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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_{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°C and $T_{min} > 23$°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,

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influx of new air masses, barometric pressure, air temperature and air humidity [1–3] and other environmental 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 electromagnetic 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 thermoneutral 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 temperature [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 may increase the thermal load, suppress the decrease of rectal temperature, decrease REM, increase sleep disruption 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 according 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

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

PMV	PET (°C)	Thermal perception	Grade of physiological stress
		Very cold	Extreme cold stress
–3.5	4		
		Cold	Strong cold stress
–2.5	8		
		Cool	Moderate cold stress
–1.5	13		
		Slightly cool	Slight cold stress
–0.5	18		
		Comfortable	No thermal stress
0.5	23		
		Slightly warm	Slight heat stress
1.5	29		
		Warm	Moderate heat stress
2.5	35		
		Hot	Strong heat stress
3.5	41		
		Very hot	Extreme heat stress

McGullagh and Nelder [27]. The class of models known as Generalized Linear Models, or GLMs, was formally introduced by Nedler and Wedderburn [28]. The components of a GLM are as follows:

- The aim is to model the distribution of a stochastic response 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:

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

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: $\mathrm{Var}[y] = \varphi \upsilon(\mu)/A$ where φ is a possibly unknown, positive *scale parameter*, A is a known *prior weight*, and $\upsilon(\mu)$ is a known function of μ called the *variance function*.
- The distribution of y has a density of known form, namely

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

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 θ, and the mean, μ, will depend on the particular distribution, and the relationship between μ 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 μ. 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 simplify the connection between the mean and the response variables. It may also achieve other goals such as to stabilize the variance. The natural link for the Poisson distribution is the log link: $n = \log(\mu)$, $\mu = e^n$, the variance function is $\upsilon(\mu) = \mu$ 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).

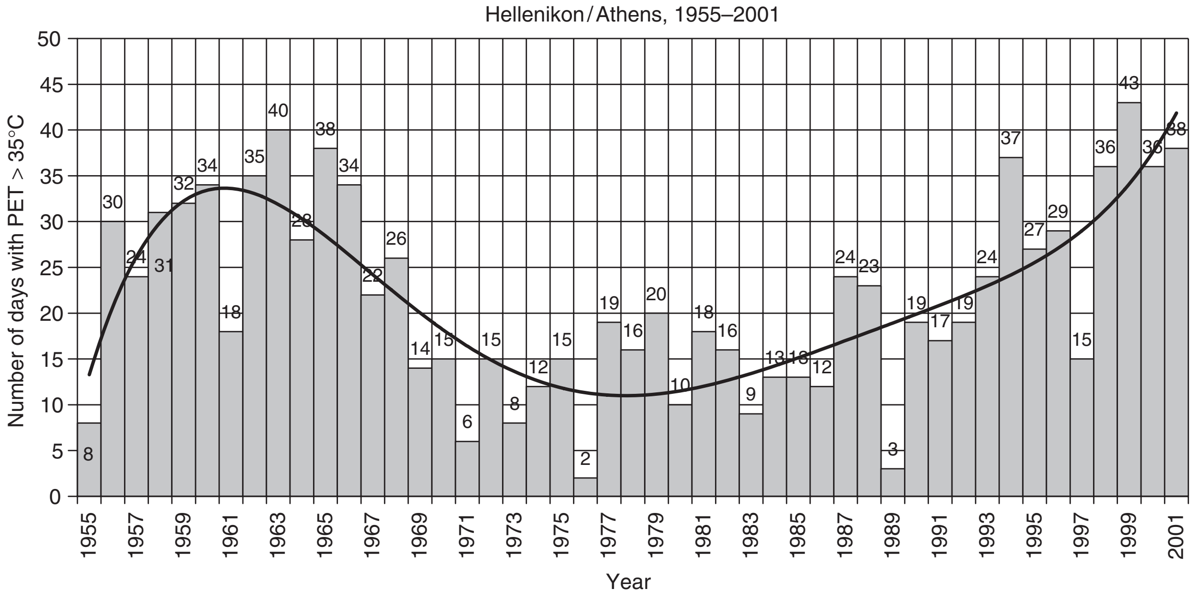

Fig. 1. Number of days with PET > 35°C for Hellenikon/Athens, during the period 1955–2001, along with the polynomial fitting.

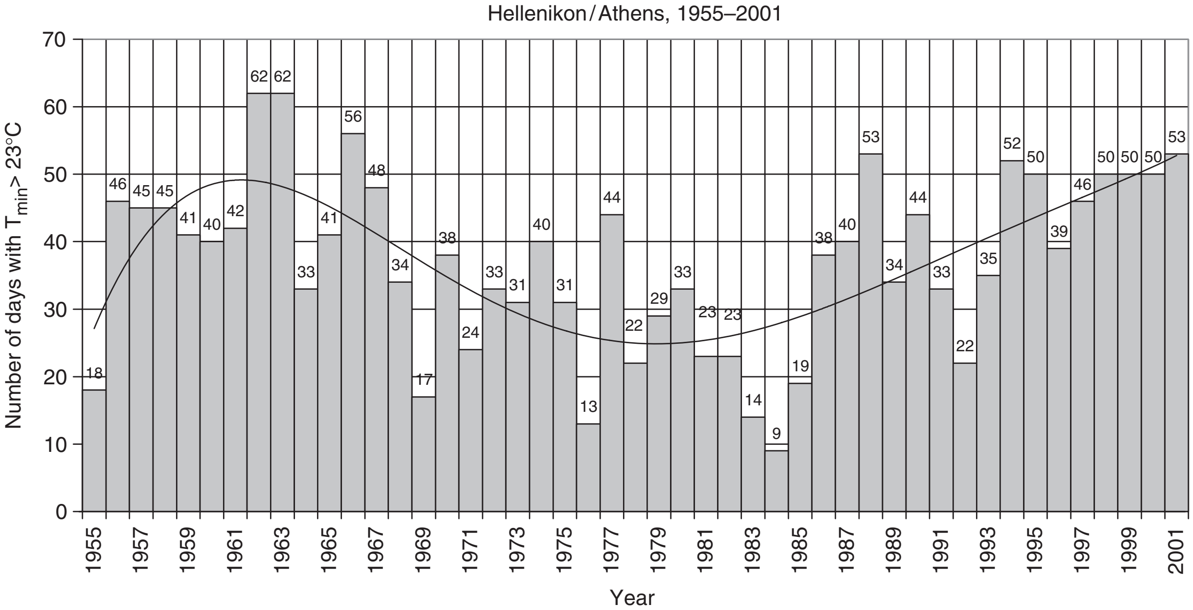

Fig. 2. Number of days with $T_{min} > 23°C$ for Hellenikon/Athens, during the period 1955–2001, along with the polynomial fitting.

The total number of days with $T_{min} > 23°C$ 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 + 2sd (sd: standard deviation) especially on days with heavy thermal load (PET > 35°C). It is demonstrated that cases of SD also exceed the lower limit of the mean − 2sd during intense cold conditions (PET < 4°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_{min} during the night and influence sleep quality and quantity. This is

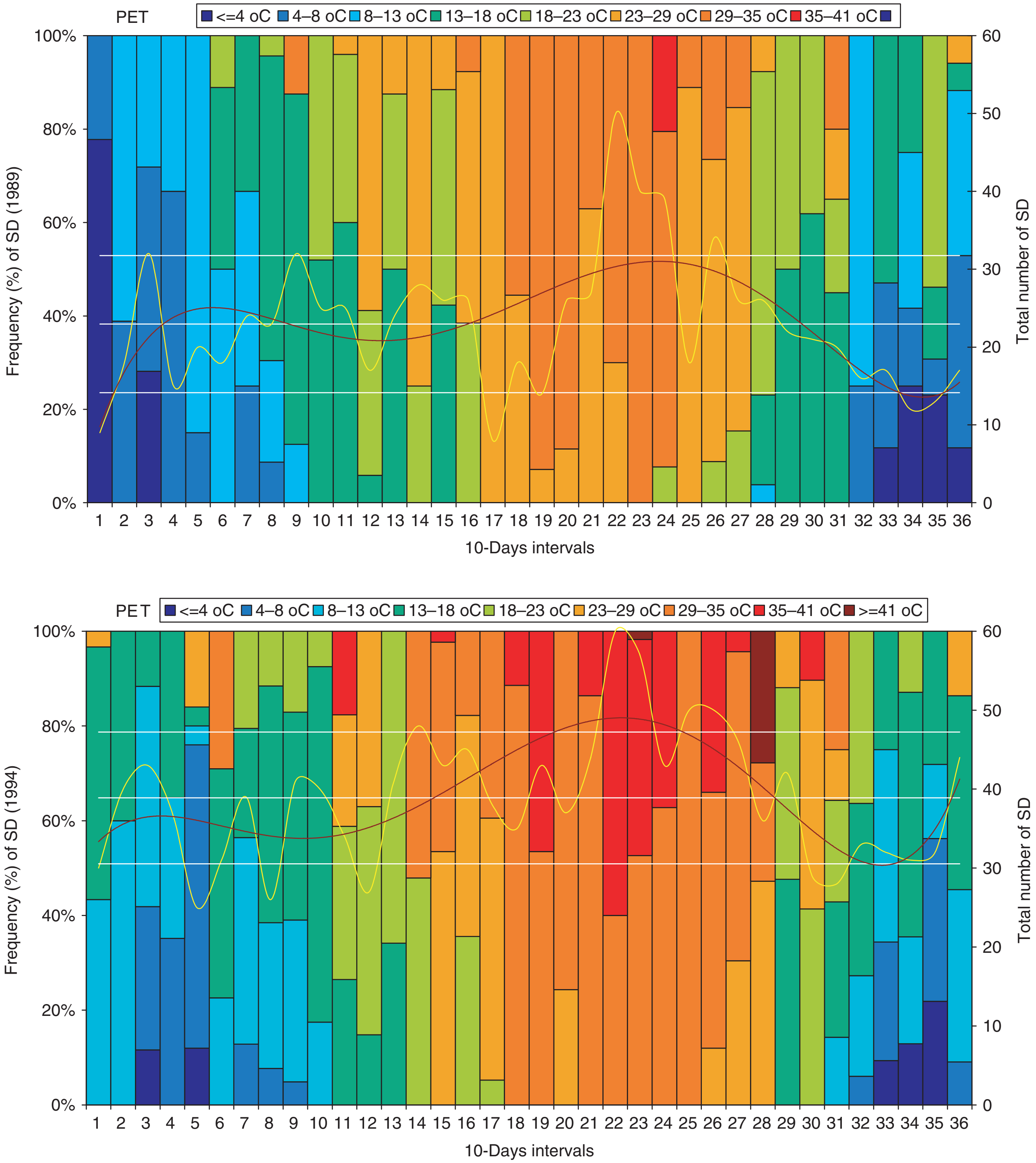

Fig. 3. Frequency (%) of sleep disturbances per 10-day interval as a function of PET classes, along with the variation of the total number of admissions per 10-day interval (yellow line), the polynomial fitting (brown line) and the mean, mean + 2sd, mean – 2sd (white lines), during the year 1989 (upper panel) and the year 1994 (lower panel).

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 (%)

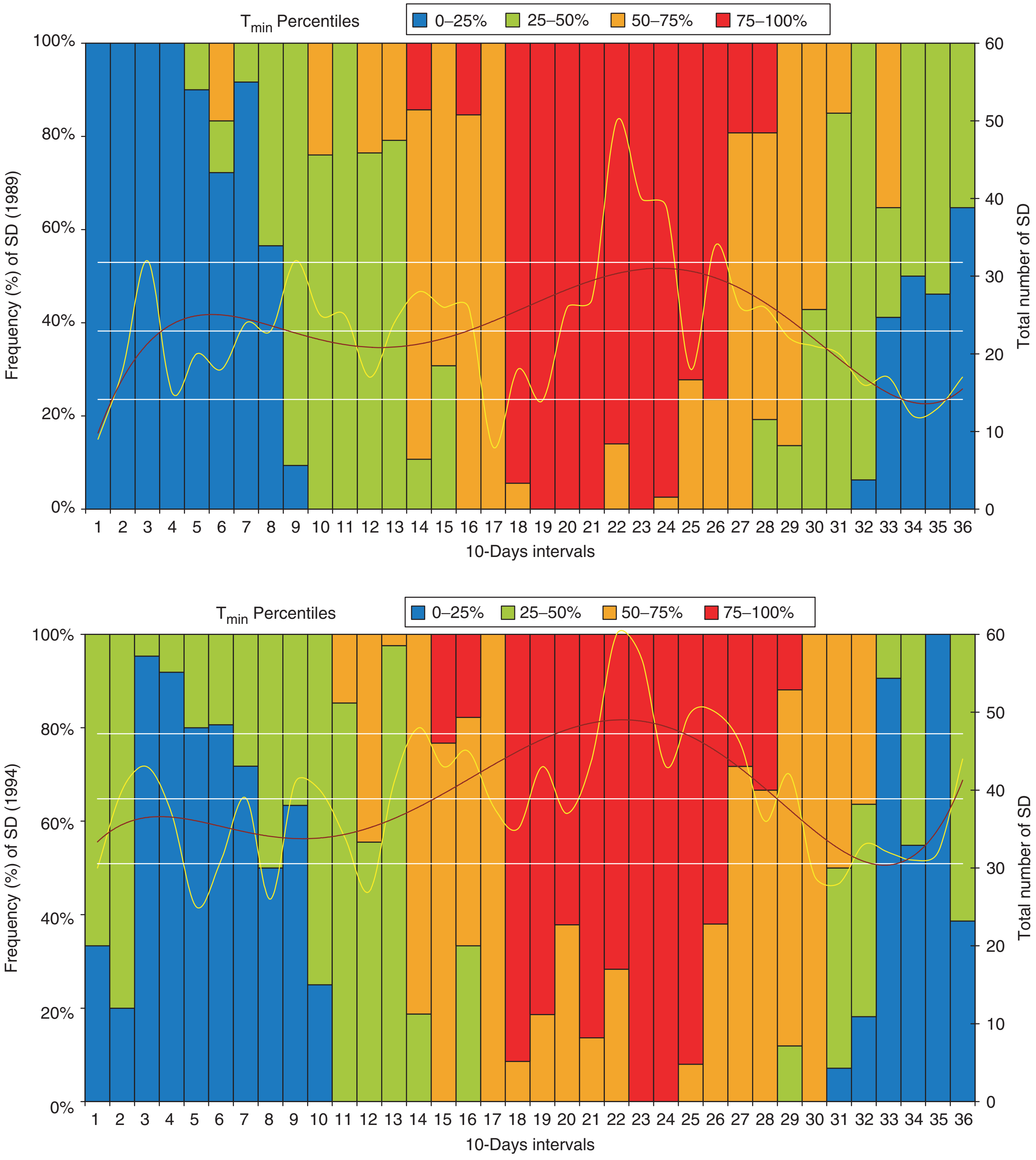

Fig. 4. Frequency (%) of sleep disturbances per 10-day interval as a function of T_{min} percentiles, along with the variation of the total number of admissions per 10-day interval (yellow line), the polynomial fitting (brown line) and the mean, mean + 2sd, mean – 2sd (white lines), during the year 1989 (upper panel) and the year 1994 (lower panel).

of the SD per 10-day interval are illustrated as a function of T_{min} quartiles, along with the variation of the total number of admissions per 10-day interval. The cases of SD exceed the mean + 2sd especially during the days that correspond to the upper quartiles of T_{min}($T_{min} > 19.6°C$ [1989], $T_{min} > 20.6°C$ [1994]), whereas SD episodes fall below the mean – 2sd during days within the lower quartiles of T_{min} ($T_{min} < 9.2°C$ [1989], $T_{min} < 14.4°C$ [1994]).

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 $p < 0.001$)

	b coefficient ± SE	Significance level
	1989	
T_{mrt} (°C)	0.016 ± 0.004	<0.001
ΔT_{mrt} (°C)	0.000 ± 0.015	0.963
PMV	0.082 ± 0.019	<0.001
ΔPMV	0.028 ± 0.054	0.597
PET (°C)	0.017 ± 0.004	<0.001
ΔPET (°C)	0.005 ± 0.009	0.585
SET (°C)	0.019 ± 0.005	<0.001
ΔSET (°C)	0.007 ± 0.010	0.498
T_{min} (°C)	0.021 ± 0.006	<0.001
ΔT_{min} (°C)	-0.018 ± 0.017	0.300
	1994	
T_{mrt} (°C)	0.012 ± 0.003	<0.001
ΔT_{mrt} (°C)	-0.002 ± 0.012	0.856
PMV	0.066 ± 0.014	<0.001
ΔPMV	0.044 ± 0.038	0.255
PET (°C)	0.013 ± 0.003	<0.001
ΔPET (°C)	0.008 ± 0.006	0.207
SET (°C)	0.016 ± 0.003	<0.001
ΔSET (°C)	0.009 ± 0.008	0.244
T_{min} (°C)	0.015 ± 0.004	<0.001
ΔT_{min} (°C)	-0.012 ± 0.012	0.321

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 T_{mrt} links to an 1.6% (1.2%) 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 other indices and the minimum air temperature, Table 2 shows that an increase of 1°C results in 1.7% (1.3%), 1.9% (1.6%) and 2.1% (1.5%) of the probability of suffering from SD in 1989 (1994), for PET, SET* and T_{min} respectively. The day-to-day changes of the used variables do not seem to be significantly correlated with SD.

The b-coefficient extracted (Table 2) was greater in 1989 (mild thermal conditions) than in 1994 (intense thermal conditions), that is the higher the thermal load, the lesser the association among the meteorological and human-biometeorological variables and the SD. 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, $T_{\mathrm{min}} > 23$°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].

In 1989, moderate to heavy thermal load (PET > 30°C) was linked to a 7-fold increase in the risk (odds ratio = 6.583, 95% CI 2.138–20.273, 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).

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 = 0.261), while for the year 1989 the risk seemed to be increased 5-fold (odds ratio = 4.99, 95% CI 1.496–16.653, significant level = 0.009). Taking into account the results extracted by the risk analysis, we suggest that with a mild thermal environmental, the SD events develop more abruptly compared to a hot thermal environment, when applying the same thermal threshold.

Conclusions

The results of this analysis suggest that there is a significant positive relationship between the human-biometeorological indices and minimum air temperature with SD for the two years examined. In a mild thermal 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_{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

1 Faust V, Hole G: Weather-dependent sleep disturbances in psychiatric patients: Psychiatr Clin (Basel) 1972;5(5):265–288.

2 Hentschel HD: Climate, weather, noise and sleep disturbances (Klima, wetter, larm und schlafstotorungen): Diagnostik 1976;9(16): 527–529 (in German).

3 Whitton JL, Kramer P, Eastwood R: Weather and infradian rhythms in self-reports of health, sleep and mood measures: J Psychosom Res 1982;26(2):231–235.

4 Pandey J, Grandner M, Crittenden C, Smith MT, Perlis ML: Meteorologic factors and subjective sleep continuity: a preliminary evaluation: Int J Biometeorol 2005;49:152–155.

5 Sher L: The effects of natural and man-made electromagnetic fields on mood and behavior: the role of sleep disturbances: Med Hypotheses 2000;54(4):630–633.

6 Libert JP, Bach V, Johnson LC, Ehrhart J, Wittersheim G, Keller D: Relative and combined effects of heat and noise exposure on sleep in humans: Sleep 1991;14(1):24–31.

7 Muzet A, Libert JP, Candas V: Ambient temperature and human sleep: Experientia 1984;40(5):425–429.

8 Glotzbach SF, Heller HC: Temperature regulation: in Kryger MH, Roth T, Dement WC (eds), Principles and Practice of Sleep Medicine. Saunders, New York, 1999, pp. 289–304.

9 Haskell E, Palca JW, Walker JM, Berger RJ, Heller HC: The effects of high and low ambient temperatures on human sleep stages: Electro Clin Neurophysiol 1981;51:494–501.

10 Parmeggiani PL: Influence of the temperature signal on sleep in mammals: Biol Signal Recept 2000;9(6):279–282.

11 Candas V, Libert JP, Muzet A: Heating and cooling stimulations during SWS and REM sleep in man: J Therm Biol 1982;7(3):155–158.

12 Teramoto Y, Tokura H, Ioki I, Suho S, Inoshiri R, Masuda M: The effect of room temperature on rectal temperature during night sleep: J Therm Biol 1998;23(1):15–21.

13 Karacan I, Thornby JI, Anch AM: Effects of high ambient temperature on sleep in young men: Aviat Space Envir Md 1978;49(7): 855–860.

14 Okamoto-Mizuno K, Mizuno K, Michie S, Maeda A, Lizuka S: Effects of humid heat exposure on human sleep stages and body temperature: Sleep 1999;22(6):767–773.

15 Okamoto-Mizuno K, Tsuzuki K, Mizuno K: Effects of mild heat exposure on sleep stages and body temperature in older men: Int J Biometeorol 2004;49(1):32–36.

16 Parmeggiani PL: Interaction between sleep and thermoregulation: an aspect of the control of behavioural states: Sleep 1987;10:426–435.

17 Okamoto-Mizuno K, Tsuzuki K, Mizuno K: Effects of humid heat exposure in later segments on sleep stages and body temperature in humans: Int J Biometeorol 2005;49(4): 232–237.

18 Libert JP, Di Nisi J, Fukuda H, Muzet A, Ehrhart J, Amoros C: Effect of continuous heat exposure on sleep stages in humans: Sleep 1988;11:195–209.

19 Höppe P: The physiological equivalent temperature – a universal index for the biometeorological assessment of the thermal environment: Int J Biometeorol 1999; 43:71–75.

20 Fanger PO: Thermal Comfort, New York, McGraw Hill, 1972.

21 Jendritzky G, Menz G, Schirmer H, Schmidt-Kessen W: Methodik zur raumbezogenen Bewertung der thermischen Komponente im Bioklima des Menschen (Fortgeschriebenes Klima-Michel-Modell): Beitr Akad Raumforsch Landesplan No. 114, 1990.

22 Gagge AP, Fobelets AP, Berglund LG: A standard predictive index of human response to the thermal environment: ASHRAE Trans 1986;92:709–731.

23 Matzarakis A, Rutz F, Mayer H: Estimation and calculation of the mean radiant temperature within urban structures: in de Dear RJ, Kalma JD, Oke TR, Auliciems A (eds) Selected Papers from the Conference ICB-ICUC'99, Sydney: WCASP-50, WMO/TD No. 1026, 2000, pp. 273–278.

24 VDI: Interactions between atmosphere and surfaces. Calculation of short-wave and long-wave radiation. VDI guideline 3789, Part 2, Blatt 2. Beuth, Berlin, 1992.

25 VDI: Methods for the human-biometerological assessment of climate and air hygiene for urban and regional planning. Part I: Climate, VDI guideline 3787, Part 2, Beuth, Berlin, 1998.

26 Matzarakis A, Mayer H: Another kind of environmental stress: Thermal stress: WHO Newsletter 1998;18:7–10.

27 McGullagh P, Nelder JA: Generalized Linear Models. 2nd edn, Chapman & Hall, 1997, p. 450.

28 Nedler JA, Wedderburn RWM: Generalized linear models: J Roy Stat Soc Ser A 1972;135: 370–384.

29 Sagawa S, Shiraki K, Mohamed K, Miki K: Sweating and cardiovascular responses of aged men to heat exposure: J Gerontol 1988;43: M1–M8.

30 Inoue Y, Nakao M, Araki T, Murakami H: Regional differences in the sweating responses of older and younger men: J Appl Physiol 1991;71:2453–2459.

31 Inoue Y: Longitudinal effects of age on heat-activated sweat gland density and output in healthy active older men: Eur J Appl Physiol Occup Physiol 1996;74:72–77.

32 Hellon RF, Lind AR: Observation on the activity of sweat glands with special reference to the influence of ageing: J Physiol 1958;133:132–144.

33 Yousef MK, Dill DB, Vitez TS, Hillyard SD, Goldman AS: Thermoregulatory responses to desert heat: age, race and sex: J Gerontol 1984;39:406–414.