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Measurement and Analysis of Winter Microclimate of Waterfront Settlements in Severe Cold Region

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Abstract. To study the characteristics of winter microclimate environment of waterfront settlements in severe cold region, relative humidity, wind speed and air temperature of waterfront settlements in Daqing were measured during typical weather day in winter. The outdoor microclimate environment of each site was quantitatively analyzed, and the outdoor microclimate environment of waterfront settlements evaluated by calculating the wind chill temperature (WCT) of each section. The results showed that solar radiation and air temperature have significant influence on the relative humidity in waterfront settlements. The flexible layout of buildings could reduce the adverse effects of wind of severe cold regions in waterfront settlements. Total solar radiation and wind speed led to the difference in air temperature in different areas. The cold degree between the building gable walls was the highest, and the thermal comfort was the worst. The cold degree of enclosed building layout was the lowest, and the thermal comfort was the best.

1. Introduction

Urban waterfront settlements refer to the living space around the public water body. Waterfront settlements is an essential representative of urban human settlements, and many residents have favored it because of its excellent environmental conditions. The unique climate of the water body can affect the micro-environment of residential area, which located near the water body. Li carried out computer numerical simulation of the wind-heat environment of enclosed residential buildings and put forward a reasonable strategy of wind environment optimization design in suburban areas [1]. Zhang simulated the outdoor wind and heat environment of Hefei residential areas in summer. The results showed that the ventilation corridor of the whole area could be destroyed, and the wind speed around the buildings could be smaller when the size of the building row or skirt house was larger. The small building space made the radiation increase and caused the temperature to be high [2]. Li and others used ENVI-met software to simulate the micro-environment of different building layout in Qingdao residential area in summer. The results showed that the layout of the site-type building was better than that of enclosed and row layout pattern [3]. To study the characteristics of winter microclimate environment of waterfront settlements in severe cold region, Xiangge Garden residential area was chosen as a representative settlements for measuring. Through the analysis of the field measured data, it provided technical guidance and theoretical basis for the transformation, design, and construction of the waterfront residential areas in severe cold regions.

2. Methods

2.1. The climate characteristics of Daqing

Daqing, located in Heilongjiang Province of China, is known as hundreds of lakes. Liming Lake has the area of water at 0.94 km^2. The climate of Daqing belongs to temperate continental monsoon climate and winter is long and cold with little snow. The annual average temperature is 4.2 ℃. The average temperature of the coldest month is -18.5 ℃ and the hottest month is 23.3 ℃. The extreme minimum temperature is -39.2 ℃ and the extreme maximum temperature is 39.8 ℃. The average wind speed is about 3.8 m/s, and the main direction of winter wind comes from northwest and summer comes from southeast.

Figure 1. Measurement sites.

2.2. Measurement sites

Xiangge Garden residential area, which located on the eastern shore of Liming Lake, is 0.15 km^2. The distance between the settlements and the lakeshore is about 50 meters. The layout of residential buildings is multi-storey and high-rise mixed layout. On the whole, the multi-storey building in the district is row layout pattern, and the layout of high-rise building includes determinant and encirclement. During this survey, the lake surface of Liming Lake has been frozen and covered with snow. The trees and shrubs in the residential area have fallen leaves, and the grassland has also withered. Sites are shown in figure 1. Site 1 is located in the interior of the enclosed building, and site 5 is located in the interior of the row layout pattern. Site 2 and site 6 are located on the road. Site 3 is located near the shore, about 50 meters away from the lake. Site 4 is located in the open space, with 12-story high-rise residential buildings on the north and west sides and 5-story multi-storey houses on the east side. Site 7 is located between two building gable walls, the east and west sides are 17-story slab high-rise residence.

2.3. Measurement methods

The survey time was from 10:00 to 16:00 on December 31, 2018. The relative humidity, wind speed, and air temperature were measured at 1.5 m above the ground at each of these sites. The on-site measurement process was divided into three test teams, with a Kestrel 5500 Weather Meter at each site. The measuring interval was one hour, the data was recorded once a minute, three times were recorded, and the average value of the recorded data of three times was taken as the measured value of the site. The information of measurement instrument is shown in table 1.

Table 1. Information on measurement instrument.

Name	Range	Accuracy
Kestrel 5500 Weather Meter	Temperature：−90 to 70 ℃	± 0.1℃
	Wind Speed：0.4 to 40.0 m/s	± 0.1 m/s
	Wind Direction：0° to 360°	± 5°
	Relative Humidity：5 % to 95 %	± 3 %

2.4. Urban climate parameters

On December 31, 2018, the weather in Daqing turned cloudy, and the air temperature ranged from -11 ℃ to -18 ℃. Relative humidity was 27.7 % ~ 52.9 %. The wind speed was 1.6 ~ 3.3 m/s, the average wind speed was 1.8 m/s, and the dominant wind direction was northwest wind. The sunrise time was 7: 23, and the sunset time was 16:01. The total solar radiation was from 0 to 491.4 W/m^2, and the solar scattering radiation was from 0 to 191.6 W/m^2. The variation of solar radiation is shown in figure 2.

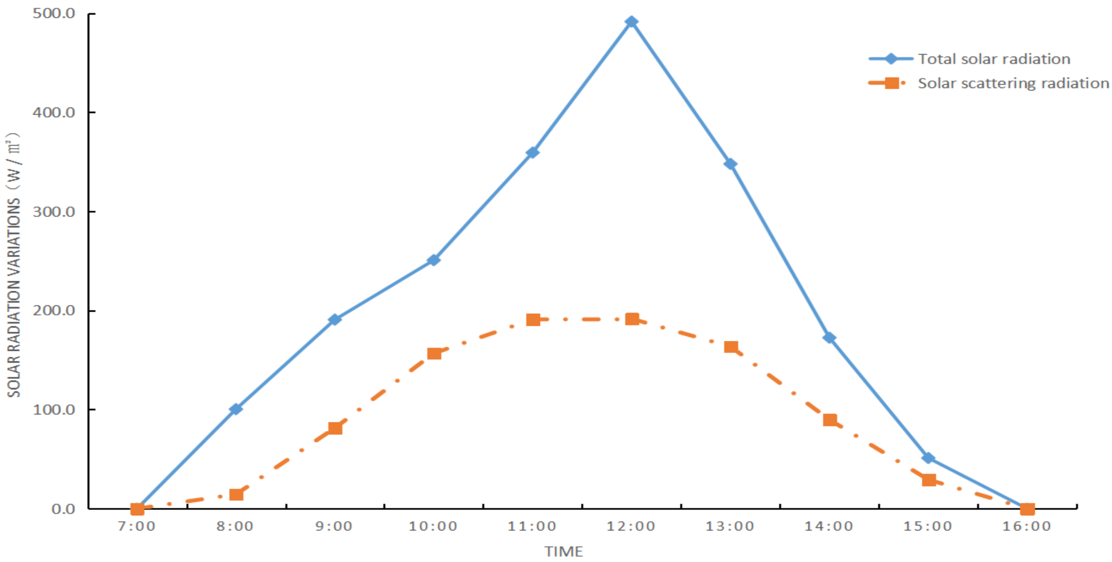

Figure 2. Solar radiation variations.

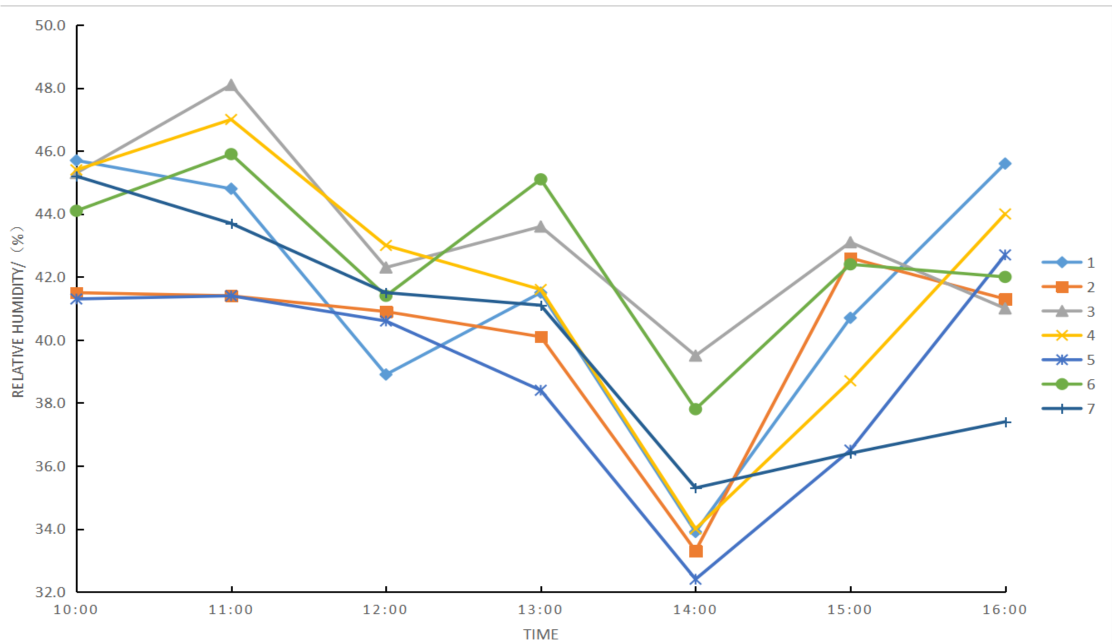

Figure 3. Hourly variation of relative humidity of sites.

3. Results and analysis

3.1. Relative humidity analysis

The hourly variation of relative humidity at each site in waterfront settlements is shown in figure 3, and the average relative humidity at each site is shown in table 2. The variation of relative humidity at each site was approximately the same. From 10:00 to 11: 00, relative humidity reached a relatively high value, and the solar radiation was very low. With the increase of solar radiation, air temperature also increased. But relative humidity of each site decreased continuously, reaching a low value at 14:00. Since then, the relative humidity has been increasing under the influence of the decreasing temperature. The highest average relative humidity was site 3 and the lowest was site 5, because the average air temperature of site 3 was the lowest and site 5 was the highest. Thus, the influence of solar radiation and air temperature on the relative humidity of the residential area was significant.

Table 2. Average relative humidity by site.

Site	1	2	3	4	5	6	7
Average relative humidity / (%)	41.6	40.2	43.3	42	39	42.7	40.1

Table 3. Average wind speed by site.

Site	1	2	3	4	5	6	7
Average wind speed / (m▪s^{-1})	0.3	0.5	2.3	1.8	0.7	0.6	2.5

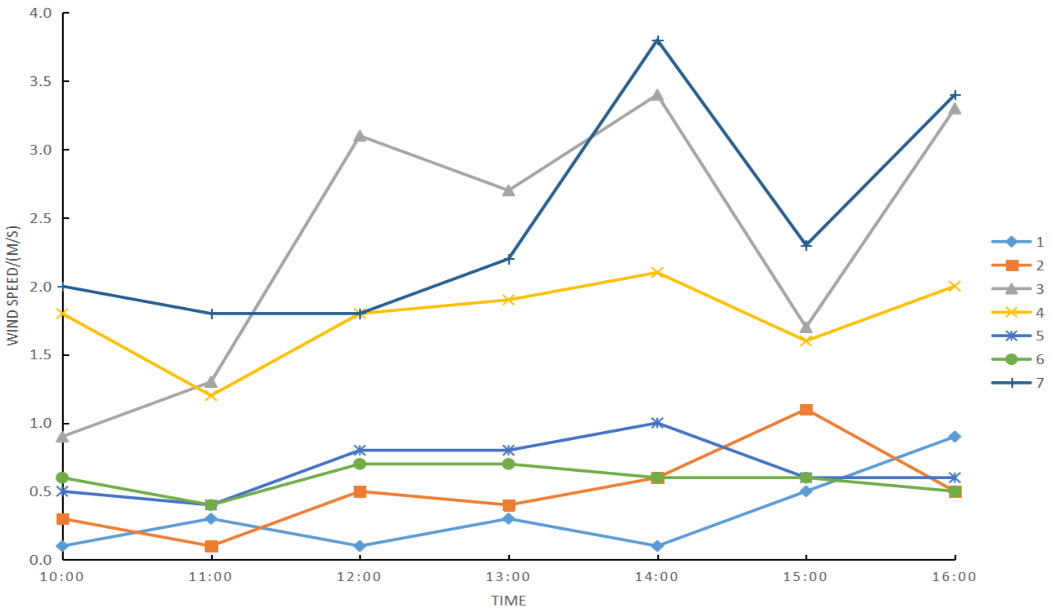

Figure 4. Hourly variation of wind speed of sites.

3.2. Wind speed analysis

The hourly variation of wind speed at each site in waterfront settlements is shown in figure 4, and the average wind speed at each site is shown in table 3. The variation curve of wind speed at site 3 fluctuated the most and was significantly higher than other sites. The maximum difference could reach 2.5m/s, because the dominant wind direction during the test period was northwest direction, and the lakeside was relatively open. The maximum average wind speed was 2.5 m/s at site 7. At 14: 00, the wind speed was more significant, with a peak of 3.8 m/s. Because site 7 was between the two residential gable walls, and angular flow wind appeared in the survey, which made the wind speed change instability. The wind speed of site 2, site 4 and site 6 has little change, and the average wind speed was 0.5 m/s, 1.8 m/s and 0.6 m/s, respectively. The average wind speed of site 4 was relatively high, because site 4 was surrounded by four buildings, and the internal airflow vortex was produced, which made the wind speed fluctuate considerably. The average wind speed of the site 1 and site 5 were 0.3 m/s and 0.7 m/s, respectively, and the difference was up to 0.4 m/s. This was due to the narrow tube effect of buildings between site 5, which made the average wind speed higher than that of enclosed buildings. It was shown that the wind environment of an enclosed building layout was better than that of the row layout pattern.

Li [4] and Ma [5] have studied the wind environment of winter in cold region by using computer software numerical simulation method. The results showed that the wind environment of row layout pattern was the worst in winter. The wind environment of enclosed building layout was relatively comfortable, and the difference in daily average wind speed between the two types of buildings could be up to 1.5 m/s. The conclusion was consistent with the result of our paper, and the setting of boundary conditions in numerical simulation led to the difference. Therefore, flexible layout of buildings could reduce the adverse effects of wind of severe cold regions in waterfront settlements.

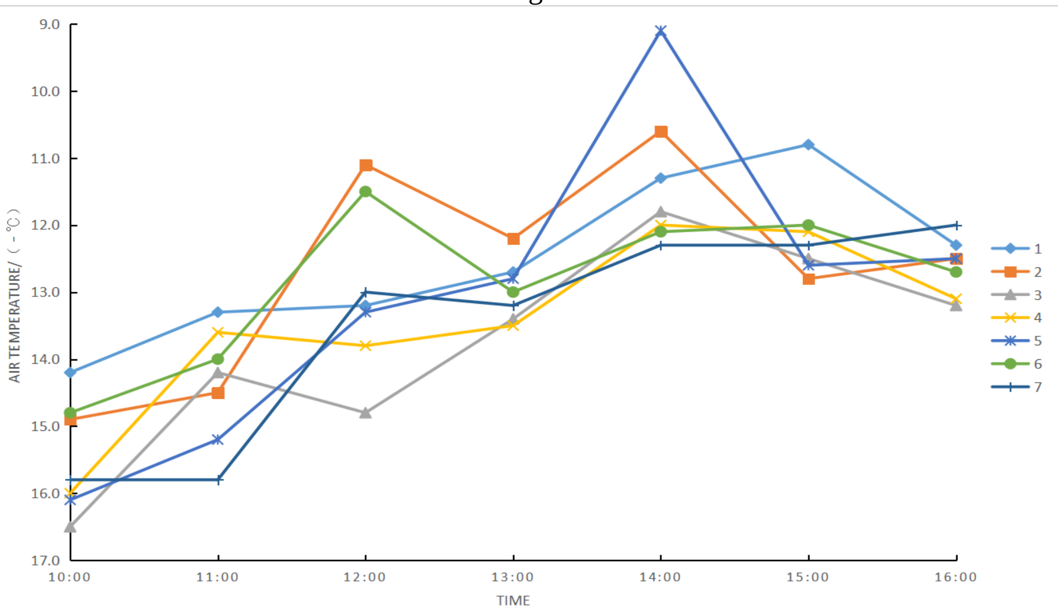

Figure 5. Hourly variation of air temperature of sites.

3.3. Air temperature analysis

The hourly variation of air temperature at each site in waterfront settlements is shown in figure 5, and the average air temperature at each site is shown in table 4. Air temperature is the most direct microclimate factor that we can sense. The maximum difference of air temperature at site 5 could reach 7 °C. And at 14: 00, air temperature at site 5 was the highest, then it began to drop, and the rate of decline was significantly higher than other sites. The average air temperature of site 2, site 4 and site 6 were -12.7 °C, -13.4 °C and -12.9 °C, respectively. The average air temperature of site 4 was relatively low, because it was in the wind shadow area, the wind environment was relatively unstable, and the heat loss was more. The average air temperature of site 3 was the lowest, which was -13.8 °C, because the wind speed of this site was high, and the heat loss was fast. The second was site 7, which was -13.5 °C. Because it was at the corner of the building, and the complex corner airflow caused it to lose more heat. Thus total solar radiation and wind speed led to the difference in air temperature in different areas.

Table 4. Average air temperature by site.

Site	1	2	3	4	5	6	7
Average temperature / (℃)	−12.5	−12.7	−13.8	−13.4	−13.1	−12.9	−13.5

3.4. Wind chill temperature analysis

3.4.1. Calculation method of wind chill temperature

Wind chill temperature (WCT) is a comprehensive evaluation index considering the influence of air temperature and wind speed on the cold degree of the environment. The formula is

$$WCT = 13.12 + 0.6215 \bullet t - 11.37 \bullet v_{10}^{0.16} + 0.3965 \bullet t \bullet v_{10}^{0.16}$$

In the formula, WCT is the wind chill temperature, ℃; V_{10} is the wind speed at the height of 10 m of the standard meteorological observatory, $km \cdot h^{-1}$; t is the air temperature, ℃. If the wind speed is measured at an altitude of 1.5 m, the formula should be multiplied by 1.5. When $V_{10} \leq 4.8\ km \cdot h^{-1}$, it can be considered as static wind and the wind chill temperature is equal to the air temperature. The classification of wind chill temperature and thermal sensation is shown in table 5.

Table 5. Classification of wind chill temperature and thermal sensation.

Classify	Wind chill temperature / ℃	Thermal sensation
1	－10 to －24	Slightly cool
2	－25 to －34	Cool
3	－35 to －59	Cold
4	＜－60	Very cold

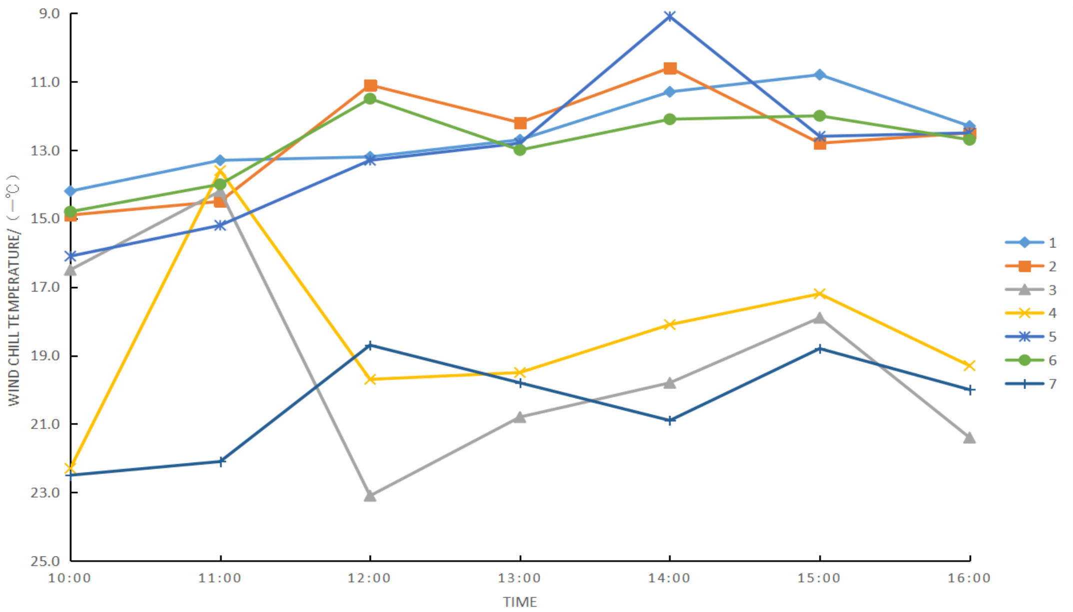

Figure 6. Hourly variation of wind chill temperature of sites.

Table 6. Average wind chill temperature by site.

Site	1	2	3	4	5	6	7
Average wind chill temperature/(℃)	－12.5	－12.7	－19.1	－18.5	－13.1	－12.9	－20.4

3.4.2. Wind chill temperature

The hourly variation of wind chill temperature at each site in waterfront settlements is shown in figure 6, and the average wind chill temperature at each site is shown in table 6. The wind chill temperature of site 3 fluctuated the most, and the degree of cold was higher than that of other sites. The wind chill temperature of site 1, site 2, site 5, and site 6 was relatively high, the fluctuation was relatively stable. The average wind chill temperature of site 7 was the lowest, which was -20.4 ℃. The degree of cold was higher than that of other sites, and the thermal comfort was the worst. The average wind chill temperature of site 3 and site 4 were -19.1 ℃ and -18.5 ℃, respectively. The degree of cold was relatively high, and the thermal comfort was relatively poor. The average wind chill temperature of site 1 was -12.5 ℃, the cold degree was the lowest, and the thermal comfort was the best. The average wind chill temperature of site 5 was -13.1 ℃, which was 0.6 ℃ lower than that of site 1. It was indicated that the thermal comfort of the enclosed building layout was better than that of the row layout pattern. The average wind chill temperatures of site 2 and site 6 were -12.7 ℃ and -12.9 ℃, respectively. The cold degree was relatively low, and the thermal comfort was relatively good.

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4. Conclusions

Analysis of the relative humidity led to the following conclusions: Solar radiation and air temperature had significant influence on relative humidity. Relative humidity of each site decreased continuously and reached a low value at 14:00, and then the relative humidity was gradually increased by the decrease of air temperature. The average relative humidity of site 3 was the highest, and site 5 was the lowest, because the average air temperature of site 3 was the lowest and site 5 was the highest.

Analysis of the wind speed led to the following conclusions: The wind environment of site 3 was poor, because the space was relatively open, and there was no building occlusion. The average wind speed of site 7 was higher than that of other sites, because it was between the two residential gable walls, and angular flow wind appeared in the survey, which made the wind speed change instability. The average wind speed of site 4 was relatively high, because it was surrounded by four buildings, which resulted in internal airflow vortex and made the wind speed fluctuate considerably. The average wind speed of site 1 and site 5 were 0.3 m/s and 0.7 m/s, respectively. Therefore, the wind environment of enclosed building layout was better than row layout pattern, and flexible layout of buildings could reduce the adverse effects of wind of severe cold regions in waterfront settlements.

Analysis of the air temperature led to the following conclusions: Solar radiation and wind speed led to the difference in temperature in different areas of waterfront settlements. The maximum difference of air temperature at site 5 could reach 7 ℃. At 14: 00, the air temperature of site 5 was the highest, because the intensity of solar radiation was more substantial at this time. The average air temperature of enclosed building layout was 0.6 ℃ higher than that of row layout pattern. Therefore, thermal environment of enclosed layout was better than row layout pattern. The average air temperature of site 3 was the lowest because the wind speed was high, and the heat loss was fast. And the second was site 7, because it was at the corner of the building, and the complex corner airflow caused it to lose more heat. The average air temperature of site 2, site 4 and site 6 were -12.7 ℃, -13.4 ℃ and -12.9 ℃, respectively. The average air temperature of site 4 was relatively low, because the wind environment of this site was unstable and the heat loss was much higher.

Analysis of the wind chill temperature led to the following conclusions: The average wind chill temperature between building gables was the lowest, which was -20.4 ℃. The degree of cold was higher than that of other sites, and the thermal comfort was the worst. The average wind chill temperature near the shore and in the open space was lower, which was -19.1 ℃ and -18.5 ℃, respectively. The degree of cold was relatively high, and the thermal comfort was relatively weak. The average wind chill temperature of enclosed building layout was the highest, which was -12.5 ℃, the cold degree was the lowest, and the thermal comfort was the best. The average wind chill temperature of row layout pattern was -13.1 ℃. Thus, the thermal comfort of enclosed building layout was better than that of row layout pattern. The average wind chill temperature of roads were -12.7 ℃ and -12.9 ℃, respectively. The cold degree was relatively low, and the thermal comfort was relatively good.

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