Human Discomfort Due To Environmental Conditions: Study case: "Thessaloniki, Greece"

F. K. Vsoniakos[a], , N. Zoumakis[a], N. Papadakis[b], A. Kelessis[c], P. Kassomenos[d], M. Staliopoulou[a]

[a]*Environmental Process Laboratory, Atmospheric Physics Group, A.T.E.I. of Thessaloniki, P.O. Box 141, 57 400 Sindos, Thessaloniki, Greece, e-mail: envatm@gen.teithe.gr*
[b]*Hygiene Laboratory, Faculty of Medicine, Aristotelian University of Thessaloniki, Thessaloniki, Greece*
[c]*Environmental Department, Municipality of Thessaloniki, Thessaloniki, Greece*
[d]*Laboratory of Meteorology, Department of Physics, University of Ioannina, Ioannina, Greece*

Abstract
Since air pollution levels are strongly dependent on atmospheric conditions, it is important to take both into consideration when examining the effects of weather on human health. In this study, the discomfort conditions were estimated by using several air-quality stress indices based on air-pollutant concentrations in the center of Thessaloniki. Also, the temporal fluctuations in heat waves, were analysed by using several thermal stress indices, like the number of hot days during the summer period, for the years 1970-2005, with maximum temperatures greater than a threshold temperature. It was found that air quality conditions in the urban area of Thessaloniki can be characterized as acute for the last years, with respect mainly to photochemical pollutants and suspended particulates (PM_{10} and $PM_{2.5}$). The consequence is that discomfort to humans in the center of Thessaloniki due to environmental conditions is caused by temporary thermal stress during the heat waves and permanent air quality stress.

Keywords: climate change, air pollution, air-quality indices, heat waves

Aims and background
Climate change is already happening and represents one of the greatest environmental, social and economic threats facing the planet. Increasing temperatures cause particular problems for cities where the buildings and roads act like a giant storage heater often making cities several degrees warmer than the surrounding countryside. Increases in the risk of illness and death related to extreme heat stress and elevated pollution levels are very likely[1,2]. Air pollution has been recognized as a health hazard, since the early decades of the last century, when severe air pollution episodes followed industrialization in Europe and U.S.A. International standards on air pollution quality have been based mostly on studies that followed these air pollution episodes [3,4].
The environmental factors (air temperature, air humidity, airflow, radiation from the sun and nearby hot surfaces, etc.) and personal factors (age, health and physical condition, thermal resistance of clothing, level of physical activity, etc.) affect the heat balance between the human body and the environment and are the main source of discomfort conditions. As mentioned previously, heat waves have a much greater health effect in cities than in surrounding suburban and rural areas; first, air temperatures have higher values in densely built areas due to the urban heat island effect; second, air pollution is usually higher in urban areas and, in many studies, has demonstrated a synergistic effect with heat on mortality[5].
On the basis of the meteorological data obtained at the Meteorological Station of the Department of Meteorology and Climatology of the Aristotle University of Thessaloniki[6], the temporal fluctuations in heat waves (HW), from 1970-2005, were analysed by using

several thermal stress indices (*TSI*). Meteorological conditions exert a large influence on pollution concentrations and dispersion and they also affect the impact of pollution on mortality and morbidity. Since air pollution levels are strongly dependent on atmospheric conditions, it is important to take both into consideration when examining the effects of weather on human health[7,8]. The air quality conditions in Thessaloniki (for the last years) are defined on the basis of the SO_2 and CO concentrations, the main photochemical pollutants (NO_2 and O_3), the aromatic hydrocarbons and suspended particulates (PM_{10} and $PM_{2.5}$) measured in the commercial and industrial area of Thessaloniki[9-14].

Results and discussion

In the last few years there is a growing concern for the contribution of air pollution concentrations to health effects. The increase of emissions from traffic and industrial activities are responsible of the increased air pollution levels in Thessaloniki. The city center is characterized by heavy car traffic and most of the industrial activities are located to the NW of the city. The climate of Thessaloniki is Mediterranean with hot dry summers and wet mild winters. The thermal stress on people during heat waves is combined with the high air pollution concentrations in the urban area of Thessaloniki.

Air pollution levels

Fig. 1 presents the annual averages of (a) the SO_2 and (b) CO concentrations in Benizelou monitoring station, representative for central Thessaloniki, during the period 1992–2009. The observed significant decreasing trend in SO_2 concentrations is mainly due to the usage of low-sulfur fuels (since fall 1989) and the catalytic converters in cars has significantly reduced the CO concentrations (only after 1991 the catalyst equipped cars occupy an important fraction of the total passenger cars).

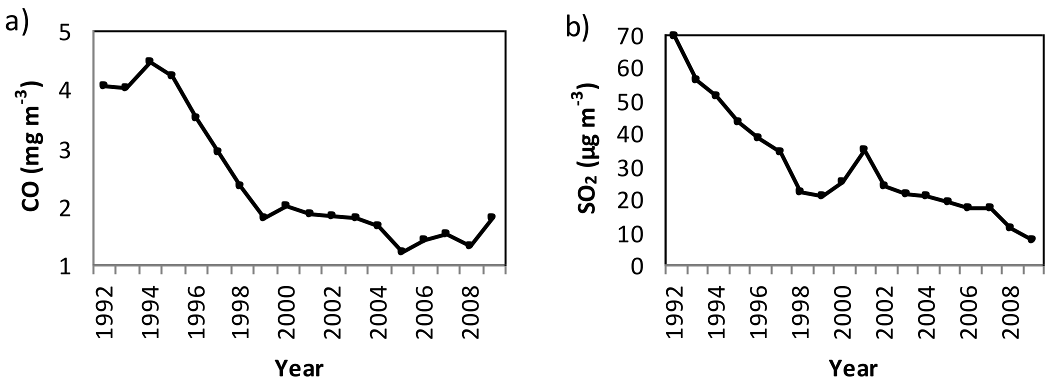


Fig. 1. Annual averages of the (a) CO and (b) SO_2 concentrations in the commercial center of the city (Benizelou monitoring station).

Fig. 2a shows the mean monthly values of PM_{10} in Benizelou (during the period 2004–2009) and Agia Sofia (during the period 2001–2009) monitoring stations at the urban city center and Kordelio monitoring station (representative for the industrial area of Thessaloniki in the west part of the city) during the period 2001–2009. Moreover, the mean monthly values of PM_{10} and $PM_{2.5}$ (for the years 2007, 2008 and 2009) in Benizelou monitoring station are illustrated in Fig. 2b. It is evident from the above figures that PM_{10} and $PM_{2.5}$ concentrations measured in all monitoring stations, considerably exceed the air quality standard proposed by the European Union (yearly average of 40 μg/m^3 by the year 2005 and 20 μg/m^3 by 2010). The occurrence of elevated PM_{10} concentrations levels is attributed mainly to traffic emissions, industries (e.g., cement fabrication, mineral dust, waste incineration, etc.), local topographical and meteorological conditions (see-land breeze and nocturnal inversions) and synoptic scale atmospheric circulation (e.g., anticyclonic conditions and/or advection of warm air masses).

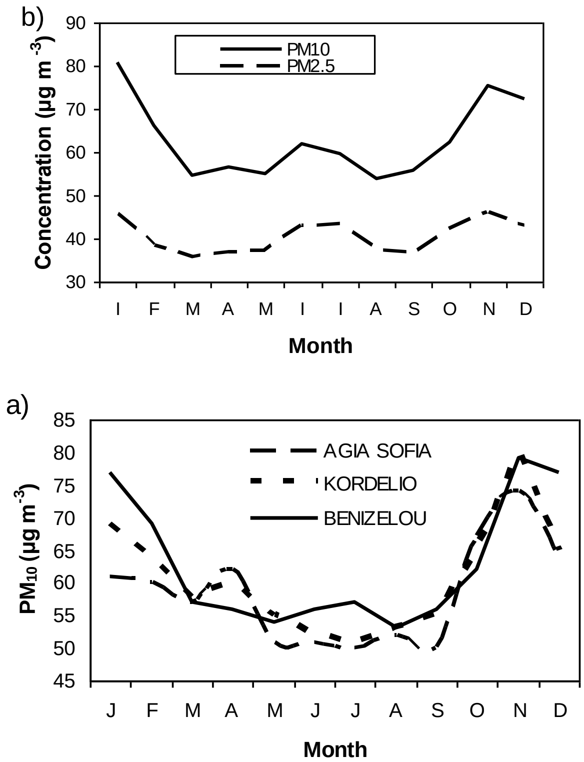


Fig. 2. Seasonal variations of the mean monthly values: (a) of PM_{10} in Benizelou (solid line), Agia Sofia (dashed line) and Kordelio (dotted line) monitoring stations and (b) PM_{10} (solid line) and $PM_{2.5}$ (dashed line) in Benizelou monitoring station.

The mean monthly values of NO_2 in Agia Sofia and Kordelio monitoring stations are presented in Fig. 3a (for the same periods as in Fig. 1). Also, the annual averages of NO_2 and O_3 at the urban city center (in Benizelou monitoring station) and O_3 in Eptapyrgio monitoring station (an elevated peripheral urban background site at 174 m asl) during the period 1992–2009 are illustrated in Fig. 3b. It is evident from the above figures that NO_2 and O_3 concentrations show a steady increase in the formation of photochemical pollution in the urban area of the city. When sea breeze develops, the Thessaloniki bay acts as a large reservoir of air pollutants, which are collected with land breeze during the night and advected back to the city during the sea-breeze hours, participating in transport and transformation processes on the next day. The land-see breeze conditions, that often prevail in greater Thessaloniki area, enhance the formation of a photochemical cloud moving from coastline, passing the urban city center and transported during daytime to the suburban area, especially in the NE part of the city (e.g., see the observed significant increasing trend in O_3 at the peripheral monitoring station).

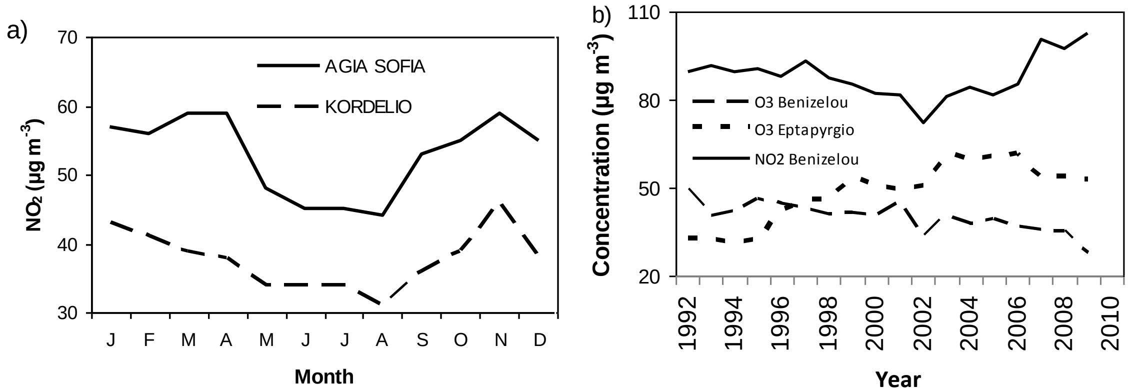


Fig. 3. (a) Mean monthly values of NO_2 concentrations in Agia Sofia (solid line) and Kordelio (dashed line) monitoring stations, and (b) the annual averages of NO_2 (solid line) and O_3 (dashed line) in Benizelou monitoring station (at the urban city center) and O_3 (dotted line) in Eptapyrgio monitoring station (an elevated peripheral site).

The measurements of major aromatic volatile organic compounds: benzene, toluene, ethylbenzene and xylenes (which were made at the Municipal Air Quality Network of Thessaloniki[14], from November 2003 until October 2004) show that the fraction of aromatic compounds must be considered important in the commercial city center. These measurements indicate the dominance of toluene (4.73 ± 2.51 ppb) among all the aromatic species investigated, such that the toluene concentrations (for the same period) are comparable with the critical limits recommended by WHO. It is important to note that the measurements in street canyons, where a substantial part of the city's activities take place, benzene and toluene measurements were found much higher. For example, the mean benzene concentrations, close to the much-frequented street Egnatia at the commercial city center (in Benizelou monitoring station), were found 8.5 ±2.4 μg/m^3 during the period 2005 – 2006. It is evident that benzene concentrations, at the urban city center, considerably exceed the air quality standard proposed by the European Union (i.e., the annual limit value of 5 μg/m^3). However, the annual mean calculated value for benzene (2.7 ±1.2 μg/m^3) during the period 2007 – 2009, in 25 Martiou monitoring station (in the east residential area of the city, with moderate traffic) is less than the EU recommended annual limit value (although WHO considers no safe limits for benzene).

Air quality stress indices

The correct understanding of the pollution levels over an urban region is an important input for health policy. This is particularly true for high polluted urban regions such as the Thessaloniki basin; so, it is important to recognize the levels of atmospheric quality by means of the air quality indices. For the human biometeorological assessment of the mean annual stress of air pollution, the Air Quality Stress Index ($AQSI_1$) is given by the relationship[3,4].

$$AQSI_1 = \frac{1}{4}\left(\frac{C(SO_2)}{RC(SO_2)} + \frac{C(NO_2)}{RC(NO_2)} + \frac{C(PM_{10})}{RC(PM_{10})} + \frac{C(benzene)}{RC(benzene)} \right) \qquad (1)$$

where *C*, is arithmetical mean annual values (in μg/m^3); in the denominator *RC* are the threshold pollutant concentration values in accordance with EU directives [(SO_2: 20 μg/m^3; NO_2: 40 μg/m^3; PM_{10} : 40 μg/m^3 (20 μg/m^3 by the year 2010); benzene: 5 μg/m^3)]. Moreover, the air quality stress index $AQSI_{TH}$ is a modification of equation (1) regarded the replacement of benzene with O_3 in Thessaloniki case:

$$AQSI_{\mathrm{TH}} = \frac{1}{4}\left(\frac{C(SO_2)}{RC(SO_2)} + \frac{C(NO_2)}{RC(NO_2)} + \frac{C(PM_{10})}{RC(PM_{10})} + \frac{C(O_3)}{RC(O_3)} \right) \qquad (2)$$

In addition, a planning-related air quality index ($AQSI_2$), for short-term air pollution stress, is given by the equation:

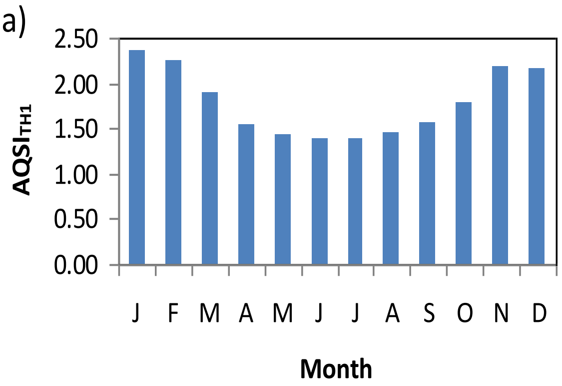
$$AQSI_2 = \frac{1}{4}\left(\frac{N(SO_2)}{PN(SO_2)} + \frac{N(NO_2)}{PN(NO_2)} + \frac{N(PM_{10})}{PN(PM_{10})} + \frac{N(CO)}{PN(CO)} \right) \qquad (3)$$

where, N is the number of cases per calendar year, for which the individual air-pollutant specific EU threshold (limit) values are exceeded and PN (the denominators in the above relationship) is the permitted number of cases per calendar year [e.g., SO_2: 350 μg/m^3 (1 hour mean value) and PN = 24; NO_2: 200 μg/m^3 (1 hour mean value) and PN = 18; PM_{10}: 50 μg/m^3 (daily mean value) and PN = 35; CO: 10 mg/m^3 (highest daily running 8-hour average value, starting from the 17:00 h of the previous day) and PN = 1]. A graded assessment scale is available for the air-quality annual stress indices: $AQSI_1$ and $AQSI_2$, which e.g. can serve as basis for planning specific recommendations with respect to the air quality (Table 1).

Table 1. Assessment of the air quality conditions on the basis of $AQSI_1$ and $AQSI_2$

Level	Description of Stress Category	Air-quality stress indices: $AQSI_1$ and $AQSI_2$
I	Very low air-quality stress	$AQSI_1$, $AQSI_2 < 0.2$
II	Low air-quality stress	$0.2 \leq AQSI_1$, $AQSI_2 < 0.4$
III	Moderate air-quality stress	$0.4 \leq AQSI_1$, $AQSI_2 < 0.6$
IV	Distinct air-quality stress	$0.6 \leq AQSI_1$, $AQSI_2 < 0.8$
V	Strong air-quality stress	$AQSI_1$, $AQSI_2 \geq 0.8$
VI	Extreme air-quality stress	Independent of $AQSI_1$ and $AQSI_2$

The air-quality stress indices ($AQSI$) are calculated on the basis of the main pollutants (SO_2, NO_2, PM_{10}, CO, O_3 and benzene) measured on an hourly basis, at the urban city center (in Benizelou monitoring station of the Municipal Air Quality Network of Thessaloniki).These indices are used for characterizing air-quality conditions in the urban area of the city and the effects of air pollution on human health. Fig. 4a illustrates the monthly mean components of the air-quality stress index $AQSI_{\mathrm{TH1}}$ in the urban area of Thessaloniki, during the period 1989–2000. Also, the air-quality annual stress indices: $AQSI_{\mathrm{TH1}}$ [with RC(PM_{10}) = 40 μg/m^3], $AQSI_{\mathrm{TH2}}$ [with RC(PM_{10}) = 20 μg/m^3], $AQSI_1$ [with RC(benzene) = 5 μg/m^3] and $AQSI_2$, at the urban city center during the period 1992–2009, are presented in Fig. 4b (except for the $AQSI_2$ and $AQSI_1$ values estimated for the years 1997–2002 and 2005 – 2006, respectively). It is evident from the above figures, that the results for the different annual indices $AQSI$ (at the Benizelou Street monitoring station) show values considerably higher than the threshold value 0.8, which indicate strong permanent air quality stress in the center of the city.



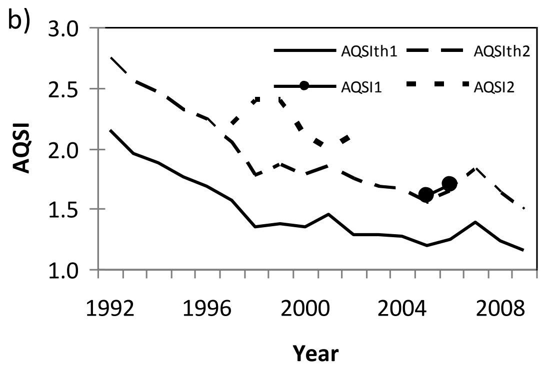


Fig. 4. (a) The monthly mean components of the air-quality stress index $AQSI_{TH1}$ and (b) the air-quality annual stress indices: $AQSI_{TH1}$ (solid line), $AQSI_{TH2}$ (dashed line), $AQSI_1$ (small circles) and *AQS* (dotted line) in the urban area of Thessalon

Assessment of thermal components

Heat waves are rare events that vary in character and impact even in the same location. Arriving at a standardized definition of a heat wave is very difficult. The maximum air temperature and duration are the essential heat-wave components. Thus, a heat wave can be defined based on a threshold temperature (T_{hd}). However, these threshold temperatures vary regionally and fail to address the differences between populations in response to temperature, and also within a single population over time. Consequently, a heat wave is defined as a period of *d* or more days (i.e., the duration of HW), with a maximum daily temperature $T_{MAX} \geq T_{hd}$ (e.g., an extreme heat wave episode is considered a sequence of at least 3 consecutive days with $T_{MAX} \geq 37\ ^oC$).

Fig. 5a illustrates the temporal fluctuations of average summer (June, July and August) values of the daily maximum (T_{MAX}), average ($\bar{T}$) and minimum (T_{MIN}) air temperatures in the urban area of Thessaloniki, during the period 1970-2005. The highest average summer T_{MAX} values (with a threshold average temperature for the summer period: $T_{hd} = 31\ ^oC$) were recorded in 1977 (31.17 ^{o}C), 1985 (31.37 ^{o}C), 1987 (31.10 ^{o}C), 1988 (32.23 ^{o}C), 1994 (31.40 ^{o}C), 1998 (32.17 ^{o}C), 1999 (31.63 ^{o}C), 2000 (32.23 ^{o}C), 2001 (32.10 ^{o}C), 2002 (31.20 ^{o}C) and 2003 (32.57 ^{o}C). As it is seen in the Fig. 5a, the average summer values of T_{MAX},$\bar{T}$ and T_{MIN} depict linear warming trends ($P<0.05$). Another important characteristic of Thessaloniki recent climate is the increasing trend in cumulative maximum temperature excess (CT_{TD}) above the threshold temperature ($T_{hd} = 30\ ^oC$)[15,16], as well as the increasing trend in the frequency N_{TD} of hot days (with $T_{hd} = 33\ ^oC$) as shown in Figs. 5b ($P<0.05$). Finally, it is concluded that the results for these indices (*AQSI* and

TSI) indicate high thermal and strong air quality stress in the urban city center.

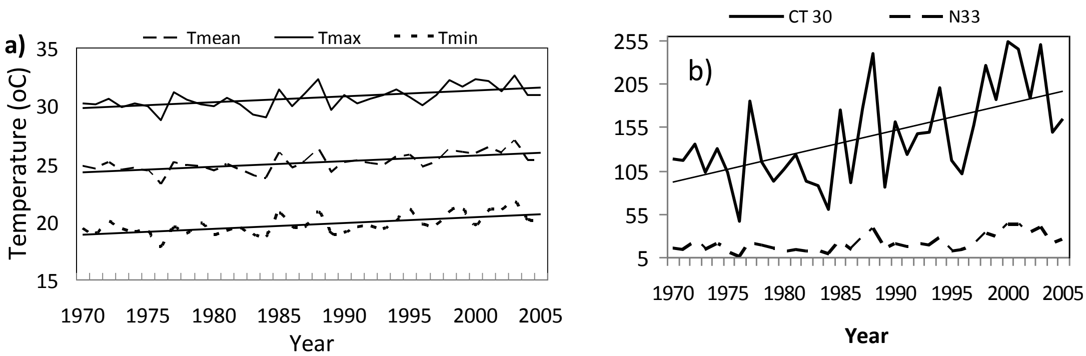


Fig. 5. The temporal fluctuations: (a) of average summer values of the daily maximum (solid line), average (dashed line) and minimum (dotted line) air temperatures, and (b) CT_{30} (solid line) and N_{33} (dashed line) in the urban area of Thessaloniki, during the period 1970-2005.

Conclusions

The results demonstrate that air quality conditions in Thessaloniki can be characterized as acute for the last years, with respect mainly to photochemical pollutants and suspended particulates (PM_{10} and $PM_{2.5}$)[17,18]. The occurrence of elevated PM_{10} concentrations levels is attributed mainly to traffic emissions, industries, local topographical and meteorological conditions and synoptic scale atmospheric circulation. On the other hand, the local atmospheric circulations contribute to ozone accumulation, by transporting increased background ozone.

It is concluded that the air quality information obtained by the *AQSI* and thermal stress indices might be quite useful towards the characterization of discomfort due to environmental conditions in an urban area, like Thessaloniki, with extremely complex physiographic characteristics. The results for these indices (and temporal fluctuations in heat waves) indicate high thermal and strong air quality stress in the urban city center. The thermal stress indices N_{33}, CT_{30} and the average summer values of T_{MAX}, $\bar{T}$ and T_{MIN} depict linear warming trends, during the period 1970-2005. Furthermore, the critical factors which lead to higher air-quality stress indices are the photochemical pollutants and elevated PM_{10} and $PM_{2.5}$ concentrations levels. Combined with the thermal effects of the heat waves, the stress on humans due to environmental conditions has been very injurious to public health. On the other hand, the risk of severe and prolonged extreme heat wave episodes is also increasing probably due to the climatic changes. These topics are discussed further in the accompanying article.

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