

An evaluation of the nature and timing of summer human thermal discomfort in Athens, Greece

G. R. McGregor^{1,*}, M. T. Markou², A. Bartzokas², B. D. Katsoulis²

¹School of Geography and Environmental Sciences, The University of Birmingham, Edgbaston Park Road, Birmingham B15 2TT, United Kingdom

²Laboratory of Meteorology, Department of Physics, University of Ioannina, 45101 Ioannina, Greece

ABSTRACT: An assessment of the summer human thermal climate over the period 1966–1995 for Athens, Greece, was undertaken using the predicted mean vote (PMV). At the seasonal (diurnal) time scale human thermal discomfort reaches a maximum over a 20 d (4 to 6 h) period centred on the end of July (14:00 h LST). Not only are general levels of thermal discomfort variable at the intra- and inter-annual time scales, but the timing of discomfort season onset and cessation is highly variable from year to year. Mann-Kendall tests for trends of discomfort season diagnostics revealed that there has been a tendency towards an increase in the length of the discomfort season over the study period. The implications of Athens' harsh human thermal climate for staging athletic events are discussed, and the concept of cool and warm synthetic summers is introduced as a basis for the planning of human activities.

KEY WORDS: Human thermal comfort · Bioclimate · Summer · Onset · Duration · Predicted mean vote · Athens · Greece

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1. INTRODUCTION

Greece, because of its Mediterranean climate, is a popular tourist destination. However, tourism is highly seasonal, with the majority of tourists visiting Greece in the summer months, which are characterized by sunshine, high temperatures and varying humidity levels. Because of the importance of the tourist industry to the Greek economy, a number of biometeorological assessments at a variety of time scales have been undertaken for Greek tourist locations (see e.g. Metaxas 1970, Giles et al. 1990, Matzarakis & Mayer 1997). Although these have confirmed conventional wisdom concerning the general nature of Greece's summer human thermal climate, to date no attempt has been made to establish a climatology of the onset, duration and cessation of the season of human thermal discomfort for any of Greece's important tourist destinations. Such a study of the dynamics of summer dis-

comfort is important from the point of view of establishing how variable the human climate is for locations that are otherwise assumed to be invariant in terms of the timing and the severity of the season of discomfort. The aim of this paper is therefore to fill this research gap and present an assessment of the inter-annual variability of the timing of the onset and cessation and thus the duration of the discomfort season for Athens. Athens was chosen for the study for 2 reasons: first, it is the tourist capital and gateway of Greece and, second, the available meteorological data for this location covers a long period of time and is highly reliable. This is not the case for other popular tourist destinations in Greece. As a general background to the study, an assessment of the general nature of Athens' human thermal climate for average, warm and cool summers is also presented, along with the concept of cool and warm synthetic summers.

This paper is divided into 7 sections. Data and methods are outlined in Section 2. The general nature of Athens' human thermal climate for an average, warm and cool summer is discussed in Section 3, and an

*E-mail: g.r.mcgregor@bham.ac.uk

analysis and interpretation of 'synthetic' worst case hot and cold summers is presented in Section 4. This is followed in Section 5 by an analysis of discomfort season onset and cessation. Results are discussed in Section 6, and conclusions drawn in Section 7.

2. DATA AND METHODS

There have been various attempts to design empirical indices for the assessment of human thermal comfort. Such indices as the effective temperature (Houghten & Yaglou 1923) and the discomfort index (Thom 1959) attempt to integrate the thermal and humidity effects of the environment and represent in one value the level of thermal stress. These have been applied at a variety of scales from global to local (Gregorczyk & Cena 1967, Terjung 1968, Jauregui 1991, McGregor 1993, 1995a,b). Recently in the field of bioclimate assessment, there has been a move away from the use of empirical indices to the use of more complex biophysical models. These incorporate physiological parameterizations and attempt to model the man-environment exchange of heat based on an evaluation of the human energy balance equation (Fanger 1972, Gagge 1980, Jendritzky & Nubler 1981, Hoppe 1993). When applied, their power as tools for bioclimatic analysis is very clear (de Dear & Leow 1990). One such energy-balance-based human thermal comfort index, which has been applied widely, is the predicted mean vote (PMV) of Fanger (1972).

PMV represents the predicted mean vote on a thermal sensation scale of a large population exposed to a given set of ambient conditions. The PMV is derived by relating empirically the human heat balance to a vote of thermal sensation. The PMV equation is a steady-state model. It establishes a thermal strain based on steady-state heat transfer between the body and the ambient environment. Once the strain has been calculated, a thermal comfort vote, which represents the thermal sensation, is assigned to the calculated level of strain. This assignment is based on a postulated link between the deviation from the minimum load on the heat balance and thermal comfort. A neutral thermal sensation, which equates with heat balance (conservation of energy), is assigned a PMV value of zero.

In order to calculate the thermal strain imposed on the body by ambient conditions, the heat balance equation is solved such that

$$H - E_d - E_{sw} - E_{re} - D = R + C$$

where H = internal heat production, E_d = latent heat loss due to water vapour diffusion through the skin (invisible sweating), E_{sw} = latent heat loss due to sweating, E_{re} = latent heat loss due to respiration, D =

dry respiration heat loss, R = radiative heat loss from the surface of a clothed body, and C = convective heat loss from the surface of a clothed body.

All terms in the heat balance equation have measurable values apart from clothing surface temperature (in terms R and C) and the convective heat transfer coefficient (in term C), both of which are functions of each other. In order to solve the heat balance equation, an initial value of clothing temperature is estimated, and the heat transfer coefficient is calculated followed by the computation of a new clothing temperature. Both the heat transfer coefficient and clothing temperature are calculated by iteration until both are known to a satisfactory level.

For the state of heat imbalance, the heat balance equation is written as $L = H - E_d - E_{sw} - E_{re} - D - R - C$ where L = the thermal load on the body.

Thermal strain (TS) is a function of heat load (L) and metabolic rate (met). If all variables are held constant, apart from air temperature (T_a) and met , then mean votes from climate chamber experiments can be used to express TS as a function of T_a and a variety of metabolic rates (activity levels). If L , as determined from the heat balance equation, is substituted for T_a , the partial derivative of TS with respect to L at TS = 0 can be plotted against a range of metabolic rates. An exponential curve can then be fitted to the plotted points and integrated with respect to L , with L renamed as PMV. Therefore in simplified form:

$$PMV = \exp(met) \cdot L$$

where $L = f(P_a, T_a, T_{mrt}, T_{cl})$, and P_a = partial vapour pressure, T_a = dry bulb air temperature, T_{mrt} = mean radiant temperature, T_{cl} = clothing surface temperature.

With PMV expressed in this way it can now be scaled to predict thermal sensation votes as expressed on the ASHRAE (American Society of Heating, Refrigeration and Air-conditioning Engineers) 7-point scale (Table 1).

Table 1. Classification of predicted mean vote (PMV) values for assessment of thermal environmental conditions by a collective of people according to the 7-point ASHRAE psychophysical voting scale

| PMV | Human sensation |
|-----|-------------------|
| -3 | Cold |
| -2 | Cool |
| -1 | Slightly cool |
| 0 | Neutral (comfort) |
| 1 | Slightly warm |
| 2 | Warm |
| 3 | Hot |

Scaling is based on the fact that for each environmental condition (dose), TS is the mean vote or response of all subjects exposed to that dose (Fountain & Huizenga 1995).

As for all thermal comfort indices PMV has a number of limitations. Perhaps the major limitation is that skin temperature and evaporative heat loss are constrained to values for comfort at a given activity level. The PMV equation also only applies to sedentary subjects exposed to steady-state conditions for a long period at a constant metabolic rate, e.g. sitting. Moreover the PMV has been developed based on the average response of mid-latitude inhabitants and therefore does not take into account the factor of acclimatization when applied in a climate context different to that for which it was developed. Despite this problem the PMV is considered appropriate for the analysis presented here, as most tourists visiting Greece during the summer are from the mid-latitudes. Like other models, the PMV is most reliable near the middle of the thermal sensation scale. For conditions divergent from the comfort zone (outside the range $-0.5 < \text{PMV} < 0.5$) the PMV may be under- or over-estimated, as it only predicts thermal sensations for populations and not individuals. Doherty & Ahrens (1988) have estimated that within the comfort zone the expected error of the PMV is around half of a thermal sensation scale. Outside the comfort zone the expected error is one-third of a thermal sensation scale value for each degree Celsius change in effective temperature, which is the temperature of a still saturated atmosphere that has the same general effect upon comfort as ambient conditions. As activity levels increase away from sedentary conditions, the error also increases to in excess of 1 scale value.

The PMV model, as implied above, only predicts what a hypothetical average person would feel. Interpersonal differences in sensation are assumed to be negligible, such that exposure to the same dose would induce the same response in all individuals. Daily variations in the physical and psychological state are also not accounted for in the PMV model; day-to-day variations in the thermal sensation value may be up to a value of 1 for the same environmental conditions, depending on a person's physical and psychological well-being.

Despite the limitations of the PMV model, extensive testing in both laboratory and field situations has revealed PMV to be a good predictor of mean responses for sedentary individuals wearing clothing suited for temporally constant and spatially uniform environments. For this reason the PMV is perhaps one of the most widely used thermal comfort indexes. It has been used to explicitly define the comfort zone for ISO standard 7730 (ISO 1984). Because of its universal

acceptance for bioclimatic assessment in non-tropical environments the PMV is used in this study.

PMV values for Athens were calculated on an hourly basis for the warm part of the year (1 June to 30 September) over the 30 yr period 1966–1995 using the WINCOMF program (Fountain & Huizenga 1995).

The database required to run the WINCOMF PMV model comprises hourly values of temperature, relative humidity and atmospheric pressure, all of which were obtained from the National Observatory of Athens meteorological station (altitude = 107 m; $37^{\circ}58'N$, $23^{\circ}43'E$). Data from this site are quality assured and homogenous. Conscious of the limitations of the PMV as a human thermal comfort index, PMV was calculated for a sedentary human subject (a metabolic rate of 1 met or 58 W m^{-2}) wearing 0.5 clo units (ASHRAE Standard 55 summer). Such an activity and clothing state equates with that of a lightly clothed person sitting. It should be noted that clothing was kept constant for the period June–September. This may create a false impression of the level and timing of cold-related discomfort towards the end of summer, as people would naturally respond by wearing more than 0.5 clo units during any cooler weather experienced at this time of the year. Two ventilation states were also considered, namely calm conditions and a wind speed of 3 m s^{-1} . Activity, clothing and ventilation states are considered realistic for a person sitting in a street café sheltered from the sun. A maximum wind speed of 3 m s^{-1} was set as it is considered that this represents the threshold beyond which wind becomes a nuisance factor (de Freitas 1990), resulting in people moving indoors.

Hourly PMV values for both ventilation states were used to examine the diurnal and seasonal march of human comfort for a number of warm season/summer (June–September) situations: (1) an average summer, (2) a warm and a cool summer, and (3) a synthetic cool and a synthetic warm summer.

The average summer is defined as that for which the average daily temperature equals the 30 yr summer mean. Warm and cool summers are defined as those summers with the highest and lowest mean daily temperatures respectively, with the proviso that the mean monthly value of each of the 4 months (June–September) does not deviate markedly from the mean value of the whole summer. Based on these criteria 1985, 1993 and 1983 were selected as the average, warm and cool summers respectively. PMV was computed for synthetic cool and warm summers in order to provide an insight into the worst-case human comfort scenario at either extreme of the discomfort scale. The synthetic warm (cool) summer comprises the 30 yr maximum (minimum) mean daily temperature for each of the 122 d from June 1 to September 30, 1966–1995.

In addition to examining the diurnal and seasonal characteristics of human comfort, the timing of the onset and cessation of the season of discomfort was also determined. According to Fanger (1972) for PMV values above 2 or below -2 about 75% of people do not feel comfortable. Given this, an absolute value of 2 is used here to define the discomfort threshold. The onset (cessation) of the discomfort season was defined as the day number from the beginning of June when there was (was no longer) 3 or more consecutive days with a PMV greater than or equal to a value of 2 at 14:00 h winter standard time (15:00 h civil summer time). 14:00 h was selected, as this hour possesses the greatest frequency of hours with PMV values in excess of 2. A 3 d period was chosen for the definition of season onset and cessation as 3 consecutive days represent the most commonly occurring duration with PMV values sustained at or above the threshold value of 2.

3. THERMAL COMFORT CHARACTERISTICS FOR AVERAGE, WARM AND COOL SUMMERS

A 30 yr climatology of summer PMV values for 14:00 h identifies a 20 d period from late July as the core period of high PMV and thus discomfort (Fig. 1). Lowest values occur at the beginning of June and at the end of September. Light wind reduces PMV by about 0.5 around the middle of summer and by about 1.5 at the beginning and at the end of summer. During the core period, conditions of discomfort during daylight hours may be maintained for several days. From a consideration of the frequency distribution of the length of day sequences with PMV values greater than or equal to 2 at 14:00 h, it is clear that sequences of 3 d of discomfort dominate. In extreme cases, 20 consecutive days of discomfort may be experienced (Fig. 2).

The diurnal and seasonal march of human comfort for the average summer in Athens, as represented by 1985, is characterized by rising levels of discomfort centred around the climatological core period of dis-

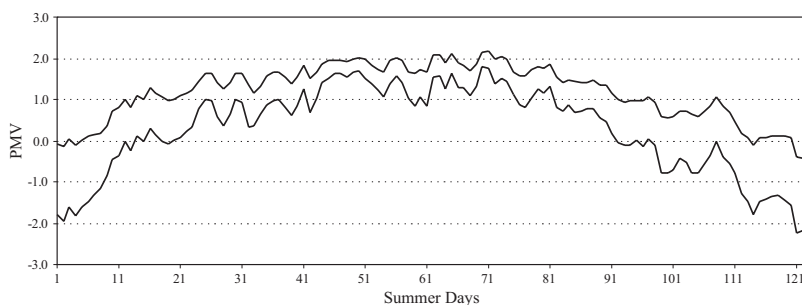


Fig. 1. Mean PMV variation at 14:00 h during summer (June 1–September 30) in Athens, for calm (upper curve) and light wind (lower curve) conditions (1966–1995)

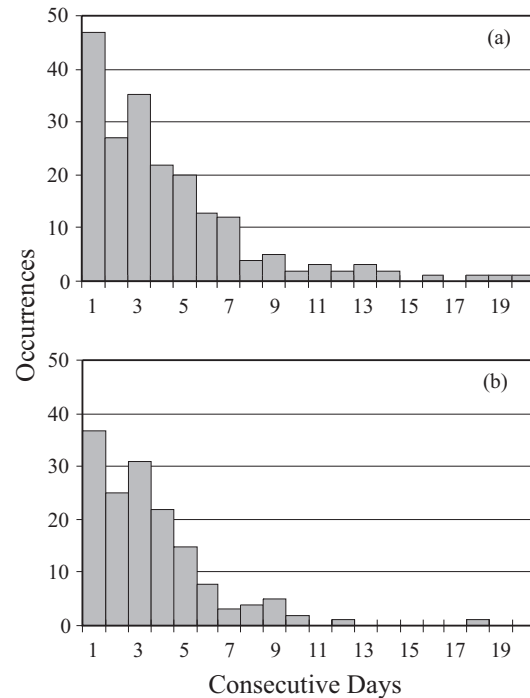


Fig. 2. Number of consecutive days with PMV ≥ 2 at 14:00 h during summer (June 1–September 30) in Athens, for (a) calm and (b) light wind conditions (1966–1995)

comfort. Thereafter discomfort levels due to heat stress fall (Fig. 3a), but discomfort reappears due to low temperatures by middle September during the night and early in the morning. In terms of the average diurnal cycle, as represented by 1985, generally the earliest (latest) hours of discomfort are around 10:00 (18:00) h. Characteristic of summer is a short period of discomfort in the middle of June followed by a period of near-neutral conditions before the onset of the core months of discomfort. This seems to be a distinct feature of the human climate of Athens, as it appears in almost all summers. By September, the season of discomfort appears to be well over, with only a few hours, centred around 14:00 h, falling in the slightly warm category.

Human comfort conditions for the hot summer of 1993 contrast markedly with those for the average summer as portrayed by 1985 (Fig. 3b). For the warm hours of the day, PMV exceeds a value of 2 (warm to hot) for a greater number of summer days occasionally reaching values well over 3 (hot to very hot). Furthermore, on days with prolonged conditions of discomfort, PMV values may exceed a value of 2 as early (late) as 09:00 (20:00) h. On the same days relief from warm conditions may be delayed until after 24:00 h,

when neutral conditions prevail through to around 08:00–09:00 h. Discomfort due to low temperatures, for the clothing ensemble used in this study, is observed only by the end of September, during the night and early in the morning. In reality discomfort may not be experienced, as theoretically people would adjust their clothing accordingly.

For the case of cool summers as exemplified by 1983 (Fig. 3c), the number of hours of discomfort during the core period is small compared to that for an average and especially a warm summer. In terms of the diurnal cycle the onset of conditions of discomfort is delayed by around 1 or 2 h compared to that for an average or hot summer respectively. Generally neutral conditions are obtained after 17:00 h following a period of around 5–6 h of discomfort. This is in stark contrast to the situation evident for the warm summer of 1993 (Fig. 3b). Absent for the cool summer is the period of slightly warm to warm conditions in early to mid June, as found for the average and warm summers. Contrasts with the warm and average summers are also evident for the days following the core period of discomfort, as most August and September days during the warm hours of the day are characterised by neutral to slightly cool conditions. Furthermore, the early morning hours fall into the cool category, with cold conditions attained on several occasions.

Although not shown in graphical form, the diurnal and seasonal pattern of discomfort for conditions of low wind (3 m s^{-1}) conditions resembles closely that for calm conditions. Wind, however, does result in a reduction of mean PMV values with a maximum influence on minimum values; discomfort conditions at the cool end of the scale are enhanced.

That the summers of 1983, 1985 and 1993 contrast in terms of their human thermal conditions is clear when the number of hours for which PMV was greater than or equal to 2 is considered (Table 2). When compared to the cool and average summers, the number of hours of discomfort ($\text{PMV} \geq 2$) for the warm summer of 1993 is 3.2 and 1.7 times greater respectively. Greatest contrasts occur at 18:00 and 19:00 h, when the 1993 to 1983 and 1985 ratios of hours with $\text{PMV} \geq 2$ are 4.3 and 2.6 respectively.

4. WARM AND COOL SYNTHETIC SUMMERS

As noted above, the warm and cool synthetic summers are comprised of a time series of 24 hourly PMV values computed based on meteorological measurements for the warmest and coldest day, respectively, for each of the 122 summer days during the period 1966–1995.

Both the warm and cool synthetic summers (Fig. 4) represent extremes of the warm and cool summers discussed above. In the case of the former, the majority of the hours between 09:00 and 17:00 h are dominated by conditions of discomfort throughout the summer period (Fig. 4a). Only a slight sense of respite comes towards the end of the summer, with a reduction in the number of hours falling within the warm-to-hot category. For extreme days, centred around the core period of discomfort, warm to hot conditions prevail up to 24:00 h, with the ensuing hours falling within the neutral to warm category.

In stark contrast to the situation portrayed by the warm synthetic summer, the cool synthetic summer is dominated by slightly cool to cold conditions throughout the summer (Fig. 4b). It is only during the daylight hours from around 09:00 h that neutral conditions are obtained. Mild stress induced by slightly warm conditions is very much restricted to the core period of discomfort from late July to early August and during the day from 11:00 to 16:00 h. For the pre-sunrise hours, either side of the core period of discomfort, thermal sensation conditions fall well within the cold category. A further feature of the synthetic cool summer is the onset of very cold conditions during daylight hours in the last few days of September. Such conditions are usually restricted to the nocturnal hours at the end of the summer.

Although not shown here, as the situation for calm conditions described above represents the ‘best’ worst-case scenario for planning, the effect of wind on the thermal sensation conditions for the warm and cool synthetic summers is an overall reduction in the hours falling on the warm side of the neutral thermal sensation category. The most dramatic effect of wind is for

Table 2. Thermal comfort characteristics for average, warm and cool summers: number of hours greater than or equal to a PMV of 2

| Winter standard time | 1983 (cool) | 1985 (average) | 1993 (warm) |
|----------------------|-------------|----------------|-------------|
| 08:00 | 1 | 0 | 0 |
| 09:00 | 1 | 2 | 3 |
| 10:00 | 3 | 6 | 11 |
| 11:00 | 8 | 12 | 22 |
| 12:00 | 15 | 26 | 44 |
| 13:00 | 17 | 35 | 53 |
| 14:00 | 20 | 36 | 57 |
| 15:00 | 18 | 36 | 54 |
| 16:00 | 14 | 32 | 53 |
| 17:00 | 12 | 26 | 45 |
| 18:00 | 6 | 9 | 22 |
| 19:00 | 2 | 4 | 12 |
| Total | 117 | 224 | 376 |
| % | 4.0 | 7.7 | 12.8 |

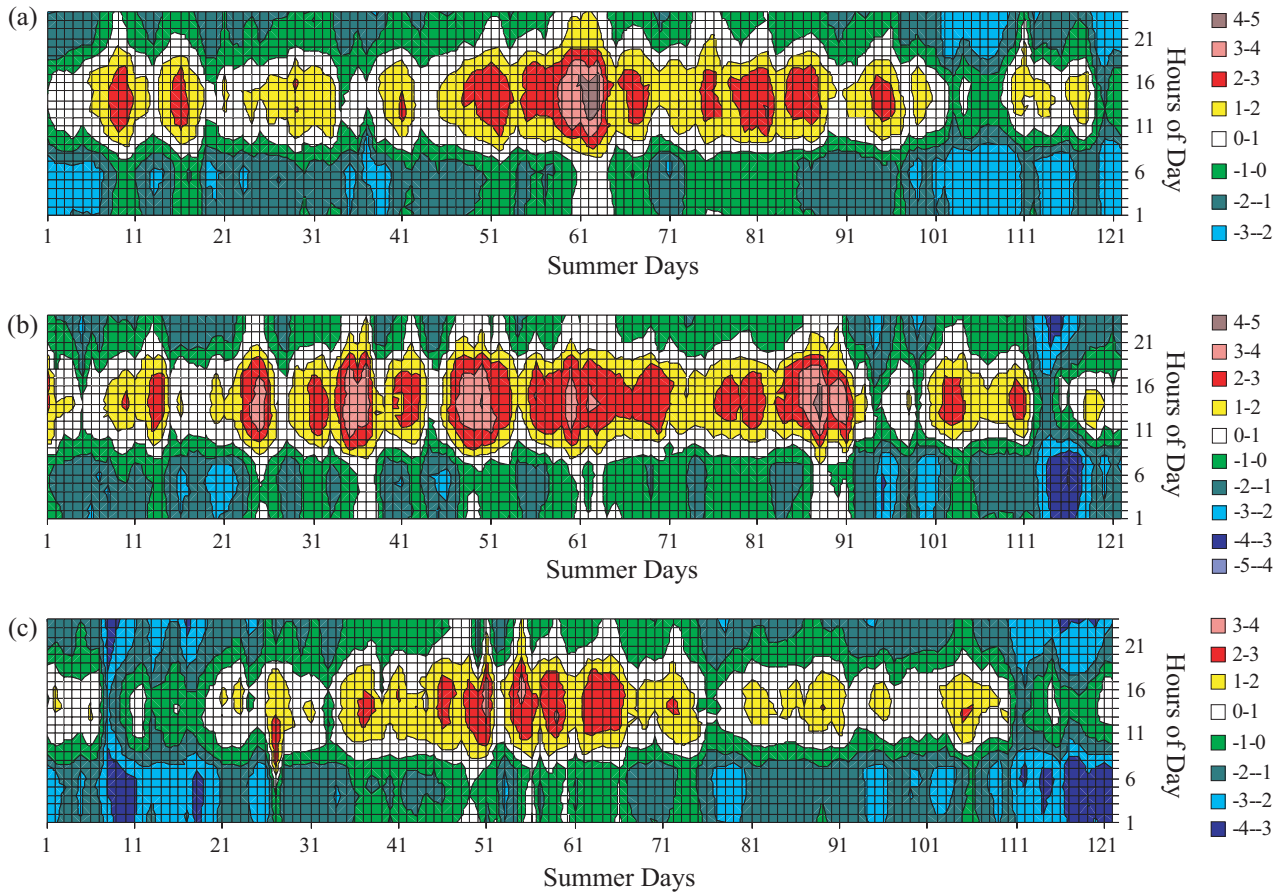


Fig. 3. Hourly summer (June 1–September 30) values of PMV index in Athens, for calm conditions for (a) 1985 average, (b) 1993 warm and (c) 1983 cool summers. Time is winter LST

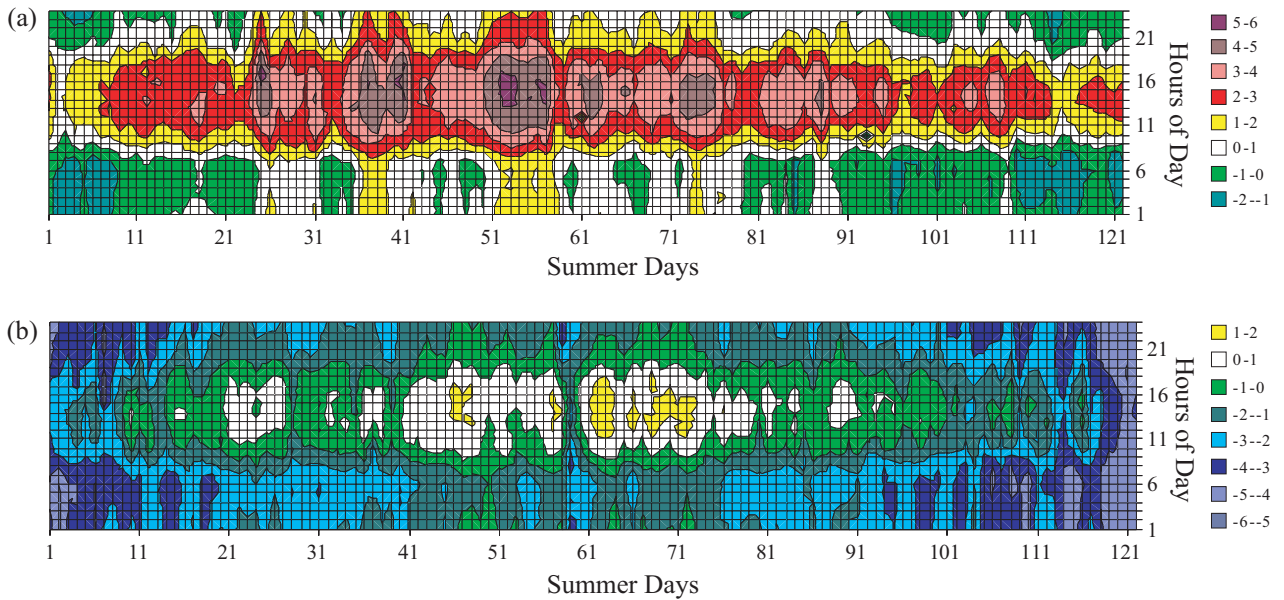


Fig. 4. Hourly synthetic summer (June 1–September 30) values of PMV index in Athens, for calm conditions for (a) warm and (b) cool synthetic summers. Time is winter LST

the cool synthetic summer, as mild conditions of discomfort are replaced by neutral conditions during daylight hours around the normal core period of discomfort. Furthermore, the early (late) season period of cold finishes (begins) much later (earlier), with light wind conditions in the cool synthetic summer compared to the cool summer of 1983 (Fig. 3c) and the cool synthetic summer with calm conditions (Fig. 4b).

Table 3. Discomfort season onset and cessation from June 1 for (a) calm conditions and (b) light wind conditions ($v = 3 \text{ m s}^{-1}$). x : mean date; σ : standard deviation; SE_x : standard error of the mean; Sk : skewness

| | x | σ | SE_x | Earliest | Latest | Sk |
|-----------------------|--------|----------|--------|----------|--------|------|
| (a) Calm | | | | | | |
| Onset (n = 29) | 2 Jul | 17.95 | 3.33 | 8 Jun | 15 Aug | 0.78 |
| Cessation (n = 29) | 24 Aug | 17.62 | 3.27 | 22 Jul | 27 Sep | 0.37 |
| (b) Light wind | | | | | | |
| Onset (n = 26) | 6 Jul | 15.77 | 3.09 | 11 Jun | 4 Aug | 0.11 |
| Cessation (n = 26) | 20 Aug | 17.30 | 3.39 | 18 Jul | 27 Sep | 0.24 |

5. DISCOMFORT SEASON ONSET AND CESSATION

As an analysis of hourly PMV values for each summer revealed that the maximum frequency of hours with a $PMV = 2$ occurred at 14:00 h (15:00 h for summer time), discomfort season onset and cessation were defined in relation to this hour. Descriptive statistics for the onset and cessation are given in Table 3. The number of years (n) used in the calculation of statistics is different for the 2 wind speed conditions. This is because the criteria upon which the definition of onset and cessation are based (3 consecutive days with $PMV \geq 2$ at 14:00 h) were not met for 1 year (1976) for the case of calm conditions and for

4 years for light wind conditions (1969, 1970, 1971, 1976).

According to the criteria adopted in this study, discomfort season onset for calm conditions occurs in early July, with cessation in late August. The effect of light winds is to delay (bring forward) discomfort season onset (cessation) by 4 d. Standard deviation and earliest and latest statistics for onset and cessation (Table 3) suggest a considerable amount of inter-annual variability of discomfort season characteristics. This is very clear when onset and cessation dates are plotted as a time series (Fig. 5). The years 1983 and 1990 are notable for their foreshortened and prolonged discomfort seasons respectively for calm winds. Also of

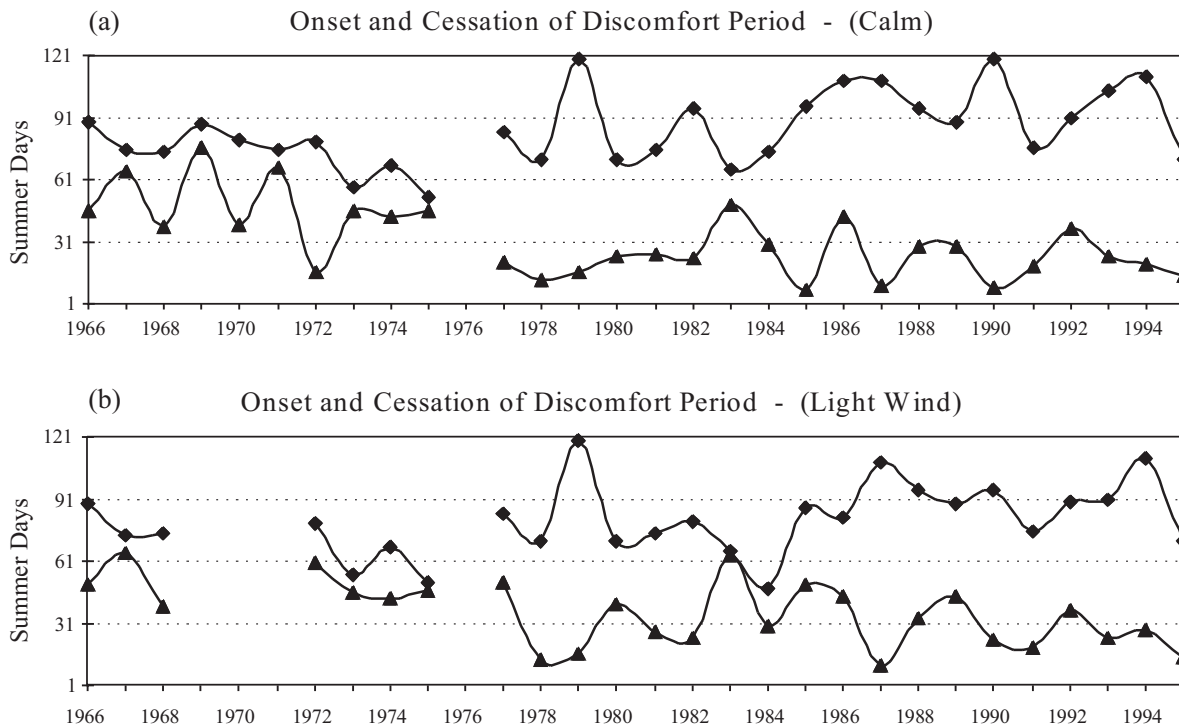


Fig. 5. Onset (lower curves) and cessation (upper curves) of discomfort period at 14:00 h during summer (June 1–September 30) in Athens, for (a) calm and (b) light wind conditions (1966–1995)

Table 4. (a) Discomfort season duration statistics in days for calm conditions and light wind conditions ($v = 3 \text{ m s}^{-1}$). (b) As in (a) but without the years in which onset and cessation of discomfort cannot be defined. n: number of years; \bar{x} : mean; σ : standard deviation; $SE_{\bar{x}}$: standard error of the mean; Max., Min. and Sk: maximum, minimum and skewness respectively

| | n | \bar{x} | σ | $SE_{\bar{x}}$ | Max. | Min. | Sk |
|--|----|-----------|----------|----------------|------|------|------|
| (a) All years | | | | | | | |
| Calm | 30 | 52 | 30.72 | 5.61 | 111 | 0 | 0.04 |
| Light wind | 30 | 39 | 29.67 | 5.42 | 104 | 0 | 0.38 |
| (b) Without years of undefined onset or cessation | | | | | | | |
| Calm | 29 | 54 | 29.61 | 5.50 | 111 | 7 | 0.06 |
| Light wind | 26 | 45 | 27.12 | 5.32 | 104 | 3 | 0.38 |

note is that during the first 10 yr of the study period the discomfort season starts mainly in July, for both calm and light winds conditions, whereas in the last 20 yr discomfort conditions appear to have started in June. Cessation also seems to have changed in time; it occurs mainly in August in the first period, while it is displaced to September during later years.

Table 4a presents discomfort season duration statistics. Mean and maximum duration for season-long calm (light wind) conditions is 52 (39) d and 111 (104) d respectively. Values of zero appear for minimum dura-

tion as the criteria adopted for onset and cessation definition were not met for 1 year (1976) for calm conditions and for 4 years for light wind conditions (1969, 1970, 1971, 1976); hence a discomfort season could not be defined for these years. However if these years are not included in the analysis (Table 4b) the minimum durations for calm and light wind conditions are 7 and 3 d respectively. If discomfort season duration is plotted for both the original and smoothed (5 yr moving averages with binomial coefficients) series, a trend towards a longer discomfort season in recent years appears evident (Fig. 6). That this trend is statistically significant (at the 0.05 level) was confirmed by a Mann-Kendall test of randomness against the trend and is most likely due to an earlier start and/or a later cessation of the discomfort season. Because of the lack of definition of onset and cessation dates for the years mentioned above, the application of a statistical test, in order to investigate a possible trend in onset and cessation dates of the discomfort season, is not possible. However, if the non-defined values are replaced with the study period mean and Mann-Kendall tests are applied, the results show statistically significant trends (towards earlier and later onset and cessation dates respectively). This supports the findings of the trend analysis of discomfort season duration.

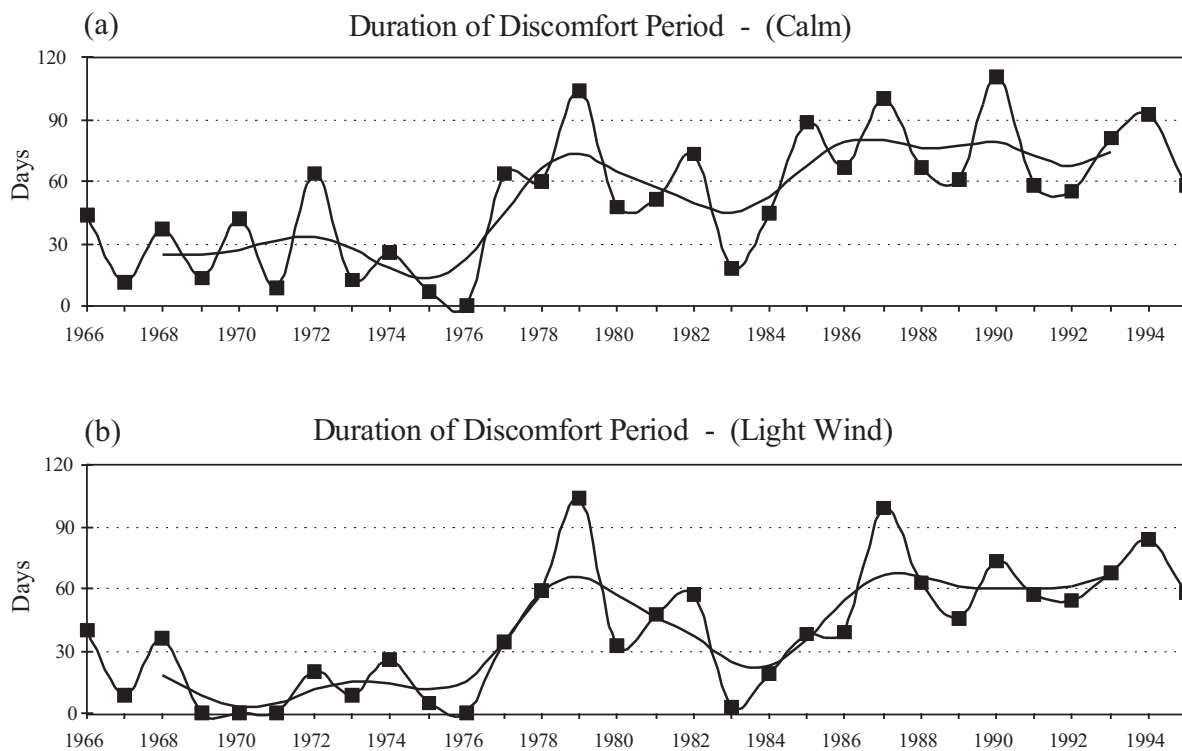


Fig. 6. Duration of discomfort period at 14:00 h during summer (June 1–September 30) in Athens, for (a) calm and (b) light wind conditions (1966–1995). Five-year moving averages with binomial coefficient weights are also shown

Table 5. Association between discomfort season characteristics

| | Correlation coefficient | Significance level |
|--------------------|-------------------------|--------------------|
| Calm | | |
| Onset–cessation | -0.39 | 0.05 |
| Onset–duration | -0.84 | 0.01 |
| Cessation–duration | +0.83 | 0.01 |
| Light wind | | |
| Onset–cessation | -0.34 | 0.05 |
| Onset–duration | -0.80 | 0.01 |
| Cessation–duration | +0.84 | 0.01 |

An evaluation of the relationships between onset date, cessation date and duration (Table 5), revealed a strong association between discomfort duration on the one hand and onset and cessation dates on the other. The correlation coefficients are above 0.80 (absolutely), indicating that a longer discomfort duration is due either to an earlier onset or to a later cessation. In contrast, an association between onset and cessation dates seems doubtful. Although the correlation coefficient is statistically significant at the 0.05 level, its low values (-0.39, -0.34) indicate that an early onset does not necessarily lead to a late cessation.

6. DISCUSSION

Analysis of hourly summer human thermal comfort conditions for Athens for 2 wind speed conditions and a sedentary human state has revealed that conditions of discomfort at the seasonal and diurnal scales are the norm. Although such a finding confirms conventional wisdom, the fact that discomfort is a recurring feature of daylight hours between June and the end of September bears implications for the planning of human activities. This is especially so in the case of special events such as the summer Olympics or the European Athletics Championships. As a core period of discomfort centred on the daylight and early evening hours of late July to early August exists, then athletic events, which naturally involve high levels of activity and thus increased metabolic rates, should either be avoided during the core period of discomfort or planned well after sunset, when human thermal conditions are at the neutral level or below (on the cool side). Not only does this make sense in terms of decreasing the likelihood of heat stroke, but also from the point of view of athletic event performance times, especially for middle to long distance running events, as there is ample evidence that these are closely associated with ambient human thermal conditions (Trapasso & Cooper 1989, Zhang et al. 1992). Furthermore, given that visit-

ing athletes from mid- to high-latitude locations will not acclimatise immediately to Athens' high levels of human thermal stress, a significant period of acclimatisation will be required if successful and non-detrimental participation in athletic events is desired.

In relation to the planning of human activities in general, the analysis results for the warm (1993) and cool (1983) summers and warm and cool synthetic summers are informative, as these represent extreme scenarios at either end of the human thermal comfort scale. In general hot (cool) summers are characterised by a marked increase (reduction) in the frequency, duration and magnitude of conditions of discomfort for the calm and light wind speed conditions at both the diurnal and seasonal scales. In terms of athletics events these should be planned according to the distribution of discomfort recorded for the extreme summer of 1993 or the warm synthetic summer. Hypothetically, the best athletic performances would be attained under conditions similar to the cool synthetic summer. Of interest is the fact that, although 1993 was a summer of extreme heat, mortality levels were lower than that recorded for 1987. This may be attributed to the preparedness of the population of Athens, as in response to the marked health effects of the 1987 heat waves the National Observatory of Athens was issuing general heat wave warnings by the early 1990s. A further factor that may have mitigated against high mortality levels in 1993 was the increased use and availability of air conditioning by this time.

The variability in summer human thermal conditions at the intra-seasonal and inter-annual scales observed for Athens is most likely related to variations in atmospheric circulation characteristics at the synoptic time scale, especially the relative predominance of northerly to north-easterly winds (Etesians) and southerly winds (sirocco and/or sea breeze) over Athens. Based on the findings of Bartzokas & Metaxas (1996), who objectively classified summer pressure patterns over the northern hemisphere, it appears that cool summers in Athens, as exemplified by 1983, are related to the prevalence of negative pressure anomalies over the central and eastern Mediterranean. Such a pressure configuration leads to an increase in the east to west pressure gradient, an increased frequency and/or magnitude of Etesian winds and the transport of cool air masses from central Europe over the Athens area and thus a moderation of summer heat.

In comparison, summers dominated by high levels of discomfort, such as 1993, result from the prevalence of southerly to south-easterly sirocco winds. These winds are often associated with anticyclonic ridging over the eastern Mediterranean and diffuse areas of high pressure extending from eastern Europe to the Persian Gulf (Maheras & Kutiel 1999) or the eastward passage

of centres of low pressure. In the former case, hot dry continental air is advected from North Africa, while in the latter case, warm moist air associated with the warm sector of a low-pressure system is advected from the Mediterranean Sea over the Athens area. Air temperatures under such flows can reach in excess of 35°C, thus reducing the body's ability to regulate heat stress by sensible heat transfer to the atmosphere. The conditions of discomfort generated by the continental and maritime tropical air masses are often exacerbated by the concomitant development of sea breezes. Sea breeze flows often advect very moist air over the Athens area and raise humidity levels. The body's ability to shed heat through latent heat transfer and the sweating process becomes much reduced under such conditions, thus negating the potential cooling effects provided by sea breezes. Although sensible heat transfer as a heat loss pathway is restored after sunset, the continuation of moist sea breeze flows maintains daytime levels of discomfort due to high evening humidity levels. A further factor that may play a role in inducing discomfort under sea breeze circulation conditions is atmospheric pollution. This is because Athens is surrounded by mountains with high peaks, well above the inversion level, from all directions except the south to south-west. The additive factor of high pollution loads with excess heat and humidity may therefore lead to very high levels of discomfort, with implications for human health. Such a lethal combination of heat stress and high pollution may have played a role in causing the excess deaths that have been reported for several heat wave episodes in Athens (Katsouyanni et al. 1993).

A distinct feature of Athens' human thermal climate is the inter-annual variation in discomfort season onset, cessation and thus duration. The timing of these is controlled by the coincidence of seasonal changes in the atmospheric circulation over southern Europe with the seasonal heating cycle. Recent studies have shown that seasonal atmospheric circulation change over southern Europe is closely related to the pressure differential between the western and eastern Mediterranean, which has been referred to as the Mediterranean Oscillation (MO) (Maheras & Kutiel 1999, Maheras et al. 1999, Bartzokas & Lolis 2000). An exploration of the linkages between the MO and interannual variability of discomfort season onset is considered to be beyond the scope of the current paper. They will be investigated in a future study.

The protraction of Athens' discomfort season over the last decade, as observed in this study, appears to be a result of an increasingly earlier (later) discomfort season onset (cessation). Although this may seem self evident, phenological studies (Jaagus & Ahas 2000, Otterman et al. 2002) have only shown earlier arrival times for spring in Europe as opposed to changes in seasonal

timing at the beginning and end of the summer. Protraction of the season of discomfort may be related to systematic changes in the timing of seasonal atmospheric circulation changes and thus the timing of the climatological seasons (Cheng & Kalkstein 1997) over southern Europe. Although no studies have been specifically directed at determining this, there appears to have been changes in the frequency of European circulation types (Bardossy & Caspary 1990, Nemesova & Klimperova 1995, Huth 2001). For example, Bardossy & Caspary (1990) have shown an increasing southerliness of flow over Europe at the annual time scale, while for summer Huth (2001) has demonstrated an increasing frequency of anticyclones. This appears to have occurred in concert with an abatement of easterly winds and an increased frequency of calm conditions in the central Mediterranean area (Pirazzoli & Tomasin 1999). In terms of Athens' human thermal climate, such changes may mean an increasing frequency of periods of thermal discomfort.

Although atmospheric circulation change appears to be a good candidate for explaining changes in the nature of Athens' discomfort season, urbanisation, through the urban heat island effect, may also account for part of the observed change. For example, Philandras et al. (1999) have shown that up to the late 1960s summer maximum temperature for Athens covaried with that at a nearby rural location (Aliartos). However from the early 1970s, when the rate of urbanisation was particularly rapid, this covariant behaviour broke down as a result of Athens' maximum temperature diverging away from that of Aliartos. As there was no change in the nature of temperature recording in Athens, this divergent behaviour has been attributed to an urbanisation effect. Obviously this idea needs testing, along with a consideration of the possible role of observed global warming.

7. CONCLUSIONS

Application of the PMV model using observations of temperature and atmospheric moisture content has facilitated a climatological description of Athens' summer human thermal climate for 2 constant wind speed conditions. Study results have shown that for a situation analogous to a shaded street-side café and calm to light wind conditions, a seated person can expect to experience thermal discomfort during daylight hours on the majority of days between July and August. At the seasonal (diurnal) time scale, discomfort reaches a maximum over a 20 d (4 to 6 h) period centred on the end of July (14:00 h LST that is 15:00 h summer time), which bears implications for the planning of outdoor activities, especially those that involve high levels of

metabolic activity. In relation to this, human thermal conditions for synthetic warm and cool summers have been presented as a basis for recreation and sports planning and management.

Not only does the general level of summer discomfort vary at the inter-annual time scale, but discomfort season onset and duration demonstrates a marked inter-annual variability. Both may be a consequence of inter-annual variations in atmospheric circulation characteristics over southern Europe. In this respect the role that the Mediterranean Oscillation plays in governing the general nature of atmospheric circulation over Greece, and thus human thermal comfort levels at the seasonal time scale and the timing of discomfort season onset at the inter-annual time scale, needs further investigation. Future research on the synoptic bioclimatology of Athens should therefore be directed to searching for changes in the climatology (timing, frequency and magnitude) of heat stress producing synoptic conditions over Greece. The role of urbanisation in producing longer seasons of discomfort also warrants investigation, as does the synergistic effects of air pollution and thermal stress for engendering discomfort. Future analyses could also be directed at establishing the levels of discomfort for varying activity levels and changing clothing ensembles over the summer period not only using the PMV but other energy balance based models.

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