BIOCLIMATIC AND AIR QUALITY CONDITIONS IN THE GREATER ATHENS AREA, GREECE, DURING THE WARM PERIOD OF THE YEAR: TRENDS, VARIABILITY AND PERSISTENCE

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ABSTRACT

The aim of this work is to study the bioclimatic conditions as well as the air quality for three different regions of the greater Athens area (GAA), during the warm period of the year for the time period 2001-2005. Furthermore, the thermal discomfort and the air pollution persistence within 24 hours were studied. Finally, both the variability and the trend of the bioclimatic and air quality conditions during the examined period were studied. In order to determine the human thermal comfort-discomfort levels, a widely used biometeorological index, the Cooling Power Index, and microclimatic data (air temperature and wind speed) were used. On the other hand, data concerning the air pollutant concentrations surface ozone (O_3) and particulate matter with aerodynamic diameter less than 10μm (PM_{10}) measured over this area were used for the determination of the air quality levels.

The performed analysis indicates throughout the examined area degradation of the air quality and intensive thermal discomfort episodes. More specifically, during the warm period of the year a relatively high frequency of days, in the city center of Athens showing thermal discomfort and air quality degradation, simultaneously, is observed. On the contrary, on the suburban GAA's monitoring sites a reduction of the frequency of days with thermal discomfort is observed while the number of days with air pollution exacerbations is relatively high. In any case, during the examined period the environmental conditions due to bioclimatic and air quality parameters seem to be rather degraded.

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KEYWORDS:
Bioclimatic conditions, air pollution, Athens, Greece

1. INTRODUCTION

After decades of industrialization, air pollution has become a major environmental issue for both developed and developing countries. Poor air quality has both acute and chronic effects on human health [1, 2]. The association between high ambient pollutant concentrations and severe health problems and excesses in daily mortality and morbidity has been the subject of a number of studies conducted around the world [3-5]. Air quality has emerged as a major factor contributing to the quality of living in urban areas, especially in densely populated and industrialized areas. Air pollution control is needed to prevent the situation from becoming worse in the long run. This is especially essential where certain sensitive groups in the population are concerned, such as children, asthmatics, and elderly people [6, 7]. Several epidemiological studies have shown an association between particulate air pollution and health effects [8-13].

The growth Athens' city during the last decades and the phenomenon of urbanization obviously have led to the creation of a microclimate with explicit effects on human thermal comfort-discomfort. Thermal comfort, as it is well known, is defined as the condition of mind, which expresses satisfaction with the thermal environment, absence of thermal discomfort, or conditions in which 80% or 90% of humans do not express dissatisfaction [14]. Conventionally, thermal comfort is achieved when the heat production from the human organism counterbalances with the exchange of heat with the environment, aiming at the maintenance of constant body temperature at 37°C, indicating a very limited breadth of favorable microclimatic parameters. During the hot period of the year, the human body develops defensive mechanisms such as perspiration in order to maintain its temperature on normal-bearable levels. The high levels of humidity in the environment when combined with low wind speed and high temperature may result to the suspension of such defensive mechanisms of the human body. This causes thermal discomfort and may, therefore, lead to heat stroke [15]. The human thermal comfort-discomfort is estimated by thermal bioclimatic indices such as the Physiologically Equivalent Temperature (PET), the Universal Thermal Climate Index (UTCI), the Cooling Power index, the Thom's discomfort index (DI), etc. The thermal index Physiologically Equivalent Temperature (PET) is based on the total energy balance of the human body [16, 17] interpreting the grade of the thermo-physiological stress [18]. It describes the effect of the thermal environment as a temperature value (°C) and can be quantified easier for non-specialists in this topic. For nighttime situation, air temperature corresponds very close to the PET value. It has been applied in heat waves and climatic variability studies [19, 20] and weather impacts on health [21]. Furthermore, the UTCI equivalent temperature for a given combination of wind, radiation, humidity and air temperature is defined as the air temperature of the reference environment, which produces the same strain index value. Some applications require the categorization of the different values of UTCI in terms of thermal stress [22].

2. DATA AND METHODOLOGY

2.1. Study area

The city of Athens is located in an area of complex topography within the Athens basin (~ 450 km^2). Mountains surround the city with heights ranging from 400 to 1500 m (Fig. 1). Openings between these mountains exist at the northeast and at the west of the basin, while to the south there is the sea (Saronikos Gulf). The Athens basin has a southwest to northeast major axis and is bisected by a cluster of small hills. The prevailing winds in the Athens basin blow from N and NE in late summer, fall and winter and from SSW and SW in the spring and early summer. These NE and SW directions coincide with the major geographical axis of the basin. The ventilation of the basin is poor during the prevalence of local circulation systems, such as sea/land-breezes along the major NE-SW geographical axis of the basin [23].

The GAA, like most metropolitan areas in the world, has significant air pollution problems. These problems are the result of high population density and the accumulation of major economic activities in this region, while the intense sunshine contributes to the high levels of photochemical air pollution especially during the summer months. The air pollution problems are often exacerbated by factors that favour the accumulation of air pollutants over the city, such as, topography (basin surrounded by mountains), narrow and deep street canyons and adverse meteorological conditions such as temperature inversions, low wind speed, high temperature, extensive periods of dryness [24].

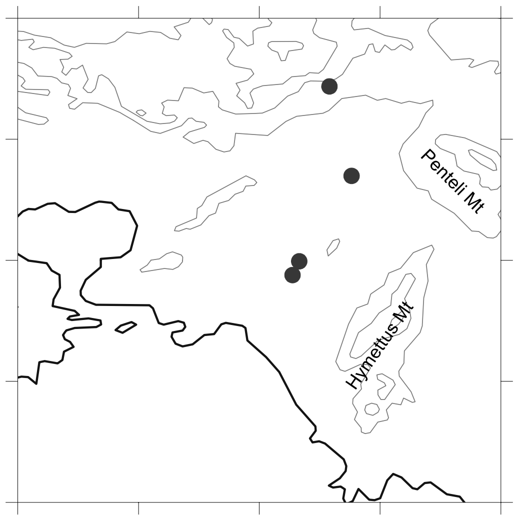

FIGURE 1 - Network of the sampling stations.

2.2. Data

The objective of this study is to examine the association of spells with human thermal discomfort and air pollution episodes during the hot period of the year. In this work as the hot period of the year is taken into account the period between May and September [25, 26]. For this purpose data of air temperature (°C), wind speed (m/s), and data concerning concentrations of air pollutants such as surface ozone (O_3) and particulate matter with aerodynamic diameter less than 10μm (PM_{10}) were used. These data were recorded at four different stations of the environmental monitoring network that belongs to the Greek Ministry of Environment, Energy and Climate Change and concern the period 2001-2005. The four different monitoring stations are Patission (PAT), Aristotelous (ARI), Lykovrissi (LYK) and Thrakomakedones (THR). From ARI monitoring station only the PM_{10} concentrations were used.

2.3. Methodology

In this study, in order to express the human thermal comfort, the biometeorological index known as Cooling Power (CP) was used, against more complex thermal indices because of the simplicity in the calculation process (two meteorological parameters, air temperature and wind speed, are needed as independent variables) and the data availability. The CP index, developed by Siple and Passel [27] describes the losses of energy, per units of time and body surface, which a human organism can tolerate, taking into consideration the wind speed V (m/s) and the air temperature T (°C). For estimating CP index, in W/m^2, equation (1) proposed by Tzenkova et al. [28], has been applied.

$$CP\ (W/m^2) = 1.163 * (10.45 + 10V^{0.5} - V) * (33 - T) \quad (1)$$

The classification of the CP index values, with the equivalent sensation of thermal comfort-discomfort is given in Table 1 [29].

TABLE 1 - Classification of CP index values.

CP (W/m^2)	Classification of human comfort
CP<0	Endothermal - very hot discomfort
0<CP≤174	Atonic – hot discomfort
175≤CP≤349	Hypotonic – hot sub comfort
350≤CP≤699	Neutral - comfort
700≤CP≤1049	Tonic – cold sub comfort
CP≥1050	Cold discomfort

TABLE 2 - Limit values for the protection of human health for O_3 and PM_{10} [24, 25].

Ambient Pollutant	Threshold concentration
O_3	Maximum daily 8-hour mean value: 120 μg/m^3
PM_{10}	Mean daily value: 50 μg/m^3

In order to study the air quality and the days with air pollution episode, the thresholds values of O_3 and PM_{10} concentrations came from the European Union framework directive [30] and the two affiliated directives [31, 32]. Table 2 presents the threshold values for O_3 and PM_{10} concentrations for human health protection.

3. RESULTS AND DISCUSSION

The percentage of days with intense thermal discomfort and air pollution episodes was studied. The persistence of the phenomenon described above within a day was also examined.

3.1. Human thermal discomfort

Fig. 2 (upper panel) shows the percentage of days with rather intense thermal discomfort (0<CP≤174 W/m^2) and with intense thermal discomfort (CP≤0 W/m^2). Fig. 2 (lower panel) presents the mean daily number of consecutive discomfort hours in both cases.

Concretely, column-A represents the percentage of days with rather intense thermal discomfort (0<CP≤174 W/m^2), while column-B the percentage of days with intense thermal discomfort (CP≤0 W/m^2). Column-C represents the mean

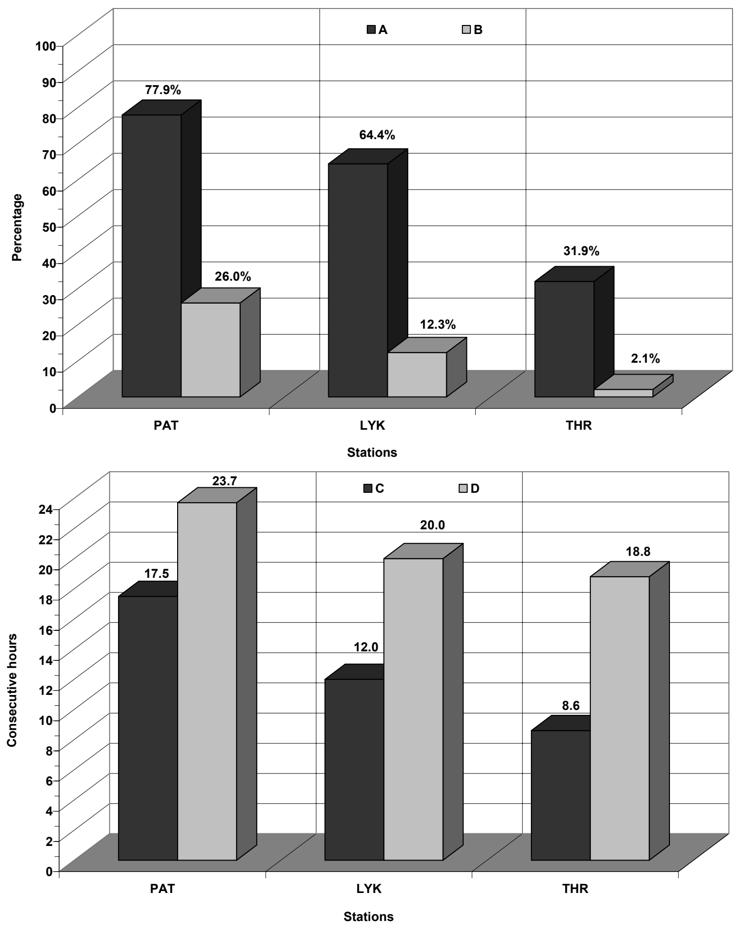

FIGURE 2 - Percentage of days with thermal discomfort (upper panel) and the mean daily number of consecutive discomfort hours (lower panel) during the warm period 2001-2005.

daily number of consecutive hours with rather intense thermal discomfort while column-D the mean daily number of consecutive hours with intense thermal discomfort. It is rather obvious in Fig. 2 that Patission (city centre station) appears the highest frequencies of discomfort levels between the three examined stations within the GAA.

Days with rather intense thermal discomfort cover a 77.9% of the under examination time period while days with intense thermal discomfort reach up to 26.0%. Also the mean daily number of consecutive discomfort hours seems to be high enough, 17.5 and 23.7 respectively in both cases of thermal discomfort levels (Fig. 2, lower panel). A slight improvement seems to appear in human thermal comfort-discomfort conditions at Lykovrissi station. From the same figure it is obvious that at Thrakomakedones station (suburban), the improvement in rather intense and intense thermal discomfort days, as well as the mean daily number of consecutive thermal discomfort hours is bigger.

3.2. Air pollution episodes

Fig. 3 illustrates the percentage of days with air pollution episodes, concerning the pollutants O_3 and PM_{10}, simultaneously in the three examined stations during the warm period of the years 2001 through 2005. Concretely, columns A and B represent the percentage of days with PM_{10} and O_3 episodes, respectively. Column-C represents the mean daily number of consecutive hours with PM_{10} episodes while column-D represents the same for O_3 episodes. In this study the term "number of consecutive hours with PM_{10} episodes" means the daily total of consecutive hours during which PM_{10}'s hourly concentrations exceeded the corresponding daily PM_{10}'s threshold.

As it appears from Fig. 3 during the warm period of the year in all the examined monitoring stations the percentage of days with air pollution episode due to PM_{10} and the persistence of this phenomenon are both quite high. More specifically, during the examined period the mean daily number of consecutive hours with air pollution episode due to PM_{10} ranges between 15 and 18 hours in all of the examined monitoring sites. Furthermore, the percentage concerning surface ozone episodes is quite high for the stations Lykovrissi and Thrakomakedones while for Patission station is zero.

The zero percentage of days with air pollution episodes concerning O_3 in the city center is due to the increased levels of NO_2 as a result of traffic. Regarding the

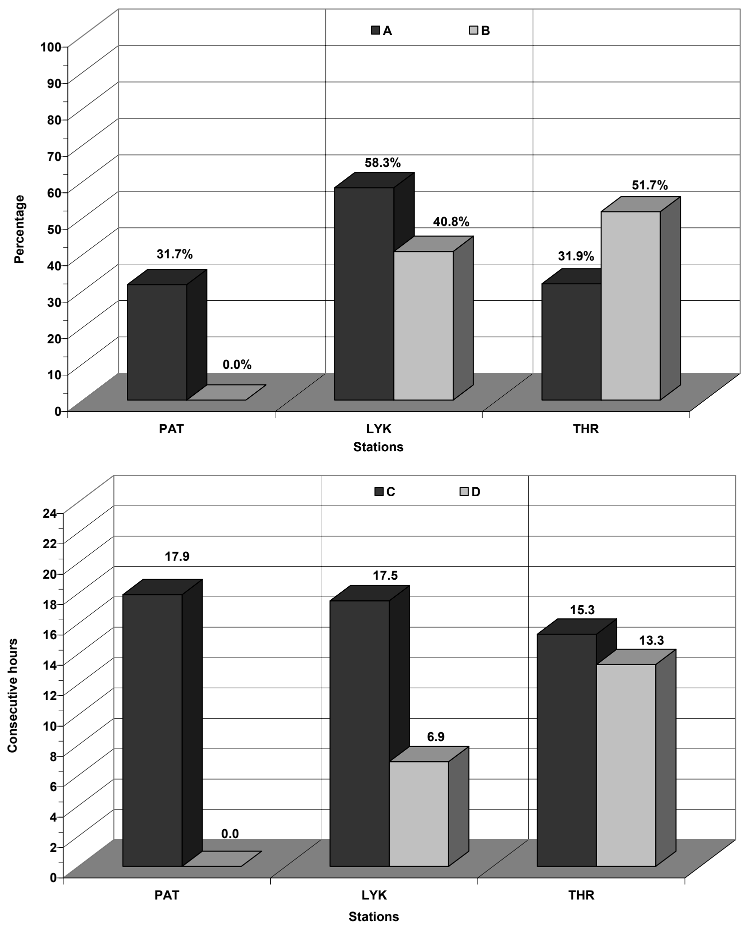

FIGURE 3 - Percentage of days with air pollution episode (upper panel) and the mean daily number of consecutive hours with air pollution episode (lower panel) during the warm period 2001-2005.

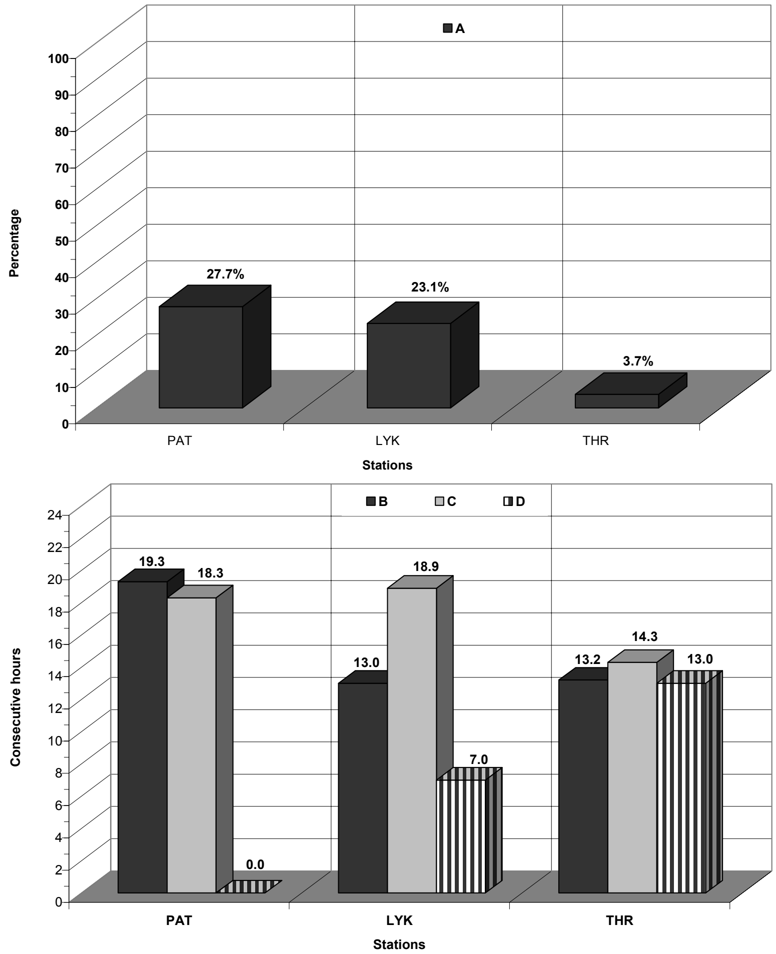

FIGURE 4 - Percentage of days with coexistence of thermal discomfort and air pollution (upper panel) along with consecutive hours with thermal discomfort, PM_{10} episodes and O_3 episodes (lower panel) during the warm period 2001-2005.

persistence, the number of consecutive hours during the day with high O_3 concentrations is on average 6.9 and 13.3 consecutive hours for Lykovrissi and Thrakomakedones station, respectively. The difference on ozone concentration levels in areas with intense vehicle traffic (Patission and Lykovrissi) and areas with low traffic (Thrakomakedones) is obvious.

3.3. Coexistence of air pollution and thermal discomfort

At each station throughout the warm period of years 2001-2005 the incidence of days with thermal discomfort along with air pollution episode were calculated as well as the mean daily number of consecutive hours in each case, respectively. All the above are shown in Fig. 4 where column-A represents the percentage of days with rather intense thermal discomfort ($0<CP\leq174$ W/m^2) and air pollution episodes, simultaneously. Column-B represents the mean daily number of consecutive hours during the day with rather intense thermal discomfort. Columns C and D represent the mean daily number of consecutive hours during the day with PM_{10} and O_3 concentration levels over their thresholds, respectively.

According to Fig. 4 at Patission station (city center) in 27.7% of the examined days, the coexistence of thermal discomfort and air pollution is indicated. Furthermore, the fact that 19.3 consecutive hours per day are hours with rather intense thermal discomfort while during the same day, for 18.3 consecutive hours the PM_{10} concentration exceeds its threshold indicates the persistence of the phenomenon. About the same pattern is indicated at Lykovrissi station while at Thrakomakedones station the situation is rather improved. In any case when in a day the air pollution and thermal discomfort coexistence appears, the persistence of the phenomenon is intense.

4. CONCLUSIONS

According to the above analysis the quality of atmospheric environment in the examined area shows to be quite impaired. The city center (Patission) appears to have a great number of days with rather intense thermal discomfort (77.9%), while days with air pollution episodes and thermal discomfort simultaneously reach up to 27.7% during the period May-September. The situation improves as we move close to the suburbs of the city (Thrakomakedones).

Moreover, the number of consecutive hours during the day with simultaneously rather intense thermal discomfort and air pollution exacerbations creates both significant problems and burdensome on health of the under consideration area residents. These results clearly indicate that air quality monitoring of the GAA is imperative in order to take all the appropriate measures for the public health protection.

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