THE EXTREME HEAT WAVE IN ATHENS IN JULY 1987
FROM THE POINT OF VIEW OF HUMAN BIOMETEOROLOGY

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Abstract—At the end of July 1987 a heat wave came over Greece and had as a consequence an increase in the mortality to double the normal values. Predicted mean vote (PMV), physiologically equivalent temperature (PET), and for comparison discomfort index (DI) as thermal indices as well as core temperature, mean skin temperature, and skin wetness as body parameters are calculated for that period based on meteorological data of the Meteorological Institute of the National Observatory in the centre of Athens and of the suburban station New Philadelphia of the Hellenic National Weather Service. The results for the thermal indices and the body parameters indicate a very high thermal stress on people. In addition, the air quality stress index (AQSJ) has been used for characterizing air quality conditions in Athens during the heat wave. The results for AQSJ in July 1987 display high pollution in the centre of Athens in the period of the heat wave. Combined with the thermal effects of the heat wave the stress on humans due to environmental conditions has been very injurious to health.

Key word index. Heat wave, Athens, urban climate, thermal stress, air quality.

1. INTRODUCTION

In the summer of 1987 Greece was plagued by a heat wave, which was not without human consequences. During the period from 20 to 31 July 1987 the mortality in Greece increased extraordinarily. In the greater Athens area more than 1000 residents died between 20 and 31 July (Katsouyanni et al., 1988). However, it is unclear how many of these deaths can be ascribed directly to the heat wave, since there was also smog to contend with in Athens. It should also be borne in mind that Athens has a high portion of elderly and retired people who are particularly susceptible to these conditions.

This paper deals with the thermal and air quality components of the urban climate in Athens during this heat wave. On the basis of the meteorological data for Athens, the thermal comfort of man is analysed in a thermo-physiologically significant manner by using human biometeorological indices from models for the human energy balance. Furthermore air quality conditions in Athens during the heat wave are assessed by the air quality stress index, which is evaluated from air pollution data from the centre of Athens.

The heat wave in July 1987 has been also investigated by Giles and Balafoutsis (1990) as well as Giles et al. (1990). They analysed the thermal conditions, not only in Athens, but also in Thessaloniki and calculated thermal indices like the discomfort index or relative strain index which are not derived directly from the human energy balance. Therefore, they gave no regard to the specific physiological parameters of people, like thermal resistance of clothing or activity; they investigated the next heat wave in July 1988 in Greece in the same way too.

2. METHODS FOR HUMAN BIOMETEOROLOGICAL ASSESSMENT OF THE THERMAL COMPONENT OF URBAN CLIMATE

2.1. Predicted mean vote

In modern human biometeorology assessing thermal comfort of man in a physiologically significant manner means the interpretation of the human energy balance equation with its resulting energy fluxes and physiological parameters (Maeyer, 1990). Nowadays, one of the most popular models is Fanger’s (1972) ‘comfort equation’ for indoor climate, which allows the calculation of the so-called ‘predicted mean vote’ (PMV). PMV predicts a mean judgement of the thermal environment for a large sample of people by a value according to the seven-step ASHRAE comfort scale (Table 1).

Jendritzky et al. (1979) have extended the comfort equation for application in outdoor conditions to the so-called ‘Klima-Michel’ model. Based on that model the derived PMV values, thermal component of urban climate can be assessed by a single index. In addition, Jendritzky et al. (1979) developed a human biometeorological classification for-thermal stress on man using PMV values (Table 2). As an example for working with PMV Jendritzky and Nübler (1981) have analysed the thermal environment in Freiburg, a small city in the south-west of Germany.
Table 1. Classification of PMV values for assessment of thermal environmental conditions by a collective of people according to the seven-step ANHRAE Psychro-Physical Voting Scale (Jendritzky et al., 1979)

<table>
<thead>
<tr>
<th>PMV values</th>
<th>Human sensations</th>
</tr>
</thead>
<tbody>
<tr>
<td>−3</td>
<td>Cold</td>
</tr>
<tr>
<td>−2</td>
<td>Cool</td>
</tr>
<tr>
<td>−1</td>
<td>Slightly cool</td>
</tr>
<tr>
<td>0</td>
<td>Neutral (comfort)</td>
</tr>
<tr>
<td>+1</td>
<td>Slightly warm</td>
</tr>
<tr>
<td>+2</td>
<td>Warm</td>
</tr>
<tr>
<td>+3</td>
<td>Hot</td>
</tr>
</tbody>
</table>

Table 2. Classification of thermal stress on humans according to ranges of absolute PMV values (Jendritzky et al., 1979)

<table>
<thead>
<tr>
<th>Ranges of PMV values</th>
<th>Thermal stress levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No stress</td>
</tr>
<tr>
<td>0.1−0.5</td>
<td>Resting range</td>
</tr>
<tr>
<td>0.6−1.2</td>
<td>Slight stress</td>
</tr>
<tr>
<td>1.3−2.0</td>
<td>Moderate stress</td>
</tr>
<tr>
<td>2.1−3.0</td>
<td>Strong stress</td>
</tr>
<tr>
<td>&gt;3.0</td>
<td>Very strong stress</td>
</tr>
</tbody>
</table>

2.2. Physiologically equivalent temperature

Mayer and Höppe (1987) have shown that it might be useful for urban planners and other people who have less contact with the field of thermo-physiology to describe the thermal bioclimate by a more relevant measure. One of these measures is the physiologically equivalent temperature, PET.

PET is a human biometeorological index which can be calculated from the energy balance model MEMI (= Munich Energy Balance Model for Individuals) by Höppe (1984). MEMI is a steady-state two-node model in which the sweat rate is a function of not only the mean skin temperature, but also the core temperature of man. The heat fluxes are calculated separately for clothed and unclad parts of the body surface. The body parameters, age and sex of a person are considered in calculating the metabolic rate and the sweat rate. More details of MEMI can be found in Höppe (1984) and Mayer and Höppe (1987).

The fundamental idea of the establishment of PET is the transfer of the actual thermal bioclimate to an equivalent fictive indoor environment in which the same thermal stress can be expected. For calculation of PET the following assumptions are made (Mayer and Höppe, 1987):

(a) as for typical indoor climates, the mean radiation temperature equals the air temperature, (b) the air velocity is set to a plausible indoor value of 0.1 m s⁻¹; (c) the vapour pressure of the ambient air is assumed to be 12 hPa (relative humidity r h = 50\% at air temperature $T_a = 20\degree C$); and (d) the work metabolism which has to be added to the basal metabolism is set to 80 W (light sedentary work) and the clo-value of clothing is assumed to be 0.9.

PET now can be calculated as the air temperature at which the energy balance for the assumed indoor conditions is balanced with the mean skin temperature and sweat rate as calculated for the actual outdoor conditions.

The bioclimate characterized by PET can be assessed more easily by the thermo-physiological layman, having experience of room temperatures and corresponding thermal comfort conditions. So for example almost everybody can characterize indoor thermal conditions with an air temperature of 30\degree C, while only experts can interpret as a thermo-physiological parameter what a mean skin temperature of 35.7\degree C means for somebody walking in a sunny street canyon.

According to its definition and to general experience of thermo-physiology, PET values around 20\degree C can be characterized as comfortable. Higher values indicate an increasing probability of heat stress, whereas lower values indicate conditions too cool for comfort (Mayer and Höppe, 1987).

By use of PET Höppe and Mayer (1987), as well as Mayer and Höppe (1987), have assessed different urban structures in Munich with regard to urban planning.

2.3. Discomfort index

As already mentioned the development in human biometeorology has shown that the assessment of the thermal component in urban climates should be based on indices derived from the human energy balance. Since not all of these models like MEMI are published in English, readily available to the public in scientific journals, it was impossible for Giles et al. (1990), based on the human energy balance, to consider thermal indices such as PMV or PET, besides the discomfort index DI (Thom, 1959). In order to compare the results with regard to thermo-physiological relevance, DI and PMV, as well as PET, were calculated in this paper. With the use of DI it is also possible to classify the thermal environment for the population (Table 3):

Table 3. Classification of the thermal environment in summer according to ranges of Discomfort Index DI (Giles et al., 1990)

<table>
<thead>
<tr>
<th>DI</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>DI &lt; 21.0\degree C</td>
<td>No discomfort</td>
</tr>
<tr>
<td>21.0 ≤ DI &lt; 24.0\degree C</td>
<td>Under 50% population feels discomfort</td>
</tr>
<tr>
<td>24.0 ≤ DI &lt; 27.0\degree C</td>
<td>Over 50% population feels discomfort</td>
</tr>
<tr>
<td>27.0 ≤ DI &lt; 30.0\degree C</td>
<td>Most of population suffers discomfort</td>
</tr>
<tr>
<td>29.0 ≤ DI &lt; 32.0\degree C</td>
<td>Everyone feels severe stress</td>
</tr>
<tr>
<td>DI ≥ 32.0\degree C</td>
<td>State of medical emergency</td>
</tr>
</tbody>
</table>
however, there are restrictions due to the fact that the essential parameters—wind velocity and radiation flux—are not taken into account.

For estimating DI in °C the following equation by Giles et al. (1990) has been applied:

\[ DI = T_a - 0.55(1 - 0.01 \text{ r.h.})(T_a - 14.5), \] (1)

where \( T_a \) is air temperature in °C and r.h. is relative humidity in %.

3. WEATHER IN ATHENS DURING THE HEAT WAVE

For the period of the heat wave, i.e. from 20 to 31 July 1987, meteorological data of two stations in Athens were used. The station of the Meteorological Institute of the National Observatory of Athens (abbreviated as OB) is situated in the centre of Athens at 107 m a.s.l. The suburban station New Philadelphia of the Hellenic National Weather Service (abbreviated as PH) lies at the northern outskirts of Athens at 137 m a.s.l., about 8 km from station OB. The meteorological data comprise of air temperature \( T_a \), vapour pressure \( V_p \), horizontal wind velocity \( v \) and global radiation \( S + D \). The calculations have been done for the daily times of maximum and minimum air temperature.

An analysis of the synoptic conditions in Greece from 19 to 27 July 1987 and a characterization of the heat wave by the discomfort index of Thom (1959) is given by Prezerakos (1989).

3.1. Air temperature \( T_a \)

The daily maxima and minima of \( T_a \) for the period 20–31 July for both stations are given in Fig. 1. At the end of the investigated period the air temperature was quite normal for the greater Athens area.

At the station OB the highest daily maximum of \( T_a \) occurred on 23 July with a value of 41.9°C and the lowest daily maximum of \( T_a \) on 28 July with 35.0°C. At the suburban station PH the highest daily maximum was 43.6°C on 27 July, which was the highest measured air temperature during the heat wave throughout the greater Athens area. The lowest daily maximum of \( T_a \) at PH was 36.0°C on 28 July.

The highest daily minima of \( T_a \) were measured on 27 July with 29.2°C at PH and on 24 July with 29.9°C at PH. On 20 July the lowest daily minima of \( T_a \) were recorded at OB with 25.6°C and at PH with 24.4°C.

Figure 1 shows that the heat wave in Athens fell off from 27 July. During the heat wave itself the daily maxima of \( T_a \) at the suburban station, PH, were higher than at the station OB in the centre, due to the lightly built-up area. Concerning the daily minima of \( T_a \), however, the values at OB were prevailing due to the urban heat island effect.

3.2. Vapour pressure \( V_p \)

At OB the daily maximum values of \( V_p \) ranged between 17.9 hPa on 22 July and 27.3 hPa on 26 July; the daily minimum values of \( V_p \) varied between 17.3 hPa on 21 July and 24.2 hPa on 28 July. At the suburban station, PH, the daily maximum values of \( V_p \) ranged between 17.6 hPa on 20 July and 23.3 hPa on 28 July, and the daily minimum values of \( V_p \) between 16.5 hPa on 23 July and 21.6 hPa on 28 July.

3.3. Wind velocity \( v \)

The horizontal wind velocity \( v \) was measured at both stations, 10 m above ground. Based on those data, a power law was used to extrapolate \( v \) at the height of 1.1 m above ground, which corresponds to the average height of the centre of gravity of adults. This height is often used in human biometeorology for the assessment of the thermal environment.

At both stations in Athens \( v \) was comparatively low. The highest value of \( v \) was calculated for 23 July with 2.3 m s\(^{-1}\) at OB and PH.

3.4. Mean radiation temperature \( T_{\text{net}} \)

The mean radiation temperature \( T_{\text{net}} \) in the models for human energy balance represents a suitable measure for the stress on a human due to the heat effect of

![Fig. 1. Daily maxima and minima of air temperature \( T_a \) at the station OB in the centre of Athens and the suburban station PH for the period 20–31 July 1987.](image)
the radiation from the surrounding sphere. The estimation of $T_{nr}$ for outdoor climates used in this investigation is explained in detail at Jendritzky et al. (1979) and Jendritzky (1990). The meteorological data necessary for calculating $T_{nr}$ came largely from both stations. The calculations for $T_{nr}$ were done for OB as well as PH, with regard to comparable street canyons in east–west direction with the roadway width of 25 m and the width of sidewalks as 3 m. The height of the buildings is 30 m at OB and 25 m at PH. Concerning the body of a standing subject, the view factor of the built-up surroundings was 0.85 for the station OB and 0.84 for the suburban station PH. A value of 70% was used for the shortwave albedo of man.

The results (Fig. 2) allow for both stations that the minimum values of $T_{nr}$ were in the range of $T_s$. The maximum values of $T_{nr}$ varied between 66 and 71°C. At the station OB the minimum values of $T_{nr}$ were a little higher than at the suburban station PH where $T_{nr}$, however, reached higher maximum values resulting from the effects of direct solar radiation on the lightly built-up area.

### 4. RESULTS OF THE HUMAN BIOMETEOROLOGICAL ASSESSMENT OF THE THERMAL COMPONENT OF URBAN CLIMATE DURING THE HEAT WAVE

Combined with Table 3, Fig. 3 shows, for both stations, that during the heat wave most of the population in Athens suffered thermal discomfort in the daytime. In general, thermal conditions, indicated by $D_I$, were similar to the air temperature conditions (Fig. 1), i.e. at the times of the daily maximum values of $T_s$ $D_I$ were nearly always higher at the suburban station PH than at station OB in the centre, whereas at the times of the daily minimum values of $T_s$ $D_I$ were prevailing at station OB. The highest value of $D_I$ with 31.1°C occurred at both stations in the daytime of 26 July, which means, according to the classification in Table 3, that everyone in Athens felt severe heat stress. The highest daily minima of $D_I$ were calculated with 24.8°C on 24 July at the suburban station PH and with 25.7°C on 27 July at OB in the centre of Athens. Hence it follows, that during the night of 26–27 July 1987 over 50% of the population in the centre of Athens felt thermal discomfort and had no restful sleep. At that time, however, under 50% population has suffered thermal discomfort in the suburbs of Athens.

For calculation of $PMV$ as a thermo-physiologically relevant index the following parameters of man have been used: metabolic rate 257 W (walking), age 35, weight 75 kg, height 1.75 m, light clothing (heat transfer resistance $r_{cl}=0.5$ clo), position is walking. Actual meteorological input parameters for the 'Klima-Michel' model and for MFMI are $T_s$, $VP$, $v$ and $T_{nr}$.

At both stations the $PMV$ values were comparatively high during all days of the heat wave (Fig. 4). At the times of the daily maximum values of $T_s$ they ranged between 5.4 and 6.9 at the central station OB and between 5.8 and 7.2 at the suburban station PH. At the times of daily minimum values of $T_s$ $PMV$ reached values between 1.1 and 2.2 at OB and between 1.0 and 1.9 at PH.

During the last 3 days of July 1987, with comparatively normal weather conditions for Athens, $PMV$ values between 4.7 and 5.2 (maximum thermal conditions) and 0.2 and 1.1 (minimum thermal conditions) were calculated.

The results for $PMV$ show that at the times of minimum values of $T_s$ $PMV$ values can cover the whole thermo-physiological scale from no stress to strong stress.

On both stations thermal stress was lower at night by a factor of 3. At that time thermal stress at OB in the centre of Athens was a little higher than at PH, due to the heat island effect. Conversely, during the day thermal stress at the suburban station PH was stronger because of the higher $T_{nr}$ values.
The heat wave in Athens in July 1987

Fig. 3. Daily maxima and minima of discomfort index $DI$ at the station OB in the centre of Athens and the suburban station PH for the period 20–31 July 1987.

Fig. 4. Daily maxima and minima of predicted mean vote $PMV$ at the station OB in the centre of Athens and the suburban station PH for the period 20–31 July 1987.

The behaviour of $PET$, which is based, like $PMV$, on the energy balance of man, shows no significant difference to $PMV$ (Fig. 5). However, assessment of the thermal environment by use of $PET$, supplies quantitative results which are clearer for most people. The $PET$ values at the times of daily maximum values of $T_a$ ranged between 49.0 and 55.8°C at OB and between 50.9 and 57.8°C at the suburban station PH. At the times of daily minimum values of $T_a$, $PET$ reached values between 23.8 and 27.9°C at OB and 23.0 and 28.5°C at station PH. For the last 3 days in July 1987, with comparatively normal weather conditions in Athens, no thermal stress was calculated for the night-time, while at daytime $PET$ values of about 40°C indicate normal thermal stress for people in Athens in summer.

In addition to the thermal indices $PMV$ and $PET$ values of core temperature $T_c$, mean skin temperature $T_{sk}$, and skin wetness $h$ parameters have been calculated as body parameters of man. By many studies of work in heat (Reichel et al., 1985; Wyndham et al., 1965; Eichna et al., 1945) the following threshold values of $T_c$, $T_{sk}$, and $h$ for indicating thermal stress were derived:

(a) increase of $T_c$ by more than 1.5°C (as a rule $T_c > 38.3^\circ$C);
(b) $T_{sk} > 34.9^\circ$C; and
(c) $h > 0.7$.

Values of $h$ over 0.25 represent thermal discomfort (Gagge et al., 1969).

For the times of daily maximum values of $T_a$ during the heat wave $T_a$, calculated by the model MEMI for a walking man, shows very high values at both stations (Fig. 6) which are lying close to the threshold value for heat stress of working people. That means higher values of $T_a$ (over 38.3°C) for working people which for thermo-physiological reasons would have the consequence of stopping all physical work.
Fig. 5. Daily maxima and minima of physiologically equivalent temperature PET at the station OB in the centre of Athens and the suburban station PH for the period 20–31 July 1987.

Fig. 6. Daily maxima and minima of core temperature $T_c$ at the station OB in the centre of Athens and the suburban station PH for the period 20–31 July 1987.

Here the highest $T_c$ value with 38.1°C in the daytime and the lowest $I_a$ value of 3.1°C in the night-time were calculated at the suburban station PH. In addition, it can be stated for both stations that in the nighttime $T_c$ did not reach neutral thermal values (36.8°C).

During the heat wave the values of $T_{ak}$ in the daytime were at both stations about 2°C higher than the threshold value of 34.9°C for heat stress (Fig. 7). $T_{ak}$ ranged between 36.5 and 36.9°C at OB and between 36.7 and 36.9°C at the suburban station PH. At night-time $T_{ak}$ reached values between 34.3 and 33.0°C at OB and between 34.2 and 34.9°C at PH which means that even at night-time $T_{ak}$ nearly reached the threshold value for heat stress. During the last 3 days of July 1987 with typical summer weather conditions in Athens, $T_{ak}$ ranged from 36.2 to 36.5°C in the daytime and from 33.4 to 34.2°C at night.

The skin wetness $b$ at the times of daily maximum values of $T_a$ was between 0.60 and 0.81 at OB and between 0.61 and 0.82 at PH (Fig. 8). At the times of daily minimum values of $T_a$, $b$ reached values between 0.17 and 0.36 at OB and between 0.12 and 0.57 at PH. The comparatively high $b$ values at the suburban station PH on 20 and 25–27 July mainly resulted from the very low wind velocity. The threshold value by Gagge et al. (1969) for thermal discomfort, which means $b > 0.25$, was always overstepped in the daytime and was sometimes overstepped at night-time. During the last 3 days of July 1987 the values of $b$ at night were remarkably lower than the days before.

Concerning the clothing of man, it can be stated according to Höppe (1984) that increased heat transfer resistance of clothing, i.e. higher values of $I_a$, decreased the values of $T_{ak}$, but increased the values of $b$. In order to minimize thermal stress due to clothing, therefore, Höppe (1984) suggested an optimum clothing with $I_a$ values between 1.0 and 1.4 clo for subtropical regions.
The heat wave in Athens in July 1987

5. AIR QUALITY CONDITIONS IN ATHENS DURING THE HEAT WAVE

During the heat wave in July 1987 air pollution in Athens was slightly lower than usual, because the population of Athens tried to escape to the shores and beaches due to the insufferable thermal stress in the city. As indicators for air pollution in Athens during the heat wave, the average daily values of the concentrations of nitrogen dioxide (NO₂), nitrogen monoxide (NO), sulphur dioxide (SO₂), ozone (O₃), dust, and carbon monoxide (CO), measured at the station 'Patisson Street' of the Greek Ministry of Environment in the centre of Athens, are listed in Table 4 for the period from 18 to 31 July 1987. For the same station, Table 4 additionally contains the mean values of NO₂, NO, SO₂, O₃, dust and CO for the whole year 1987.

For the human biometeorological assessment of the air pollution during the period of the heat wave in Athens the air quality stress index AQSI according to Baumüller et al. (1984) has been used. AQSI₁₂₄ is the air quality stress index related to a whole day and is calculated on the base of average daily concentrations of the four prevailing air pollutants:

\[ AQSI_{124} = \sum_{i=1}^{4} \frac{\text{average daily value}}{\text{MI-24 h-value}}. \]  

In Equation (2) i means the four prevailing air pollutants, which were NO₂, dust, O₃, and CO during the heat wave in Athens. As reference quantities for the average daily concentrations of air pollutants the threshold values for 24 h of these air pollutants according to the VDI standards abbreviated as MI-24h-value (VDI, 1987) have to be used in (2), because corresponding leading values of the European Community are not available. The following MI-24h-values have been used:

- NO₂: 100 µg m⁻³
- Dust: 300 µg m⁻³
- O₃: 50 µg m⁻³
- CO: 10 mg m⁻³.
Table 4. Average daily concentrations of NO₂, NO, SO₂, dust, O₃, and CO measured at the station 'Patisson Street' of the Greek Ministry of Environment in the centre of Athens during the period of 18–31 July 1987 and in addition average values for the year 1987

<table>
<thead>
<tr>
<th>Date</th>
<th>NO₂ (24h) µg m⁻³</th>
<th>NO (24h) µg m⁻³</th>
<th>SO₂ (24h) µg m⁻³</th>
<th>Dust (24h) µg m⁻³</th>
<th>O₃ (24h) µg m⁻³</th>
<th>CO (24h) mg m⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.07 (Saturday)</td>
<td>155</td>
<td>138</td>
<td>63</td>
<td>183</td>
<td>53</td>
<td>6.0</td>
</tr>
<tr>
<td>19.07 (Sunday)</td>
<td>149</td>
<td>139</td>
<td>63</td>
<td>183</td>
<td>56</td>
<td>5.7</td>
</tr>
<tr>
<td>20.07 (Monday)</td>
<td>184</td>
<td>167</td>
<td>71</td>
<td>221</td>
<td>74</td>
<td>7.5</td>
</tr>
<tr>
<td>21.07 (Tuesday)</td>
<td>107</td>
<td>105</td>
<td>51</td>
<td>130</td>
<td>96</td>
<td>5.7</td>
</tr>
<tr>
<td>22.07 (Wednesday)</td>
<td>85</td>
<td>25</td>
<td>39</td>
<td>92</td>
<td>97</td>
<td>3.5</td>
</tr>
<tr>
<td>23.07 (Thursday)</td>
<td>90</td>
<td>52</td>
<td>41</td>
<td>106</td>
<td>79</td>
<td>3.9</td>
</tr>
<tr>
<td>24.07 (Friday)</td>
<td>93</td>
<td>53</td>
<td>33</td>
<td>82</td>
<td>80</td>
<td>3.3</td>
</tr>
<tr>
<td>25.07 (Saturday)</td>
<td>122</td>
<td>119</td>
<td>48</td>
<td>143</td>
<td>64</td>
<td>4.3</td>
</tr>
<tr>
<td>26.07 (Sunday)</td>
<td>156</td>
<td>130</td>
<td>68</td>
<td>174</td>
<td>63</td>
<td>5.7</td>
</tr>
<tr>
<td>27.07 (Monday)</td>
<td>213</td>
<td>218</td>
<td>109</td>
<td>254</td>
<td>67</td>
<td>9.7</td>
</tr>
<tr>
<td>28.07 (Tuesday)</td>
<td>114</td>
<td>94</td>
<td>41</td>
<td>127</td>
<td>37</td>
<td>5.4</td>
</tr>
<tr>
<td>29.07 (Wednesday)</td>
<td>60</td>
<td>33</td>
<td>17</td>
<td>45</td>
<td>56</td>
<td>2.5</td>
</tr>
<tr>
<td>30.07 (Thursday)</td>
<td>59</td>
<td>19</td>
<td>13</td>
<td>36</td>
<td>83</td>
<td>2.4</td>
</tr>
<tr>
<td>31.07 (Friday)</td>
<td>166</td>
<td>111</td>
<td>50</td>
<td>143</td>
<td>43</td>
<td>6.6</td>
</tr>
<tr>
<td>Year 1987</td>
<td>105</td>
<td>162</td>
<td>57</td>
<td>165</td>
<td>29</td>
<td>6.7</td>
</tr>
</tbody>
</table>

Table 5. Human biometeorological assessment of the air quality stress index (AQSI) according to Baumüller et al. (1984)

<table>
<thead>
<tr>
<th>AQSI</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0–0.5</td>
<td>Barely stressed</td>
</tr>
<tr>
<td>0.5–1.0</td>
<td>Slightly stressed</td>
</tr>
<tr>
<td>1.0–1.5</td>
<td>Moderately stressed</td>
</tr>
<tr>
<td>1.5–2.0</td>
<td>Distinctly stressed</td>
</tr>
<tr>
<td>&gt; 2.0</td>
<td>Heavily stressed</td>
</tr>
</tbody>
</table>

At the base of AQSI values Baumüller et al. (1984) have suggested a human biometeorologically relevant assessment of air pollution conditions (Table 5). The results for AQSI24 during the heat wave at the Patisson Street station in the centre of Athens show values higher than 2.0, which indicate heavily stressed air quality conditions (Table 6). The highest value of AQSI24 of 5.3 was on 27 July which was also the day with the highest thermal stress values. For comparison, the annual value of AQSI in 1987, based on the 24-h mean values, is 2.9 which, for example, is considerably higher than in large cities in West Germany.

6. CONSEQUENCES OF THE HEAT WAVE FOR PEOPLE

During the period of the heat wave the mortality rate was very high and in many areas of Greece reached more than double the normal mortality for this period. Katsouyanni et al. (1988) report that between 21 and 31 July 1987, 2960 admissions were registered at the 68 hospitals in Athens, from which 926 people died because of heat stroke, heat exhaustion, or other heat-related conditions. The hospitals of Athens were overcrowded and perhaps, therefore, some fatal cases may not have been reported to hospitals. As mentioned above the heat wave probably induced more than 1000 deaths in the greater Athens area, and in addition nearly the same number of people died in the rest of Greece.

7. DISCUSSION

The weather conditions during the heat wave in July 1987 in Athens were extremely severe. Air temperature reached maximum values of 44°C and minimum values of 24°C. Therefore, there was little chance for
people in Athens to recover from the weather conditions during sleep. In addition, the vapour pressure was high, too. Global radiation had high values at this time of year and in general the wind velocity reached low values.

Regarding only the values of air temperature and vapour pressure, they were no longer typical for a Mediterranean climate but for a mixture of desert and humid tropical.

The human biometeorological assessment of the heat wave by use of the indices PMV and PET, which consider all thermo-physiologically relevant meteorological and human parameters, indicates very high heat stress for human beings in the daytime. Heat stress was a little higher in the suburban regions of Athens due to the lightly built-up areas, resulting in more effective global radiation. At night-time thermal stress on people did reduce, but was still assessed as moderate, which means that recovery was not possible. At night thermal stress on people was slightly higher in the centre of Athens than in the suburban regions due to the heat island effect. Altogether, the results show that the heat wave in Athens in July 1987 was an event caused by synoptic weather conditions. The heat wave itself was only slightly modified by the different urban structures in Athens.

An advantage of the assessment of the thermal environment by use of PMV represents at the same time a disadvantage of the application of PET. By use of PMV graduated descriptions can be obtained, whereas an analogous graduated system is still missing by PET. The advantage of PET, however, is the description of the thermal environment in relation to a high number of experienced indoor climates (Mayer, 1990).

Compared with DI the results for PMV and PET show a better accuracy. Further, DI values in the daytime reveal smaller differences between the stations PH and OB in Athens than the values for PMV and PET. In addition, for both stations in Athens the differences of the DI values between daytime and night-time are also smaller than for the PMV and PET values. The reasons for these features lie in the definition of DI by Thom (1959). The estimation of DI is confined to air temperature and air humidity and does not take into consideration other meteorological parameters such as mean radiation temperature $T_{\text{r}}$ or wind velocity $v$ which are very important for human appreciation of the thermal environment, and therefore represent input parameters in models for the human energy balance. Here, the greatest effect is initiated by $T_{\text{r}}$.

During the heat wave in July 1987 in Athens air quality stress on people also occurred which represented an additional stress for humans. Air quality conditions are not to be considered separately in the discussion of the next heat wave in Greece in July 1988 by Giles et al. (1990), as well as Giles and Balafoutis (1990), but a similar high air quality stress in Athens can be assumed for that time. The consequence is that stress to humans in Athens due to environmental conditions is caused by permanent air quality stress and temporary heat stress.

REFERENCES


