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Trends in energy load demand for Athens, Greece: weather and non-weather related factors

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ABSTRACT: This study examines the characteristics of energy demand for the Greater Athens area in Greece, and explores its relationship with variations in temperature. Energy demand in Athens varies both seasonally and from year to year. The latter shows an increasing trend, which is associated mainly with economic, social and demographic factors. The former is controlled by prevailing weather fluctuations and also by factors unrelated to weather effects (weekend and holiday effects). Weekends and public holidays always appear to have much lower values of energy demand than weekdays. Analysis of our data series has indicated that the relation between energy demand and temperature is non-linear and that the optimum ambient temperature for low levels of energy demand is 22°C. This temperature was also used as the base temperature for the calculation of heating and cooling degree-days. The sensitivity of energy load to air temperature is greater during the cold period of the year. Under a changing climate, regional models predict a warming for Athens by the 21st century that will be associated with a decrease in demand during the milder and shorter winter period and with an increase in demand during the hotter and longer summer period.

KEY WORDS: Degree-days · Energy demand trends · Ambient temperature · Climate change

1. INTRODUCTION

Weather fluctuations have a significant impact on different sectors of the economy. One of the most sensitive is the electricity market, because power demand is linked to several weather variables (mainly air temperature). Consumption of electricity is particularly sensitive to weather, since large amounts of electricity cannot be stored and thus electricity that is generated must be instantly consumed. For this reason, an effective model of future electricity consumption is needed.

Recent studies have investigated the influence of ambient air temperature, most often represented by heating and cooling degree-days, on electrical energy consumption (Al-Zayer & Al Ibrahim 1996, Henley & Peirson 1997, Sailor 2001, Valor et al. 2001, Pardo et al. 2002). Other common independent variables, such as relative humidity, clearness index and wind speed (Sailor & Muñoz 1997, Bard & Nasr 2001), and derived variables including latent enthalpy-days, cooling radiation-days and clothing insulation units (known as 'clo' units) (Lam 1998, Yan 1998) have been used by other researchers for the development of statistical models for energy consumption.

In many cases modelling of electric energy consumption is multivariate, consisting of a mix between climate and other important economic factors. The main constituents of these economic factors are energy prices, income and energy demand index (Arsenault et al. 1995, Eltony & Al-Mutairi 1995, Zarniko 1997, Lam 1998, Beenstock et al. 1999, Nasr et al. 2000). Other studies modelled the energy consumption of the different economic sectors (e.g. industrial, commercial, and residential) within a country (Smyth 1996, Eltony & Hosque 1997). Co-integration techniques for establishing long- and short-term energy demand relationships with climate factors have also been performed (Bard & Nasr 2001).

This study aims to provide a comprehensive analysis of the relationship between electrical energy

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demand and air temperature for Athens, Greece. We initially identify the general trends that govern energy demand in the area of Athens (yearly, seasonal, daily, hourly). We then seek to determine the relationship between energy demand and ambient monthly or daily air temperature. The cooling and heating degree-days concepts (CDD and HDD) have also been employed by truncation of the temperature series at a constant base temperature that was deemed appropriate characterization of Athens weather. Most existing studies on the subject are empirical studies of the relation between energy consumption and climate, many of which are only published in internal reports of utility companies. Our study aims to bridge this gap in the literature and complement the theoretical studies Valor et al. (2001) for Spain and Sailor & Muñoz (1996) and Sailor (2001) for the USA. Furthermore, this study provides an insight into future energy demand under a changing climate using regional climate model (RCM) predictions up to the year 2100.

2. DATA DESCRIPTION

Hourly energy consumption data were made available by the Strategy and Planning Department of the Public Power Corporation of Greece for the Greater Athens area. These data refer to total hourly residential and commercial electricity consumption (kWh) spanning the period from January 1993 to December 2001 (9 yr of data). Additionally, meteorological data from the station at the National Observatory of Athens (NOA) were also used. 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. Although the station lies near the center of Athens, it is isolated from heavy traffic and densely built areas. The meteorological data from the station used in this study are hourly values of temperature that cover the same time period as the energy consumption data.

Daily variation in air temperature, gross national product (GNP) for the Greater Athens area (Attika) and energy consumption for the period 1993–2001 is depicted in Fig. 1. Energy consumption shows a clearer upward trend than does air temperature. The increase in energy demand is largely due to economic growth and also to greater usage of air conditioners in residential and commercial situations as GNP increases. Similar results are obtained when monthly mean values of energy consumption and air temperature are plotted.

The link between hot weather and increased electricity demand is also evident in other countries where use of air conditioners has increased (Lam 1998). From Fig. 1, it is obvious that there are 2 components in energy load variations: seasonal and yearly. The former is mainly influenced by the prevailing weather conditions and the latter by economic, social and demographic factors.

3. ELECTRICITY LOAD AND AIR TEMPERATURE

3.1. Daily, weekly and monthly electricity load variability

In this section we seek to determine the time periodicity in energy load data. More specifically, we investigate whether energy consumption has a monthly, diurnal or hourly cycle. Such a cycle can be appropriately studied using seasonal variation indexes.

The monthly seasonal variation index (MSVI), following Valor et al. (2001), can be defined as:

$$\mathrm{MSVI}_{ij} = E_{ijk} / \overline{E_j} \tag{1}$$

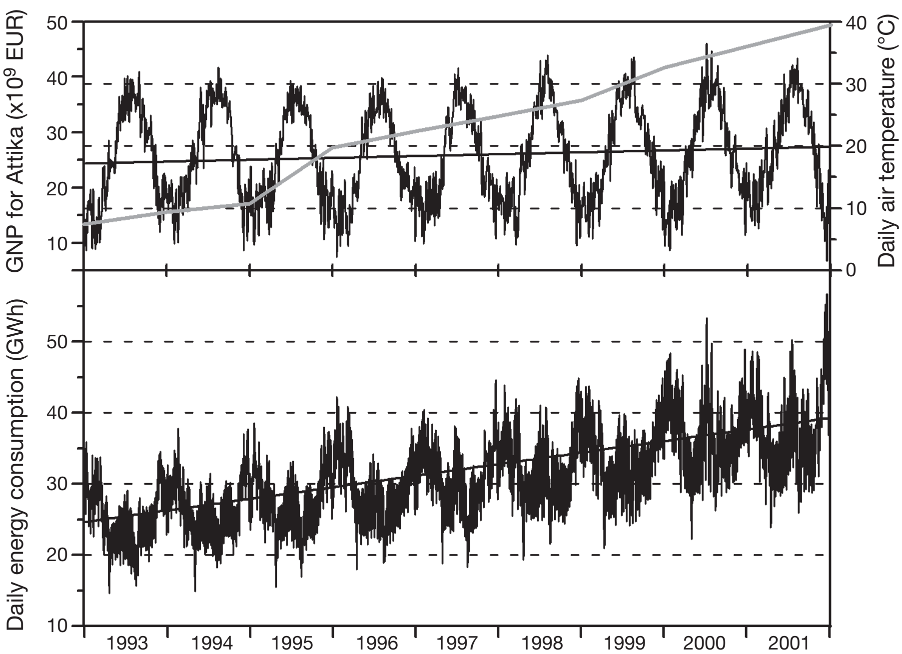

Fig. 1. Gross National Product (GNP, grey line), daily air temperature, and daily energy consumption, Greater Athens (Attika), 1993–2001. Solid black lines: trends

where $MSVI_{ij}$ is the index value for month i in year j, E_{ij} is the monthly energy consumption for month i in year j and $\overline{E_j}$ is the mean monthly consumption for year j (mean of 12 values of E_{ij} for year j).

The average value of MSVI yields the relative behaviour throughout the months of the year, whereas maximum and the minimum values of MSVI reveal deviations from mean behaviour.

Fig. 2 depicts the monthly seasonal profile of MSVI for energy load from 1993 to 2001. The behavior of MSVI shows a high consumption of electricity in January, which thereafter gradually decreases until May. The gradual decrease of electricity demand as the weather warms coincides with a decrease in demand for heating. As we move into summer, there is (as expected) an increasing trend in electricity demand, mainly due to extensive use of air conditioners. This tendency continues throughout the summer until September, with the exception of August when a significant fall in demand is evident. The August fall is due to the fact that a major proportion of the population of greater Athens area is on summer vacation during this month. Electricity demand also falls slightly in October, which is representative of the transition from summer to winter, before gradually increasing again in subsequent months to reach a maximum in December. The load values in December are even higher than those in January and February (which are colder months than December), due to increased energy requirements during the festive Christmas period.

To explore the daily fluctuation of energy load, the daily variation index (DSVI; after Valor et al. 2001) is defined as:

$$DSVI_{ijk} = E_{ijk} / \overline{E_{jk}} \quad (2)$$

where $DSVI_{ijk}$ is the value of the index for day i of week j of year k, E_{ijk} is the energy consumption for the particular day, and $\overline{E_{jk}}$ is mean daily consumption for week j of year k.

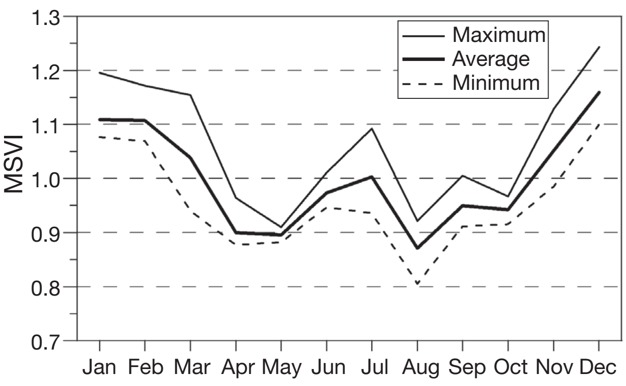

Fig. 2. Mean monthly seasonal variation index (MSVI) of electricity consumption, 1993–2001

Fig. 3a depicts the variation of DSVI according to day of the week. It is clear that energy consumption is significantly lower during the weekends (especially on Sundays) due to reduced economic activities over this period. Lower levels of consumption are also observed on Mondays compared to the other days of the week, because of the inertia caused by the reduced economic activities during the weekends.

Moreover, electricity consumption also decreases during holidays that fall between Monday and Friday and also on the days that follow a holiday or are placed between 2 holidays (due again to inertia caused by reduced economic activity). This effect is easily appreciable from Fig. 3a, where the minimum value of weekdays is comparable with the weekend average value. Moreover, the minimum DSVI curve for weekdays is more clearly separated from the average curve than the minimum values for the weekend (see also Valor et al. 2001). In Fig. 3a, the absolute minimum value for Monday is due to a Greek holiday related to the start of Lent (Ash Monday).

Fig. 3b demonstrates the seasonal characteristics of DSVI. More specifically, Fig. 3b indicates that weekday energy consumption is higher in July, whereas weekend consumption is higher in January. This reflects the fact that air conditioning use falls sharply

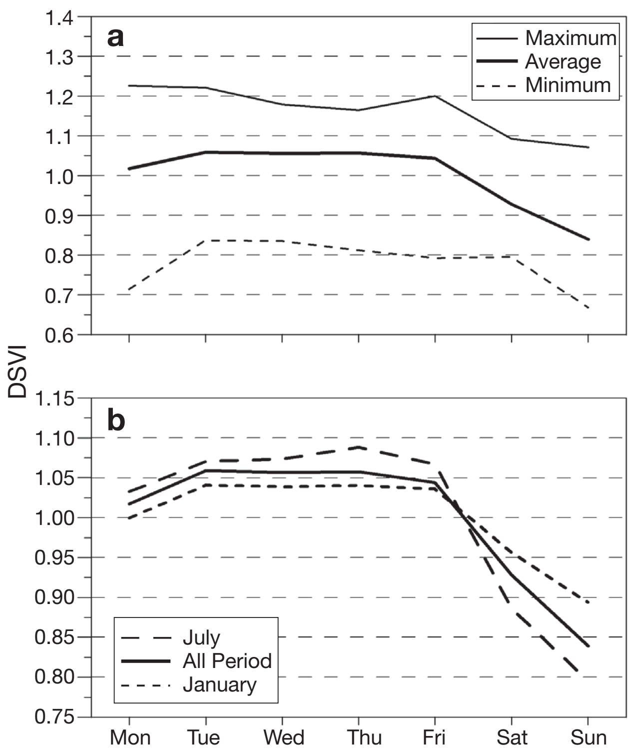

Fig. 3. (a) Daily seasonal variation index (DSVI) of electricity consumption and (b) DSVI of electricity consumption for 2 distinct months (January and July), 1993–2001

during weekends in July, because people are away from their offices and tend to go outdoors or out of the city boundaries where it is substantially cooler. In January, people tend to stay indoors during weekends, leading to relatively higher energy use.

Given that our data include hourly values of energy consumption, we extended our study further from that of Valor et al. (2001) by defining HSVI, the hourly seasonal variation index, which shows diurnal variation in energy consumption. From the hourly values, we calculated the average diurnal variation for each month (24 average hourly values each month). In this way, an average 24 h period is available for each month, so that for each year, 12 such 24 h periods are present. HSVI is therefore defined as:

$$\mathrm{HSVI}_{ijk} = E_{ijk} / \overline{E_{jk}} \quad (3)$$

where HSVI_{ijk} is the value of the index for hour i of the average 24 h period of month j in year k, E_{ijk} is the electricity consumption for a certain hour, and $\overline{E_{jk}}$ is mean monthly energy consumption for month j in year k.

In Fig. 4a, the hourly variation during a 24 h period is evident. The first maximum close to midday is due to extensive use of electricity both for household (heating, cooking) and business (office heating, server and PC usage) needs during the working hours of the day. The second maximum is due to the use of lighting and heating/cooling that uses additional heaters or air conditioners during the late afternoon and early evening hours.

It is worth noting the differences in HSVI when studying it in different seasons, most notably summer and winter. As a characteristic example we present, in Fig. 4b, the months of January and July.

During January, there are 2 distinct maxima in energy demand, one close to midday (due to heating, cooking or office needs) and another in the evening. The evening maximum reflects needs for extra heating and home entertainment (e.g. television), as most people stay indoors. The pattern in July is different. Apart from the midday maximum which occurs at approximately the same time as that in January, the evening maximum occurs much later and is much less pronounced than that in January. Moreover, in the late afternoon/early evening, there is a decrease in demand that reflects the high level of recreational activities (such as eating out) and the late return home that is common in summer.

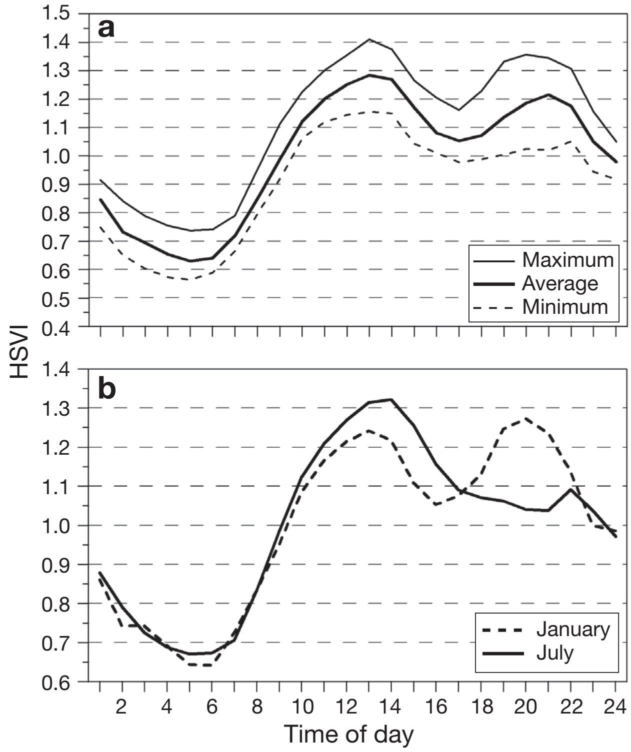

Fig. 4. (a) Hourly seasonal variation index (HSVI) of energy consumption and (b) HSVI energy consumption for January and July, 1993–2001

3.2. Relationship between energy load and temperature

The variation in daily energy consumption and mean daily air temperature for the whole of 2001 is plotted in Fig. 5. Regular variations in energy consumption,

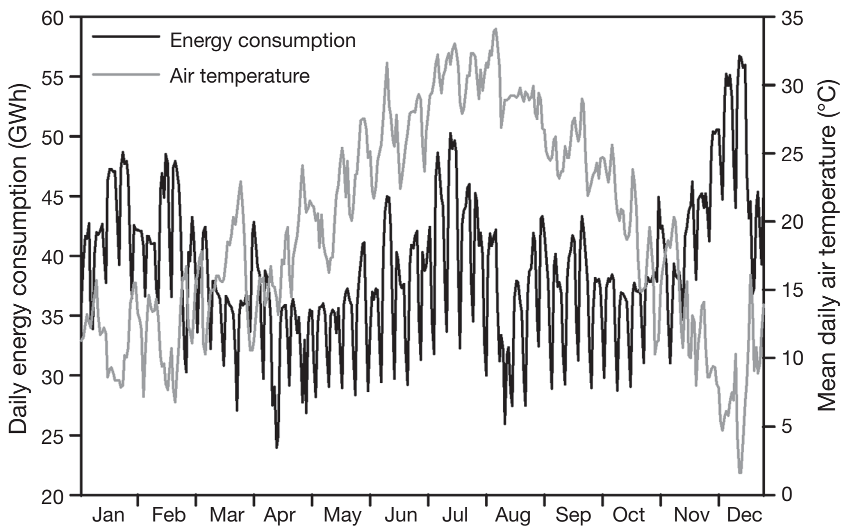

Fig. 5. Variation in daily energy consumption and mean daily air temperature, 2001

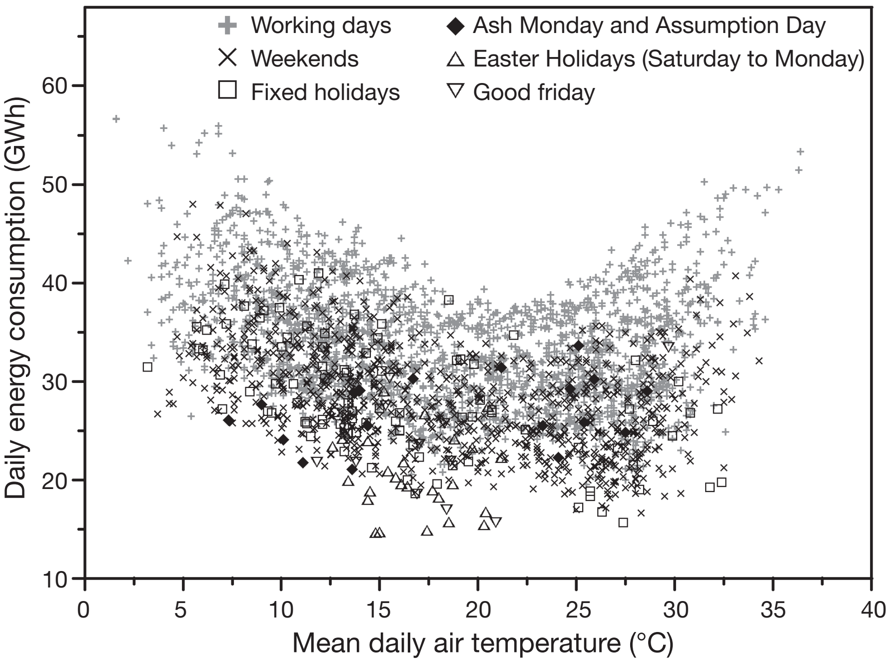

Fig. 6. Scatter plot of daily energy consumption versus daily mean air temperature, 1993–2001

discussed in Section 3.1, are apparent in the energy consumption plot (black line). In contrast, mean daily air temperature has a much less regular variability, and follows a typical seasonal trend. Energy consumption is closely linked to mean daily air temperature; the maximum values of the former coincide with extremes of the latter. During January, the maximum values of energy consumption are related to the appearance of the lowest temperatures. During the transient season of March–April, when air temperatures are constantly rising, energy consumption levels are kept nearly constant until about May. Despite the rise, temperatures are still comfort levels, and so consumption is nearly constant. Fig. 6 shows that energy demand and consumption are greatly reduced during weekends and holidays compared to demand during working days. The lowest values of energy consumption exist during the long Easter weekend (Good Friday to Easter Monday) and other fixed holidays (15 August, Christmas), irrespective of daily mean air temperature. Since weekends/holidays seem to correlate less closely with air temperature, we chose to separate holidays from working days and explore their correlation with air temperature separately (Fig. 7).

Fig. 7 shows that the relationship between energy consumption and air temperature is not linear, instead presenting 1 minimum and 2 maxima. The minimum value appears around 22°C and is the temperature that will be used subsequently for the calculation of heating and cooling degree-days. Around this temperature, there exists an area where energy consumption shows no sensitivity to air temperature. Outside this area, energy consumption increases with an increase (due to air conditioning needs) or decrease (due to extra heating needs) of air temperature. However, there are certain limits beyond which energy consumption does not

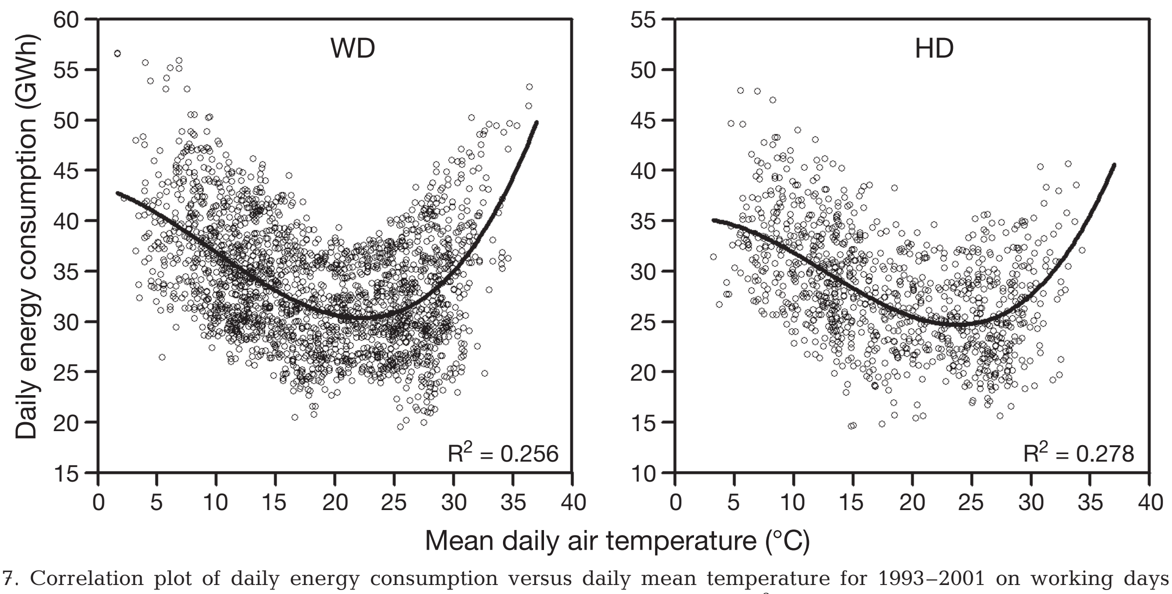

Fig. 7. Correlation plot of daily energy consumption versus daily mean temperature for 1993–2001 on working days (WD) and weekends/holidays (HD). Black lines: best fit curves; R^2: correlation coefficients

increase further. This happens in both branches of the curve corresponding to winter and summer. This may be due to the limiting power of air conditioning systems and to the insulating capacity of buildings (Valor et al. 2001).

In individual years, the relationship between energy and temperature has approximately the same shape, with a tendency of increasing correlation coefficients in more recent years.

Fig. 8 depicts the correlation between energy consumption and temperature for 1993, 1997 and 2001. The correlation between energy consumption and temperature is non-linear and has 2 maxima and 1 minimum. The minimum value is always around 22°C, and the correlation is higher in the case of working days (WD) than in the case of weekends/holidays (HD). Correlation between energy load and temperature is higher in more recent years. In all 3 years examined, the winter branch of the curve is more developed than the summer branch, which indicates faster response of the system during the cold period of the year. Although the summer branch is less developed, it has tended to increase in more recent years, but still remains lower that the winter branch.

4. HEATING AND COOLING DEMANDS

Since the energy-temperature relationship is non-linear and has 2 branches, it would be more convenient for further data interpretation to separate these 2 branches. The easiest way to achieve this is to use the

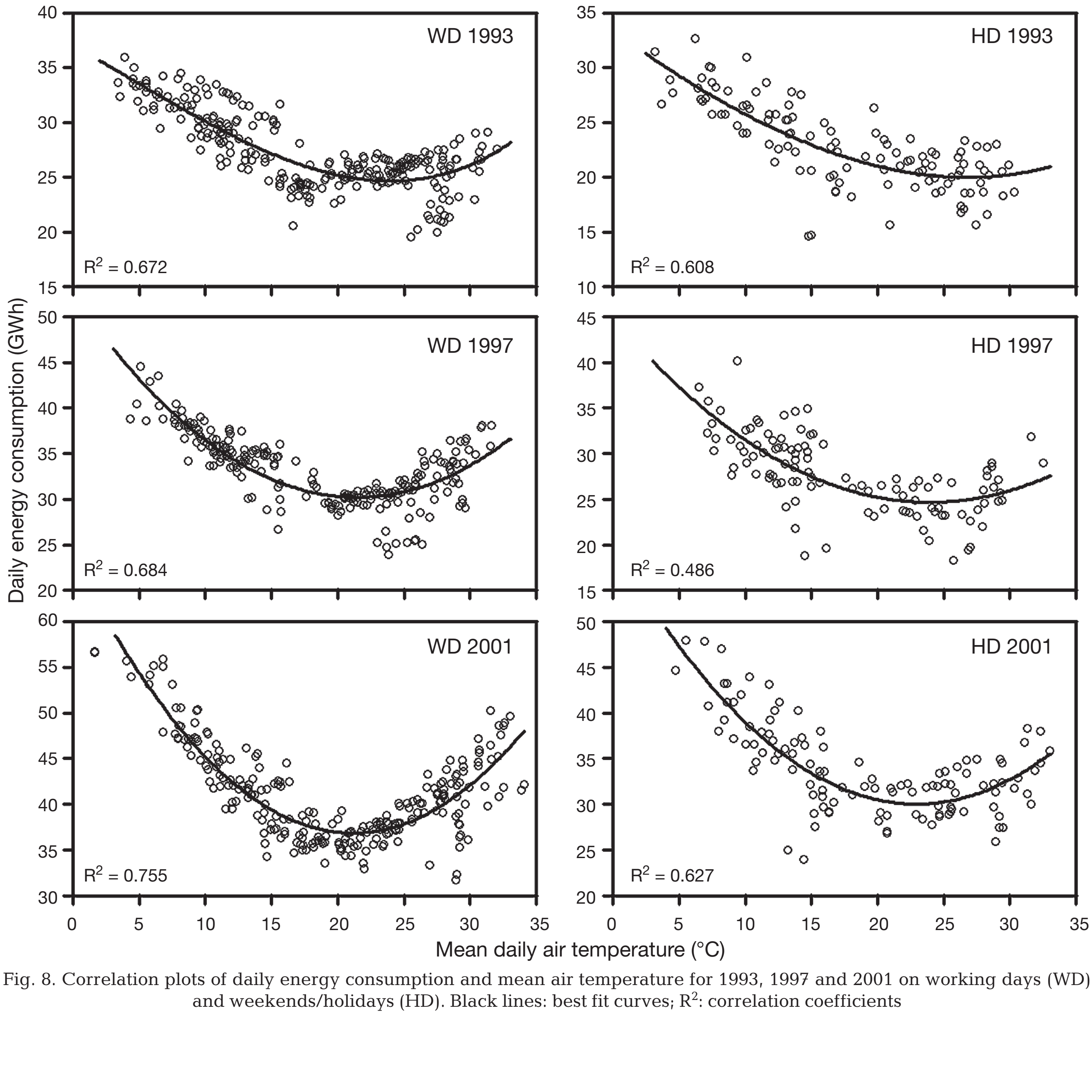

Fig. 8. Correlation plots of daily energy consumption and mean air temperature for 1993, 1997 and 2001 on working days (WD) and weekends/holidays (HD). Black lines: best fit curves; R^2: correlation coefficients

concept of degree-days (DD) (firstly introduced by Thom 1952, 1954, 1962), which is defined as the difference of mean daily temperature (T) from a base temperature (T_B):

$$DD = T - T_B \quad (4)$$

As base temperature, we define the ambient air temperature at which solar and internal (from electric lighting, equipment and people) gains offset heat losses from buildings (Eto 1988); at this point, energy demand shows no sensitivity to air temperature. In our case, the base temperature can be identified using the above correlation plots of energy consumption with air temperature (Fig. 7, mainly using the plot for the working days [WD]). Base temperature should be the temperature where energy consumption is at its minimum. If this temperature is chosen, then the degree-day index is positive in the summer branch and negative in the winter branch. Instead of having both positive and negative values for this index, the definition of 2 indices is used: heating degree-days (HDD) and cooling degree-days (CDD).

For the calculation of the HDD and CDD indices, the following equations were used:

$$HDD = \max(T^* - T, 0) \quad (5)$$

$$CDD = \max(T - T^{**}, 0) \quad (6)$$

where T^* and T^{**} are the base temperatures for HDD and CDD respectively, which can be either the same or different, and T is the mean daily temperature as calculated from the hourly available meteorological data.

HDD (CDD) is a measure of the severity of winter (summer) conditions in terms of the outdoor dry-bulb air temperature, an indication of the sensible heating (cooling) requirements for the particular location. The unique base temperature of 18.0°C is commonly used to calculate HDD and CDD, especially in the analysis of the impact of weather on energy consumption (Quayle & Diaz 1980, Le Comte & Warren 1981, Eto 1988, Badescu & Zamfir 1999, Valor et al. 2001, Pardo et al. 2002, Hart & de Dear 2004). However, other climatic areas could require other base temperatures.

In order to achieve the best adjustment for consumption data in each state, Sailor & Munoz (1997) used a base temperature of 18.3°C for calculating degree-days on Ohio, Louisiana and Washington and 21.0°C for Florida. Engle et al. (1992) used 2 different bases (50°F and 65°F) to calculate HDD and 2 others (65°F and 70°F) for calculating CDD. In Spain, Valor et al. (2001) and Pardo et al. (2002) used the base temperature of 18.0°C. In relatively hot climates such as in Jordan, the recommended base value is 15.5°C; in the Kingdom of Saudi Arabia, depending on different regions within the country, it ranges between 17.8°C and 21.1°C (El-Shaarawi & Marsi 1996). In Turkey, a unique base temperature of 15°C is adopted by Kadioğlu & Şen (1999) and Kadioğlu et al. (1999). For the Athens area, and only for the specific calculation of CDD for the 4 summer months (June to September), the 25°C and 28°C base temperatures were used (Tselepidaki et al. 1994).

Another possibility could be to select 2 different base temperatures for the heating and cooling indices, because a non-sensitive temperature interval is observed around 18°C. For instance, Beenstock et al. (1999) defined HDD by taking T^* = 10°C and CDD by selecting T^{**} = 25°C. Within these 2 limits a 'comfort zone' could be established, in which no heating or cooling is required. A well-ventilated home needs almost no heating between 12.8 and 18.3°C in the USA (Quirk 1981). In Turkey, Kadioğlu et al. (2001) used different base levels (15 and 24°C) for calculations of HDD and CDD, respectively. Cartalis et al. (2001), in their study of climate change in the southeastern Mediterranean (especially the area of Greece), used the threshold values of 15.5 and 18°C for HDD and CDD calculations, respectively. In our case, for the calculation of both HDD and CDD (Eqs. 5 & 6) for the whole available data sample (1993–2001), the same base temperature of 22°C was selected (T^* = T^{**} = 22°C).

Fig. 9 presents the total annual variation of HDD and CDD in order to identify possible changes in the variation of the 2 indices for the period under examination (1993–2001). Values in Fig. 9 show that total values of HDD are larger than those of CDD. This would indicate that we have more cold than warm days per year. However, CDD and HDD values are sensitive to the selection of the base temperature which, in our case, is on the high side. If a lower base temperature had been chosen (such as 18°C, as commonly used in the literature), days defined as warm would be much more frequent and days defined as cold much less so. Another

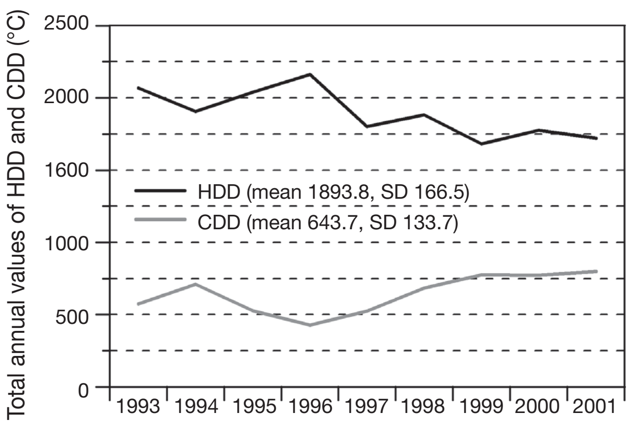

Fig. 9. Total annual variation in heating degree-days (HDD) and cooling degree-days (CDD) for 1993–2001 using 22°C as base temperature

feature evident from Fig. 9 is a declining trend for HDD and an increasing trend for CDD. This trend of degree-days indices is probably due to a warming in the Athens area experienced over the last decade (Founda et al. 2004). The increasing trend of CDD is also due to demand for air conditioning—more pronounced in more recent years—from an expanded population.

Fig. 10 shows daily energy consumption in relation to values of CDD and HDD as they were calculated using 22°C as the base temperature for 3 separate years: 1993, 1997 and 2001. The 2 branches (summer and winter) have been successfully separated into 2 independent correlation functions. From Fig. 10 it becomes apparent that correlation is higher for the heating degree-days, signifying that the response of the system is faster during the cold period of the year.

Fig. 11 shows statistics using box-whisker plots for daily energy consumption, daily mean air temperature, and heating and cooling degree-days for the whole period examined. It is worth noting that the large deviations from the mean and median in HDD in winter and CDD in summer are followed by similarly large deviations in energy consumption. Moreover, the largest deviations from the mean in energy consumption occur during the summer and winter months when hot and cold temperature extremes (respectively) are more common. The same is true for the heating and cooling degree-days.

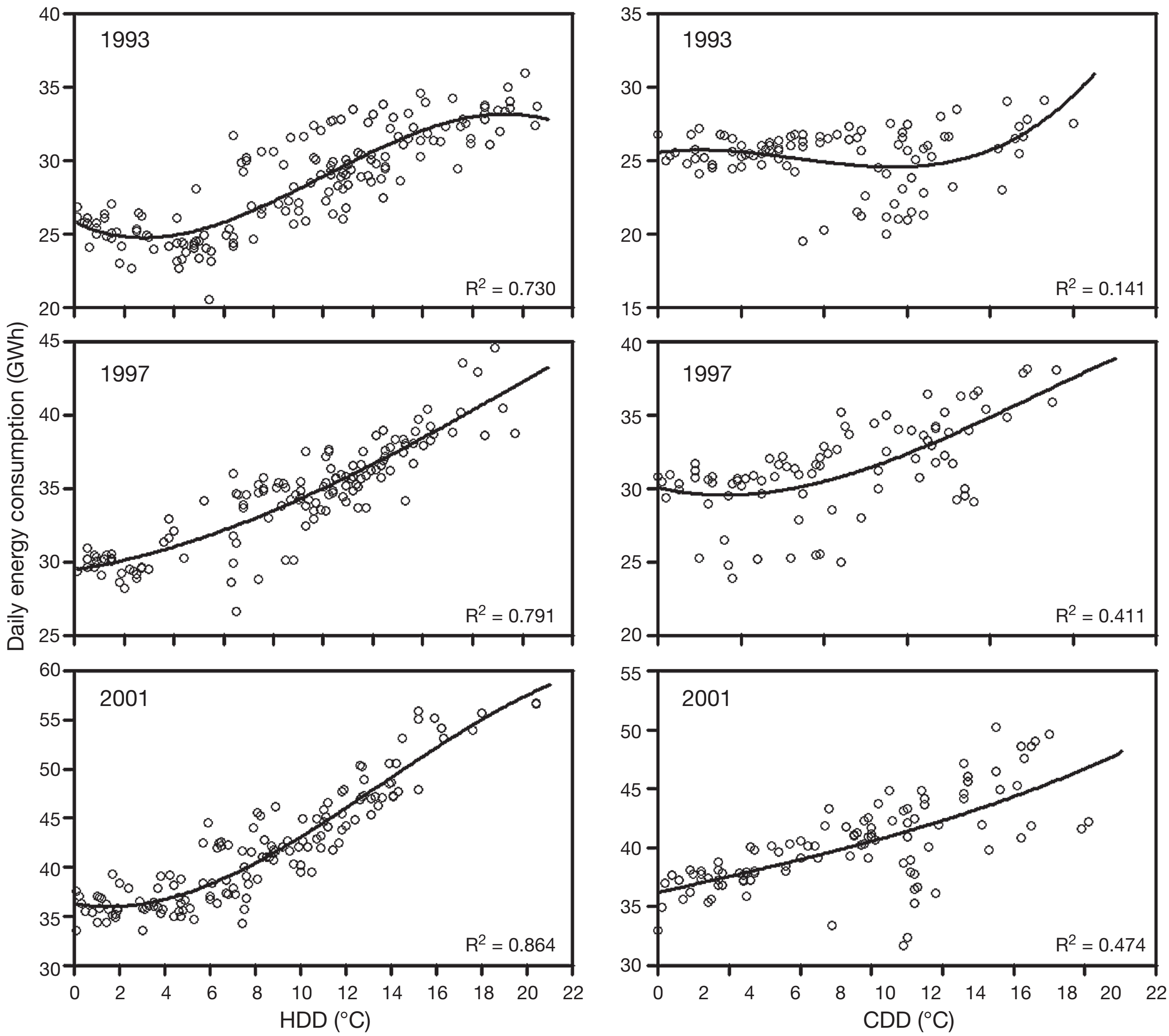

Fig. 10. Daily energy consumption with HDD and CDD for working days only and for years 1993, 1997 and 2001. Black lines: best fit curves; R^2: correlation coefficients

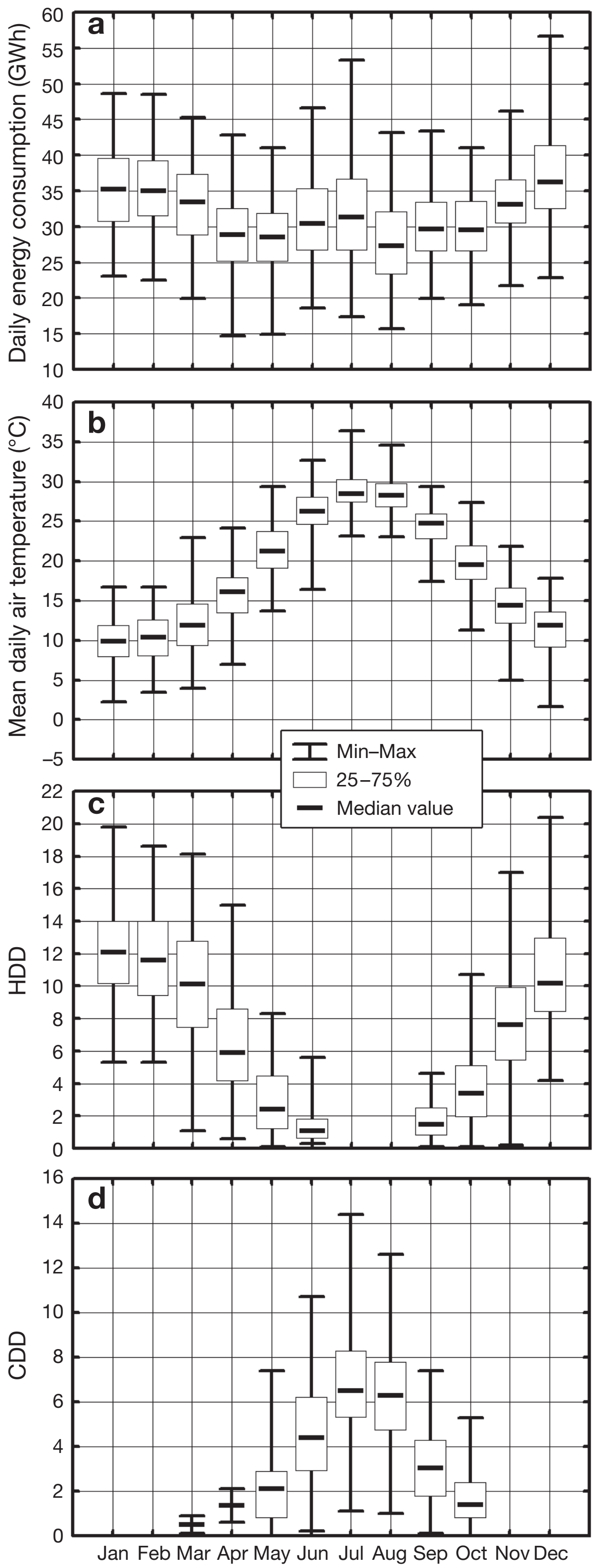

Fig. 11. Box-whisker plots for (a) daily energy consumption, (b) daily mean air temperature, (c) HDD and (d) CDD, 1993–2001

5. FUTURE ENERGY DEMANDS UNDER FUTURE CLIMATE CHANGE

The area of Europe and especially the Mediterranean have been the subject of several studies of climatic variations (Goosens & Berger 1986, Metaxas et al. 1991, Palutikof et al. 1992, Sahsamanoglou & Makrogiannis 1992, Bartzokas & Metaxas 1993, Cubasch et al. 1996, Palutikof & Wigley 1996, Proedrou et al. 1997, Rosenzweig & Tubiello 1997). According to the European Climate Assessment (ECSN 1995), the variation of annual and seasonal mean temperatures during the last century for a number of European stations indicates a warming trend for almost all parts of Europe. However, it should be mentioned that a relative cooling was observed for the eastern Mediterranean for the period 1981–1990.

Palutikof & Wigley (1996) estimated temperature changes for the Mediterranean on the assumption that carbon dioxide is abruptly doubled, and found increases from 0.7 to 1.6°C for every degree of mean global temperature increase. Cubasch et al. (1996) found that by the year 2100, the temperature increase will be 2.5°C for the Mediterranean Sea, 3 to 4°C for the coastal zones of the Mediterranean, and 5.5°C for Morocco. Finally, Rosenzweig & Tubiello (1997) reported that, as early as 2020, a temperature increase from 1.4 to 2.6°C may occur in the Mediterranean due to increased emissions of greenhouse gases. On the other hand, according to Mitchell et al. (1995), the temperature in the Mediterranean may decrease by 1 to 2°C between 1975 and 2030–2050, while according to Hegerl et al. (1996), a possible decrease in temperature in the central Mediterranean is possible, especially during summer.

Extreme temperatures have an impact on daily peak power demands primarily through increased air conditioner or heating use, as people attempt to maintain an expected level of comfort. Thus, as extreme temperatures become more common, both air conditioner/heater use and energy demand are expected to increase. Power utilities may have to adopt new strategies in order to meet these increased demands. Furthermore, extra demand coupled with hot temperatures can cause transmission lines to sag, thus simultaneously stressing the integrity of the distribution system (Colombo et al. 1999).

Since our study so far has demonstrated that energy demand is linked to climatic conditions, it is expected that with warmer weather, decreased demand should be typical in winter and increased demand should be typical in the summer. Moreover, the effect of higher temperatures chiefly in summer is likely to be considerably greater on peak energy demand than on net demand, suggesting that there will be a need to install additional generating capacity over and above that needed to cater for underlying economic growth.

For the purposes of this study, in order to investigate future energy demands in relation to temperature rises, we used temperature data from the HadRM3P RCM (UKMO 2002), which has a horizontal resolution of 50 × 50 km. HadRM3P had been integrated for two 30 yr periods: the 'control period' (1961–1990) and the 'future period' (2070–2099). We have used the 2 SRES (Special Report on Emissions Scenarios) A2 and B2 emission scenarios for the future projections (Nakicenovic & Swart 2000, Houghton et al. 2001). For HadRM3P under the B2 scenario the annual mean temperature warmings across Europe by 2100 are mostly 70 to 80% of those under the A2 scenario. Prior to 1991, experiments under scenarios 'A2' and 'B2' are identical (Christensen & Christensen 2003). For consistency with the future period, we have used model data for the control period, instead of measurement data for Athens. To be able to project future energy demand, the same technology use is assumed between the control and the future period (UNDP 2002).

Table 1 presents mean patterns of energy demand related to temperature for the present (control) and 2 future (A2 and B2 scenarios) periods using a simple extrapolation of the non-linear trend between temperatures and energy load of the control period. For the cool period of the year (November to April), a decreasing trend in energy demand is evident as warmer conditions dominate by the end of the 21st century, especially under the A2 scenario. The gain in energy demand is about 10% for the A2 scenario and less so for the B2 scenario. For the warm period of the year (May to October), an increasing trend is evident in the period 2070–2099, especially under the A2 scenario. The results show a 5% increase in demand under the A2A scenario. However, the increases reach as much as 30% in the hot summer months of July and August, when the demands for air conditioning are at their peak.

Table 1. Energy demands and daily mean temperatures for present day (control) and 2 future SRES climatic scenarios (B2 and A2)

	Mean daily temperature (°C)	Mean daily energy (MWh)
Winter (November to April)		
Control (1961–1990)	8.56	1667
B2 (2070–2099)	11.69	1570
A2 (2070–2099)	12.93	1536
Summer (May to October)		
Control (1961–1990)	22.16	1254
B2 (2070–2099)	26.82	1287
A2 (2070–2099)	28.49	1306

Climate projections and hence impacts are associated with uncertainties, which begin with different socio-economic assumptions that affect projections of greenhouse gas emissions, and flow through differing potential emission scenarios and ranges of greenhouse gas concentrations, radiative forcing, and climate system responses and feedbacks. These in turn affect the estimation of the range of potential impacts, in our case the impacts on energy consumption.

6. CONCLUSIONS

In this study, the relationship between energy load and ambient temperature was studied using data for the Greater Athens area in Greece. A yearly increasing trend in energy demand was identified, which is due to steady economic growth and hence continuing improvement in income per household. Seasonal trends in energy demand were also examined and found to be due both to weather fluctuations and to factors unrelated to weather such as weekend and holiday effect factors. Energy demand shows minimum values in the transient seasons of the year (spring and autumn) and peaks in winter (December in particular, but also January) and summer (July). It is also lower during public holidays and weekends than during normal working weekdays. We have gone further than Valor et al. (2001) in that hourly data were used and hourly trends relating to energy load were identified. When we examined hourly variation in energy demand, we found that it is higher during midday and late afternoon in all seasons. The relationship between energy demand and air temperature is not linear and presents 1 minimum and 2 maxima. The minimum value appears to be around 22°C and is the temperature that was used for the calculation of heating and cooling degree-days. Around this temperature, energy demand shows no sensitivity to air temperature. Outside this area, energy consumption increases with the increase (due to air conditioning demands) or decrease (due to extra heating demands) of air temperature. RCM results predict a gradual warming by the end of the 21st century. This will be associated with a fall (rise) in energy demand during future milder (hotter) winters (summers).

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