoided.

(3) The urban ventilation path, scattered morphology and green space system have remarkable effect on promoting the ventilation and alleviating the urban heated island effect.

This wind and thermal environment simulation and morphology optimization work is still in its infancy. It is necessary to formulate the needs using professional Wind and Thermal Environment Assessment Tool with the urban planning program. Overall, the wind and thermal environmental assessment is professional, with high degree of difficulty. It is required to integrate the numerous professional and technical information including urban planning, geography, climate, and promote comprehensive cooperation in the government management, regulations, policies and the public participation, to achieve satisfactory effect.

Acknowledgment

This article is sponsored by National Natural Science Foundation of China (Grant NO. 51308087, 51278078) and the Fundamental Research Funds for the Central Universities (Grant NO. DUT13RW306)

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