THE IMPACT OF TEMPERATURE INCREASE IN GREECE ON THE ENERGY DEMAND OF BUILDINGS

Triantafyllia Nikolaou[*1], John Kapsomenakis[2], Dionysia Kolokotsa[3], Mattheos Santamouris[4], and Stylianos Zerefos[5]

1 Technical University of Crete,
Electronic & Computer Engineering Department
University Campus Kounoupidiana
73100 Chania, Greece
**Corresponding author: tnikolaou@isc.tuc.gr*

2 Centre for Atmospheric Physics
& Climatology, Academy of Athens,
84 Solonos Str.
10680 Athens, Greece

3 Technical University of Crete,
Environmental Engineering Department
University Campus Kounoupidiana
73100 Chania, Greece

4 University of Athens, Physics Department,
Group Building Environmental Studies,
University Campus
15784 Athens, Greece

5 Hellenic Open University,
18 Aristotelous Str.
26335 Patras, Greece

ABSTRACT

The increase of the ambient air temperatures in urban areas during the past few decades, due to the heat island phenomenon and the warming of the lower atmosphere, has strong impact on the energy profile of buildings, the comfort conditions, the air pollution and the indoor environment, especially in the Mediterranean regions with hot climate conditions. The present paper focuses on the investigation of the impact of the temperature increase in nine Greek cities over the last forty years on the energy demand of buildings. This research is very crucial in order to understand climatic future trends, to establish the development of new technologies and techniques (such as ventilation strategies and smart materials) aiming to reduce the energy consumption of buildings, to improve the urban microclimate, as well as to steer specific policy actions. The methodology developed for this research includes: a) Analysis of climatic data: hourly data series 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) are presented and analysed. b) Simulation studies: In order to evaluate the potential impact of temperature variation on the energy demand of buildings, specific energy simulation studies have been performed using the Virtual Building Dataset (VBD) tool. The simulation process includes the determination of typical building for the simulations, the development of the required climate data files and the performance of 369 simulations using the VBD tool, which has been developed by coupling TRNSYS with Matlab. c) Analysis of the simulation results: the annual heating and cooling loads of the typical building for the nine Greek cities and for the period 1970-2010. 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 has 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.

KEYWORDS

Temperature increase, heating demand, cooling demand, climatic change

1 INTRODUCTION

The phenomenon of climatic change in association with local ambient air temperatures increase due to urban heat island is very intense the major cities of South East Mediterranean, where recent studies have shown unusual temperature anomalies (Mihalakakou et al., 1998; Livada et al., 2007; Founda, 2011 and Zanis et al., 2009). In the case of the Greek capital city of Athens, the specific topography combined with the augmenting urbanisation and industrialisation contributed to a significant increase of the ambient temperature during the last 30 years (Giannopoulou et al., 2011; Mihalakakou et al., 2002). Multiyear studies have shown that the intensity of the average summer period heat island intensity may reach values close to 7-8 ºC (Santamouris et al., 1999). Consequently, the urban heat island acts in local level by increasing the outdoor temperature, while extreme phenomena are attributed to climate change.

Based on the outcomes of numerous studies the increase of urban temperatures has a serious impact on the energy consumption of buildings. In (Hassid et al., 2000; Santamouris et al., 2001) 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 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. A review on the impact of climate change on air condition systems in terms of performance and reliability is performed in (Yau and Pean, 2011) showing that the research should focus on the future energy needs for heating and cooling due to climate change.

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 30ºC for almost 85% of the hot period, while periods of about 216 continuous hours above 30 ºC were recorded (Santamouris et al., 2007b; Pantavou et al., 2011; Sakka et al., 2012).

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 (Cartalis et.al, 2001) 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 (Asimakopoulos et al., 2012) 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.

The aim of the present research is 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. The results of this work are very crucial for determining the climatic future trends, establishing the development of new technologies and techniques, such as ventilation strategies and smart materials for reducing the energy consumption of buildings, for improving the urban microclimate, as well as for steering specific policy actions (Kapsomenakis et al., 2013).

2 ANALYSIS OF THE CLIMATIC DATA

Hourly values of air temperature and relative humidity covering the period 1970-2010 from nine Greek meteorological stations of the Hellenic National Meteorological Service (HNMS) were used in the present study. The locations of the meteorological stations are shown in

Figure 1. It is noted that the accuracy of temperature measurement devices (thermometers) is 0.2 °C and of the relative humidity measurement devices is 1%.

Figure 1: The nine meteorological stations

2.1 Temperature and relative humidity trends

The intra-annual variability of the mean temperature along with the intra-annual variability of diurnal temperature range are analyzed in details in (Kapsomenakis et al., 2013). 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 (Feidas et al., 2004; Philandras et al., 2008; Nastos et al., 2011). Relative humidity trends are doubtful. More specifically, over Eastern Continental Greece relative humidity shows a statistically significant (at 95 % confidence level) downward trend during spring and summer. On the contrary, upward trends are observed over South and South-eastern Aegean which, in some cases, are statistically significant at a 95 % confidence level. Finally in Western Greece weak and not statistically significant -upward or downward- trends prevail. To summarize, statistically significant upward trends are observed in air temperatures at all stations.
The results discussed above for individual stations in Greece are also evident when we calculate the average values of air temperature for all 9 stations as can be seen in Figure 2 for 02:00 and 14:00 Local Time (LT). The temperature increase trends per decade for 2:00 as well as for 14:00 LT can be extracted by the trend lines. For 2:00 the temperature increase per decade is 0.58°C, 0.37°C, 0.27°C and 0.14°C for June – July – August (JJA), September – October – November (SON), March – April – May (MAM) and December – January – February (DJF) respectively. Therefore it is clear that upwards trends in Figure 2 are larger at night and significantly greater during summertime.

2.2 Heating & cooling degree hours trends

Furthermore, the number of Heating/Cooling Degree-Hours is calculated in a seasonal base as well as their linear trends (using Mann-Kendall statistical test) for the period 1970-2010. As depicted in Figure 3 the average increase of Cooling Degree Hours (CDH) based on the trend lines is 472 CDH, 21.5 CDH and 16.8 CDH per decade for JJA, SON and MAM respectively. (Kapsomenakis et al., 2013).

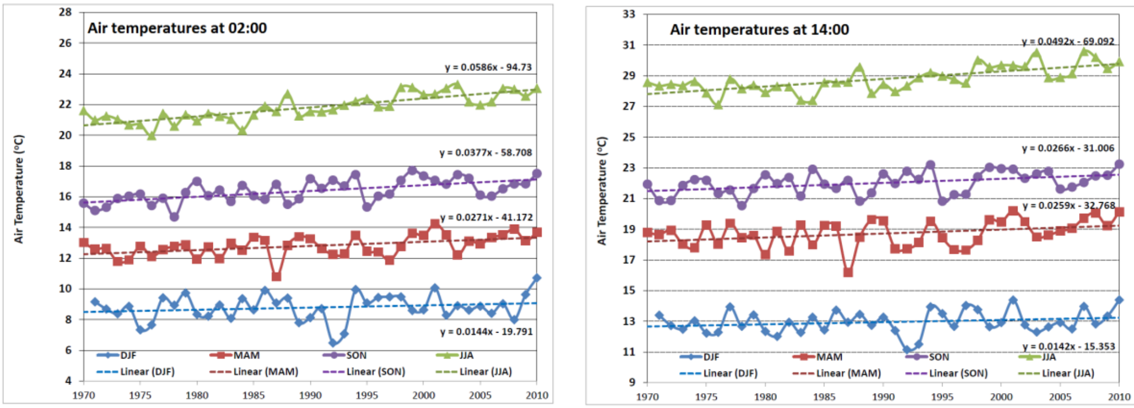

Figure 2: Mean seasonal air temperature average over all stations time-series at 02h and 14h local time. Linear trend lines are dashed

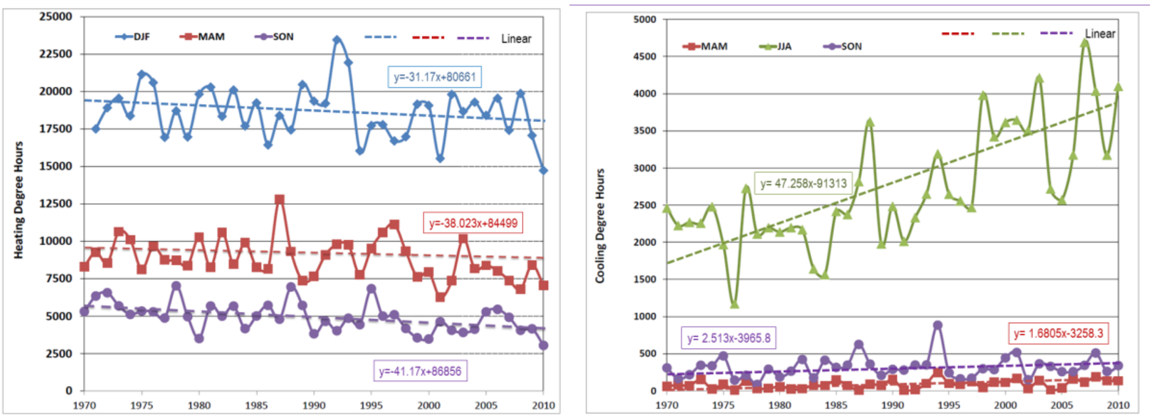

Figure 3: Mean seasonal heating and cooling degree hours average over all stations time-series. Linear trend lines are dashed.

3 THE IMPACT ON THE ENERGY CONSUMPTION OF BUILDINGS

In order to evaluate the potential impact of temperature variation on the energy consumption of buildings, specific energy simulation studies have been performed using the Virtual Building Dataset (VBD) tool, described in detail in (Nikolaou et al., 2009). The VBD consists of 30,000 buildings with detailed constructional, operational, energy and indoor thermal comfort annual data. The overall procedure for the creation of this tool was developed by coupling TRNSYS with Matlab. The simulation process has been conducted following 3 steps:

Step 1: Typical office building selection: The building that has been used for the simulations was chosen as "typical office building" in Greece taking as a criterion its annual heating and cooling load (kWh/m2y) that has to correspond to the 50% of the cumulative frequency distributions of thermal and cooling loads respectively of the 30,000 buildings included in

VBD. In (Kapsomenakis et al., 2013) the constructional, operating and energy characteristics of the selected typical office building for the purpose of this research are analyzed in detail.

Step 2: Development of climate data files: Based on the records of the data for the years 1970-2010, 41 files according to TMY2 format for each city (one file for each year) were created, by developing a suitable program in Matlab, in order to be used as inputs to the VBD tool. Since only Dry Bulb Temperature and Relative Humidity values were included in the files of the records, the remaining required data (except the Dew Point Temperature values) are derived from hourly meteonorm files for each city. Regarding the values of the Dew Point Temperature, they have been calculated in an hourly base of each year from the respective hourly data of Dry Bulb Temperature and Relative Humidity, using part of the Bögel modification, also known as the Arden Buck equation (Buck, 1981).

Step 3: Simulations and results: Forty one simulations for the nine Greek cities (totally 369 simulations) have been performed using the VBD tool along with the climate data files developed in step 2. The results include annual heating and cooling load values for the years 1970-2010 for each city and they are analysed below.

Figure 4 provide the calculated values of the annual heating and cooling load for four cities covering the four climatic zones in Greece. As can be seen from these figures an important temporal decrease of the heating load and a significant increase of the cooling loads, are calculated. As expected, the calculated increase of the cooling load is much higher than the corresponding decrease of the heating load. More specifically, in Heraklion, which is situated at the southern part of the country, the annual heating load has been reduced by 23%, i.e. from 34.3 kWh/m^2/y to 26.5 kWh/m^2/y. The reduction of the heating load is of similar order in Athens and Corfu and approaches 20%. The heating load has been reduced from 39.4 kWh/m^2/y to 31.7 kWh/m^2/y and from 45.5 kWh/m^2/y to 36.2 kWh/m^2/y in Athens and Corfu respectively. In Larisa, the reduction is much lower and close to 6% i.e. from 48.2 kWh/m^2/y to 45.5 kWh/m^2/y. Concerning the annual cooling load, the calculated increase varies between 15% to 29% for the overall forty year period. In particular, in Heraklion the cooling load has been increased from 93.7 kWh/m^2/y to 120.9 kWh/m^2/y, in Athens from 99.5 kWh/m^2/y to 124.8 kWh/m^2/y, in Corfu from 81.9 kWh/m^2/y to 101.2 kWh/m^2/y, while in Larisa the load has been increased from 87.2 to 100.7 kWh/m^2/y. The annual variation of the heating and cooling load has a symmetrical temporal variation per year. Figure 5 presents the relationship between the annual heating and cooling load in the four selected cities. As shown, the higher the annual cooling load the lower the heating one.

Figures 6 and 7 present a linear fit of the annual variation of the heating and cooling load in the four selected cities respectively. It is calculated that the average reduction of the heating load is close to 1.0 kWh/m^2 per decade. In particular, it is 0.84 kWh/m^2 in Larisa, 1.01 kWh/m^2 in Heraklion, 1.04 kWh/m^2 in Athens and 1.4 kWh/m^2 in Corfu. As for the increase of the cooling load, it is much higher than the corresponding decrease of the heating load and ranges between 4.5 to 6.2 kWh/m^2 per decade. In particular, the maximum increase is presented in Athens, 6.2 kWh/m^2, mainly because of the complementary effect of the urban heat island phenomenon. For the rest of the cities, the calculated increase per decade is close to 5.6 kWh/m^2 in Corfu, 4.5 kWh/m^2 in Heraklion and 4.4 kWh/m^2 in Larisa.

Increase of the cooling and decrease of the heating load of buildings may have a very serious impact on the energy balance of the country. Cooling in Greece is mainly provided by air conditioners and heat pump systems while oil and natural gas are mainly used for heating purposes. In addition electricity production in Greece relies upon fossil fuels, i.e. lignite, and oil (Agoris et al., 2004). The Increase of the cooling loads will raise the peak electricity demand in the country and will oblige utilities to build additional power plants to satisfy the demand. Such a scenario will increase the cost of electricity as kWh produced during peak conditions is more expensive.

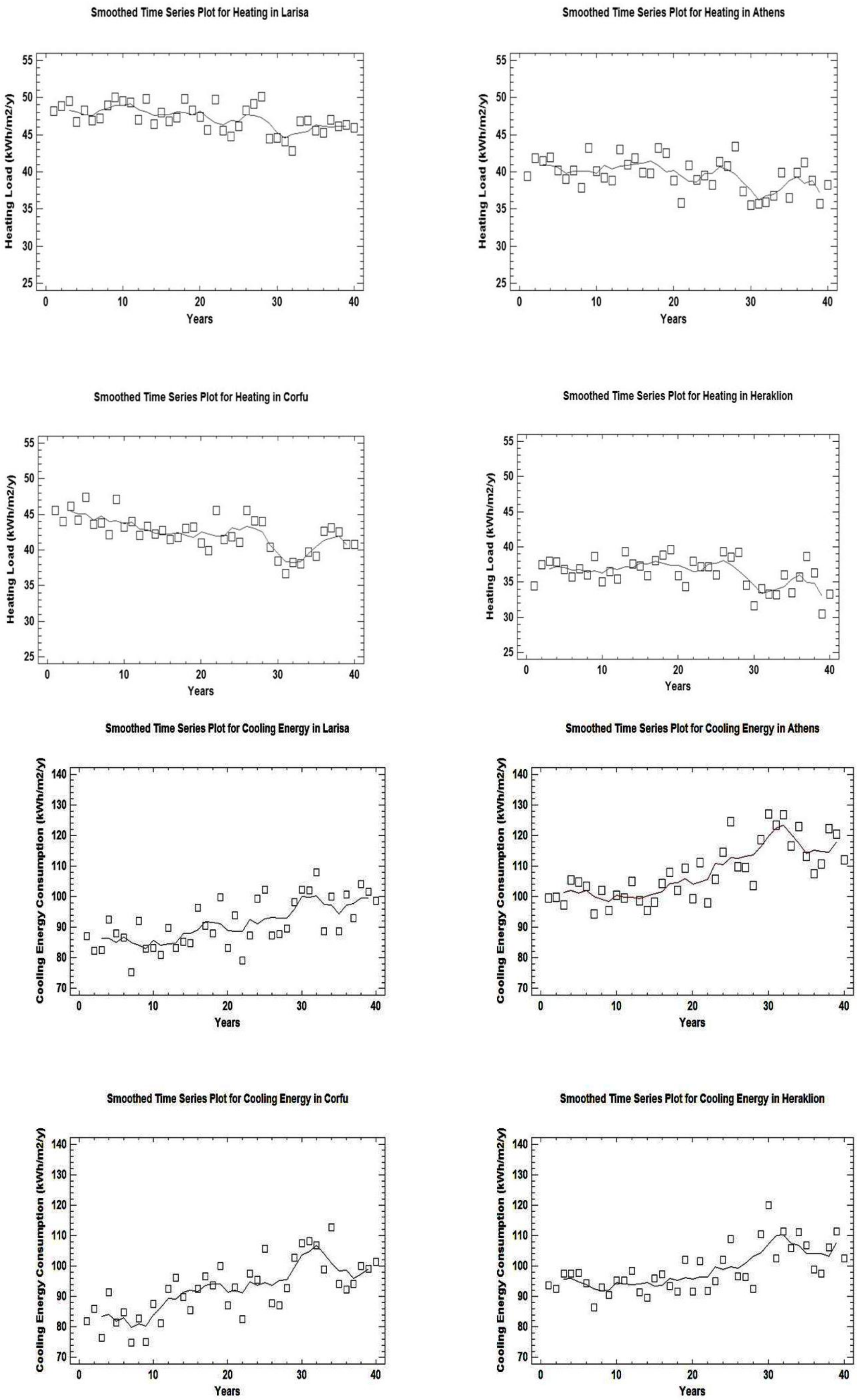

Figure 4: Annual variation of the heating and cooling load in four Greek cities.

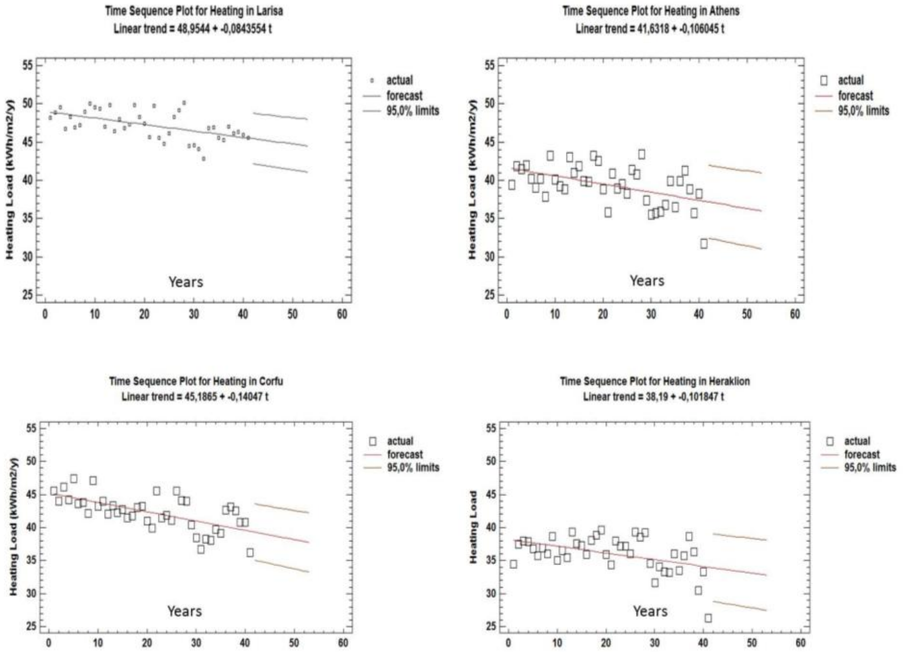

Figure 5: Correlation between the annual heating and cooling load for the four selected Greek cities.

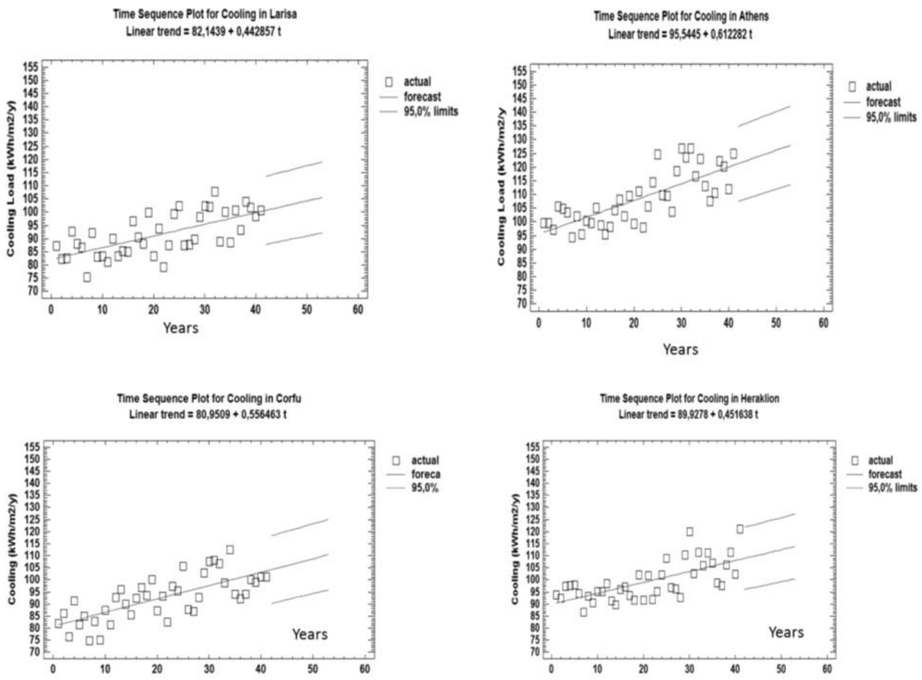

Figure 6: Linear Correlation of the annual variation of the heating load for four Greek cities.

Higher ambient temperatures will also oblige more citizens and in particular low and mid income households to install air conditioners to provide indoor comfort. Actually, the penetration of air conditioners in low and mid income residential buildings is quite limited. Additional users will increase the absolute energy consumption for cooling and will further increase the peak electricity demand. This will increase the energy cost especially of low income citizens in the country. According to (Santamouris et al., 2007a), the annual cost of cooling in low income households in Greece is almost the double per unit of surface and person than in high income households. This is because the high majority of low income citizens lives in non-insulated and non-thermally protected buildings. Decrease of the heating needs may contribute towards lower imports of oil and natural gas, however, the relative benefit is much lower than the damage caused by the increase of the cooling demands.

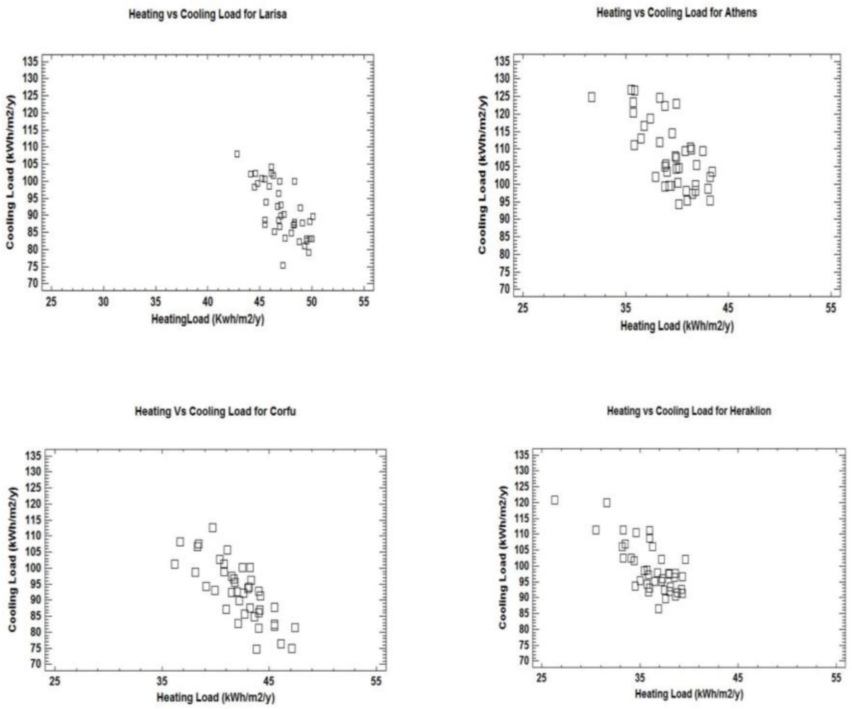

Figure 7: Linear Correlation of the annual variation of the cooling load for four Greek cities.

4 CONCLUSIONS

The last forty years have been characterized by very important anomaly trends of the ambient air temperatures in Greece and the South Eastern Mediterranean. These trends are the resultant of man-made global climatic change in the area and the augmentation of the heat island phenomenon in the major urban zones in Greece. The increase of the ambient air temperature is found to be more significant during the summer than during the winter period. Important increasing and decreasing trends have been calculated for the annual cooling and heating degree days in major urban locations of the country (Kapsomenakis et al., 2013).The phenomenon is statistically significant at a 95% confidence level.

Higher ambient air temperatures have a significant impact on the energy consumption of buildings. Detailed simulations performed for four major urban areas of Greece using hourly climatic data for a forty year period, have shown that the heating load of buildings decreases by about 1.0 kWh/m^2 per decade while the cooling load increases by almost 5.0 kWh/m^2 per decade. Thus, this important climatic phenomenon increases considerably the total energy consumption of the buildings sector and has significant economic and social consequences. Given that climatic forecasts for this geographic area predict an important amplification of the climate change phenomena for years to come (Asimakopoulos et al., 2012) the expected energy penalty is expected to increase considerably in the future.

The results of the study make evident that proper mitigation and adaptation techniques have to be undertaken in order to confront global climatic change and local heat island phenomena and also counterbalance their impact on the energy and environmental quality of buildings. In our opinion it is the main research priority for the future. Several studies presenting suggested mitigation and adaptation techniques for different countries have been already carried out (Gupta and Gregg, 2011). Simulation studies have shown that when proper mitigation and adaptation techniques are undertaken, both the energy consumption and the environmental quality in the built environment can be improved considerably (Asimakopoulos et al., 2012).

Mitigation techniques should include any anthropogenic intervention to reduce heating sources and enhance the sinks of temperature anomalies. Mitigation technologies are not sufficiently promoted, although there are significant research actions. In particular research on materials for the outdoor urban environment, is of high importance (Karlessi et al., 2011). On the other hand, the adaptation of the building sector deals with possible technological adjustments to climatic anomalies in order to moderate the energy and environmental impact and cope with the consequences.

Adaptation technologies are very well developed, and are the subject of sophisticated and advanced research that has permitted to develop materials, systems and techniques for the building sector that contribute highly in the reduction of energy consumption and the improvement of indoor environmental quality, In particular, the development and use of passive and advanced cooling techniques for buildings offer very significant possibilities to improve the energy performance of buildings during the summer period (Santamouris and Kolokotsa, 2013).

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