Energy Conversion and Management 74 (2013) 353–365

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Forty years increase of the air ambient temperature in Greece: The impact on buildings

J. Kapsomenakis [a], D. Kolokotsa [b,*], T. Nikolaou [c], M. Santamouris [d], S.C. Zerefos [e]

[a] Centre for Atmospheric Physics and Climatology, Academy of Athens, Greece
[b] Technical University of Crete, Environmental Engineering Department, GR 73100 Crete, Greece
[c] Organisation for the Development of Western Crete, Crete, Greece
[d] University of Athens, Physics Department, Group Building Environmental Studies, Athens, Greece
[e] Hellenic Open University, Patras, Greece

ARTICLE INFO

Article history:
Received 19 January 2013
Accepted 2 May 2013
Available online 20 June 2013

Keywords:
Climatic change
Temperature increase
Cooling demand
Heating demand

ABSTRACT

Air temperatures in urban areas continue to increase because of the heat island phenomenon (UHI) and the undeniable warming of the lower atmosphere during the past few decades. The observed high ambient air temperatures intensify the energy demand in cities, deteriorate urban comfort conditions, endanger the vulnerable population and amplify pollution problems especially in regions with hot climatic conditions. The present paper analyses 40 years of hourly data series from nine meteorological stations in Greece in order to understand the impact of air temperature and relative humidity trends on the energy consumption of buildings. Using a typical office building, the analysis showed that for the period in question the heating load in the Greek building sector has decreased by about 1 kWh/m^2 per decade, while the cooling load increased by about 5 kWh/m^2 per decade. This phenomenon has major environmental, economic and social consequences, which will be amplified in the upcoming decades in view of the expected man-made climatic changes in this geographic area.

1. Introduction

Man-made global climatic change in association with local phenomena – like air ambient temperatures due to urban heat island – prolong the duration of hot spells and increase the frequency of heat waves [1]. The phenomenon of increased warming is very intense in South East Mediterranean where recent studies have shown unusual temperature anomalies due to climate change [2–5]. In parallel, recent analysis has shown that the heat island phenomenon is present in the major cities of the specific area, while presenting a noteworthy increase in its intensity [6–8]. For example the capital city of Athens, experiences significant variations in ventilation patterns as it is surrounded by high mountains from the east and the north, while it is influenced by the sea breeze from the south. The specific topography combined with the augmenting urbanisation and industrialisation contributed to a significant increase of the ambient temperature during the last 30 years [9,10]. This phenomenon is mostly pronounced in the central and western parts of the city, characterised by strong anthropogenic heat generation, significant industrial activity and high urban density [11,12]. Multiyear studies have shown that the intensity of the average summer period heat island intensity may reach values close to 7–8 °C [13]. Consequently, the urban heat island acts in local level by increasing the outdoor temperature, while extreme phenomena are attributed to climate change.

Nowadays it is evident that the increase of urban temperatures has a serious impact on the energy consumption of buildings by raising significantly the energy demand for cooling, while lowering slightly the energy demand for heating. Different studies have been carried out in various cities in order to evaluate the energy impact of heat island based on real climatic data. In [14,15], the spatial distribution of the cooling needs of different typical buildings was calculated for different urban zones in the city of Athens. It is calculated that due to the heat island effect, the cooling needs as well as the peak electricity demand for cooling in the affected areas, increased up to 100% compared to the corresponding load in the suburban areas around the city. In [16] the impact of climate change on the built environment in Australia was investigated. Using future projection scenarios the adaptation of buildings on future energy needs was assessed. The research showed that the existing building energy demand increase is nearly linear correlated with the increase of the average external air temperature. Moreover, taking into account climate change an increase of cooling capacity between 28% and 59% will be required. A review on the impact of climate change on air condition systems in terms of performance and reliability is performed in [17]. The review

* Corresponding author. Address: Environmental Engineering Department, Polytechnioupolis, Kounoupidiana, 73100 Chania, Crete, Greece. Tel.: +30 28210 37808.
E-mail address: dkolokotsa@enveng.tuc.gr (D. Kolokotsa).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.05.005

Nomenclature

$T_o(h)$	hourly mean outdoor temperature	RH	Relative Humidity
N	number of hours	T_{dp}	dew point temperature
HDH	Heating Degree Hours	°C	degree celsius
CDH	Cooling Degree Hours	U	overall heat transfer coefficient
T	dry bulb temperature	ach	air changes per hour

showed that the research should focus on the future energy needs for heating and cooling due to climate change.

Moreover, the urban heat island deteriorates the environmental quality in low income housing and affects indoor and outdoor thermal comfort conditions. Monitoring studies of low income housing in the areas affected by the heat island in Athens were performed during the period of heat waves. The experiments have shown that indoor temperatures exceeded 30 °C for almost 85% of the hot period, while periods of about 216 continuous hours above 30 °C were recorded [18–20]. In parallel, high urban temperatures contribute towards higher concentrations of pollutants [21], while the urban ecological footprint increases considerably. Studies show that the concentration of ozone varies in a linear way with ambient temperatures in the city [22].

Climatic model forecasts of future ambient temperatures in the specific geographical area, as well as projections of the expected energy consumption of the building sector reveal an important temperature increase followed by a considerable increase of the energy consumption for cooling purposes. In [23] the energy impact of the climatic change in the area was evaluated using various climatic models for the next twenty years. It was found that a significant increase of the cooling and decrease of the heating degree days have to be expected. The area of Athens as well as Central Macedonia, Crete and the Aegean islands may be the areas most affected during the summer period. Another similar study [24] has evaluated the energy impact of the climatic change in Greece up to 2100, using various climatic models. It was reported that the energy demand of buildings for cooling purposes may increase up to 248%, while the heating demand may decrease up to 50% until 2100.

To this end, the analysis of the climatic change in the South East Mediterranean region as well as its impact on the energy demand for buildings is of a major importance in order to understand future trends and steer specific policy actions. The present paper aims to investigate the energy and environmental impact of climate change and the trends recorded over the last forty years on the building sector in Greece. Hourly data have been analysed for all major cities of the country and the ambient temperature evolution and characteristics are investigated in detail. Using advanced building simulation techniques and the validated Virtual Building Dataset (VBD) tool [25], the annual heating and cooling load of a typical office is extracted for all years and climatic zones.

The paper is structured in three more sections. In Section 2 the climatic data are analysed and presented, while Section 3 includes the impact of climate change to the buildings' energy consumption. Finally Section 4 summarises the main conclusions of the paper and highlights further development needs.

2. Analysis of the climatic data

Hourly values of air temperature and relative humidity covering the forty year period 1970–2010 from nine Greek meteorological stations of the Hellenic National Meteorological Service (HNMS) were used in the present study. The stations were selected based on the following criteria:

- Coverage of the country's different regions and climatic characteristics.
- Data availability for the period under study.
- Regular maintenance of stations and minimum number of missing data.

The locations of the meteorological stations and their coordinates are shown in Fig. 1. The accuracy of their temperature measurement devices (thermometers) and their relative humidity measurement devices is 0.2 °C and 1% respectively.

Fig. 2 presents the intra-annual variability of the mean temperature along with the intra-annual variability of diurnal temperature range. The stations at Western Greece Corfu, Aktio and Kalamata present similar patterns of mean temperature values and temperature ranges. At the same time the Heraklion, Rodos and Mytilini stations in the Aegean present similar intra-annual temperature values and diurnal temperature range characteristics. It is worth noting that Heraklion and Rodos present higher temperature values on a yearly basis than the rest of the stations. On the contrary, Mikra and Larisa stations present the lowest air temperature values among the examined stations, having also the highest diurnal temperature range. Finally, the Elliniko station, within the wider urban area of Athens, shows values that can be interpreted as mild winter and warm summer. The stations having the higher diurnal temperature range (Mikra, Larisa and Kalamata) show the highest continentality over Greece, while the stations having the lower diurnal temperature range (Heraklion and Rodos) show the lowest continentality. From the data the trends of hourly air temperature have been calculated for each station using the least square linear regression method.

It is interesting to note that all the hourly temperatures of every station show generally upward trends during the period under study. These upward trends are more prominent during the summer and in general are statistically significant at a 95% confidence level (Welch test) during all seasons except winter. In winter, upward trends are also statistically significant, but at a lower confidence level. These climatic trends are in agreement with the findings of other researchers, especially for summer trends, while in winter the trends are either positive or negative depending on the studied period, but in any case the winter trends are of lower significance. More specifically, Feidas et al. [26] found that Greece, in general, shows a cooling trend in winter for the period 1955–2001, whereas, summer shows an overall warming trend, however, neither is statistically significant. Besides, Philandras et al. [27] found statistically significant (95% confidence level) heating trends in summer for the period 1976–2000 all over Greece. Moreover the summer air temperature contributes to the annual air temperature more than winter air temperature does. This is probably the main reason of the annual air temperature increase, especially during the decade 1990. Furthermore, Nastos et al. [28] concluded that statistically significant (95% confidence level) negative trends in mean maximum and mean minimum air surface temperatures were observed during the winter while significant positive trends in both parameters examined appeared during summer. Similar results have been found concerning the analysis of the tropical days