258: Assessment of urban bioclimate in the Russian Far East

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Abstract

The results of a study of the human thermal bioclimate in the city of Birobidzhan, the capital of the Jewish Autonomous Region (JAR) in the federal district “Far East” of the Russian Federation are shown. Air temperature, the average annual temperature gradient increases by almost 20 °C if calculated with PET are compared. If only Air temperature is considered it lies at about 75 °C while it reaches almost 90 °C of PET in extreme cases. During a three months stay in Birobidzhan three prominent outdoor locations within the City where identified, mapped and 3D-modelled for the purpose of human-biometeorological analysis with RayMan. The results were revised and analysed to find preferable settlement structures in these climates and to assess the general live quality of this region based on the human thermal bioclimate.

Keywords: Thermal comfort, PET, extreme climate

1. Introduction

The City of Birobidzhan is the capital of the Jewish Autonomous Region (JAR) in the Russian Far East. It has about 70.000 inhabitants which makes it a medium sized city in the Russian Far East federal district and it is located on a latitude of 48° N which puts it on the same latitude as for example Freiburg in south western Germany. While Freiburg enjoys a very moderate climate with warm summers and mild winters the JAR experiences a very extreme climate influenced by monsoon cycles and the Siberian high pressure centre. This results in warm and wet summers and extremely cold winters with air temperature (T_a) down to - 43 °C. Due to those extreme differences in T_a over the year it is very interesting to analyse the local human thermal bioclimate in relation to the structures of larger settlement areas. For this purpose the model RayMan [8,9] was applied to calculate the Physiologically Equivalent Temperature (PET) which was first introduced by Mayer and Höppe [1,2] and is based on the Munich energy-balance model for Individuals (MEMI).

These models and indices are influenced by the meteorological factors:

- Air Temperature (T_a),
- Relative humidity (RH),
- Wind velocity (V)
- Radiation in this case represented by the cloud cover (c)

and Thermal-physiological factors

- Activity
- Clothing

of which the meteorological factors are analysed in the study.

2. Goals and Hypotheses

The goal was to assess the influence of the different climate factors apart from T_a such as RH, v and c (or respectively the Global radiation G) on the human thermal bioclimate. Meaning the way the human body experiences his thermal environment as well as the influence of settlement structures on these climate factors. It is assumed that the already extreme values of T_a will be intensified even more by the influence of the regional climate. The assumption is that in winter the main impact will come from wind velocity v which results in an increased reduction of the experienced temperature in comparison to T_a while in summer the major impact lies with the relative humidity RH leading to the effect of a raised thermal experience. In both cases the radiation fluxes plays a significant part as well since they are, in combination with wind speed, the most influential factor for thermal comfort in urban environments [3,4,5,6]. However in a case of regular cold- as well as heat stress conditions at one location it is neither preferable to reduce the mean radiant temperature, nor to increase it since that would inevitably intensify one of the two effects [3,4,8]. Based on these assumptions it can be hypothesized that preferable settlement structures would be designed in a way that does not lead to high values of v and also limits the accumulation of moist air.

3. Data and Methods

3.1 Area of interest

In this study the city of Birobidzhan is used as a representative medium sized settlement in the Russian Far East. As shown in figure 1 it is located close to the northern Chinese border at 48°48’05” N and 132°54’04” E at an altitude of about 154 m and. It occupies an area of ca. 200 km² and has about 74.000 inhabitants. The climate can be described as continental humid monsoon climate. The Japanese Sea is about 600 km to the east. Therefore the maritime impact can be considered negligible.

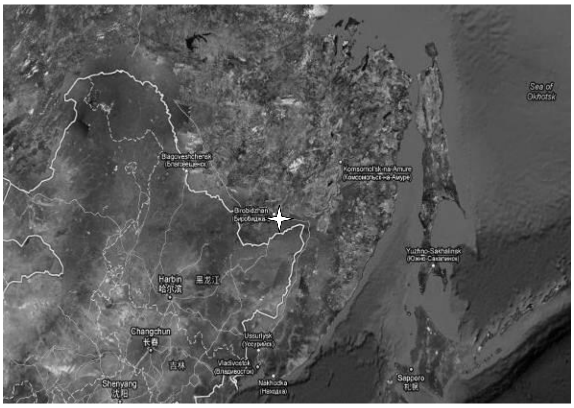

Fig. 1. The regional position of Birobidzhan (indicated by star symbol), Source: Google Maps

3.2 Data

The climate data used in this study has been obtained from www.ogimet.com in form of synop code from the WMO station near Birobidzhan in 3-hour intervals for the 11-year period from 2000 to 2010. It was then transformed into standard meteorological values using Microsoft Excel. The values where checked for errors and false values and then grouped in decades to be presented in bioclimate diagrams or tables. Since no exact data for building heights or dimensions could be obtained it was estimated using the information about the total amount of stories and through direct comparison with the environment.

3.3 Methods

PET was calculated using the RayMan model [9,10]. For this purpose an input file containing information about date, time, T_a, RH, v and c was created from the obtained meteorological data and fed into the program. As it is customary for PET calculations it was calculated for a standardized male person at the age of 35 with a body height of 1.75 m and a weight of 75 kg in a standing position generating 80 W dressed in a standard street suit equivalent to a clothing index of 0.9 [2]. In a second simulation, obstacle files where put into RayMan to simulate the structures of buildings and vegetation in certain areas of Birobidzhan. These obstacle files were created in the RayMan editor using template maps obtained from www.openstreetmap.org and the information about the buildings and vegetation dimensions. The resulting values for PET where displayed in bioclimate diagrams splitting the data in decadal occurrence frequencies. The same was done for T_a, RH and the vapour pressure VP.

4. Results

4.1 Assessment

The following results are those of the preliminary climate assessment conducted without the inclusion of obstacles into the calculations. They simply reflect the general climate conditions in and around Birobidzhan and are the basis for the latter conclusions based on the position of a person within the city structures. Even so the comparison of these results shows the great difference between T_a and PET and therefore the importance of the inclusion of the climate conditions when dealing with the human thermal bioclimate, especially in regions with extreme climate conditions. Figure 2 shows the distribution of PET classes throughout the year divided into decades (each decade representing a third of a month). As it was expected the values for PET are higher than those of T_a. Also the frequency of occurrence of extreme value classes rises significantly. For comparison figure 3 shows the distribution of T_a for the same period.

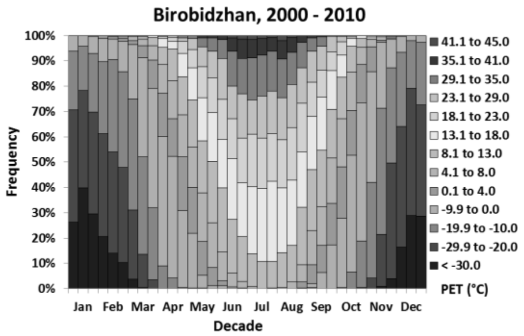

Fig. 2. PET (°C) in Birobidzhan displayed in decades for the period 2000 - 2010 in frequency of occurrence per decade

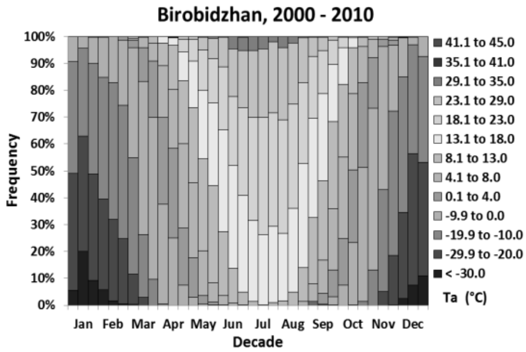

Fig. 3. T_a (°C) in Birobidzhan displayed in decades for the period 2000 - 2010 in frequency of occurrence per decade

As the comparison of the two diagrams shows, there is a great difference in the range as well as the occurrence frequencies of the displayed values. This becomes especially evident in the winter and summer months as the conditions are the most extreme in these periods. For example in the second decade of January there is a 20 % occurrence rate for values of T_a below -30.0 °C while PET values in the same class occur with a rate of 38 %. In summer values of T_a above 29.1

°C occur about 5 % of the times while PET values above 29.1 °C occur up to 25 % of the days in the first decade of July. If measured solely in T_a values above 35.0 °C are so rare that they are not even significant while PET values between 41.0 °C and 45.0 °C still account for almost 2 % of the values in the first decade of August. This difference in magnitude and frequency of the extreme T_a and PET values comes mainly from the effect of wind velocity and relative humidity. In winter there is a lot of sunshine in the JAR but due to the very low T_a values the cooling effect of wind-chill dominates over the warming effect of solar irradiation. In summer the dominant effect on thermal experience is the relative humidity which is highly dependent on T_a and the availability of water. It doesn't follow exactly the same yearly cycle as the air temperature but instead is slightly shifted. There are two maximum areas that can be explained with different phenomena. The maximum in high summer is due two strong monsoon rainfalls resulting in a lot of water being available for evaporation. In winter there is almost no water available since it is all frozen solid but due to the low air temperature only very little water is needed to reach values of RH close to 100 %. This effect can be seen from Figure 4 showing the annual cycle of VP, an indicator for the amount of water absorbed by the air. It is the partial pressure which with the vaporized water contributes to the normal air pressure.

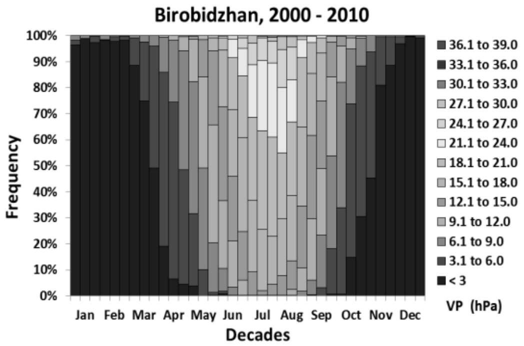

Fig. 4. VP (hPa) in Birobidzhan displayed in decades for the period 2000 - 2010 in frequency of occurrence per decade

As it is visible in the distribution of VP values there is a long time from late autumn to mid spring where VP doesn't go higher than 3 hPa. This is the result of the dependence on T_a. During the same period values for T_a are almost never above 0 °C and most of the time they are even below -10 °C. This results in a very low saturation vapor pressure.

4.2 Structural Assessment

After having seen the influence of the climate conditions of the JAR it is interesting to have a look at the influence settlement structures have on these conditions and most importantly on PET. For this purpose the same graphs as in 4.1 where created from the results obtained through the calculation of PET with the inclusion of obstacle files into the equation. The following three graphs (Figure 5 to Figure 7) show the distribution of PET for three different locations within the city of Birobidzhan. These locations where chosen for their popularity and there significance in the cities everyday live. There comparison shows that different structures in fact do have different effects on the human thermal bioclimate. There is a difference of about 5 % in the frequency of PET below -30 °C in the first decade of January between the position on the city square and a position within the residential area. Between the square and the main street there is still a difference of about 2 % with the highest frequency on the main square. In summer the same phenomenon can be seen. The frequency of extreme values falls while the settlement density rises. The difference is not as big as in winter but it still ranges between 2 % and 3 %. Interestingly between square and street the impact occurs only for the extreme values while the frequency of moderate PET values between 13 °C and 23 °C remains almost unchanged. For the residential area however the number of moderate days within the year rises significantly in comparison to the other structures (Table 1).

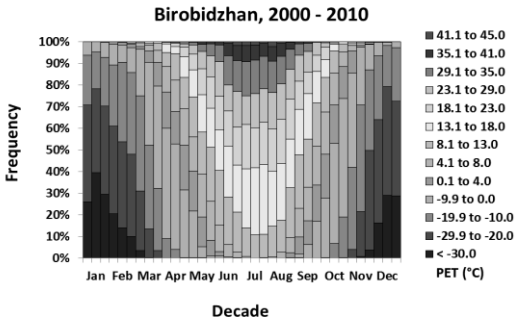

Fig. 5. Annual PET distribution on the main square of Birobidzhan (2000 - 2010)

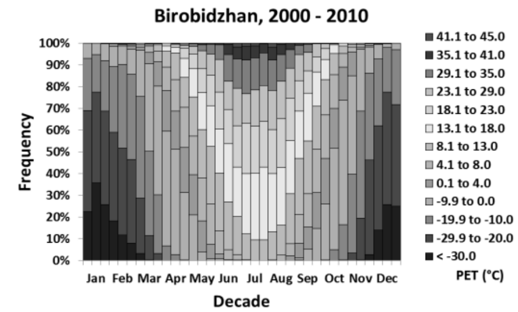

Fig. 6. Annual PET distribution in the main street of Birobidzhan (2000 - 2010)

Table 1 shows the number of days per year within a certain range of PET which represents either extreme or moderate conditions in terms of human thermal bioclimate. Very important is the difference of extreme and moderate values between the residential area and the other structures.

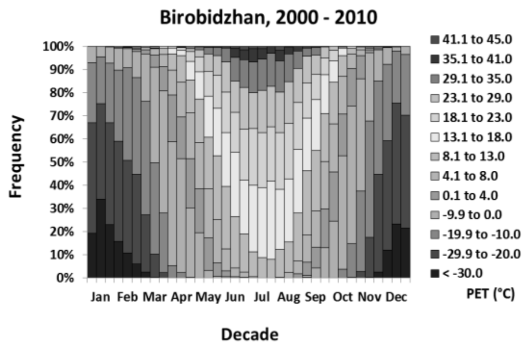

Fig. 7. Annual PET distribution in a major residential area of Birobidzhan (2000 - 2010)

It shows that the number of moderate and therefore pleasant days rises significantly within a dense structure with a lot of vegetation while the number of days with extremely low or high temperatures drops.

Table.1: Number of days per year within a certain class of PET (°C) for different structures in Birobidzhan (2000-2010)

Class (°C)	***Open Space***	***Square***	***Street***	***Residential***
<-30	21.0	21.0	18.4	16.2
<-20	68.3	68.3	66.0	63.9
<-10	117.2	117.0	115.2	114.1
<0	170.1	170.0	169.0	168.5
15≤x ≤30	65.4	64.6	66.7	69.0
18≤x≤27	37.0	36.3	37.9	39.6
>29	19.5	19.7	17.6	15.3
>35	6.0	6.5	5.1	4.1
>41	1.0	1.2	0.9	0.8

6. Conclusions

There is a significant impact of the extreme climate conditions, apart from the air temperature, on the human thermal bioclimate which intensifies the already harsh conditions within the JAR but there are ways to reduce the influence of these conditions on the human body. There are a lot of forest areas around the city which can be quantified in terms of urban climatological assessments with PET [1,2,8] . Also the different city structures can be very helpful in providing information for urban planning purposes and justifications. For that matter it seems to be best to create fairly dense structures with a lot of vegetation like the residential area "Bumagina" which was analyzed in this paper. It shows a dense building structure with a lot of trees (mostly birch) of different heights which helps to reduce wind speed significantly and also provides shade in summer. In winter the shading effect is limited since the trees are without leaves at that time of year which is of advantage during winter because of the higher input of solar radiation. Never the less it is of importance not to stop at this point but rather to continue with the research since it can be very helpful in finding solutions for other regions which might change to more extreme climates due to global climate change. It will be very interesting to split the calculations as done above into different seasons as well as times of day and to include different kinds of clothing and activity into the calculations. Also the application of other micro scale models and tools could provide further information and details for the micro climatic evaluation of urban configurations including urban design and architecture.

7. Acknowledgements

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8. References

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