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Human-Biometeorological Effects on Sleep Disturbances in Athens, Greece: A Preliminary Evaluation

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**Key Words**
Sleep disturbances · Minimum air temperature · Thermal indices · Athens

**Abstract**
The aim of this study was to examine the effects of the daily minimum air temperature and human-biometeorological variables, as well as their day-to-day changes, on sleep disturbances (SD) in the inhabitants of Athens, Greece. The SD dataset used for the analysis included the daily records of the psychiatric emergency unit of the Athens University Medical School for the years 1989 (with mild thermal load) and 1994 (with heavy thermal load). The meteorological variables for the estimation of the thermal indices were recorded by the meteorological station of Hellenikon, which is located at the headquarters of the Hellenic National Weather Service. The mean radiant temperature ($T_{\text{mrt}}$) and the thermal indices predicted mean vote (PMV), physiologically equivalent temperature (PET) and standard effective temperature (SET*) have been analyzed.

The first step was to assess the SD frequencies as a function of the meteorological and human-biometeorological variables on the basis of 10-day intervals to determine the influence of the examined variables on SD. The daily SD records were included as Poisson random variables in the applied Generalized Linear Models (GLM). The extracted results suggested that a considerable increase in SD existed in 1994 compared to 1989. This was due to the many consecutive days with heavy thermal load (PET $>35^\circ$C and $T_{\text{min}} > 23^\circ$C) in 1994 compared to the lack of such days in 1989. Furthermore, statistically significant ($p<0.01$) positive relationships were found between minimum air temperature, all thermal indices and SD.

**Introduction**
The quality and quantity of sleep have commonly been associated with weather variables, such as solar flux,
influx of new air masses, barometric pressure, air
temperature and air humidity [1–3] and other environ-
mental factors, such as electromagnetic fields, heat and
noise exposure. Pandey et al. [4] studying the meteorologic
factors and the subjective sleep continuity, found that
high barometric pressure, low precipitation and lower
temperatures were significantly correlated with good sleep
continuity. Sher [5] suggests that the development of sleep
abnormalities in persons exposed to artificial electromag-
netic fields may predict the onset of a psychiatric disorder
at a later time. Libert et al. [6] studied the relative and
combined effects of heat and noise exposure on sleep in
humans and showed that, in both objective and subjective
measures, sleep was more disturbed by heat than by noise.
The high thermal load at night-time resulted in a reduced
total sleep time and in an increased sleep disruption, while
increased noise at night only influenced the total number
of sleep-stage changes.

On the other hand, ambient temperature represents an
important factor for human sleep [7,8]. It has been
suggested [9] that ambient temperature above the thermo-
neutral zone increases wakefulness and decreases slow-
wave sleep (SWS) and rapid eye movement sleep (REM).
Cool temperatures are generally a more disruptive factor
for sleep than warm temperatures, while most sleep
disruptions occur at 21°C [9]. Previous experiments have
shown that sleep time peaks at neutral ambient tempera-
ture [10], while decreases in air temperature affect SWS
and REM sleep stages more frequently than did the air
temperature increases [11]. Teramoto et al. [12] found out
that subjective sleep sensation was better when the room
temperature was first reduced from 27°C to 25.5°C over
4 h and then increased from 25.5°C to 27°C over 4 h.
Another study showed that young men suffered from
shorter total sleep time, more frequent and longer
disruptions, greater shifting between sleep stages and
delayed onset to deep sleep when exposed to intense heat
with an electric blanket at 39°C [13]. Increased relative
humidity (75%) at room temperature of 35°C led to more
disruption and a lower sleep efficiency index (SEI) [14].
For older men, even mild heat exposure during night-time
can increase the thermal load, suppress the decrease of
rectal temperature, decrease REM, increase sleep disrup-
tion and whole-body sweating. The percentage of REM
and SEI declined, while the number of sleep disruptions
and the overall percentage of wakefulness increased at
32°C, indicating inefficient and fragmented sleep [15].
Such increased wakefulness is the stereotypical effect
observed under heavy thermal load [16]. Furthermore,
the total time that people are awake is significantly
increased in a hot and humid climate (air temperature
32°C and relative humidity 80%), while the use of air
conditioning in the initial sleep hours can improve
sleep and thermoregulation [17]. Libert et al. [18], studying
the effect of continuous heat exposure on sleep stages
in humans, concluded that the protective mechanisms of
deep body temperature occurring with heat adaptation did
not interact with sleep processes.

The focus of this study was the analysis of the effects of
thermal indices and minimum air temperature on sleep
disturbances (SD) over two years with different recorded
thermal conditions, 1989 (mild thermal conditions) and
1994 (intense thermal conditions), in Athens Greece.

Data and Analysis

Two large samples of 826 and 1400 admissions for SD,
obtained from the daily records of the psychiatric
emergency unit of Eginition Hospital of the Athens
University Medical School during the years 1989 and
1994 respectively, have been analyzed. The SD dataset
did not include cases with respect to organic or respiratory
problems. The meteorological data used for the estimation
of thermal indices included daily mean air temperature,
relative humidity, wind speed and total cloud cover,
recorded by the meteorological station of Hellenikon,
which is located at the headquarters of the Hellenic
National Weather Service (longitude: 23° 44'E, latitude:
37° 54' N, altitude: 28 m amsl).

The thermal indices used in this study are PET
(physiological equivalent temperature), which is based on
the MEMI model [19], PMV [20,21] and SET* [22]. The
radiation and bioclimate RayMan model [23], which is
based on the VDI-guidelines 3787 and 3789 [24,25] has
been used for the calculations of the thermal indices, which
are dependent on the daily values of air temperature,
absolute humidity, wind speed, solar radiation, and
cloudiness. The indices mean radiant temperature (T
mrt), predicted mean vote (PMV), physiologically equivalent
temperature (PET) and standard effective temperature
(SET*) are analyzed here.

To determine the physiological damage, classes accord-
ing to the PET-values [26] have been chosen (Table 1).
Accordingly, daily weather conditions with PET >35°C
and night conditions with T
min >23°C tend to be harmful.

In order to determine the relationship between the
admissions of SD and the aforementioned meteorological
and human-biometeorological variables, we applied
Generalized Linear Models (GLM), described by
The aim is to model the distribution of a stochastic variable, \( y \), in terms of stimulus variables \( x_1, x_2, \ldots, x_p \) or known mathematical functions of them.

- The distribution of \( y \) depends on the stimulus variables through a single linear predictor: \( n = \sum_{j=1}^{p} x_j \beta_j \), where, in general, the \( x_j, s \) are known mathematical functions of the stimulus variables, not necessarily simply the variables themselves.

- The mean of \( y \) is related to \( n \) by a known function called the link function:

\[
E[y] = m = \varphi^{-1}(n), \quad n = l(m)
\]

Note that the link function transforms the mean into the linear predictor and not the other way round. Hence it acts in the same direction as a transformation of the response itself, from which the idea arose.

- The variance of \( y \) is a function of the mean: \( \operatorname{Var}[y] = \phi(v(\mu))/A \) where \( \phi \) is a possibly unknown, positive scale parameter, \( A \) is a known prior weight, and \( v(\mu) \) is a known function of \( \mu \) called the variance function.

Table 1. Ranges of the thermal indexes predicted mean vote (PMV) and physiological equivalent temperature (PET) for different grades of thermal perception by human beings and physiological stress on human beings

<table>
<thead>
<tr>
<th>PMV</th>
<th>PET (°C)</th>
<th>Thermal perception</th>
<th>Grade of physiological stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3.5</td>
<td>4</td>
<td>Very cold</td>
<td>Extreme cold stress</td>
</tr>
<tr>
<td>-2.5</td>
<td>8</td>
<td>Cold</td>
<td>Strong cold stress</td>
</tr>
<tr>
<td>-1.5</td>
<td>13</td>
<td>Cool</td>
<td>Moderate cold stress</td>
</tr>
<tr>
<td>-0.5</td>
<td>18</td>
<td>Slightly cool</td>
<td>Slight cold stress</td>
</tr>
<tr>
<td>0.5</td>
<td>23</td>
<td>Comfortable</td>
<td>No thermal stress</td>
</tr>
<tr>
<td>1.5</td>
<td>29</td>
<td>Slightly warm</td>
<td>Slight heat stress</td>
</tr>
<tr>
<td>2.5</td>
<td>35</td>
<td>Warm</td>
<td>Moderate heat stress</td>
</tr>
<tr>
<td>3.5</td>
<td>41</td>
<td>Hot</td>
<td>Strong heat stress</td>
</tr>
</tbody>
</table>

The components of a GLM are as follows:

- The distribution of \( y \) has a density of known form, namely

\[
f_Y(y; \mu, \phi) = \exp \left[ \frac{A}{\phi} (y \theta(\mu) - \gamma(\theta(\mu))) \right] + \tau \left( y, \frac{\phi}{A} \right)
\]

This distributional form can be shown to include the normal, gamma, Poisson and binomial distributions, as well as several others such as beta, inverse Gaussian and negative binomial. Note that the relationship between the canonical parameter \( \theta \), and the mean, \( \mu \), will depend on the particular distribution, and the relationship between \( \mu \) and \( n \) is defined by the link function. The link function establishes the connection between the linear predictor, \( n \), and the mean of the distribution \( \mu \). There is a so-called ‘natural link’ for each distribution. It is important to note that although the link function is in some way similar to a transformation function, it only establishes a mathematical connection between the mean and the response variables. A transformation function when applied to observations may be intended to stabilize the variance. It may also achieve other goals such as to stabilize the variance.

The natural link for the Poisson distribution is the log link: \( \eta = \log(\mu) \), \( \mu = e^\eta \), the variance function is \( v(\mu) = \mu \) and as in the case of the binomial distribution, the scale parameter is \( 1 \). Poisson models with log links are often called log-linear models and are used for frequency data.

In the models fitting procedure we used as dependent variable the daily records of SD, filed by the psychiatric emergency unit of Eginition Hospital of the Athens University Medical School, while as independent co-variates the aforementioned meteorological and biometeorological parameters were included. Models’ goodness-of-fit was evaluated through deviance residuals [27].

Results and Discussion

In order to establish how mild and hot thermal environments influence sleeping patterns, we evaluated the consecutive days (three and more) with PET > 35°C, and with \( T_{\min} > 23°C \) for the period 1955–2001, along with the polynomial fitting, in Hellenikon/Athens station.

With regards to the total number of days with PET > 35°C, there is a tremendous differentiation for the two years (Figure 1). In 1994, the total number of days reached 37 (in four episodes with 5, 4, 6 and 6 consecutive days, respectively), while only 3 days appeared in 1989 (with no episodes with consecutive days).
The total number of days with $T_{\text{min}} > 23^\circ\text{C}$ reaches 34 (in four episodes with 5, 3, 4 and 3 consecutive days, respectively) in 1989, while it increases to 52 (in eight episodes with 3, 6, 4, 6, 5, 8, 7 and 3 consecutive days, respectively) in 1994 (Figure 2).

The heat stress periods mainly occurred during summer and affected the total amount of sleep disruptions as illustrated in Figure 3. The frequency (%) of the SD per 10-day interval is shown as a function of PET classes, along with the variation of the total number of admissions per 10-day interval. The cases of SD exceed the limits of mean $\pm 2\text{sd}$ (sd: standard deviation) especially on days with heavy thermal load (PET $>35^\circ\text{C}$).

It is demonstrated that cases of SD also exceed the lower limit of the mean $-2\text{sd}$ during intense cold conditions (PET $<4^\circ\text{C}$).

In the second stage, we examined how the covariate minimum air temperature influences SD. Heat stress conditions appear at a high level of $T_{\text{min}}$ during the night and influence sleep quality and quantity. This is
especially the case in old men, since the thermoregulation during heat exposure also changes with ageing [15]. The capability to preserve core body temperature [29–31] and the sweating response [30,32] during heat exposure seem to be reduced, although other results object this conclusion [33].

The influence of the thermal environment, especially at night, on SD is shown in Figure 4, where the frequency (%) of sleep disturbances per 10-day interval as a function of PET classes, along with the variation of the total number of admissions per 10-day interval (yellow line), the polynomial fitting (brown line) and the mean, mean $\pm$ 2sd, mean $-$ 2sd (white lines), during the year 1989 (upper panel) and the year 1994 (lower panel).
of the SD per 10-day interval are illustrated as a function of $T_{\text{min}}$ quartiles, along with the variation of the total number of admissions per 10-day interval. The cases of SD exceed the mean $+2\sigma$ especially during the days that correspond to the upper quartiles of $T_{\text{min}}$ ($T_{\text{min}} > 19.6^\circ\text{C}$ [1989], $T_{\text{min}} > 20.6^\circ\text{C}$ [1994]), whereas SD episodes fall below the mean $-2\sigma$ during days within the lower quartiles of $T_{\text{min}}$ ($T_{\text{min}} < 9.2^\circ\text{C}$ [1989], $T_{\text{min}} < 14.4^\circ\text{C}$ [1994]).

![Figures showing frequency of sleep disturbances and total number of admissions](image-url)
We then applied GLM to the variables examined. The relationships between SD and the meteorological and human-biometeorological co-variates appeared to be statistically significant. Interpreting the results extracted by the GLM and considering that the response variable is Poisson distributed, we can suggest that there is a positive correlation between all variables and SD (Table 2).

An increase of 1°C in the meteorological index PMV seems to be related with SD more than the other indices do. An increase by 1 unit in PMV is associated with an 8.5% (6.8%) increase in the probability of suffering from SD in 1989 (1994). The thermal index PMV seems to be related with SD more than the other indices do. An increase by 1 unit in PMV is associated with an 8.5% (6.8%) increase in the probability of suffering from SD in 1989 (1994). Regarding the thermal environment, when applying the same thermal conditions (PET > 35°C, SET > 23°C) seemed to have a significant influence on SD, the analysis resulted in similar findings, that is for the year 1994, the risk doubled (odds ratio = 1.95, 95% CI 0.609–6.234, significant level = 0.001) of observing the daily number of SD admissions in the upper quartile (i.e., > 4 cases with SD per day) compared to the lower quartile (i.e., < 2 cases with SD per day). This is in agreement with Libert et al. [18], who suggested that the effect of a hot environment on sleep stages does not decrease under continuous heat exposure over time. Besides, heat stress during sleep increases sleep disruption and reduces SWS and REM [9,13,14].

In 1989, moderate to heavy thermal load (PET > 30°C) was linked to a 5-fold increase in the risk (odds ratio = 4.636, 95% CI 1.837–11.699, significant level = 0.01). Regarding the T_{min} influence on SD, the analysis resulted in similar findings, that is for the year 1994, the risk doubled (odds ratio = 1.95, 95% CI 0.609–6.234, significant level = 0.001) of observing the daily number of SD admissions in the upper quartile (i.e., > 4 cases with SD per day) compared to the lower quartile (i.e., 1 case with SD per day). In contrast to the year 1994, where a moderate to heavy thermal load (PET > 30°C) was linked to a 5-fold increase in the relative risk (odds ratio = 4.636, 95% CI 1.837–11.699, significant level = 0.01). Taking into account the results extracted by the risk analysis, we suggest that with a mild thermal environment, the SD events develop more abruptly compared to a hot thermal environment, when applying the same thermal threshold.

### Table 2. Results from the Generalized Linear Models for the evaluation of the effect of thermal indices and T_{min} on the development of sleep disturbances (shaded parameters are statistically significant at \( p<0.001 \))

<table>
<thead>
<tr>
<th></th>
<th>b coefficient ± SE</th>
<th>Significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1989</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( T_{\text{mrt}} ) (°C)</td>
<td>0.016 ± 0.004</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta T_{\text{mrt}} ) (°C)</td>
<td>0.000 ± 0.015</td>
<td>0.963</td>
</tr>
<tr>
<td>PMV</td>
<td>0.082 ± 0.019</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta PMV )</td>
<td>0.028 ± 0.054</td>
<td>0.597</td>
</tr>
<tr>
<td>PET (°C)</td>
<td>0.017 ± 0.004</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta PET ) (°C)</td>
<td>0.005 ± 0.009</td>
<td>0.585</td>
</tr>
<tr>
<td>SET (°C)</td>
<td>0.019 ± 0.005</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta SET ) (°C)</td>
<td>0.007 ± 0.010</td>
<td>0.498</td>
</tr>
<tr>
<td>( T_{\text{min}} ) (°C)</td>
<td>0.021 ± 0.006</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta T_{\text{min}} ) (°C)</td>
<td>-0.018 ± 0.017</td>
<td>0.300</td>
</tr>
<tr>
<td>1994</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( T_{\text{mrt}} ) (°C)</td>
<td>0.012 ± 0.003</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta T_{\text{mrt}} ) (°C)</td>
<td>-0.002 ± 0.012</td>
<td>0.856</td>
</tr>
<tr>
<td>PMV</td>
<td>0.066 ± 0.014</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta PMV )</td>
<td>0.044 ± 0.038</td>
<td>0.255</td>
</tr>
<tr>
<td>PET (°C)</td>
<td>0.013 ± 0.003</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta PET ) (°C)</td>
<td>0.008 ± 0.006</td>
<td>0.207</td>
</tr>
<tr>
<td>SET (°C)</td>
<td>0.016 ± 0.003</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta SET ) (°C)</td>
<td>0.009 ± 0.008</td>
<td>0.244</td>
</tr>
<tr>
<td>( T_{\text{min}} ) (°C)</td>
<td>0.015 ± 0.004</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>( \Delta T_{\text{min}} ) (°C)</td>
<td>-0.012 ± 0.012</td>
<td>0.321</td>
</tr>
</tbody>
</table>

This might be due to the short-term acclimatisation effect that happened in the year 1994, where the incidence of a great number of consecutive days with very hot conditions (PET > 35°C, \( T_{\text{min}} > 23°C \)) had already increased the level of the SD average from 22.9 to 38.9 per 10-day interval. Thereafter, extreme peaks in SD happened less often compared to 1989. The variability of SD is higher in 1989 than in 1994, as illustrated in Figures 3 and 4, where the variation of the total number of SD per 10-day interval is also shown.

In 1994, heavy thermal load (PET > 34°C) seemed to double the risk (odds ratio = 2.00, 95% CI 0.679–5.894, significant level = 0.209) of observing the daily number of SD admissions in the upper quartile (i.e., > 5 cases with SD per day) compared to the lower quartile (i.e., < 2 cases with SD per day). This is in agreement with Libert et al. [18], who suggested that the effect of a hot environment on sleep stages does not decrease under continuous heat exposure over time. Besides, heat stress during sleep increases sleep disruption and reduces SWS and REM [9,13,14].
environment (as shown here for the year 1989) the risk factor for the occurrence of SD is manifold to the equivalent risk factor under an intense thermal environment (as shown for the year 1994), when applying the same thresholds of the meteorological and human-biometeorological variables. Furthermore, even in periods with heavy thermal load, patients suffering from SD do not seem to adapt to the conditions over time.

The human-biometeorological variables used (PET, PMV, $T_{\text{mrt}}$ and SET*) are statistically associated with SD in the same way. A change of one unit in PMV corresponds to about five units in PET or SET*.

Notwithstanding the fact that human-biometeorological indices are related to SD, it has to be determined whether these effects represent direct associations with respect to body thermoregulation.

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References