VARIATIONS AND TRENDS OF THERMAL COMFORT AT THE ADRIATIC COAST

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ABSTRACT

Knowledge about the thermal comfort of humans plays an important role in health and activities, especially in tourism, recreation, leisure and sport. In spite of the efforts that have been made to investigate temperature changes during the last century, results cannot completely clarify their impacts on humans. This paper analysed variations and trends of the Physiologically Equivalent Temperature (PET) and Predicted Mean Vote (PMV), two thermal bioclimate indices based on human energy balance models. Climatic changes were analysed using data from the period of 1867-2000, taken from the meteorological station at Hvar,Croatia, a popular tourist destination island in the Adriatic Sea. This analysis of thermal bioclimate conditions has showd that changes in the examined period were within the range of one class of physiological strain for humans.

KEYWORDS: *Thermal bioclimate, Binomial moving average filter, Trend analysis, Progressive analysis*

INTRODUCTION

Until now climate change in Croatia has been investigated using minimum and maximum temperatures, daily temperature range and precipitation from inland lowland and coastal stations. The results indicate decreasing maximum temperatures and increasing minimum temperatures, leading to a significant decrease in daily temperature range (1). Hvar was not included in those investigations due to missing data for certain years. However, the changes in thermal comfort for Hvar (Fig. 1) have been investigated for the periods of 1858-1995 (2), and 1901-2000 (3). The results for the first show increasing thermal comfort trends being significant in winter, autumn and annually as the result of positive temperature trends and negative wind speed trends. The analysis for the second period show a negative trend for thermal indices in all seasons as a result of the increasing trend in wind speed, despite positive temperature trends. Similar investigations have been made for the mountainous meteorological station Zavizan (1594 m), for the shorter period of 1954-1993 (4). The trends of thermal comfort were positive in all seasons as well, but significant for summer, autumn and annually.

Figure 1: The location of Hvar

METHODS

2.1 Thermal environment

The thermal effective complex deals with the influences of the thermal environment on the well-being and health of human beings. The basis for this is the close relationship between the human thermoregulatory mechanism and the human circulatory system. For the physiologically significant assessment of the thermal environment, some thermal indices are available which are derived from the human energy balance (5, 6, 7, 8, 9).

Several investigations have been performed which use thermal indices, such as PMV or PET, for the human-biometeorological assessment of the thermal environment in different scales. Results from case studies (9) enable a process analysis, e.g. in the form of regressions between PET and meteorological input parameters such as single radiative fluxes, mean radiant temperature, air temperature, vapour pressure and wind speed. For calculating the mean radiant temperature, the human-biometeorological radiation model RayMan (10) was used, which is well suited for application in applied climatological and meteorological studies.

2.2. Trend analysis

The fluctuations and trends of seasonal and annual values of the thermal comfort indices PET and PMV, as well as the meteorological parameters that influence thermal comfort (air temperature, relative humidity, wind speed and cloudiness), were determined. Variations and trends were analysed during the period of 1867-2000, in spite of some missing data in the 20's and 40's. In order to remove short-term fluctuations the data series was smoothed by means of the weighted 11-year binomial moving average filter.

The linear trend has been tested for significance by means of the nonparametric Mann-Kendall rank statistics *t* (11, 12). For the series, which showed the significant trend identified by the Mann-Kendall coefficient *t*, a progressive analysis of the time series by means of the statistic *u(t)* was performed in order to determine the beginning of this phenomenon by means of a sequential analysis (12).

RESULTS

According to the mean annual and seasonal PET and PMV values, the mean annual thermal sensation in Hvar from 1867-2000 was slightly cool (17.4°C PET, -0.8 PMV), varying from cool winters (6.5°C PET, -3.1 PMV) to slightly warm summers (30.7°C PET, 1.6 PMV). Because of the maritime influence, autumn was warmer (19.3°C PET, -0.4 PMV) than spring (15.9°C PET, -1.2 PMV).

The PET and PMV fluctuations showed a visible warming at both the beginning of the century and around the 1950's (Fig. 2), related to decreases in wind speeds in the same periods. After the warming in the 50's, a cooling period occurred until the beginning of 80's, as the result of a decrease in temperature and simultaneous increase in wind speed. The warming in PET and PMV from the beginning of the 80's until the end of century was the result of an increase in air temperature and decrease in wind speed, but also a decrease in cloudiness from the end of the 70's until the end of the 80's.

Both human-biometeorological indices, PET and PMV, showed increasing trends in all seasons, significant for winter, autumn and annual values. These positive trends were the result of increasing temperature and decreasing wind speed. The greatest change was temperature in winter (around 0.4°C/100 years), and the smallest was temperature in spring (0.2°C/100 years). However, only the increasing trend of mean annual values of 0.4°C per 100 years was significant (Tab. 1). The wind speed decreasing trends were significant for the winter, autumn and annual values, the same as for the human biometeorological indices. Vapour pressure also contributed to the increasing trend in thermal sensation, because of increasing trends in all seasons (although statistically insignificant).

Finally, cloudiness showed positive trends in all seasons, and only the winter trend was not significant.

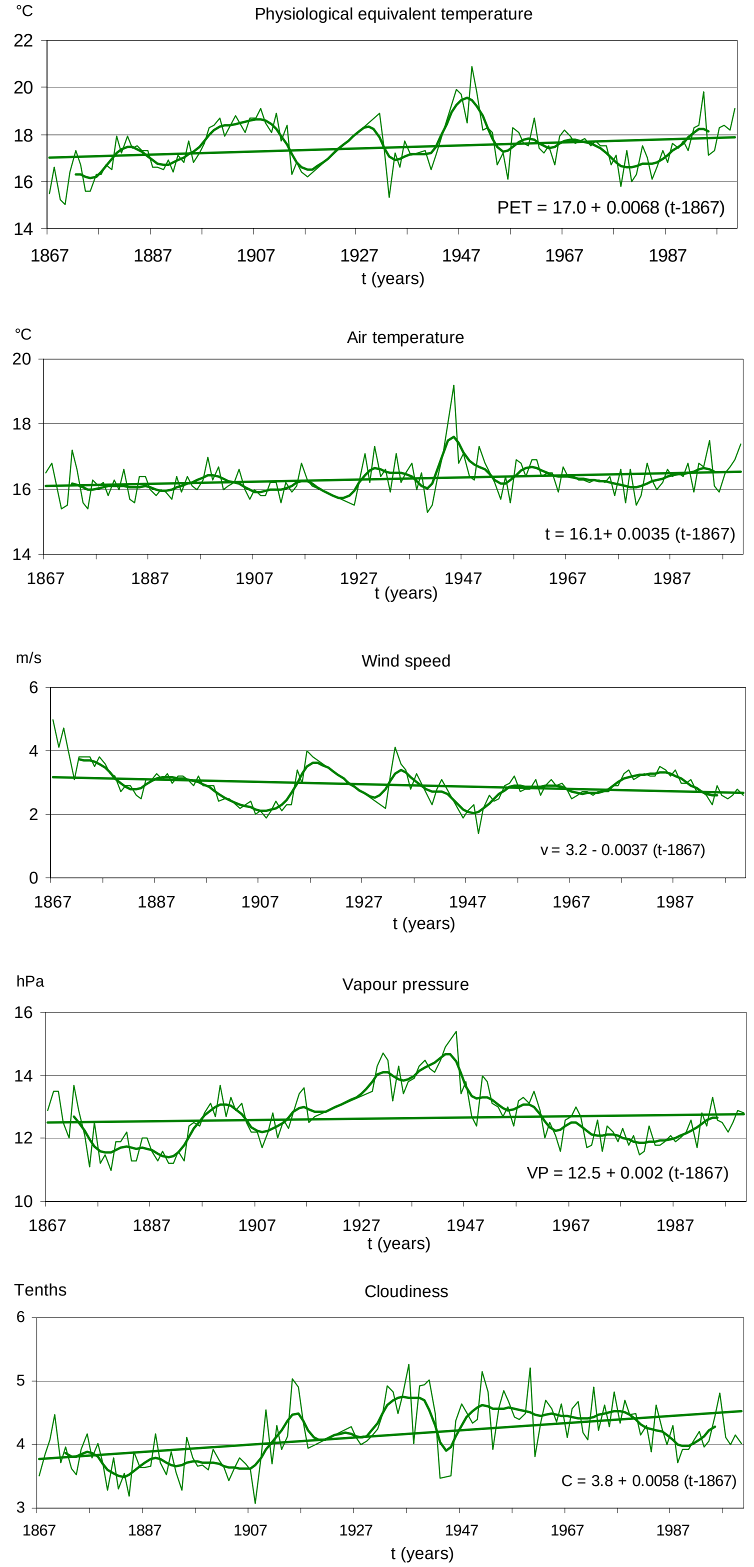

Figure 2: Annual variations of the physiologically equivalent temperature (°C), the air temperature (°C), wind speed (m/s), vapour pressure (hPa), wind speed (m/s) and cloudiness C (in tenths), including a weighted 11-year binomial moving average series, and linear trends during the period of 1867-2000 at Hvar

Table 1: Seasonal and annual trends (per 100 years) of mean physiologically equivalent temperature (PET in °C) and predicted mean vote (PMV), temperature (t in °C), vapour pressure (VP in hPa), wind speed (v in m/s) and cloudiness C (in tenths). Shading denotes trends significant at the 0.05 level according to Mann-Kendall rank statistics. Period: 1867-2000

Seasons	PET	PMV	t	VP	V	C
Winter	0.67	0.16	0.43	0.28	-0.41	0.59
Spring	0,35	0,08	0,17	0,12	-0,39	0,81
Summer	0,56	0,10	0,34	0,06	-0,11	0,73
Autumn	0,99	0,20	0,36	0,10	-0,52	0,39
Annual	0,68	0,14	0,35	0,20	-0,40	0,58

The progressive trend test was applied to the annual values of PET, which had significant increasing trend, as did the parameters influencing thermal comfort - temperature, wind speed and water vapour pressure (Fig. 3). From the graphical representation of the onward (u) and backward (u') test series of PET it can be seen that during the analysed period they overlap several times, implying the absence of a trend. The last intersection point between u and u' occurred in 1988, while u exceeded the 1.96 limit value in 1994, suggesting the beginning of a significant positive trend. However, as the effect was very recent it is advisable to await confirmation from future observations, especially because of the many changes in the previous periods. The progressive trend test for temperature shows that the increasing trend in temperature began in 1946. The increasing trend of temperature became significant in 1959 and, besides some fluctuations in the 70's, stayed significant until the end of the observing period. In spite of some similarities between PET and temperature trends, it is obvious that variations in the PET trend were the result of other meteorological parameters important for thermal comfort.

The progressive trend test for wind speed showed that, in spite of a significant negative trend for the whole period, wind speed changed from the beginning of the 30's. However, the intersection between onward and backward test series for wind speed in 1976 cannot be taken as the beginning of an increasing trend, but it is obviously corresponded with the retard in the increase of PET. Finally, the increase of PET in the last decade of the century was the result of simultaneous sharp increases in temperature.

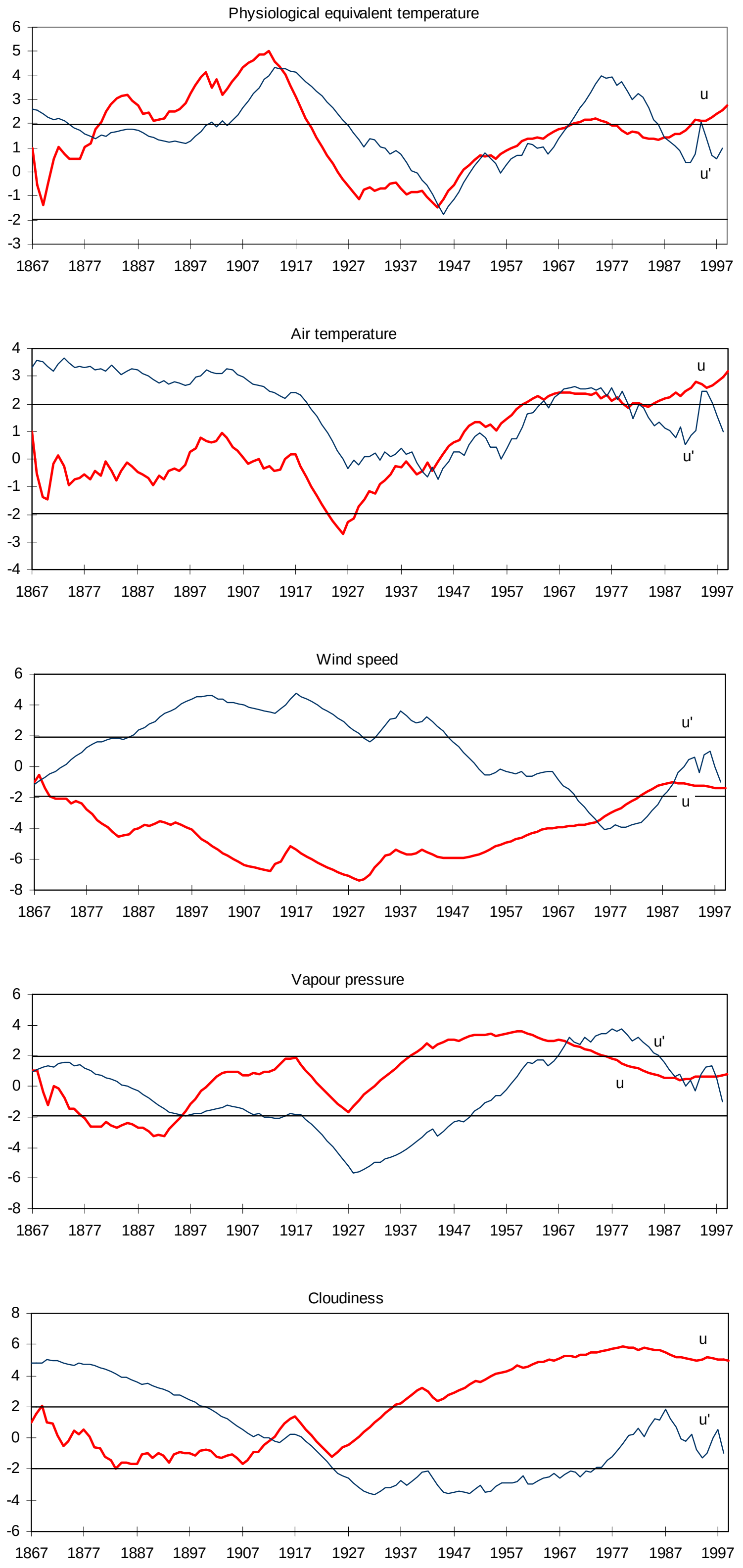

Figure 3: Progressive trend test for annual values of mean physiologically equivalent temperature, air temperature, wind speed, vapour pressure and cloudiness at Hvar, during the period of 1867-2000

CONCLUSIONS

For the assessment of the thermal environment on human beings in different scales, human-biometeorology provides well-suited thermal indices on the basis of the human energy balance. Investigations of thermal bioclimate for the quantification of the effects of atmospheric conditions on human beings require long data series to check trends, and to see if the trends are significant. The analysis of climate change through thermal indices in Hvar from the middle 19th century showed a positive trend in all seasons as a result of positive temperature trends and decreasing trends in wind speed. This result coincides with earlier investigations into the trends in thermal comfort at Hvar, calculated with a different thermal comfort index (2). On the other hand, the analysis of thermal comfort changes in Hvar from the beginning of 20th century showed the opposite trend as the result of increasing wind speed trend in the century (3). Trends of the bioclimatic conditions of tourism areas provide information for the tourism industry and govermental authorities, allowing adequate planning for the expected changes in the nature and length of the tourism season.

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