

# ANALYSIS OF 3 DECADES TEMPERATURE DATA FOR ATHENS AND THESSALONIKI, GREECE - IMPACT OF TEMPERATURE CHANGES ON ENERGY CONSUMPTION FOR HEATING AND COOLING OF BUILDINGS

K.T. Papakostas<sup>1</sup>, P. Zagana-Papavasileiou<sup>1</sup>, T. Mavromatis<sup>2</sup>

<sup>1</sup>*Process Equipment Design Laboratory, Mechanical Engineering Department, Energy Division, Aristotle University of Thessaloniki - 54124 Thessaloniki - Greece.*

<sup>2</sup>*Department of Meteorology-Climatology, School of Geology, Faculty of Sciences, Aristotle University of Thessaloniki - 54124 Thessaloniki – Greece.*

## Abstract

This paper presents the results of 30 years dry bulb temperature data analysis for the two major cities of Greece, namely Athens and Thessaloniki. The raw hourly data were obtained from the meteorological stations of the National Observatory of Athens and of the Institute of Meteorology and Climatology of the Aristotle University of Thessaloniki. Monthly average dry bulb temperatures as well as frequencies of occurrence in hours of 2°C-wide temperature intervals (bins), are presented for the decades 1983-1992, 1993-2002 and 2003-2012, and compared. The results show that the monthly average temperatures are continuously increased in every decade, as compared to the values of the previous decades. The cumulative results for the frequency of temperature bins in heating and cooling period separately, show also a continuous reduction of the low and an increase of the high temperature bins, for both cities. By estimating the energy demands for heating and cooling of a multi-storey office building, with the use of the modified bin energy method and temperature bin data, it is concluded that the heating energy requirements in every decade are decreased while the cooling energy requirements are increased. All the results indicate a warming trend, at least for the two regions examined.

## Keywords

Climate change, Cooling, Energy consumption in buildings, Heating, Modified Bin method, Temperature data

## 1. Introduction

The topic of climate change has attracted widespread attention in recent years and is an issue that numerous scientists study on various time and space scales. The reasons for climate change are complex and there are various opinions about the causes in the scientific community. The main cause, commonly accepted nowadays, is the emissions from buildings, business, agriculture and transport. In all these human activities energy is used, mainly from non-renewable energy sources (liquid, gas and solid fuels), and greenhouse gases (GHGs) are produced. The increasing atmospheric concentrations of GHGs are the dominant driver of global warming and climate change.

Recently, numerous studies have been conducted around the world into the impacts of global warming on the changes of ambient air temperature, energy consumption in built environment, electric energy demand, and related GHG emissions. Some of them analyze historical data as a proof for the ambient temperature rise while other studies estimate the climate over the next years, by using computational models of the world climate system with different scenarios for GHGs emissions. A large number of these works investigate the climate change impact on various climate indexes, such as monthly mean temperatures, heating degree days (HDD), cooling degree days (CDD), and frequency of ambient temperature intervals (bins). Many investigators focus on climate change impact on cooling and heating demands of buildings, as well as on electric energy demand, while others study the impacts on buildings' carbon emissions.

Brunetti et al. [1], by performing a statistical analysis of the ambient temperatures in Italy from 1865 to 1996, concluded that the climate during the last decades is characterized by an increase in mean daily air temperatures. The results show a positive trend in maximum and minimum temperatures which is greater in southern than in northern Italy.

Moonen et al. [2], by analyzing with the use of linear regression techniques the mean, maximum and minimum air temperatures in Italy from 1878 to 1999, deduced that the number of frost days per year has decreased significantly while at the same time the last frost day in spring occurs on average 1 month earlier than 122 years ago.

A temperature increase was also reported in the last fifty years in Bangladesh [3], with more increase in nighttime minimum temperatures compared to daytime maximum temperatures.

Lebassi et al. [4] performed an analysis of daily maximum and minimum temperatures, from records at 159 locations in California, to estimate long-term (1970-2005) variations of mean monthly air temperatures. Results showed increased trends of maximum, minimum and mean temperatures, with increases of 0.26°C, 0.04°C and 0.15°C per decade respectively.

Average monthly and yearly ambient air temperatures were calculated in Greece [5] from hourly dry bulb temperature records in the major two cities for the period 1983-2002. The results in both cities, showed increased temperature values in the 1993-2002 decade as compared to the corresponding values of the 1983-1993 decade. The average annual air temperature during the second decade was increased 1°C in Athens and 0.5°C in Thessaloniki. The warming trend in these two cities was reported also in previous research [6].

Almazroui et al. [7] studied the temperature (minimum, mean and maximum) variations for a 31-year period (1979–2009) over the Arabian Peninsula. The results showed that the temperature over Saudi Arabia has increased significantly, and the increase rate is 0.72°C and 0.51°C per decade in the dry and wet season respectively.

In a research for the Zurich-Kloten location in Switzerland [8], which is representative for the climatic situation in the Swiss Central Plateau, an analysis of hourly weather data during the period 1981-2002 was performed. The results showed that both the mean annual and (winter/summer) seasonal air temperatures rose by approximately 0.50°C per decade.

A study of outdoor design conditions for heating and cooling in Tehran, using 40 years (1967-2006) hourly data, indicated that the 1% dry bulb design temperature for cooling has risen by 0.27°C, while the 99% dry bulb design temperature for heating has increased 3.8°C [9].

In [10] the 105-year (1897–2001) surface air temperature record of the National Observatory of Athens (NOA) has been analyzed to determine indications of significant deviations from long-term average features in the city of Athens. The analysis of the whole record revealed a tendency towards warmer years, with significantly warmer summer and spring periods and slightly warmer winters (an increase of 1.23°C and 0.34°C has been observed in the mean summer and mean winter temperature, respectively). The trend analysis for the last decade of the record (1992–2001) revealed a significant increase for both warm and cold seasons, yet maximum and minimum temperature.

Warming in the last 100 years has caused about a 0.74 °C increase in global average temperature and eleven of the twelve years in the period 1995–2006 rank among the top 12 warmest years in the instrumental record (since 1880) [11]. Further warming will continue if emissions of greenhouse gases continue. It is estimated that surface air warming in the 21st century for a "low emissions scenario" will be 1.8°C, with a likely range of 1.1 to 2.9°C. Best estimate for a "high emissions scenario" is 4.0°C with a likely range of 2.4 to 6.4 °C. A temperature rise of about 0.1 °C per decade would be expected for the next two decades, even if greenhouse gas and aerosol concentrations were kept at year 2000 levels [12].

Many research works investigated the future trends of ambient temperature by using statistical and stochastic models with various scenarios of GHGs emissions or of global warming, and predicted the impact of climate change on buildings' energy demand for heating and cooling [8, 13-26] or the impact on electric energy demand [4, 27-31]. In a number of these works simplified methods were used e.g. the degree-days methods [4, 13, 15, 22, 23, 28, 31], while in others [8, 14, 16, 18, 19, 27] more sophisticated building energy simulation tools, performing hour-by-hour computation of the heating/cooling loads and of the corresponding energy use, were applied. The general conclusions are: temperature rise in the future, increased frequency of extreme events, and future changes on energy demands of buildings for heating, cooling and electric energy.

The purpose of this work is to present the results of a 30-year statistical analysis of ambient air temperature data for the two major Greek cities, namely Athens and Thessaloniki. Hourly temperature data from 1983 to 2012 were analyzed and monthly average values and binned distributions of ambient air temperature for the decades 1983-1992, 1993-2002 and 2003-2012 were calculated. The results for every decade are compared with the results of the previous ones and the seasonal and decadal trends are estimated in order to reach conclusions regarding the magnitude of ambient air temperature changes during the last 30 years. The intention is to present a reference document on the recent-past and present air temperature variations for use in energy application-oriented studies. To assess the impact of temperature data changes on the energy consumption of buildings, the energy demands for heating and cooling of a multi-storey office building were estimated, with the use of the modified bin method and temperature bin data of the 3 decades.

## 2. Temperature data analysis

### 2.1 Temperature data

Hourly dry bulb temperature data were made available from the meteorological stations of the National Observatory of Athens (NOA) [32] and of the Institute of Meteorology and Climatology of the Aristotle University of Thessaloniki (IMC/AUTh) [33]. The NOA station (37° 58' N, 23° 43' E) is located on a small hill near the Acropolis at an elevation of 107 m above sea level. The distance to the coastline is about 5 km. The IMC/AUTh station is situated at the University campus (latitude 40°37'N, longitude 22°57'E and altitude 31 m) and it is located at a distance of approximately 1 km from the sea. Although both stations lie near the town center they are isolated from heavy traffic and densely built areas.

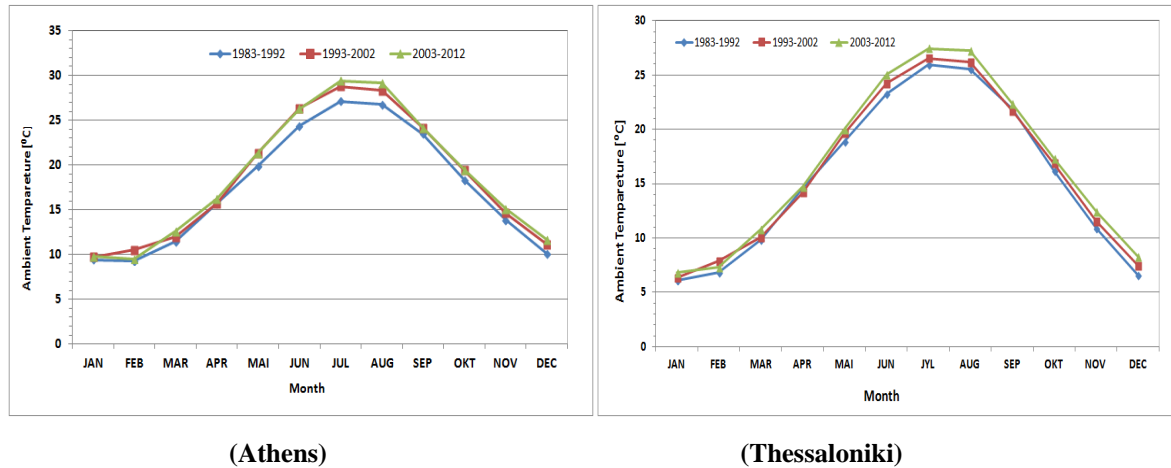
### 2.2 Monthly average temperatures

Variations in average temperature values is a good indicator of climate change, therefore the details of the monthly and annual average temperatures are taken into consideration in this discussion. The average monthly temperature values for the decades 1983-1992, 1993-2002 and 2003-2012 in the two cities are presented in table 1 and are plotted in fig. 1. These values resulted from the analysis of hourly data recorded in the two above mentioned meteorological stations. From the results it is concluded that the average annual temperature in Athens increased 1°C from the first decade (1983-1992) to the second decade (1993-2002) and 0.2°C from the second decade to the third decade (2003-2012). In Thessaloniki, the increase was 0.5°C from the first to the second decade and 0.6°C from the second to the third decade. The total increase of the annual average temperature from the first to the third decade was 1.2°C and 1.1°C for Athens and Thessaloniki respectively.

Period	Athens			Thessaloniki		
	1983-1992	1993-2002	2003-2012	1983-1992	1993-2002	2003-2012
Jan.	9.44	9.73	9.83	6.13	6.34	6.81
Feb.	9.32	10.48	9.50	6.86	7.84	7.34
Mar.	11.47	11.97	12.62	9.83	10.06	10.81
Apr.	15.77	15.74	16.25	14.58	14.17	14.74
Mai	19.93	21.34	21.40	18.86	19.62	20.05
Jun.	24.42	26.34	26.31	23.31	24.22	25.02
Jul.	27.13	28.79	29.42	25.93	26.54	27.46
Aug.	26.77	28.30	29.20	25.53	26.17	27.27
Sep.	23.50	24.16	24.13	21.92	21.69	22.34
Okt.	18.32	19.43	19.45	16.16	16.85	17.35
Nov.	13.88	14.64	15.14	10.91	11.58	12.41
Dec.	10.13	11.18	11.64	6.60	7.47	8.30
Annual	17.50	18.51	18.74	15.57	16.04	16.66

**Table 1:** Average monthly and annual temperatures of 1983-1992, 1993-2002 and 2003-2012 decades in Athens and Thessaloniki

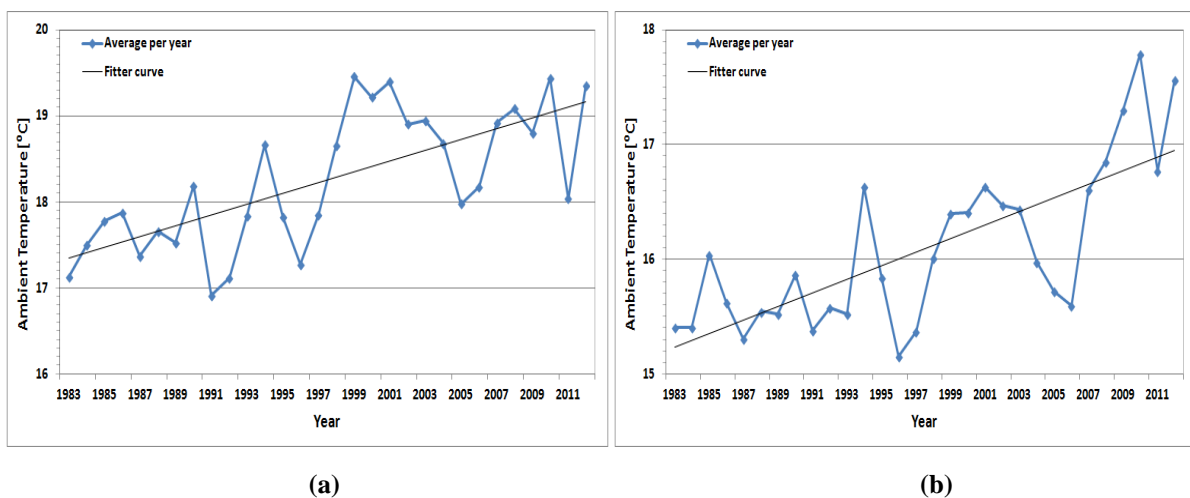
It is also obvious that there is a constant increase in average temperature for both cities and in all the months of the year. During summer, the increase ranges from 0.63 K in September to 2.43 K in August for Athens, and from 0.42 K in September to 1.74 K in August for Thessaloniki. During winter, the increase ranges from 0.18 K in February to 1.51 K in December for Athens and from 0.16 K in April to 1.70 K in December for Thessaloniki. All the comparisons are between the first and the third decade and they are leading to the conclusion that the average monthly temperatures are constantly increased in winter as well as in summer period, a fact approving a warming trend of the climate in general.



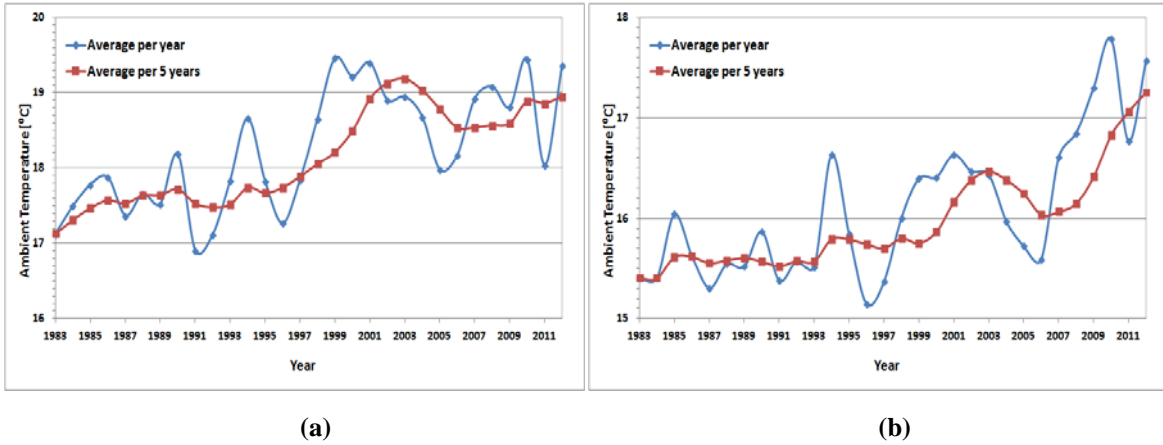
**Figure 1:** Average monthly temperatures of 1983-1992, 1993-2002 and 2003-2012 decades for Athens and Thessaloniki

### 2.3 Annual and 5 Year annual average temperatures

Figure 2 displays the annual average temperatures from 1983 to 2012, for Athens and Thessaloniki. From the presenting results it is deduced that there is an upward trend of the annual average temperature for both cities. The average increase is 0.63°C per decade in Athens and 0.57°C per decade in Thessaloniki, although the highest increase was observed in the third decade for both cities. The same qualitative trends show the 5 Year average temperature series (fig. 3).



**Figure 2:** Annual average temperatures from 1983 to 2012 for (a) Athens and (b) Thessaloniki

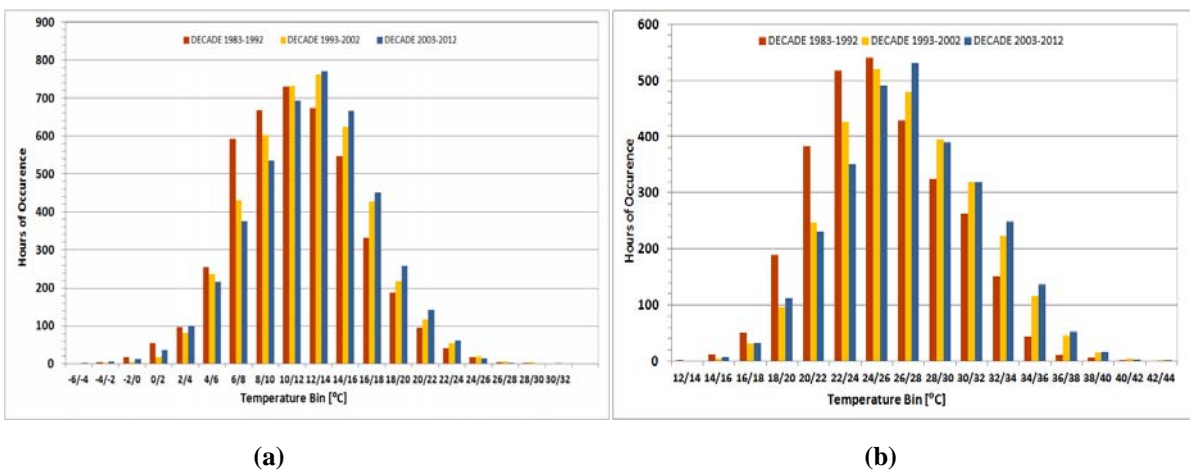


**Figure 3:** Annual and 5 Year average temperatures from 1983 to 2012 for (a) Athens and (b) Thessaloniki

#### 2.4 Temperature Bin data

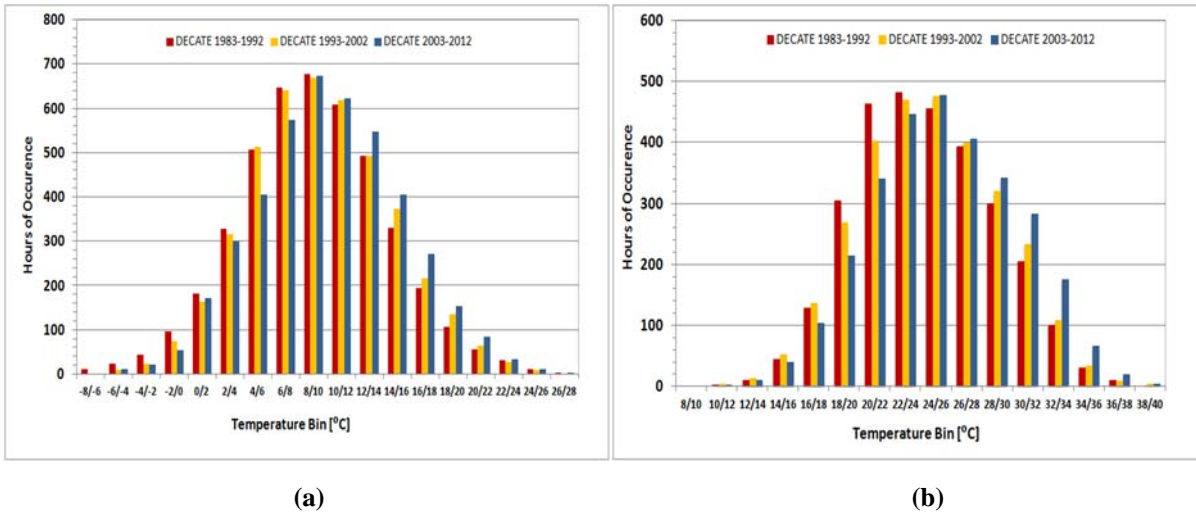
The cumulative results for the frequency of occurrence (in h) of 2 K-wide temperature bins per period (summer, winter) are shown in Figures 4 and 5, for Athens and Thessaloniki respectively. The figures show, for the three decades separately, the average number of hours that a particular temperature interval (bin) occurs in every period. The winter period, during which the buildings normally need heating, includes the months November to April. Similarly, the summer period, during which cooling is required, consists of the months June to September. It can be clearly seen that in both cities the distribution of temperature bins shifts to the right, namely in every new decade a reduction of the low and an increase of the high temperature bins is observed.

The frequency of occurrence (in h) of the low temperature bins is steadily decreased (with some exceptions in some bins during the third decade), while the frequency of occurrence of the high temperature bins is constantly increased in every decade. The most frequent temperature bin in the cooling period for Athens was 24/26°C during the 1983-1992 decade, which increased to 26/28°C during the decade 2003-2012. The corresponding most frequent temperature bin in the heating period was 10/12°C and increased to 12/14°C, between the first and the third decade. Similar results show up in the city of Thessaloniki. Furthermore, the frequency of occurrence of the peak temperature bins (>32/34°C) increased from 477 to 779 h in Athens and from 141 to 266 h in Thessaloniki. On the contrary, the frequency of occurrence of the low temperature bins (<6/8°C) was reduced from 1021 to 748 h and from 1836 to 1537 h, in the two cities respectively. The above results confirm the indication of climate change towards milder winters and hotter summers.



**Figure 4:** Temperature bin hours of occurrence. Decades 1983-1992, 1993-2002 and 2003-2012, Athens

(a) heating period (b) cooling period

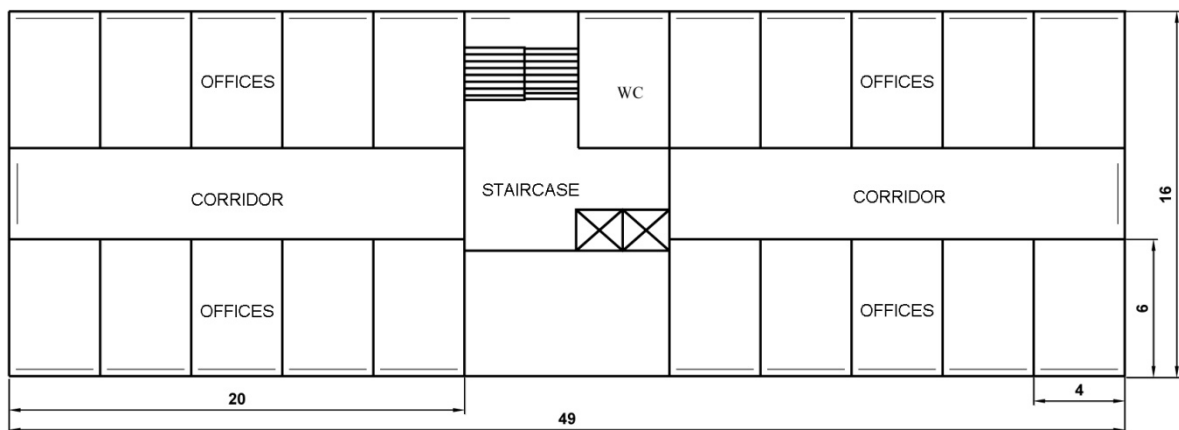


**Figure 5:** Temperature bin hours of occurrence. Decades 1983-1992, 1993-2002 and 2003-2012, Thessaloniki  
(a) heating period (b) cooling period

### 3. Impact of temperature changes on the energy demands for heating and cooling

In order to quantify the effect of temperature data changes on the energy consumption of buildings, the energy demands of an office building were estimated for heating and cooling. The energy requirements for heating were estimated adopting the classical bin method [34] while the cooling ones using the modified bin method [34, 35]. Energy requirements account for sensible loads only, since the data analysis presented in this paper refers only to dry-bulb temperature data.

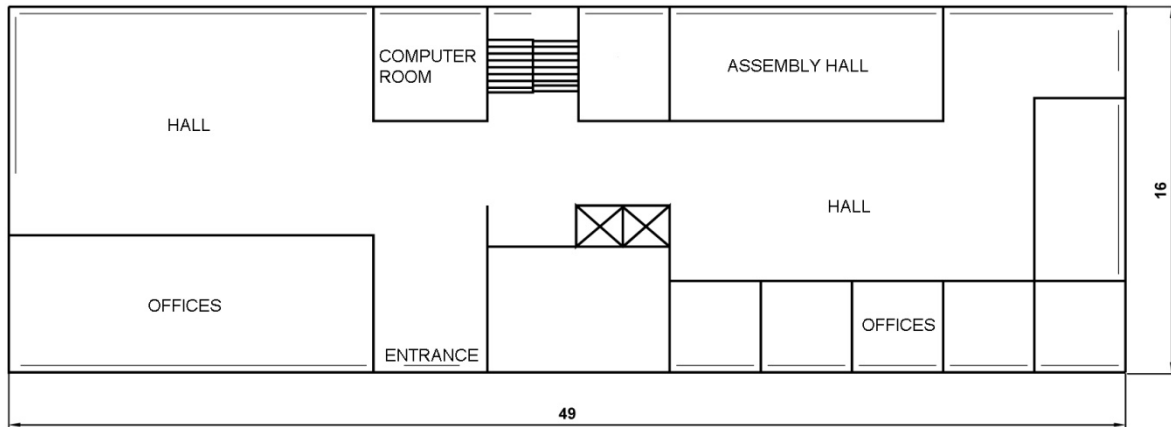
The building chosen for this study is a typical building of the university campus in Thessaloniki. It has a rectangular shape and the dimensions of its sectional view are 16x45 m. The height of the typical floor is 3m. The building features 9 floors with offices, a ground floor with the main entrance, offices, a computer room and an assembly hall, and a basement which houses the utilities. The typical floor is illustrated in Fig. 6 and the ground floor in Fig. 7. The two main elevations of the building are oriented to the north and to the south. The openings' surfaces represent about 24% of the north, 32% of the south and 12.5% of the east and west perimeter areas of the building without being shaded by any other structure.



**Figure 6:** Plan view of the building's typical floor

The building was assumed to operate from 09:00 to 20:00, with the indoor temperature maintained at 20°C during the heating period and at 26°C during the cooling period. During the rest of the day, the temperatures were assumed 15 and 30°C, respectively. The temperature of the staircases and of the entrance area was

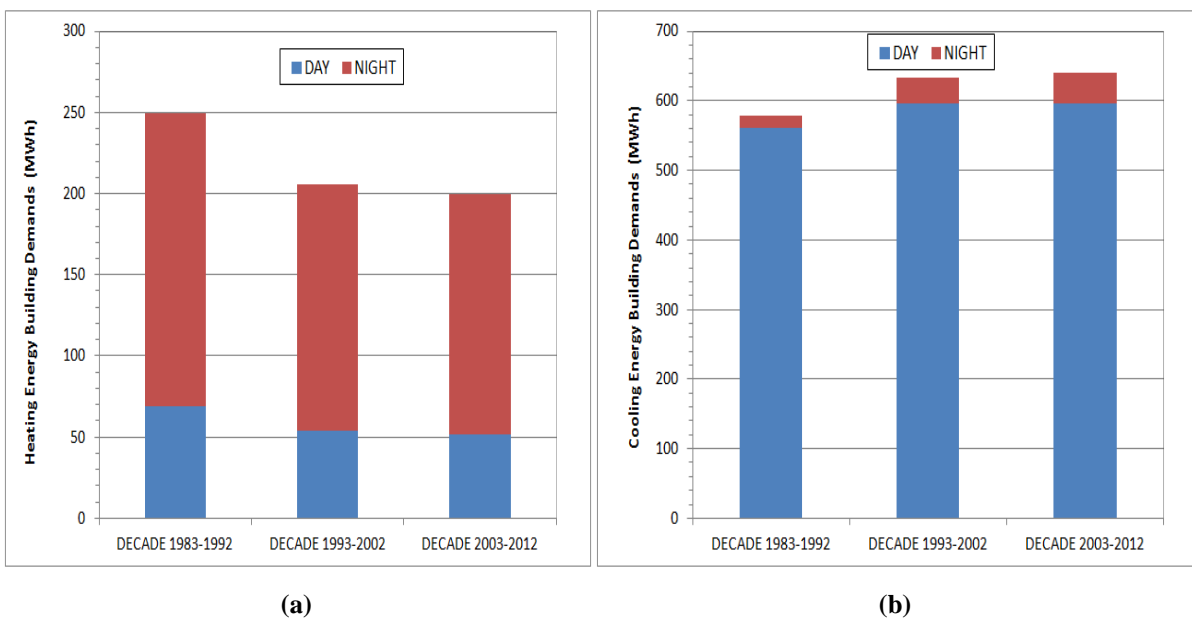
assumed 15 and 30°C around the clock, for the heating and cooling period, respectively. The ventilation rate was assumed 1 and 0 ACH in operation and non-operation periods, respectively, around the year.



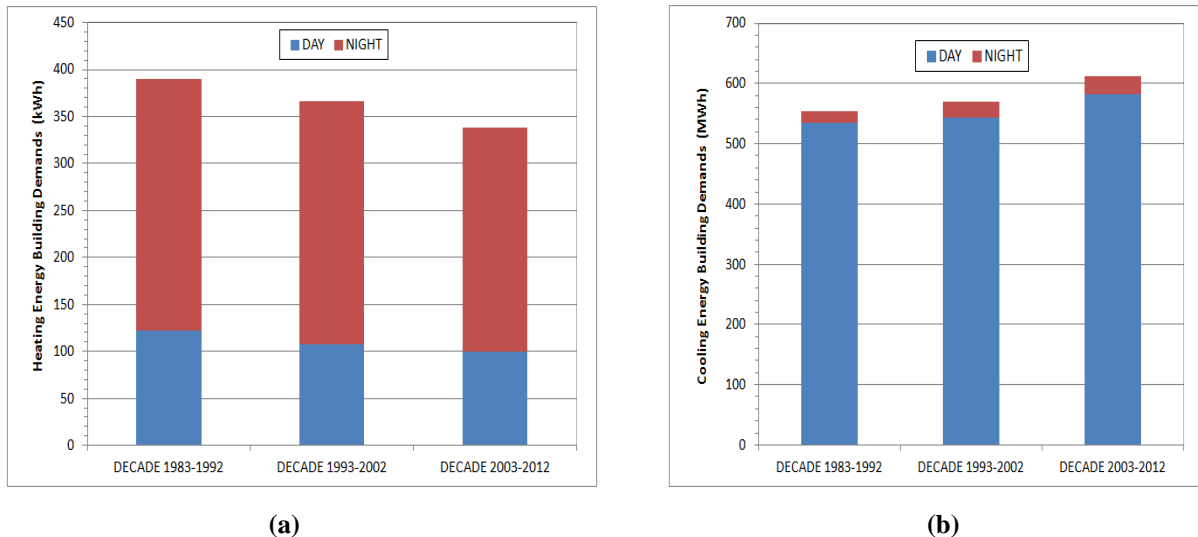
**Figure 7:** Plan view of the building's ground floor

The load calculation accounted for the solar and the conduction heat gains through glazing, walls and roofs, the internal heat gains from people, equipment and lights and the sensible heat gains from ventilation. Operating profiles for the people occupancy and for the use of lights and equipment were assumed for the calculation of the internal heat gains.

The office building was simulated by using 3 decades (1983-1992, 1993-2002 and 2003-2012) temperature bin data of both cities (Athens and Thessaloniki). Fig. 8 presents the resulting energy requirements of the building, when located in Athens, for cooling and heating periods respectively. Fig. 9 presents the same, when the building is located in Thessaloniki. It is stressed that Figs. 8-9 present the sensible energy requirement of the building, the effect of the ambient temperature on the performance coefficient of the primary equipment not being accounted for.



**Figure 8:** Energy requirements for (a) heating and (b) cooling of the office building in Athens, using data of three decades (1983-1992), (1993-2002), (2003-2012).



**Figure 9:** Energy requirements for (a) heating and (b) cooling of the office building in Thessaloniki, using data of three decades (1983-1992), (1993-2002), (2003-2012).

As it can be clearly seen, the energy requirements of the building for heating show a continuous decrease from decade to decade in both cities. In Athens, a 17.6% reduction is observed during the second decade, as compared to the first, while the corresponding reduction during the third decade is 2.8%, relatively to the second. The total heating demands reduction from the first to the third decade is 19.9% (fig. 8). In Thessaloniki, the reductions are 6.2%, 7.4% and 13.2% respectively (fig. 9).

On the contrary, the energy requirements for cooling show a continuous increase from decade to decade in both cities. The increase in Athens, between the second and the first decade is 9.6%, and between the third and the second decade is 0.9%. The total increase of cooling demands from the first to the third decade is 10.6% (fig. 8). The corresponding increases in Thessaloniki are 2.8%, 7.4% and 10.4% respectively (fig. 9). The above results show that the highest increase in cooling demands for Athens is observed during the period 1993-2002, while for Thessaloniki during the last (2003-2012). This is explained from the fact that the frequency in hours of high temperature intervals (bins) in Athens increased more in the 1993-2002 decade, while in Thessaloniki during the last (2003-2012). Finally, in both cities the same percentage increase of cooling demands was observed. The heating demands also, in Athens lessened more in the 1993-2002 decade, whilst in Thessaloniki the percentage reduction was steady in the two last decades, a fact also explained from the reductions of low temperature bins from decade to decade.

These trends towards less heating and more cooling found in this study confirm the results of previous studies [6, 22-23]. The total (heating and cooling) energy requirements were increased by 1.4% in Athens and by 0.64% in Thessaloniki. This means that the increase of the cooling energy demands almost compensates for the reduction in heating energy requirements. Taking into account that space heating is provided largely by oil- or gas-fired boiler plants whereas space cooling mainly relies on electricity, a reduction in heating energy use and an increase in cooling requirements would result in a shift towards less fossil fuels and more electrical power demand. This fact could have important implications for the nationwide energy policy in the built environment.

#### 4. Conclusions and discussion

Hourly temperature data from 1983 to 2012 measured at the meteorological stations of the National Observatory of Athens and of the Aristotle University of Thessaloniki were used to calculate monthly average values and binned distributions of ambient air temperature for the decades 1983-1992, 1993-2002 and 2003-2012. The results for every decade were compared with the results of the previous ones, while the seasonal and decadal trends were estimated in order to reach conclusions regarding the magnitude of ambient air temperature alterations during the last 30 years. Generally, any long-term (30 years or greater) temperature shifts are considered as a measure of climate change in a given region.



From the results it is deduced that, during the analysis period, the ambient temperature has a significant increasing linear trend. The 10-year annual average temperature, from the first to the third decade, increased 1.2°C for Athens and 1.1°C for Thessaloniki. The average monthly and 5-year temperature values display the same increasing trend as well. From the 3 decades temperature data comparison, it is also concluded that the frequency of occurrence (in h) of the low temperature bins is steadily decreased, while the frequency of occurrence of the high temperature bins is constantly increased in every decade. The frequency of occurrence of the peak temperature bins (>32/34°C) increased from 477 to 779 hours in Athens and from 141 to 266 hours in Thessaloniki. On the contrary, the frequency of occurrence of the low temperature bins (<6/8°C) was reduced from 1021 to 748 hours and from 1836 to 1537 hours, in the two cities respectively. The above results confirm the indication of climate change towards milder winters and hotter summers.

The consequence of the reported climate change is predicted to have strong effects on buildings' energy requirements, as their heating and cooling needs are highly related to temperature variations. Especially in Greece, a high proportion of the current building stock was built to standards that required far lower levels of thermal performance than are obligatory under current building regulations and their envelopes have poor thermal properties, so their heating and cooling demands are very sensitive to any change in ambient temperature. Energy calculations for a typical office building in both cities showed a continuous, from decade to decade, decrease of the building energy requirements for heating and a permanent increase of the energy requirements for cooling. The total heating demands reduction from the first to the third decade is 19.9% and 13.2% for Athens and Thessaloniki respectively. The corresponding total increase of cooling demands for the two cities is 10.6% and 10.4% respectively (sensible loads only).

The above results indicate significant consequences for energy production and supply systems especially since heating and cooling are provided by different energy sources. It is therefore expected a strong future shift of energy demand from primary energy towards electricity. Changes in the ambient air-temperature will have also significant consequences upon the cooling equipment performance, and the potential of using outdoor air for "free cooling".

It is evident that a changing climate and its implications will need to be reflected in future building design and refurbishment in form, material choice, thermal mass and building services. Temperature data currently used for HVAC systems design would increasingly lead to an overestimation of heating and underestimation of cooling loads in buildings and, therefore, require periodic adaptation. Likewise, the climate input data used in energy behavior calculations must be periodically re-examined and reviewed.

Further topics that might be investigated in order to get a better picture of climate change and its effects on buildings and their technical services include: study of temperature and other climatic parameters (i.e. solar radiation, relative humidity) variations in more locations, energy analysis of other types of buildings (highly insulated, with high or low solar and internal gains, with nearly zero energy demands), changes in performance of HVAC equipment (chillers and heat pumps), effects on natural ventilation and night cooling, and other issues that should be taken into consideration during the design phase in the future with the aim of better adaptation to climate change.

## References

1. M. Brunetti, L. Buffoni, M. Maugeri, and T. Nanni, Trends of Minimum and Maximum Daily Temperatures in Italy from 1865 to 1996, *Theor. Appl. Climatol.*, 66 (2000) 49-60.
2. A.C. Moonen, L. Ercoli, M. Mariotti, A. Masoni, Climate change in Italy indicated by agrometeorological indices over 122 years, *Agricultural and Forest Meteorology*, 111 (2002) 13–27.
3. S. Shahid , S. B. Harun, A. Katimon, Changes in diurnal temperature range in Bangladesh during the time period 1961–2008, *Atmospheric Research*, 118 (2012) 260–270.
4. B. Lebassi, J. E. Gonnzález, D. Fabris, and R. Bornstein, Impacts of climate change in degree days and energy demand in coastal California, *J. of Solar Energy Engineering*, 132 (2010) 0310051-0310059.

5. K.T. Papakostas, A. Michopoulos, T. Mavromatis, N. Kyriakis, Changes of temperature data for energy studies over time and their impact on energy consumption and CO<sub>2</sub> emissions. The case of Athens and Thessaloniki – Greece, *Int. J. of Energy and Environment*, 4(1) (2013) 59-72
6. K. Papakostas, T. Mavromatis, N. Kyriakis, Impact of the ambient temperature rise on the energy consumption for heating and cooling in residential buildings of Greece, *Renewable Energy*, 35(7) (2000) 1376–1379.
7. M. Almazroui , M.N. Islam, P.D. Jones, H. Athar, M.A. Rahman, Recent climate change in the Arabian Peninsula: Seasonal rainfall and temperature climatology of Saudi Arabia for 1979–2009, *Atmospheric Research* 111 (2012) 29–45.
8. T. Frank, Climate change impacts on building heating and cooling energy demand in Switzerland, *Energy and Buildings* 37 (2005) 1175–1185.
9. S. Delfani, M. Karami, H. Pasdarshahri, The effects of climate change on energy consumption of cooling systems in Tehran, *Energy and Buildings*, 42 (2010), 1952-1957.
10. D. Founda, K.H. Papadopoulos, M. Petrakis, C. Giannakopoulos, P. Good, Analysis of mean, maximum, and minimum temperature in Athens from 1897 to 2001 with emphasis on the last decade: trends, warm events, and cold events, *Glob Planetary Change* 44(1-4) (2004) 27-38.
11. IPCC (Intergovernmental Panel on Climate Change), *Climate change 2007 - the fourth assessment report*, Cambridge University Press, 2007.
12. IPCC (Intergovernmental Panel on Climate Change), *Climate change 2013 - the fifth assessment report*, Cambridge University Press, 2013.
13. S. Barthendu, S.J. Cohen, Impact of CO<sub>2</sub>-induced climate change on residential heating and cooling energy requirements in Ontario, Canada, *Energy and Buildings* 10 (1987) 99-108.
14. R. Aguiar, M. Oliveira, H. Goncalves, Climate change impacts on the thermal performance of Portuguese buildings, results of the SIAM study. *Building Serv. Eng. Res. Technol.* 23(4) (2002) 223–231.
15. P. Xu, Y.J. Huang, N. Miller, N. Schlegel, P. Shen, Impacts of climate on heating and cooling energy patterns in California. *Energy* 44 (2012) 792–804.
16. M. Dolinar, B. Vidrih, L. Kajfež-Bogataj, S. Medved, Predicted changes in energy demands for heating and cooling due to climate change, *Physics and Chemistry of the Earth* 35 (2010), 100-106.
17. M. Mourshed, The impact of the projected changes in temperature on heating and cooling requirements in Buildings in Dhaka, Bangladesh, *Applied Energy* 88 (2011) 3737-3746
18. R. Zmeureanu, G. Renaud, Estimation of potential impact of climate change on the heating energy use of existing houses, *Energy Policy* 36 (2008) 303-310.
19. M. Olonscheck, A. Holsten, J. Kropp, Heating and cooling energy demand and related emissions of the German residential building stock under climate change, *Energy Policy* 39 (2011) 4795-4806.
20. P. Seljom, E. Rosenberg, A. Fidje, J.E. Haugen, M. Meir, J. Rekstad, T. Jarlset, Modelling the effects of climate change on the energy system-A case study of Norway, *Energy Policy* 39 (2011) 7310-7321.
21. X. Wang, D. Chen, Z. Ren, Assessment of climate change impact on residential building heating and cooling energy requirement in Australia, *Building and Environment* 45 (2010) 1663-1682.
22. C. Cartalis, A. Synodinou, M. Proedrou, A. Tsangrassoulis, M. Santamouris, Modifications in energy demand in urban areas as a result of climate changes: an assessment for the southeast Mediterranean region, *Energy Conversion and Management* 42 (2001) 1647-1656.
23. M. Christenson, H. Manz, D. Gyalistas, Climate warming impact on degree-days and building energy demand in Switzerland, *Energy Conversion and Management* 47 (2006) 671-686.

24. H. Radhi, Evaluating the potential impact of global warming on the UAE residential buildings - A contribution to reduce the CO<sub>2</sub> emissions, *Building and Environment* 44 (2009) 2451-2462.
25. M.R. Gaterell, M.E. McEvoy, The impact of climate change uncertainties on the performance of energy efficiency measures applied to dwellings, *Energy and Buildings* 37 (2005) 982-995.
26. K.K.W. Wan, D.H.W. Li, W. Pan, J.C. Lam, Impact of climate change on building energy use in different climate zones and mitigation and adaptation implications, *Applied Energy* 97 (2012) 274-282.
27. L. Collins, S. Natarajan, G. Levermore, Climate change and future energy consumption in UK housing stock, *Building Serv. Eng. Res. Technol.* 31(1) (2010) 75-90.
28. K. Pilli-Sihvola, P. Aatola, M. Ollikainen, H. Tuomenvirta, Climate change and electricity consumption - Witnessing increasing or decreasing use and costs?, *Energy Policy* 38 (2010) 2409-2419.
29. S. Mirasgedis, Y. Sarafidis, E. Georgopoulou, V. Kotroni, K. Lagouvardos, D.P. Lalas, Modeling framework for estimating impacts of climate change on electricity demand at regional level: Case of Greece, *Energy Conversion and Management* 48 (2007) 1737-1750.
30. T.N.T. Lam, K.K.W. Wan, S.L. Wong, J.C. Lam, Impact of climate change on commercial sector air conditioning energy consumption in subtropical Hong Kong, *Applied Energy* 87 (2010) 2321-2327.
31. C. Giannakopoulos, B.E. Psiloglou, Trends in energy load demand for Athens Greece: weather and non-weather related factors, *Climate Research* 31 (2004) 97-108.
32. National Observatory of Athens, Climatological Bulletin, Institute of Meteorology and Physics of the Atmospheric Environment, 1983-2012.
33. Meteorological observations of Thessaloniki station, Annual edition of Institute of Meteorology and Climatology of the Aristotle University of Thessaloniki, 1982-2012.
34. ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., Atlanta, USA, 1985, [chapter 28]. pp. 28.9-28.17.
35. D. Knebel, Simplified energy analysis using the modified bin method, ASHRAE, Atlanta, USA, 1983.