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Analysis of Thermal Environment of Open Community Streets in Winter in Northern China

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Abstract

The long winter time and the harsh outdoor environment cause many inconveniences of the outdoor activities to urban residents in severe cold areas. Therefore, it is urgent to study and improve the thermal environment in urban residential streets. This paper focuses on winter thermal environment of streets in open communities of northern China, by carrying out field measurements according to the characteristics of cold climate and urban residential areas. The results show that the aspect ratios of streets can directly affect their thermal environment. With the aspect ratio increases, the air temperature decreases and the wind speed increases. At the same time, facade openings can make the average globe temperature significantly increased in the streets. This paper provides basic data for the further study of thermal environment in urban streets and the optimization design of street spaces.

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Keywords: northern china, open community, streets, thermal environment, winter

1. Introduction

In order to resist severe cold climate in winter, most buildings in residential areas are enclosed in northern China. In old districts of some cities, there are a large number of small scale enclosed residences. These residential streets are mostly city branches connecting city trunk roads and secondary roads with a high degree of openness. Commercial shops usually locate on both side of such areas and form diverse and vibrant street spaces. Open residential streets not

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only have traffic function but also bear the functions of leisure, commerce and culture. [1-2]They are the main places of daily life and activities for residents, so there is high value and practical significance to study on the thermal comfort of these spaces. As the travel of residents is difficult in winter, use efficiency and vitality of the streets are influenced by the cold weather, it is necessary to study on the thermal environment according to winter climatic characteristics in northern China, in order to create a good environment for residents, to improve the microclimate of residential areas and the comfort in the streets, and to extend the outdoor activity time of residents in cold winter.

Summing up the research status, some achievements have been made in the researches on thermal environment in urban streets, but there are also some limitations: There have been many studies on the physical environment in hot and humid climate, hot and dry climate and mild climate. The results of D.Pearlmutter [3-5] show that in the north-south oriented streets, when the H/W is in the range of 1.0-2.0, with the increase of aspect ratio, the pedestrian's thermal comfort is significantly improved. The results of Fazia Ali-Toudert [6-7] and F. Bourbia [8-9] show that the higher the aspect ratio is, the lower the air temperature in the streets and the surface temperature of buildings is. However, the current researches on cold climate conditions are relatively rare. Due to the longer winter in cold areas, outdoor environment is bad and causes a lot of inconvenience to the outdoor life of residents. So it is urgent to research and improve the environment in such streets.

Through field tests, this paper analyses and researches the current situation of street thermal environment with different aspect ratios in open residential areas of northern China. This paper can provide basic data for the further study of thermal environment in urban streets and the optimization design of street spaces.

2. Methodology

2.1 An analysis of the status quo of Open Communities

Harbin, east longitude125°42'-130°10 ', northern latitude44°04'-46°40' and altitude180~200m, a typical city in north China, is selected as the research object. With small block scale and dense road network in the old district of Harbin (Fig. 1), single buildings form the housing groups in an encircling way which have both contact and independence. With space interpenetration of urban streets and residential groups, residential areas have high accessibility and openness, facilitating the travel of residents.

Through the investigations and researches, it can be found that buildings in the residential areas are 6-8 stories, with the height of 18-24m and street width of 18-25m. The building units form relatively closed courtyards by enclosing, and the facade openings connecting inner courts and streets are settled in proper positions. Residential roads and inner courtyards surrounded by buildings are usually the most frequent public places for daily activities of residents.

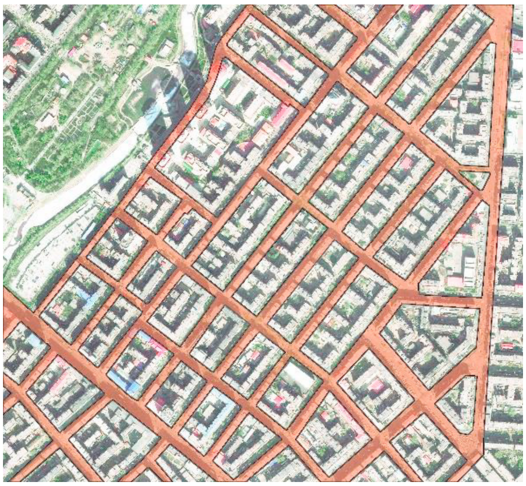

Fig. 1. Typical open residential area of Harbin old city subdivision

Fig. 2. Street measuring point arrangement and street real scene

2.2 Site description, measurement instruments and method

The three selected streets have the same orientation and different aspect ratios, as shown in Fig. 2. Six measurements points were located in the same position of the three Streets (*Street a*, *Street b*, *Street c*). *Street a* is symmetrical whose aspect ratio is 1.0, *Street b* is symmetrical whose aspect ratio is 1.1 and *Street c* is asymmetric whose aspect ratio is 1.2/1.0. More specific information about streets are shown in Table1. The ground floor of buildings in the streets are commercial shops. During the field measurement, the air temperature was -22℃~-13℃, the wind direction was southwest, the wind speed was 1.5~3m/s, and during the period of 9:00~15:00, total solar radiation intensity average value was 323 W/m2. It is known that the predominant wind direction in Harbin is southwest and the average temperature of the coldest month is -24℃~-12℃, so it was the typical winter climate characteristics when the field measurement was carried out. By synthetically considering the factors of air temperature, relative humidity, solar radiation and wind, the monitoring campaign used BES-01 temperature recorder, BES-02 temperature and humidity recorder, and Kestrel4500 mini weather station to recorded globe temperature, air temperature, relative humidity and wind speed etc. Instrument technology parameters are shown in Table 2. Before the measurement, the instruments had been calibrated many times. Fig. 3 is the setting of instruments in the study field. And the instruments were fixed on the tripods so that the sensors of temperature recorder and weather station were placed at 1.5m height. The recording time of microclimatic data was 1 min.

Table 1. Street space morphology

Street	a	b	c
Symmetry properties	symmetry	symmetry	asymmetry
Width /m	21	21	20-24
Height /m	21	24	21-24
Aspect Ratio	1.0	1.1	1.0-1.2

Table 2. Instrument technology parameters

Name &model	Measurement range	Precision	Comment
BES-01 temperature recorder	temperature： -30~50 ℃	±0.5 ℃	sampling period： 10 s~24 h
BES-02 temperature and humidity recorder	temperature： -30~50 ℃ relative humidity：0 % ~99 % RH	±0.5 ℃ ±3 % RH	sampling period： 10 s~24 h
Kestrel4500 mini weather station	wind speed0.4~ 40 m/s wind direction：0 °~ 360 ° temperature： -29~ +70 ℃ relative humidity：5 %~ 95 % air pressure：750~1100 m Bar（25℃）	±0.1 m/s ±5 ° ±1.0 ℃ ±3 % ±1.5 m Bar	sampling period： 2 s~12 h

Fig. 3. Site photos of test instrument settings

3. Results

The results show that the variation trends of air temperature in three streets with different aspect ratios were similar, but with the increase of aspect ratio, the temperature decreased gradually. The average air temperature of *Street a* was -12.3℃, *Street b* was -12.4℃and *Street c* was -12.6℃. Compared with *Street a*, the average daytime air temperature in *Street b* was 0.1 ℃ lower, and *Street c* was about 0.3 ℃ lower (Fig. 4). Compared with *Street a*, with similar street width, temperature in *Street b* was lower due to larger aspect ratio, higher constructions, and less sunlight. *Street c* was relatively complex: One measurement point had buildings of 24m height on both sides. At this point, the street aspect ratio was 1.2 and the temperature was obviously the lowest. Another measurement point with different building heights (respectively 24m and 21m on two sides) also had different temperature from *Street a* because of different street width, even though the height of buildings on sun incident side was same. At the same time, the height of buildings and the symmetry should also affected the reflection absorption of long wave radiation. Therefore, although there were two aspect ratios in *Street c*, the average temperature was still the lowest among these streets.

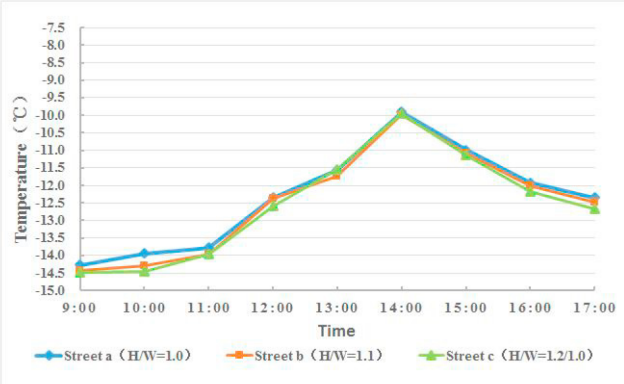

Fig. 4. Air temperature change curve of different aspect ratio streets

In Fig. 5, the changing trends of globe temperature were more uniform in the streets. However, the relationship between air temperature and globe temperature was not consistent. The globe temperature in *Street b* was the highest with 0.5℃ higher, but the peak value was significantly lower than that in the other two streets. It should have a direct relationship with large number of facade openings in *Street b*. In order to further verify the effect of facade openings on globe temperature in the streets, this paper used FLIR thermal infrared imager to shot two facade openings in *Street b*. As can be seen from Fig. 6, when the residential buildings began to implement winter heating, the surfaces of buildings had higher temperature with significant thermal radiation. The buildings in selected area adopted centralized heating mode and the materials of walls were also very similar, so the difference of heat radiation was not large. However, the appearance of facade openings would lead to different results. Compared with streets, courtyards were more likely to receive solar radiation. At the same time, due to courtyards were more enclosed, the loss of architectural radiation heat in the courtyards were less than that in the streets, so the heat in the courtyards could transfer through the facade openings to the streets. In addition, the presence of facade openings also increased the heat dissipation area of buildings and affected the thermal radiation around the openings. Although it is not conducive to building energy-saving, the extra radiation is much smaller than the total amount of heat radiation in cold regions in winter. Nevertheless, it can make people feel warmer in the streets, so it’s good for streets in winter. As one measurement point in *Street b* happened to be in the influence scope of two facade openings, so the globe temperature of *Street b* was higher than that of the other two streets before the temperature reached its peak. When the sun had a maximum angle, the effect of direct solar radiation was stronger than that of facade openings on globe temperature. Then due to the larger aspect ratio, less direct solar radiation in *Street b* leaded to lower peak value of globe temperature.

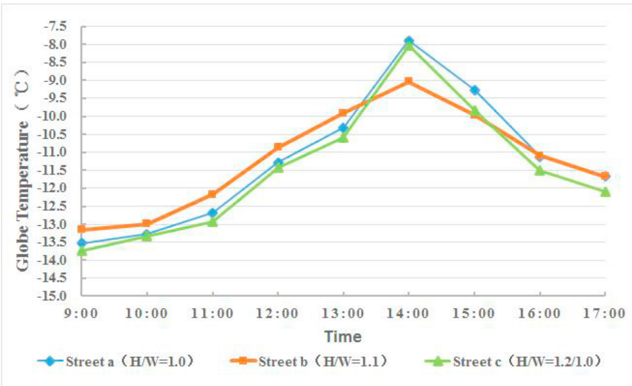

Fig. 5. Ball temperature change curve of different aspect ratio streets

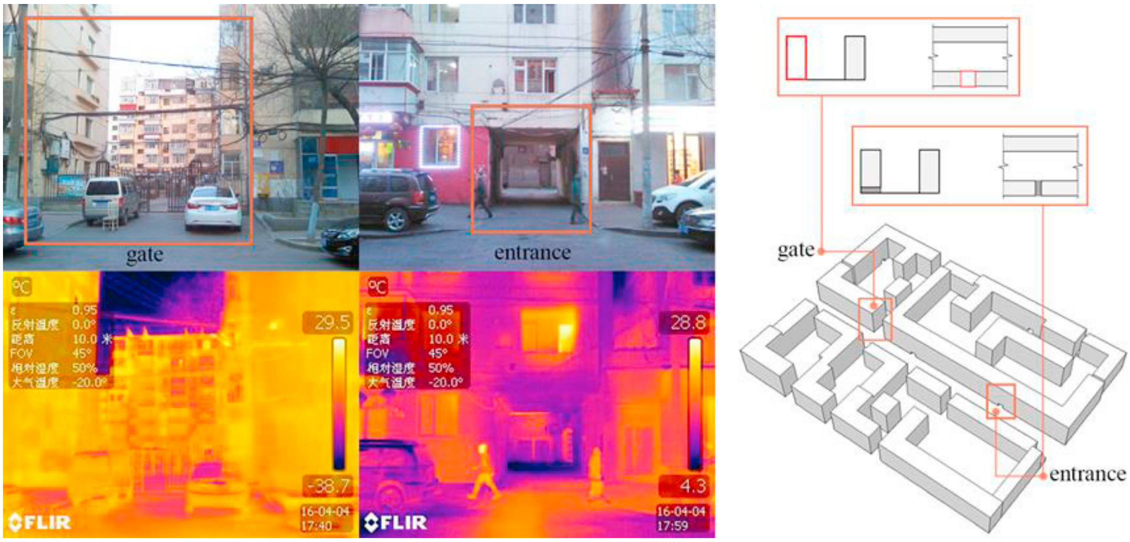

Fig. 6. Infrared images the classifications of facade openings

It is worth noticing that the sizes of facade openings were generally small and the forms were generally divided into entrances and gates. The height of the entrance was generally 3m and the width was 4~6m, in fact, this kind of facade opening couldn’t effectively increase the solar radiation. When the facade opening was gate, sun could indeed enter into streets through the gates, so as to increase the amount of solar radiation in the streets. As the width of gate was only about 10m, the influence had some limitations. Therefore, the influence of the facade openings on thermal environment in the streets also need specific analysis based on their shapes. As the sun elevation angle was low in winter, so the measurement didn’t fully reflect the advantages of facade openings, the air temperature also didn't appear to be affected too much. However, the globe temperature still had a certain influence because one measurement point in *Street b* was in the influence scope of two facade openings.

The diurnal fluctuations of relative humidity in the streets (Fig. 7) show that the relative humidity trends in *Street a* and *Street b* were exactly the same, but *Street b* was significantly lower 2~4%. As the fluctuation of wind speed was large in an asymmetric street and had a certain influence on the relative humidity, so the fluctuation of relative humidity was slightly different in *Street c*

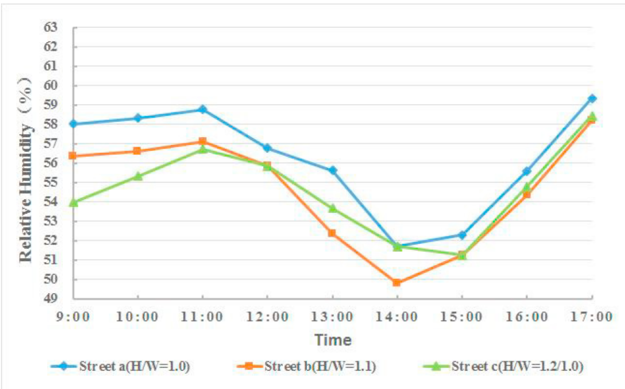

Fig. 7. Relative humidity change curve of different aspect ratio streets

Fig. 8 is the diurnal fluctuations of wind speed in the streets with different aspect ratios. The wind environment in these three streets was different, but the wind speed was also strengthened with the increase of aspect ratio. In *Street a* and *b*, the variation trends of wind speed were basically same. However, the wind speed in *Street b* was

0.3m/s~0.5m/s higher than that in *Street a*. Although the facade openings had a certain effect on the wind speed reduction, it was only limited to a small area around the openings. Therefore, the facade openings had a small impact on the wind speed in this measurement. As *Street c* was asymmetric, in which the wind environment was complex, the variation trend of the wind speed in *Street c* was rather different from the other two streets.

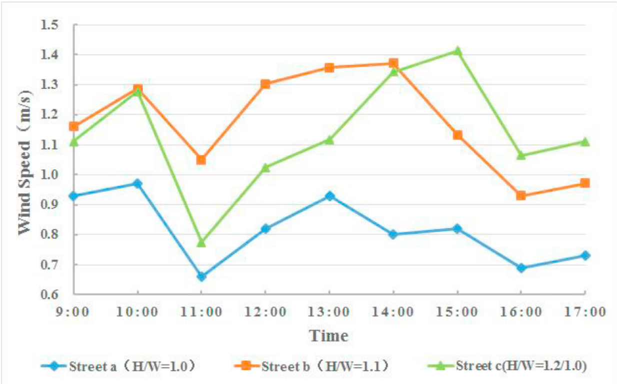

Fig.8. Wind speed change curve of different aspect ratio streets

4. Discussion

The results in this paper show: while the aspect ratio is in the range of 0.8~1.3, the higher the aspect ratio is, the lower the temperature is, the larger the wind speed is, and the worse the winter thermal environment is. Although the results of this study are contrary to those of D.Pearlmutter [3-5] et al [13-14], the reason for the differences is that the climate of their research area is dry and hot, so lower temperature in the streets is better to the thermal environment in summer. However, for severe cold areas, lower temperature is worse to the thermal environment in winter. Therefore, the results of aspect ratios for the thermal environment are still consistent based on the research data.

5. Conclusions

(1) The scale and geometries of the street spaces have significant influences on the thermal environment in the streets. By research and investigation, the aspect ratio of streets in the opening residential district in northern China is in the range of 0.8 ~ 1.3, of which 1.0 ~ 1.2 is the most common. In this range, with the aspect ratio increasing, the temperature decreases and the wind speed increases. Therefore, reducing the aspect ratio of streets moderately is conductive to improving the thermal environment in northern China in winter.

(2) Globe temperature is significantly influenced by facade openings. When the number of facade openings is larger, the average globe temperature in the streets is significantly higher. Consequently, reasonably increasing the number of facade openings can not only facilitate the travel of residents and ensure the continuity of street activities, but also increase the solar radiation and improve thermal comfort in the streets.

Acknowledgements

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Appendix

Wind speed

Time	Street a （H/W=1.0）	Street b （H/W=1.1）	Street c (H/W=1.2/1.0)

9:00	0.93	1.16	1.11
10:00	0.97	1.29	1.28
11:00	0.66	1.05	0.78
12:00	0.82	1.30	1.02
13:00	0.93	1.36	1.12
14:00	0.80	1.37	1.34
15:00	0.82	1.13	1.41
16:00	0.69	0.93	1.06
17:00	0.73	0.97	1.11

Relative humidity

Time	Street a (H/W=1.0)	Street b (H/W=1.1)	Street c (H/W=1.2/1.0)
9:00	58.02	56.36	54.00
10:00	58.33	56.60	55.34
11:00	58.79	57.13	56.72
12:00	56.79	55.85	55.85
13:00	55.64	52.39	53.68
14:00	51.72	49.81	51.70
15:00	52.32	51.27	51.25
16:00	55.61	54.37	54.80
17:00	59.36	58.20	58.44

Air temperature

Time	Street a （H/W=1.0）	Street b （H/W=1.1）	Street c （H/W=1.2/1.0）
9:00	-14.27	-14.43	-14.47
10:00	-13.94	-14.28	-14.46
11:00	-13.78	-13.96	-13.96
12:00	-12.35	-12.38	-12.60
13:00	-11.57	-11.73	-11.55
14:00	-9.90	-9.98	-10.56
15:00	-10.99	-11.07	-11.14
16:00	-11.93	-12.00	-12.19
17:00	-12.35	-12.48	-12.66

Globe temperature

Time	Street a （H/W=1.0）	Street b （H/W=1.1）	Street c （H/W=1.2/1.0）
9:00	-13.54	-13.15	-13.75
10:00	-13.27	-12.99	-13.34
11:00	-12.68	-12.17	-12.94
12:00	-11.29	-10.87	-11.42

13:00	-10.32	-9.92	-10.59
14:00	-7.89	-9.03	-8.03
15:00	-9.26	-9.96	-9.85
16:00	-11.12	-11.09	-11.51
17:00	-11.66	-11.67	-12.09

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