Study on the relationship between urban climate change and urban development construction in severe cold area

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Abstract: A sizable majority of researches show that urban climate change has great relationship with urban development construction. However, because of the big climate environment difference in summer and winter, for cities in severe cold area, urban climate environment affected by urban development construction has its own complexity compared with that in warm area.

In order to study the importance of urban development construction in affecting the urban climate environment in severe cold area, this paper takes a typical winter city Harbin in northeast China as the research objective. On the basis of analyzing the climate evolution and urban development from 1988-2017, the paper makes a correlation analysis between urban climate elements and some typical urban development construction indexes in summer and winter separately, finding the underlying mechanisms of the two factors' mutual influence. At last, according to the correlation analysis results, this paper confirms the key urban development construction indicators, and advances some urban planning strategies to avoid the negative effects that urban development construction brings to urban climate environment in severe cold area.

1. Introduction

A sizable majority of researches show that urban climate change has great relationship with urban development construction, especially in recent decades. T.R.Oke is one of the earliest experts who discuss urban size 's influence on urban heat climate[1]. Peter Bosselmann analyzes urban form and climate in 1990s[2]. Some researchers focused on studies of how urban construction affect urban climate environment in different regions. Du Yin and Rohinton Emmanuel discussed the urban climate change under urban expansion and shrinkage respectively in warm areas[3][4]. Bernard Kumi Boateng and S Piketh took Ghana and in Africa as the research object, studying the relationship between urban growth and thermal climate change. Y Shi pays much more attention on microclimate spatial distribution in sub-tropical high-density urban environment[5]. Climate change is also connected to urban planning policy in some developed countries[6][7]8. In addition, some researchers integrates climate change considerations into related urban planning technical specifications and guidelines, as well as some urban planning strategies, in order to make the research results much more effective[9][10][11].

However, because of the big climate environment difference in summer and winter, for cities in severe cold area, urban climate environment affected by urban development construction has its own complexity compared with those cities in warm area. For example, as the urban grows and develops, in summer, heat island effect in winter cities are also noticeable, extreme hot weather often happens; In winter, unreasonable urban design makes the microclimate of partial urban areas very bad, especially big wind velocity and lack of sunshine. In fact, temperatures of winter cities in China are far below those in other countries at similar latitudes; the mean temperature in January is lower than -18°C due to the cold air that comes from Siberia every year[12]. So winter cities in China face much more complicated climatic issues than those in other area.

Related research on cities in severe cold area is rare in the literature. This study took Harbin, a typical Chinese winter city, as the research objective. The main purposes of the study are (1) Analyze the climate evolution and urban development construction in recent 30 years in typical winter cities; (2) Develop the correlation analysis between urban climate and urban development construction in typical winter cities; (3) Advance some planning implication to improve climate environment in winter cities.

2. Methods

2.1 Study site

Harbin is located at 45° latitude N and 128° longitude E, and it is known as a typical winter city in northeast China. Harbin is the capital city of Heilongjiang Province, and also the transportation, political, economic, cultural and financial center of northeast China, with a total population of 9.62 million at the end of 2016. The city of Harbin encompasses approximately 53000 km^2, urban area 10198 km^2, with the GDP of 610 billion. The location map of Harbin is shown in Figure. 1.

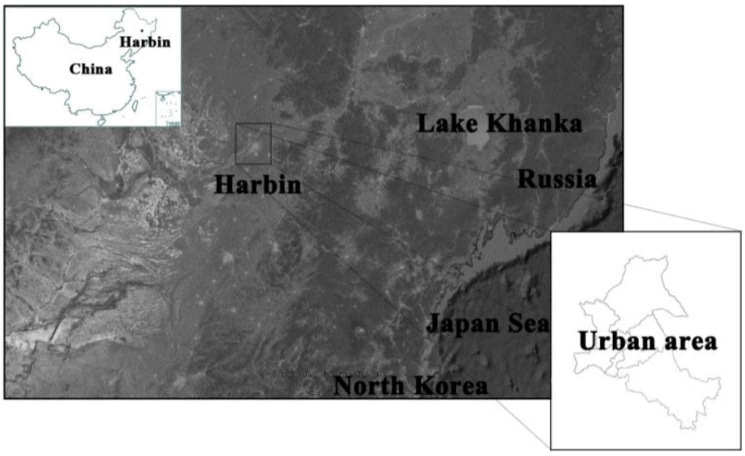

Figure 1: The Location Map of Harbin

Harbin belongs to the temperate continental monsoon climate zone, the annual mean temperature of which was 3.6℃. The mean temperature of the coldest month, January, is approximately -19.5℃, and the lowest temperature of -37.3℃ occurred on Jan 26th, 1985. The mean temperature of the warmest month, July, is approximately 22.8℃, as shown in Figure 2. Usually, summer is from June to August, in which the mean temperature is higher than 20℃; winter is from November to March, in which the mean temperature is lower than 0℃. The heating period in Harbin is from October to April, and only about 140 days in the year are frost-free.

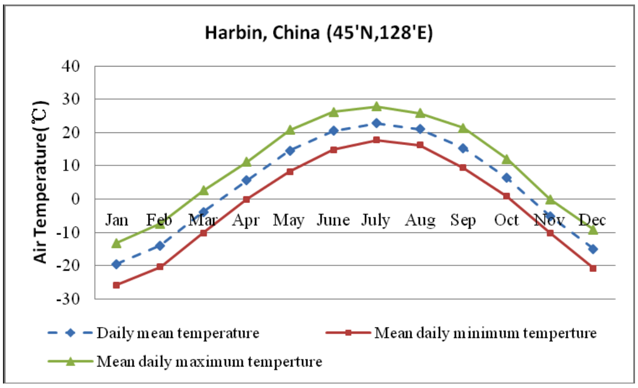

Figure 2: Mean daily mean, maximum, and minimum air temperature in Harbin ,China

2.2 Basic data analysis
Meteorological data for Harbin from the China Meteorological Data Sharing Service System from 1988 to 2017 was used to study the climate environment evolution in Harbin, which offers authoritative meteorological data for scientific research. This study used the average adjacent day or month value instead of using incomplete data in the system. The main climate parameters are temperature, sunshine duration, wind velocity and relative humanity in the 30 years. Temperature parameters contain mean temperature, minimum temperature and maximum temperature; wind velocity parameters contain mean wind velocity and maximum wind velocity; relative humanity parameters contain mean relative humanity and mean precipitation.

Urban development construction data from China City Statistical Yearbook from 1988 to 2017 was used to study the urban development construction in Harbin. The main indexes are population, urban built-up area, land use intensity, green coverage ratio and GDP. In addition, some satellite image maps of Harbin in different typical years are from the website of United States Geological Survey, through which the urban evolution in recent 30 years can be seen clearly.

2.3 Correlation analysis
Based on the meteorological data and urban development data in the 30 years of Harbin, the Person correlation analysis between meteorological data and urban development construction index is discussed. All the indexes in the Person correlation analysis pass through the test of independent. In order to show the specialty of winter cities, the analysis process was performed based on the data in summer and winter respectively. In the analysis, summer meteorological data is the mean value from June to August, winter from November to March.

3. Results

3.1 Climate environment evolution
Figure 3 shows the climate environment evolution from 1988 to 2017 in Harbin. In the 30 years, the annual mean temperature rises up 3.1℃, urban heat island effect begins to come up. The raise range of mean minimum temperature in Harbin is more than the decline range of maximum temperature within the 30 years. In addition, the temperature change characteristics shows the level of warming in winter is higher than that in summer, so the urban heat island's influence on urban temperature mainly focuses on night and winter in Harbin.

The mean sunshine duration in Harbin drops year by year. Harbin was the region of abundant solar energy resources, there was 250 days in which sunshine duration is more than 6 hours[13]. Before the year 2006, the annual sunshine duration hours are 2500, and after that, the numbers are about 2200, with a reduction of 1 hour per day. As the urban development construction advances, air pollutant concentration and total cloud cover increases and direct solar radiation decreases, so the sunshine duration reduces in the past 30 years.

Wind velocity in Harbin has a significant decline in the 30 years, the wind velocity variation slope is about 1.5m/s, and the mean wind velocity is about 2m/s in recent 5 years. The days with strong wind (11m/s) in 1960s are 10.8, but in 1990s they are only 0.6[14]. Annual maximum wind velocity reduces greatly before 1990s, and after that, the reducing speed is lower. The annual maximum wind velocity stays in about 10m/s in the nearly 15 years, which is a similar result as 'the wind energy resource census', the reserve of wind energy resource are shrinking in most region of China[15].

The mean precipitation peaked at the year 1998 with the value of 800mm, and since the year 2000, the value begins to reduce, annual mean precipitation is only about 500mm. Because of the decrease of precipitation, the relative humanity shows a decline in the 30 years in Harbin.

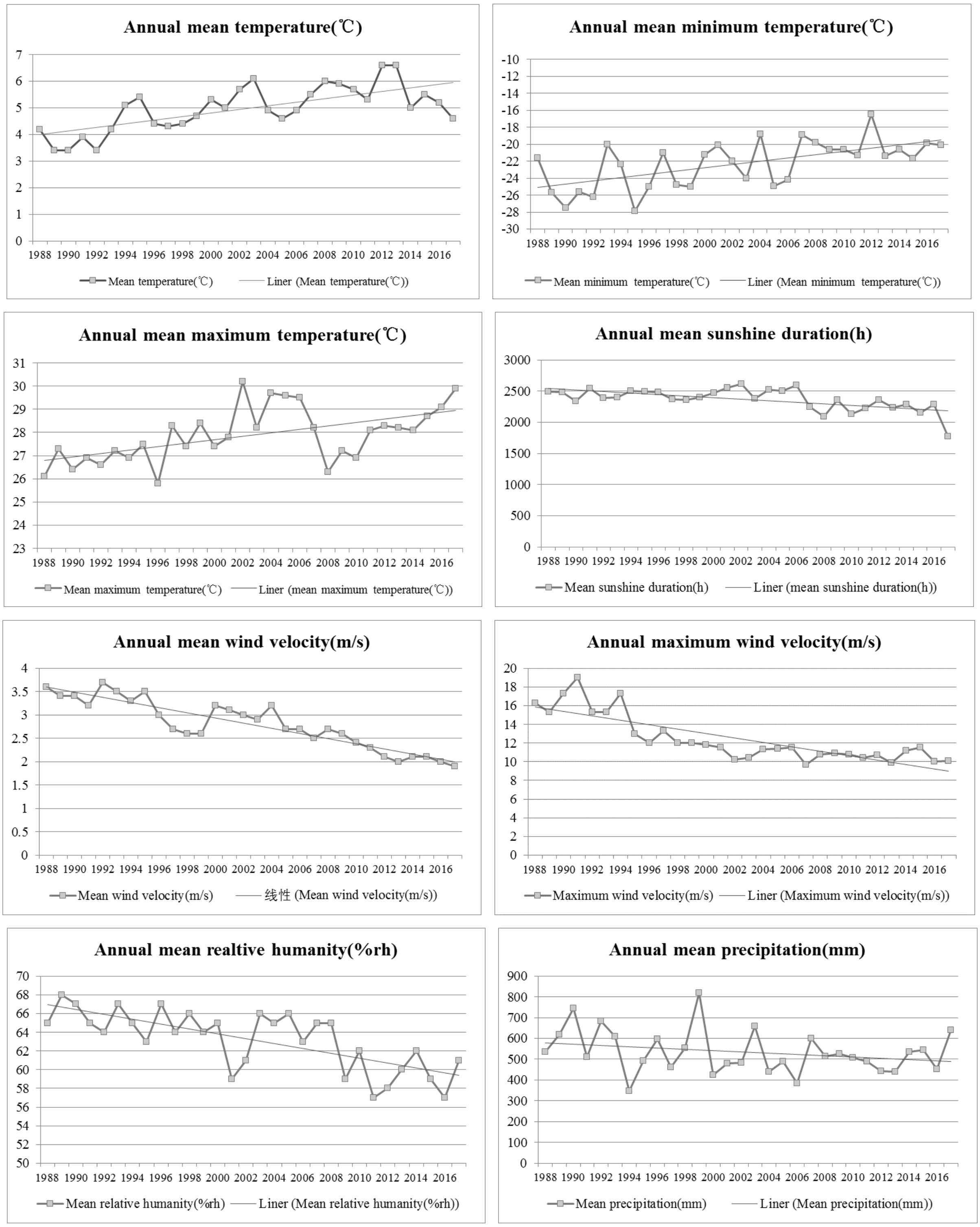

Figure 3: The climate environment evolution in the 30 years in Harbin

3.2 Urban development construction

Figure 4 shows the Harbin main urban area spatial patterns change situation in the year 1988, 1997, 2007 and 2017. Urban construction land in Harbin is expanding within the 30 years, especially in the recent 10 years. The main urban area in Harbin has a significant expansion to the north and south along the Songhua River. Table 1 shows the urban development construction condition of Harbin in typical 5 years, and it has a fastest growing in the recent 10 years, urban built-up area in 2017 is triple the number in 1988, and urban area in 2017 is nearly 6 times as that in 1988.

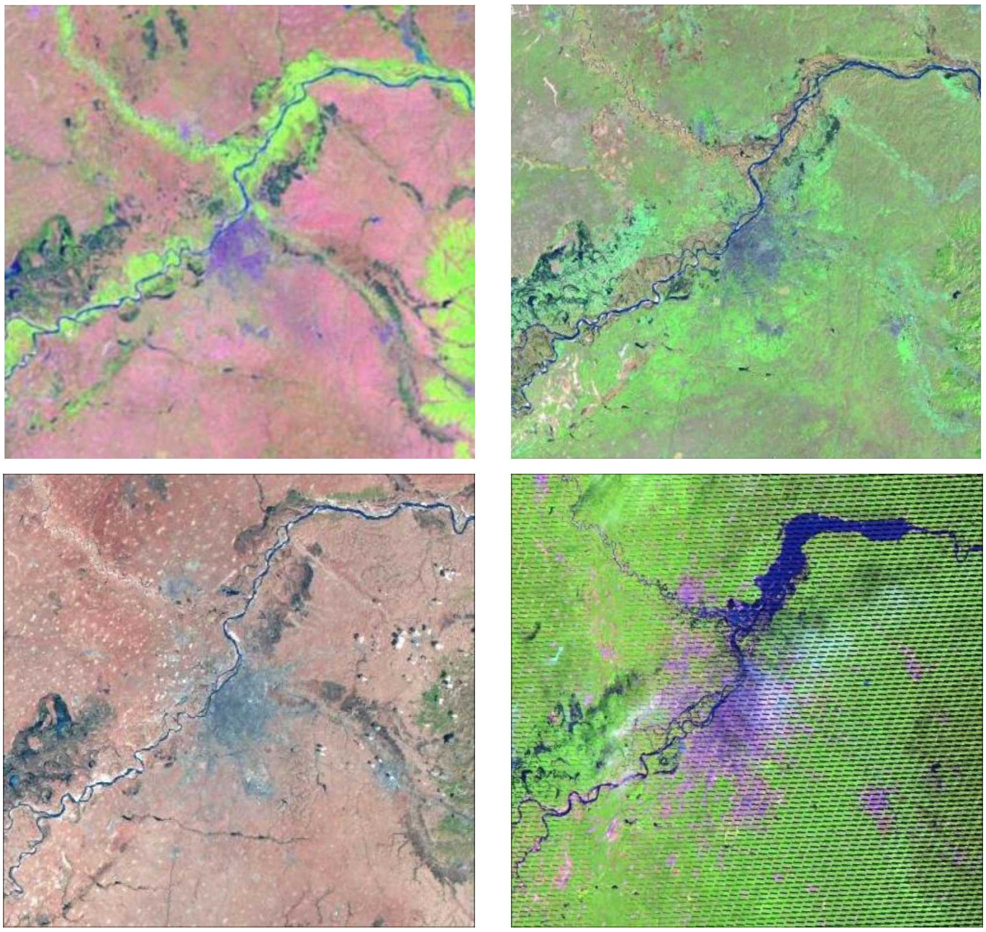

Figure 4: The Urban evolution of Harbin

Table1 Demographic and geographic information of Harbin

Items/ Year	Year 1949	Year 1988	Year 1997	Year 2007	Year 2017
Urban built-up area (km^2)	86.31	153.27	291.09	398.95	428
Urban area (km^2)	930	1637	1637	4275	10098.32
Green coverage ratio (%)	6.34	11.2	19.7	28.87	38.51
Population (Million)	0.76	2.46	2.59	3.99	5.49
GDP (Billion)	0.38	9.68	53.2	183	575

3.3 Correlation analysis

(1) Results in winter

Table 2 shows the correlation index of meteorological data and urban development in Harbin in winter. First, mean minimal temperature has no relationship with urban development, but mean maximum temperature has significant correlation with urban development factors at level 0.01 except urban exploitation, which is similar to the results of mean temperature. Land use intensity has no relationship with any three temperature indexes. Mean sunshine duration in Harbin in winter is influenced greatly by urban development construction factors except land use intensity. Mean sunshine duration declines with urban development, and the correlation coefficient is more than 0.6. Mean wind velocity has a strong relationship with all the urban development construction indexes at level 0.01. Active influence with population, urban built-up area, green coverage ratio and GDP, negative influence with land use intensity. However, urban development construction has little effect on mean relative humanity in Harbin in winter.

(2) Results in summer
Table 3 shows the correlation index of meteorological data and urban development in Harbin in summer. Mean minimum temperature has relationship with all urban development construction indexes except green coverage ratio, and all the correlation coefficients are more than 0.67. However, there is no statistically significant difference between mean maximum temperature and urban development construction indexes. Mean temperature is influenced by population, urban built-area and GDP at level 0.01. Mean sunshine duration in Harbin in summer has a negative relationship with population and urban built-up area, and the correlation coefficients are about -0.5. Mean wind velocity has a strong relationship with all the urban development construction indexes at level 0.01, active influence with population, urban built-up area, green coverage ratio and GDP, negative influence with land use intensity. The more land use intensity is, the more mean wind velocity is, which has the same result as the climate change analysis in the 30 years. However, urban development construction has little effect on relative humanity in Harbin in summer, which has the same results as that in winter.

From the correlation analysis results shown above, it is can be seen that some climate environment evolution indexes have strong relationship with urban development construction indexes except land use intensity in Harbin which is only related to mean wind velocity in both seasons. Land use intensity changes with the urban master planning updates. Land use intensity is the ratio of urban construction area and urban administrative area. In one urban master planning cycle, there is little change in urban administrative area, however urban construction area changes irregularly some time. Therefore, land use intensity in different years and urban master cycles can be similar, which in individual years maybe even smaller than the last year. As a consequence, land use intensity is an index has little effect on climate environment factors.

For showing the specialty in winter cities, there are some certain rules in winter and summer respectively.

First, for winter cities in severe cold area, there is significant difference between urban development construction’s influence on summer and winter temperature. Mean and maximum temperature are the main aspects that urban development construction affect temperature in winter, but mean and minimum temperature are the main influenced objects in summer. Based on the results mentioned above, it is can be seen that as the city grows, maximum temperature in winter is decreasing and minimum temperature in summer in increasing, furthermore, and almost all the correlation coefficients are more than 0.6, which shows a strong relationship. Urban development construction in Harbin has an irreversible influence on urban heating island effect.

Second, mean sunshine duration in Harbin declines with urban development construction in both summer and winter, which validates increasing urban heating island effect in Harbin aggravates air pollution and total cloud cover, as well as its negative effect on urban sunshine environment. In addition, green coverage ratio and GDP is related to sunshine duration only in winter, which indicates cold weather make urban green land have different effects on sunshine duration.

Third, even though the trend of mean relative humanity in Harbin of 30 years is declining, and dry island effect exists, urban development construction has a little influence on relative humanity, no significant difference. Therefore, it is deduced that urban relative humanity has much more relationship with underlying surface patterns and structure. The main precipitation pattern in winter is snowing, so the mean relative humanity in four winter months are similar to each other.

At last, Green coverage ratio has much more influence on winter than that in summer, and that maybe caused by the cold weather, which caused big difference in vegetation forms and patterns in winter compared to summer. In addition, compared with other climate parameters, green coverage ratio has the closest relationship with wind velocity in Harbin in both summer and winter. The correlation coefficients are more than 0.8, and the significances are all at level 0.01.

Table 2: Correlation index of meteorological data and urban development in Harbin in winter

Meteorological data/ Urban development factors		Population	urban built-up area	Land use intensity	Green coverage ratio	GDP
Mean minimum temperature	Person	0.322	0.316	-0.132	-0.198	0.155
	Sig.	.082	.089	.488	.403	.413
Mean maximum temperature	Person	-0.508**	-0.54**	0.167	-0.560*	0.491**
	Sig.	.004	.002	.376	.010	.006
Mean temperature	Person	-0.493**	-0.527**	0.152	-0.533*	0.479**
	Sig.	.006	.003	.423	.010	.007
Mean sunshine duration	Person	-0.611**	-0.699**	0.217	-0.705*	-0.68**
	Sig.	.000	.000	.249	.0150	.000
Mean wind velocity	Person	-0.688**	-0.648**	0.458**	-0.808**	-0.58**
	Sig.	.000	.000	.007	.000	.001
Mean related humanity	Person	0.127	0.076	-0.215	0.402	0.184
	Sig.	.502	.691	.254	.079	.330

*-Significance at 0.05 level, **- Significance at 0.01 level

Table 3: Correlation index of meteorological data and urban development in Harbin in summer

Meteorological data/ Urban development factors		Population	urban built-up area	Land use intensity	Green coverage ratio	GDP
Mean minimum temperature	Person	0.673**	0.707**	-0.455*	0.375	0.675**
	Sig.	.000	.000	.011	.104	.000
Mean maximum temperature	Person	0.361	0.358	-0.228	0.293	0.34
	Sig.	.05	.052	.225	.210	.066
Mean temperature	Person	0.562**	0.513**	-0.345	0.292	-0.488**
	Sig.	.001	.004	.062	.211	.006
Mean sunshine duration	Person	-0.499**	-0.583**	0.328	-0.286	-0.592
	Sig.	.005	.001	.077	.222	.001
Mean wind velocity	Person	-0.732**	-0.703**	0.536**	-0.815**	-0.605**
	Sig.	.000	.000	.002	.000	.000
Mean related humanity	Person	-0.307	-0.297	0.147	-0.053	-0.163
	Sig.	.099	.111	.439	.825	.39

*-Significance at 0.05 level, **- Significance at 0.01 level

4. Discussion

4.1 Implications for urban planning and design

Previous studies found that urban planning and design has close relationship with urban development construction. However, in different countries and climate region, the correlation analysis results kinds are totally different. Based on the analysis results in Harbin above, population and urban built-up area are the most important influencing factors on climate change, thus for cities in severe cold area, proper urban scale controlling and compact urban form building are available approach to mitigate the climate change. For controlling urban scale, appropriate population size and environment capacity are the main methods. For building proper compact urban form, optimizing land using structure, slowing down the speed of urban construction land expansion, proper multi-functional urban land complex are the main methods. Even though these strategies are also suitable to cities in other climatic zone, it is much more meaningful to winter cities, which can slow down the speed of climate change, meanwhile reduce the problem of urban traffic and energy consumption much more effectively.

According to the results, for optimizing temperature conditions in winter cities, decreasing the minimum and mean temperature in summer, meanwhile increasing the maximum and mean temperature in winter by taking some measures on urban development construction are available, because it has opposite effect on the two seasons. For optimizing sunshine duration and wind velocity conditions in winter cities, taking the same measure on urban development construction would has the same effect on the two seasons. Therefore, further urban planning policy and strategies need to pay attention to the difference in summer and winter.

However, urban development construction is not the only criterion affecting climate in cities. Other factors such as people's behavior, energy consumption, even the movement of the earth and the force from the universe space are also key points[16], so there are lots of measures can be taken to mitigate the climate change in winter cities. Some experts suggest make the urban climatic map to guide the urban planning practices in different seasons and urban scale, in order to ease the conflict between urban development construction and climate changes more intuitively[17][18].

In addition, for cities in severe cold area, at the same time of mitigating the climate change, adapting regional climate condition and improving local microclimate environment are also extremely important[19], as well as studying the relationship between them and urban development construction in different urban scale, through which would enhancing the entire urban climate adaption for winter cities[20]. These should be taken into deep consideration in future design and policy.

4.2 Limitations of the study

There are also some limitations in this study. There are only five urban development construction indexes discussed in this study, some other indexes may also affect climate a lot. In addition, compared with the meteorological data from related official website, in situ measurement in some typical urban area may reflect much more real problems, which should be combined with the official data in the study. Furthermore, for winter cities, there is a particular period in the whole year-marginal season, which are the periods between winter and spring, fall and winter[21]. In sunny days without cold wind, a lot of people go out for outdoor activities in marginal seasons, so the urban climate research in marginal season is also extremely important to winter cities

In further studies, the correlation relationship between climate change and urban development construction in winter cities need to be quantified by studies with more depth. Through more precise calculation and simulation results, it is useful to the cultivation of environmental urban policy in winter cities.

5. Conclusion

Based on the meteorological data and urban development construction data, this study concludes that climate change and urban development construction change a lot within 30 years in Harbin, finding that maximum temperature in winter is decreasing and minimum temperature in summer in increasing as city grows. Besides land use intensity, all four urban development construction indexes have important effects on climate change in summer and winter respectively.

The research results can be used to guide the urban planning and design for cities in severe cold area, as well as providing technical support for urban material space design based on urban climate environment adjustment in the future, enhancing the sustainable development capacity for cities in severe cold area, which are of great significance and the key points in the field of urban climate environment research.

Acknowledgement:
Natural Science Foundation of China (51278140)

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