Changing Characteristics of Comfort Index of Human Body in Bengbu City in the Past 40 Years under the Background of Climate Change

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Abstract Based on the daily meteorological data of Bengbu City during 1981 - 2020, the changing characteristics of three elements needed for the calculation of the comfort index of human body (CIHB) were discussed, and daily CIHB was classified and discussed. The results show that from 1981 to 2020, annual average temperature tended to increase significantly. Annual average wind speed and relative humidity showed a decreasing trend before 2011 but an increasing trend after 2011. The duration of the four seasons in Bengbu City mainly rose in spring, reduced in winter, declined first and then increased in summer, and rose first and then decreased in autumn. As CIHB was at grades 1 and 9 (the most uncomfortable), the three factors had different effects on them. For cold weather, the influence of relative humidity and wind speed on CIHB can not be ignored besides temperature. In hot weather, the influence of temperature was dominant, and the change of annual average temperature could well correspond to the change in the number of very hot days. In the context of climate warming, the number of cold days tended to decline generally, but it was larger in the years with fewer very cold days. Under the background of climate warming, there was no obvious change in the number of days of the overall comfort of human body. The number of hot days was closely related to the duration of summer, and the number of days of grade 8 rose significantly in the years with an increase in the duration of summer.

Key words Climate change; Human comfort; Comfort index of human body (CIHB)

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The comfort index of human body (CIHB), as a biometrical indicator, is used to evaluate the degree of feeling of the human body to the natural environment under different conditions from the perspective of climate. It not only directly affects people's daily life, but also plays an important role in production and sales, medical and health care, transportation and other fields, and occupies an important position in the application of urban meteorological environment to services. Its formulation is based on the exchange of heat between the atmospheric environment and the human body[1-2]. CIHB is comprehensively affected by various factors, such as precipitation, temperature, atmospheric pressure, solar radiation, wind speed, gender, physique, age, clothing, *etc.* Among them, air temperature, wind speed and humidity are the leading factors, in which air temperature is the main index to determine human comfort, and humidity and wind speed are auxiliary indicators[3-5]. In 1945, American geographer Brunt5s proposed the relationship between human comfort and atmospheric environment for the first time in magazine *Nature*, which made the evaluation of human comfort become widely concerned. In China, a series of evaluation models have been constructed to analyze and judge the human comfort in a certain area on the basis of previous studies since 1980, which makes certain progress in the study of regional human comfort. For example, Yu Gengkang *et al.* deeply studied the differences in human comfort under different spatio-temporal scales in Jiangsu Province based on daily meteorological data. Ma Lijun *et al.* studied the change characteristics of climate comfort based on clothing index, wind chill index and temperature and humidity index. Zhang Lijie *et al.* analyzed the influence of factors such as land and sea distribution landform and municipal construction on human comfort in Shenzhen. Various data show that under the global warming environment, the annual average temperature in Bengbu City also showed a certain upward trend, especially in the past two decades. Temperature is a key factor in calculating CIHB. Therefore, it is necessary to study the change characteristics of CIHB in Bengbu City under the background of climate change. In this paper, based on the daily climate data of Bengbu station in the past 40 years, the commonly used mature evaluation model of CIHB in China was used to analyze the annual and seasonal variation of CIHB and the weight relationship between various influencing factors in Bengbu City, so as to provide important theoretical basis for the construction of infrastructure and the reasonable development and utilization of tourism resources in Bengbu City.

1 Data sources and methods

1.1 Data sources The daily observation data of Bengbu national meteorological observation station from 1981 to 2020 was used, including daily maximum temperature, daily minimum tem-

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perature, daily average relative humidity and daily average wind speed.

1.2 Calculation method and grading standard of CIHB In this paper, CIHB was calculated based on the KSSD empirical formula which is widely used in China. In calculation, how cold people feel was rated on the basis of the most extreme sensations in the human body during the day, and 10 ℃ was used as the standard to select the temperature in the calculation (formula 1). According to the actual situation, it is divided into nine levels (Table 1).

$$CIHB = 1.88 \times T - 0.3 \times (1.8 \times T - 26) \times (1 - RH) - V^{1/2} + 3.2 \quad (1)$$

In the formula, when the minimum temperature of the day is less than 10 ℃, T is daily minimum temperature (℃); as the minimum temperature of the day is more than 10 ℃, T is daily maximum temperature (℃); RH is relative humidity (%); V is daily average wind speed.

Table 1 Classification of CIHB

CIHB	Comfort level	Human sensation	Degree of Human comfort
< −2	1	Very cold	Extremely uncomfortable
[−2, 5]	2	Cold	Very uncomfortable
[6, 17]	3	Relatively cold	Uncomfortable
[18, 29]	4	Slightly cold	Relatively comfortable
[30, 45]	5	Moderate	Comfortable
[46, 50]	6	Slightly hot	Relatively comfortable
[51, 57]	7	Relatively hot	Uncomfortable
[58, 62]	8	Hot	Very uncomfortable
>62	9	Very hot	Extremely uncomfortable

2 Analysis of climate and comfort changes in Bengbu City

2.1 Climate change

2.1.1 Air Temperature. From 1981 to 2020, the annual average temperature in Bengbu City showed an obvious rising trend, with an average increase of 0.18 ℃ every 10 years. The multi-year average of Bengbu City was 15.5 ℃. The annual average temperature was mostly lower than the multi-year average before 1994, and then it was generally higher.

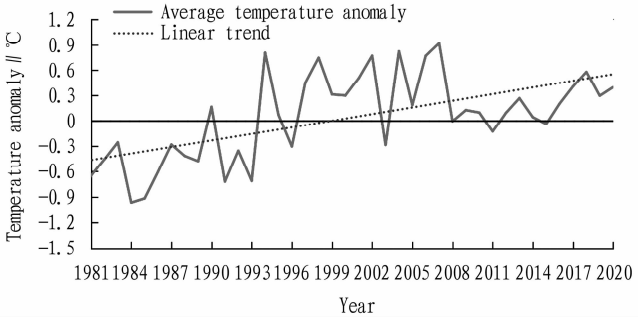

Fig. 1 Anomaly of annual average temperature in Bengbu City from 1981 to 2020

From 1981 to 2020, the annual average maximum temperature in Bengbu City showed an overall increasing trend. Before 1994, the annual average maximum temperature was lower than multi-year average, and after 1994, it was mostly higher. Among them, the highest value appeared in 2004, reaching 21.5 ℃, 1.2 ℃ higher than the multi-year average. The lowest value appeared in 1985, only 19.1 ℃, 1.2℃ lower than the multi-year average.

During 1981 – 2020, the annual average minimum temperature in Bengbu City increased significantly, with an average increase of 0.34 ℃ per decade. Before 1994, the annual average minimum temperature was generally lower than the multi-year average, and after 1994, it was generally higher. Among them, it was the highest in 2007, up to 12.7 ℃, which was 1.1 ℃ higher than the multi-year average.

2.1.2 Relative humidity. From 1981 to 2020, the annual average relative humidity in Bengbu City showed a decreasing trend, with an average decrease of 0.4% per decade. During 2004 – 2014, it was continuously lower than the multi-year average, and then began to increase.

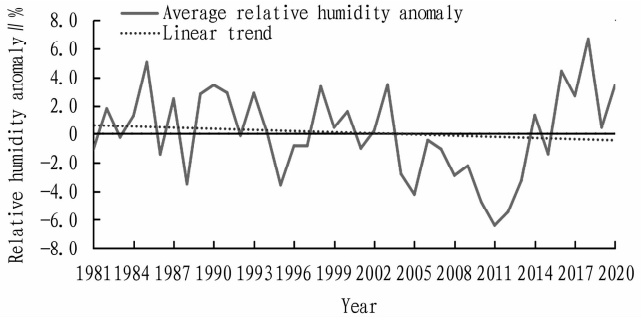

Fig. 2 Anomaly of annual average relative humidity in Bengbu City from 1981 to 2020

2.1.3 Wind speed. From 1981 to 2020, the annual average wind speed in Bengbu City showed a significant decline trend, with an average decrease of 0.25 m/s every 10 years. From 1981 to 1985, it was larger; it was generally smaller during 1986 – 1991, larger from 1992 to 2005, and then generally smaller again.

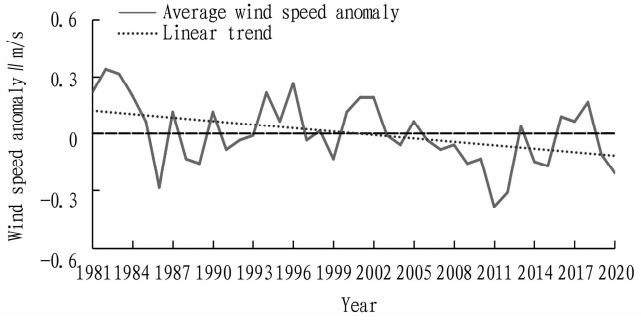

Fig. 3 Anomaly of annual average wind speed in Bengbu City from 1981 to 2020

2.1.4 Changes in the duration of four seasons. Human comfort has different characteristics in different seasons. Generally speaking, the human body feels comfortable in spring and autumn and mostly uncomfortable in winter and summer. In Bengbu City, the duration of spring mainly increased, and that of winter decreased.

That of summer decreased first and then increased. That of autumn increased first and then reduced. The influence of temperature on the duration of four seasons was obvious in summer and winter. The change of temperature in Bengbu City in the past 40 years made summer significantly longer and winter significantly shorter.

2.2 Changes of comfort index at all levels

2.2.1 Grade 1. It can be seen from Fig. 4 that the number of days of grade 1 (very cold) was smaller during 1985 – 2008 when the annual average temperature was higher, indicating that the number of extremely uncomfortable days decreased because of the high temperature under the influence of climate change. Before 1985, due to the low temperature, the number of days of grade 1 (very cold) was larger, but after 2008, the number of very cold days increased significantly although the annual average temperature in 2013 and 2018 was higher. The annual average relative humidity and wind speed both increased during this period, indicating that although the annual average temperature was high, the number of very cold days rose under the combined influence of relative humidity and wind speed during this period.

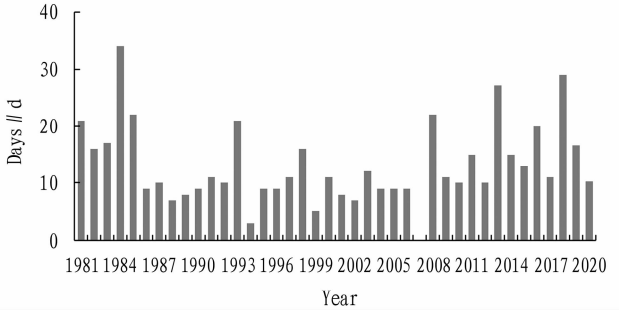

Fig. 4 Number of days of CIHB at grade 1

2.2.2 Grade 2. The number of days at grade 2 (cold) tended to decrease. The number of days of grade 2 was larger when the number of days of grade 1 was obviously smaller. It shows that under the influence of climate in this stage, although the number of very cold days was smaller, the number of cold days increased.

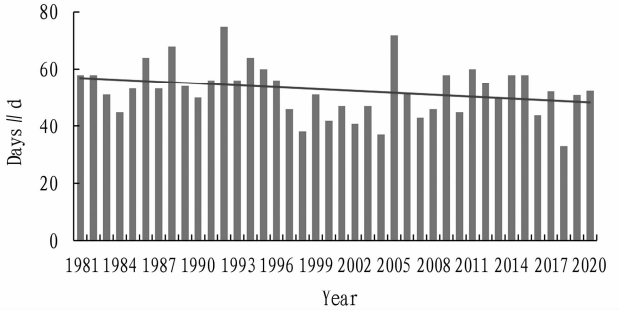

Fig. 5 Number of days of CIHB at grade 2

2.2.3 Grade 3. There was no obvious change in the number of days at grade 3 (relatively cold), but it was small after 2004, and the annual change was very obvious.

2.2.4 Grades 4 – 6. CIHB at grades 4, 5 and 6 can be classified as the set of the overall comfort of human body. The annual days of these grades had no obvious change, showing that under the background of climate change, there was no obvious change in the number of days of the overall comfort of human body.

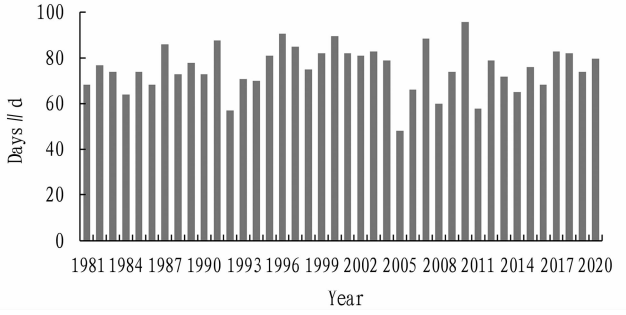

Fig. 6 Number of days of CIHB at grade 3

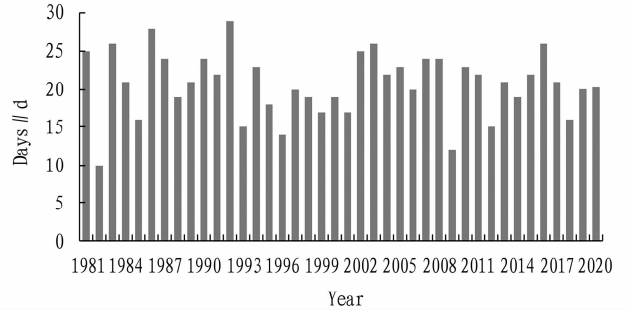

Fig. 7 Number of days of CIHB at grade 4

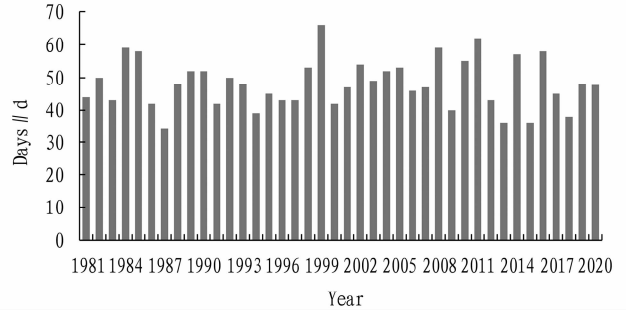

Fig. 8 Number of days of CIHB at grade 5

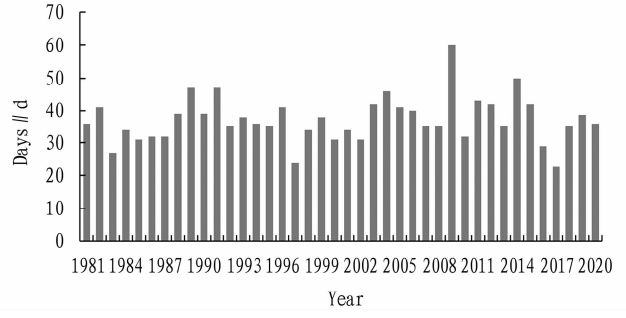

Fig. 9 Number of days of CIHB at grade 6

2.2.5 Grade 7. The number of days of grade 7 (relatively hot) was larger before 1990, and there was a plunge in the number of days in 1990. It tended to be stable after an increase in 1993.

2.2.6 Grade 8. The number of days of grade 8 (hot) had obvious annual changes before 2000, and it was larger especially in 1997 and 2000, but the annual average temperature in these two years was not the highest. In these two years, the number of high-temperature days (exceeding 35 ℃) was 13 and 10 d, respective-

ly, being at the average level. At the same time, the annual average humidity and average wind speed did not increase or decrease significantly in these two years. The duration of summer in these two years was longer, indicating that the change in the duration of the season had an important impact on the number of days of CIHB.

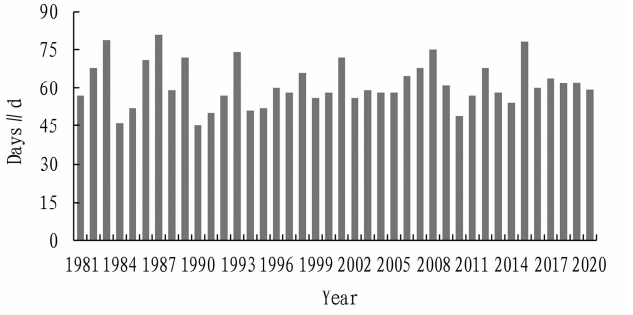

Fig. 10 Number of days of CIHB at grade 7

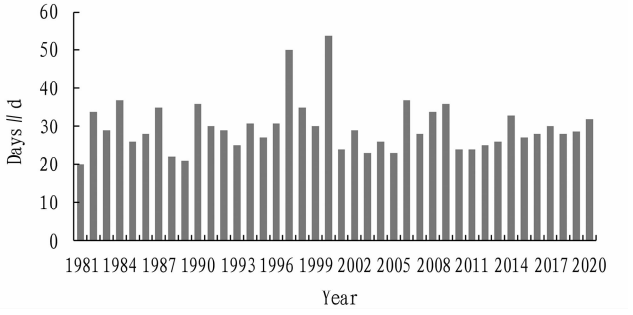

Fig. 11 Number of days of CIHB at grade 8

2.2.7 Grade 9. The number of days of grade 9 (very hot) was larger in 1994, 2002, 2013, 2017 and 2018, and at the same time, annual average temperature was higher in these years. In 1982, 1987, 2008 – 2009 and 2014 – 2015, the number of days of grade 9 was significantly smaller, but annual average temperature was lower than that of neighboring years. It shows that the change of annual mean temperature can well correspond to the change in the number of days of grade 9.

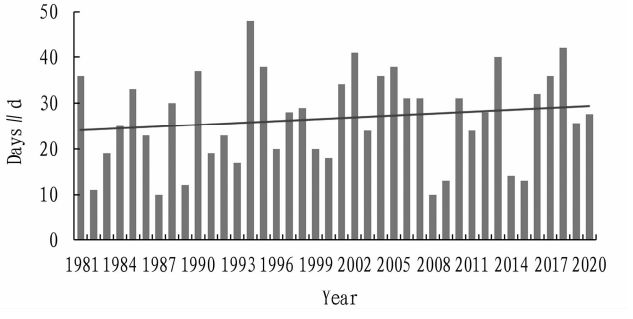

Fig. 12 Number of days of CIHB at grade 9

3 Conclusions

Based on the daily meteorological data of Bengbu City from 1981 to 2020, the changing characteristics of three elements needed for the calculation of CIHB were discussed, and daily CIHB was classified and discussed.

(1) From 1981 to 2020, annual average temperature showed a significant rising trend. Annual mean wind speed and relative humidity showed a decreasing trend before 2011 but an increasing trend after 2011.

The duration of the four seasons in Bengbu City mainly increased in spring, decreased in winter, decreased first and then rose in summer, and increased first and then reduced in autumn.

(2) When CIHB was at grades 1 and 9 (the most uncomfortable), the three factors had different effects on them. For cold weather, besides the influence of temperature, the influence of relative humidity and wind speed on CIHB can not be ignored. In hot weather, the influence of temperature was dominant, and the change of annual mean temperature could well correspond to the change in the number of very hot days.

(3) Under the background of climate warming, the number of cold days tended to decrease generally, but it was larger in the years with fewer very cold days.

(4) In the context of climate warming, there was no obvious change in the number of days of the overall comfort of human body.

(5) The number of hot days was closely related to the duration of summer, and the number of days of grade 8 increased significantly in the years with an increase in the duration of summer.

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