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Energy, economic and environmental performance of heating systems in Greek buildings

A.M. Papadopoulos *, S. Oxizidis, G. Papandritsas

Laboratory of Heat Transfer and Environmental Engineering, Department of Mechanical Engineering, Aristotle University Thessaloniki, Box 483, 54124 Thessaloniki, Greece

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Abstract

The introduction of natural gas in the Greek energy market broadened the options in the field of space heating. Residents in five major Greek cities can choose from a variety of different fuels and systems for heating their houses or working spaces; 12 more cities will be connected to the gas network within the next 5 years. Considering that space heating is the major energy consuming activity in the Greek building sector and that the environmental constrains imposed by the Kyoto protocol will be met only with difficulty, if at all, a strategy concerning the developments in space heating seems to be necessary. This however presupposes an elaborate analysis of the overall performance of the alternative systems, taking into consideration the particular conditions of the Greek energy system and the 'established' way of designing residential and mixed-use buildings. The present paper aims to present the empirical comparative results related to the three most popular heating systems operated in Greek multi-apartment and mixed-use buildings, which use three different fuels, respectively: a central oil-fired boiler, a unitary gas-fired boiler and unitary heat pumps.

Keywords: Heating systems; Residential buildings; Energy consumption; Environmental performance

1. Introduction

Local and regional parameters are of importance both to the structural features of buildings and to their HVAC systems. These 'native' features of a building stock are regarded as typical and have resulted from an evolutionary process, directly shaped by conditions such as: the local climate (mainly air temperature, solar radiation, wind direction and speed, rain, snow, etc.), geological and other environmental features (e.g. seismic activity), the availability and the cost of building components and materials, the availability and the skills of qualified personnel, the social and cultural background, the subjective operational requirements on behalf of the users (individuality versus community spirit) and, of course, the regulatory and legal framework [1,2]. A further parameter is the availability and cost of energy sources, with regard to the availability and the purchase cost of heating and cooling equipment. Thus, Greek urban buildings demonstrate, when compared to other Mediterranean countries certain particularities with respect to the use of heating systems. In most Greek cities the weather conditions during winter can be characterized as rather mild, and this is reflected both in the duration of the heating period and the mean and absolute minima of air temperature [3]. Most Greek urban buildings built prior to the 1970s did not have a central heating installation, although unitary systems are being retrofitted since the late 1980s [4]. Retail household prices of electricity are despite a series of increases since 2003, rather moderate compared to most European countries [5]. Natural gas was introduced to retail consumers in 2001. The above factors, amongst others, should be taken into consideration towards a more effective policy, since the discussion of the implementation of the European Directive 2002/91/EC on the energy performance of buildings in Greece has started in the year 2003 and is still, in February 2007, going on.

2. Heating systems in Greek buildings

The most popular heating system in Greek buildings is a central oil-fired boiler, distributing the heat produced to hydronic radiators. These central, high temperature systems use in order to deliver the heat either a two-pipe (a supply and a

* Corresponding author. Tel.: +30 2310 996015; fax: +30 2310 996012.
E-mail address: agis@eng.auth.gr (A.M. Papadopoulos).

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return pipe) scheme or a single pipe one. The former was used in older constructions, as a rule until the early 1980s, while the latter is widely used today, in combination with time-meters, volumetric flow rate or heat-meters installed in every apartment. Supply and return temperature controllers help to optimize the circulation, by means of a three-way mixing valve, which is mandatory for all buildings of more than three floors. Frequently a compensating thermostat is also used, to enable the system to respond to ambient temperature variations. In the apartments the temperature is regulated by means of a room thermostat, usually installed in the living room [6]. Such systems are nowadays retrofitted in old buildings. The older buildings, mainly those built in the 1950s and 1960s, do not have a central heating installation and are heated either by unitary oil-fired stoves or electrically driven devices (radiators, stoves). Since the 1990s air to air heat pumps, of the split unit or room air-conditioner type, have become increasingly fashionable, as their purchase cost dropped dramatically. Since the introduction of natural gas in the late 1990s it has been observed that single family gas-fired boilers have been retrofitted in the balconies of many apartments in Greek major cities' multi-storeyed buildings.

In relation to either the heat production source or the distribution systems there are a few cases of differentiation to be noted. In two medium sized cities in northwestern Greece, Kozani and Ptolemaida, there are district heating installations fed with thermal energy from nearby located, lignite-fired power generation plants. Despite the excellent potential, both in terms of radiation intensity and sunshine duration, and the fact that Greece is a leading force in Europe in the production of solar thermal systems, those are used exclusively for domestic hot water production, apart from some pilot projects [7]. Similarly, the use of biomass and geothermal energy in the building sector is practically non-existent, with the exception of the use of wood in rural, mountainous areas.

With respect to the heat distribution systems, the market is dominated by hydronic radiators, while floor systems have a small, but distinct, presence in expensive, single family houses. Fan coil units are pretty common in office buildings, but not in residential ones. Air heating is very rare in Greek buildings, mainly because of their very heavy construction due to seismic reasons, which results in high thermal inertia of the building's shell.

3. Description of the typical Greek building

This section briefly describes the typical multifamily residential building in Greece. The reason why a brief description has been opted for relates to the scope of the present paper which focuses on the heating systems' comparison, by means of building and HVAC simulation with the EnergyPlus programme [8]. Interested readers can, however, find a detailed discussion of this topic in related literature [1,9,10].

3.1. Physical description of the building

The typical multifamily building has three floors, built on top of/above a pilotis or an enclosed parking lot, and is not attached to any other building (Fig. 1). Its main façade is considered to be south oriented. There are two basement rooms that contain the boiler room and other utilities. Each apartment has a front and a rear balcony in the form of projections (overhangs) of 2 m width. The surface of each floor is 240 m^2 which is divided into two almost identical apartments (114 m^2 each), the remaining floor area being occupied by the staircase. Every apartment features a living room, a kitchen, a bathroom/WC and two bedrooms. Each room constitutes a different thermal zone for the thermal simulation.

3.2. Thermal description of the building

The building was simulated for two levels of thermal insulation corresponding to two constructional time periods:

- before the introduction of the Greek thermal insulation regulation (TIR) in 1979, building (MF 1) with no thermal insulation, and
- after 1979, building (MF 2) insulated with 5 cm of extruded polystyrene on all its construction elements, in order to comply with the TIR for the least favorable climatic zone, namely zone C [11].

It is noted that Thessaloniki lies in climatic zone C, Athens in zone B, and the southern mainland together with the islands add up to zone A, which is the warmest one.

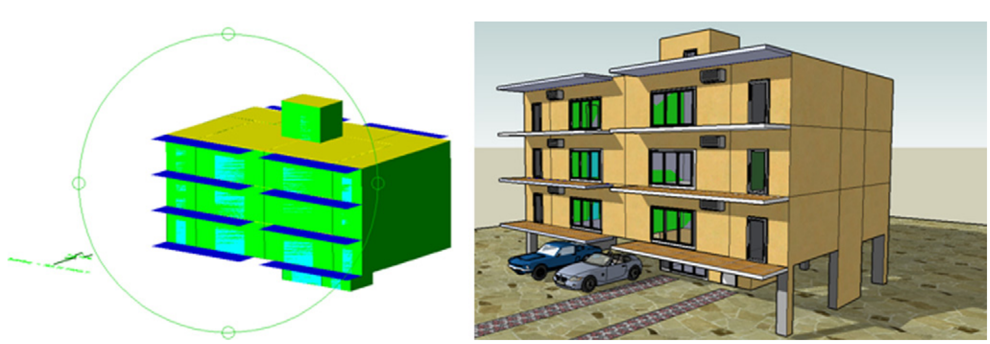

Fig. 1. The typical Greek multifamily building.

3.3. Openings

Regarding the external openings, in every apartment there is a 3 m wide balcony door in the living room, a 1 m wide door in the kitchen (both facing south) and a 2 m wide door in every bedroom (facing north). All balcony doors are 2 m high. The openings consist of aluminum frames and double 3 mm thick glass panes with a 6 mm vacuum between them. The typical thermal transmittance (U value) of the openings is 2.8 W/m^2 K. The internal doors of the apartments are wooden and are 1 m wide and 2 m high.

Internal shading of the openings is provided by drapes that are drawn when the incident solar radiation exceeds 100 W/m^2 and/or when the corresponding zone is being air-conditioned.

3.4. Internal gains

Every apartment is typically inhabited by a four-member family. Tables 1 and 2 provide the numbers and capacities of lights and electrical equipment for every room in the apartment respectively. An occupancy factor for the people and a usage factor for lights and electric equipment have been determined, based on the season of the year, the day of the week and the hour of the day.

3.5. Infiltration and ventilation

Table 3 provides the building's infiltration and ventilation rates. These are based on a natural ventilation pattern, except for the kitchen and the bathroom, where exhaust fans are additionally used. The nominal flow rates of infiltration and ventilation are being modified due to the variation of the temperature difference between the interior and the environment and also due to prevailing wind conditions, according to the following equation, as used by EnergyPlus [12]:

$$\text{air flow} = (\text{air flow}_{\text{desing}}) \times (F_{\text{schedule}}) \times [A + B(T_{\text{zone-odb}}) + C(\text{windspeed}) + D(\text{windspeed}^2)] \quad (1)$$

where air flow$_{\text{desing}}$ is the nominal air flow; F_{schedule} a usage factor (0–1) determined for every hour by the user; windspeed the wind speed; T_{zone} the indoor temperature; T_{odb} is the outdoor temperature.

In Table 4 are presented the factors A–D, as used in the simulations. In addition, further limitations have been assumed, relating to indoor or outdoor conditions depending on the users' behavior and their ability to minimize ventilation by closing the windows. These limitations are presented in Table 5.

Finally, cross mixing between the kitchen and the living room air has been assumed to take place, since in most apartments the door between these two rooms is almost always kept open.

3.6. Thermostatic controls

The heating period starts on 1st October and ends on 30th April. The rooms' temperature is regulated so as not to fall

Table 1
Lights per room

Room	Capacity (W)	Number	Total capacity (W)
Multifamily			
Staircase	40	1	40
Living room	60	3	180
Kitchen	80	1	80
Bathroom	60	1	60
Bedroom	100	1	100

Table 2
Electric equipment per room

Room	Type of equipment	Capacity (W)
Multifamily		
Living room	TV, HiFi, DVD player, etc.	250
Kitchen	PC, Printer, etc.	250
	Refrigerator	500
Bathroom	Oven	2000
	Washing machine	2000
Bedroom 1	PC, game machine, etc.	200
Bedroom 2	TV, radio	50
	PC, printer, etc.	150

Table 3
Infiltration and ventilation rates

Room	Infiltration (ac/H)	Ventilation (ac/H)
Multifamily		
Living room	0.5	2
Kitchen	1	4[a]
Bathroom	0.5	4[a]
Bedroom 1	0.5	2
Bedroom 2	0.5	2

[a] Natural plus exhaust ventilation.

Table 4
Factors for infiltration and ventilation in Eq. (1)

Factor	Infiltration	Ventilation
A	0.6	0
B	0.035	0
C	0.1	0.224
D	0.0	0.0

Table 5
Conditions for shutting off the ventilation

Limit	Type of limit	Value	
		MF	OF
Indoor temperature (°C)	Minimum	19	19
Indoor temperature (°C)	Maximum	25	25
Outdoor temperature (°C)	Minimum	10	10
Outdoor temperature (°C)	Maximum	24	23.5
Indoor–outdoor temperature difference (°C)	Minimum	−3	−5
Wind speed (m/s)	Maximum	4	4

below 21.5 °C from 06:00 till 09:00, below 20 °C from 09:00 to 13:00, below 21.5 °C from 13:00 to 23:00 and below 17 °C from 23:00 to 06:00. These values, as well as the occupational patterns and usage factors, have been determined according to field surveys in a series of residential and mixed-use buildings [13,14].

4. Description of the heating systems examined

The following heating systems have been compared:

- Central heating system fueled by an oil-fired boiler (system A)
  - With no energy meters (system A1, corresponding to an old two pipe installation),
  - With time meters (system A2, corresponding to the most popular single pipe installation),
  - With heat meters (system A3, a less used single pipe system–due to the initial cost of the heat meters).
- Unitary heat pumps (in every apartment's living room and two bedrooms, in the case of the multifamily building) and electric radiators (in the kitchen and the bathroom).
- Unitary natural gas-fired boiler installed in every apartment.

These three systems account for the vast majority of the heating installations used in Greek residential and mixed-use buildings.

4.1. Central heating system fueled by an oil-fired boiler

The nominal efficiency of the boiler is up to 85%. Space heating is accomplished by hydronic radiators. In the case of time meters the radiator with the most operating hours is taken into account for every apartment's cost calculations. In the case of heat meters the energy transfer of all apartments' radiators is used for the cost calculations.

A special note should be made, with respect to the way in which the cost of heating oil and electricity I shared in a building with many different owners be they apartments or offices. A law [15] deriving from a technical directive [16] published by the Technical Chamber of Greece in the early 1980s determines how heating bills are to be calculated. This law, which has been strongly criticized by the engineering community, allocates every apartment's heating cost mainly with respect to its volume and its openings' surface. The use of metering affects only a small portion of the total bill. Thus, the methodology favors the upper and lower floors, which have the most surfaces exposed to the external environment and therefore the bigger thermal losses, compared to the more sheltered intermediate floors. In principle, the critique against the methodology focuses on the fact that it does not encourage users to save energy, since their heating expenses are not proportional to their heating consumption. As far as the common uses' electricity costs are concerned (circulation pumps, elevator, lighting of the staircase and the ambience) weighting factors are determined for every apartment. Last but not least, it has been considered typical for every apartment to make use of an electric water heater of 4 kW capacity and 80 l volume for the provision of hot water.

4.2. Unitary heat pumps and electric radiators

In this type of system every room is heated by an air to air heat pump, of the room air conditioner type, except for the kitchens and bathrooms which are heated by electric radiators. The nominal, average seasonal coefficient of performance (COP) of the heat pump is for Greek climatic conditions 2.75. The hot water production is the same as in the previous Section 3.1.

4.3. Unitary gas-fired boilers

The efficiency of the gas boilers is assumed to be 0.9, whilst the heat distribution is also carried out by hydronic radiators. In this system hot water is produced by the gas-fired boilers.

5. Energy costs and resulting emissions

In order to determine the fuel oil cost at 0.65 €/l the heating oil cost during the last heating season (winter of 2005–2006) has been taken into consideration as well as the current developments in the international oil prices. In the case of the natural gas, retail prices have been determined according to the regional gas distribution company's pricelists [17]. The detailed domestic tariffs are presented in Table 6. The electricity tariffs for domestic use are determined by the Public Power Corporation, which is still serving the household sector in a monopolistic market [18]. Due to the fact that the electricity cost is calculated on a 4-month basis, the prices of the particular tariff (Table 7) were deducted to a monthly basis, in order to achieve a comparison to the other fuels. It should be noted that the household electricity tariffs in Greece follow a total consumption depending pattern, with the cost per electric kWh increasing as the 4-monthly consumption values increase, irrespective of peak and off-peak consumption. This pattern in practice forbids the installation of central – and more efficient – electrically driven heat pumps, which are, with respect to their technical features, favorable heating systems for the mild winters of central and southern Greece.

The oil, natural gas and electricity emission factors for CO_2, PM10 and SO_2 are presented in Table 8 [19]. In order to determine the electricity generation emission factors, the contribution of every different fuel to the total annual (2005) electricity generation mix was taken into account, as shown in Table 9 [20].

Table 6
Domestic use natural gas tariffs

Consumption (kWh)	Fixed charge (€)	Charge per kWh (€/kWh)
0–7,182	0.053260276	0.045606188
7,183–33,145	0.115397255	0.038131158
33,146	0	0.039316733

Table 7
Domestic use electricity tariffs[a]

Consumption (kWh)	Fixed charge (€)	Consumption (kWh)	Charge (€/kWh)
0–200[b]	0.48		0.06987
201–500			
201–400	1.27	0–200	0.07197
401–500	2.18	201–400	0.09171
		401–500	0.11257
501–750	7.705	0–200	0.07197
		201–400	0.09171
		401–500	0.11257
		501–750	0.15059
751–1100	7.78	0–200	0.07197
		201–400	0.09171
		401–500	0.11257
		501–750	0.15059
		751–1100	0.15204
1101	7.89	0–200	0.07441
		201–400	0.09483
		401–500	0.11639
		501	0.15421

[a] Deducted to monthly from a 4-month basis.
[b] Minimum charge: 5.92 €.

Table 8
Fuel emission factors

Pollutant	Emission factor (g/MJ)		
	Fuel oil	Natural gas	Electricity
Carbon dioxide (CO_2)	68.479980	50.234390	102.223969
Sulphur dioxide (SO_2)	0.4821240	0.0002512	0.6221296
Particulate matter (PM10)	0.0033165	0.0023861	0.0459684

Table 9
Contribution of fuels to the national electricity mix[a]

Fuel	Percentage (%)
Lignite	59.72
Diesel	6.14
Natural gas	14.27

[a] The remaining generation comes from RES and imports.

Table 10
Final energy consumption of the multi-family buildings

System	Fuel	Athens (kWh)		Thessaloniki (kWh)	
		MF 1	MF 2	MF 1	MF 2
A	Fuel oil	46,377	17,885	76,225	32,309
	Electricity	28,197	28,066	28,277	28,167
B	Electricity	47,430	35,410	60,715	41,885
C	Natural gas	53,766	26,837	81,829	40,503
	Electricity	18,616	18,565	18,655	18,595

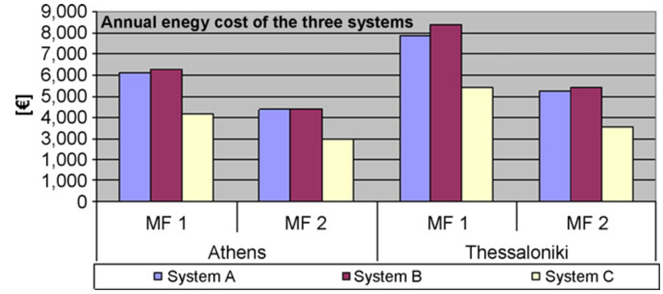

Fig. 2. Annual energy cost of the three systems.

6. Results

Table 10 presents the final energy consumption values for the two thermal insulation cases and all the possible systems and fuels for both major cities, Athens (zone B) and Thessaloniki (zone C). The respective resulting energy costs are depicted in Fig. 2. As can be observed, the electrical heating (system C) is the most expensive one. Still, in cases of low heating loads (due to insulation and milder climatic conditions that favor the use of heat pumps) its operational cost is comparable to that of the oil-fired central heating boiler. As was expected, the cheaper system is the gas-fired one (for both space heating and hot water provision), a fact that explains its rapid penetration in the cities where it is available. Fig. 3 presents the fuels' cost, coupled with the respective primary energy consumption of each system. However, it should be mentioned that part of the high primary energy consumption of system C is due to the very low efficiency of the Greek electricity generation system which is lignite based.

The primary energy consumption largely determines the emissions produced by every system, as shown in Table 11. However, taking into consideration that the location and nature of the emitted gases significantly differ, a direct comparison is not always feasible or indeed meaningful. One needs to bear in mind that in the case of oil-fired central boiler systems fuel gases are exhausted some meters above the roof of the building, whilst in the case of the unitary natural gas-fired boilers this takes place directly in the street canyon at the height of each apartment. Furthermore, the emissions resulting from electricity consumption pollute the area where the generation plants are located. Such differentiations, though insignificant on a national level, should be of interest when focusing on a

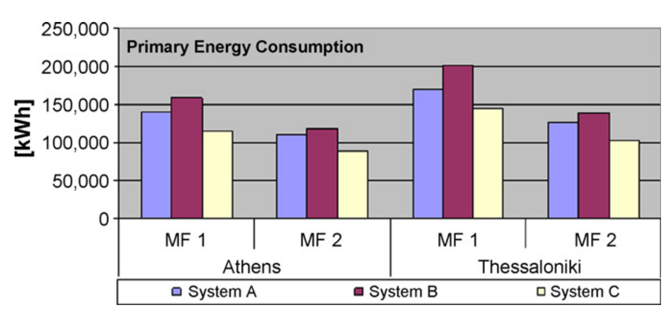

Fig. 3. Primary energy consumption of the three systems.

Table 11
Emissions produced by each system

System	Fuel	Pollutant	Athens		Thessaloniki	
			MF 1	MF 2	MF 1	MF 2
A	Fuel oil	CO_2 (kg)	12,817	4,943	21,067	8,930
		PM10 (kg)	2.60	1.00	4.36	1.85
		SO_2 (kg)	76.90	29.60	126.40	53.60
	Electricity	CO_2 (kg)	10,573	10,487	10,625	10,537
		PM10 (kg)	4.75	4.70	4.78	4.74
		SO_2 (kg)	64.30	63.80	64.70	64.10
B	Electricity	CO_2 (kg)	17,569	13,127	22,861	15,704
		PM10 (kg)	7.90	5.90	10.30	7.00
		SO_2 (kg)	106.90	79.90	139.10	95.60
C	Natural gas	CO_2 (kg)	9,723	4,853	14,798	7,325
		PM10 (kg)	0.46	0.23	0.70	0.35
		SO_2 (kg)	0.05	0.02	0.07	0.04
	Electricity	CO_2 (kg)	6,934	6,916	6,945	6,925
		PM10 (kg)	3.10	3.10	3.10	3.10
		SO_2 (kg)	42.20	42.10	42.30	42.10

micro-scale level, especially with respect to the street canyon effect [21].

Considering the environmental restrictions in force in Greece it is not easy to conclude which is the best system. Thessaloniki and Athens rank amongst the most highly polluted European cities, and the same goes for the region in north-western Greece, where the lignite-fired power plants are located. Thus, to re-locate the pollution sources due to space heating of urban buildings cannot be considered only with respect to minimizing emissions in absolute terms; one has also to think of their spatial allocation.

A special issue, to which has already been referred, arises due to the methodology used when billing the apartments for their heating costs. Fig. 4 depicts the annual heating costs for two selected apartments: one is a second storey eastern apartment of the insulated building in Athens and the other is a western apartment on the first floor – above the pilotis – of the non-insulated building in Thessaloniki. In the case of central heating system there are the aforementioned three ways to measure the heating consumption in every apartment (no meters A1, time meters A2 and heat meters A3) and thus, to allocate the corresponding costs. It is of great interest to notice, that the lower the heating load of an apartment is, the higher – proportionally to the other apartments – its heating costs develop. Especially in the case of the insulated second floor apartment in Athens the electrically driven system is cheaper than the central oil-fired system in all cases, except when using heat meters. On the other hand in the non-insulated apartment of the first floor in Thessaloniki, the use of meters results in an increase of its heating costs. In addition, the electric system which is the most autonomous out of the three considered, leads by far to the highest costs; a result which is, from an energy economics' point of view, rather irrational.

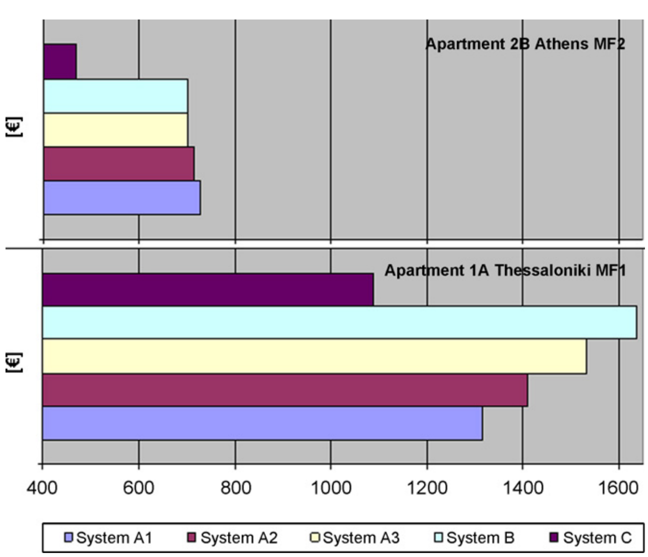

Fig. 4. Annual energy costs of selected apartments.

The overall conclusion is that the use of meters results in financial savings only in the case of apartments which present low heating loads (intermediate floors) and adds heating cost in the case of apartments with high load (last and first floors). Still, and given the legislation in force, even with heat metering the cost distribution is unfair to the occupants of apartments on intermediate floors. However, despite the metering related issues, the unitary gas-fired boiler appears to be the most economic solution, though the actual savings compared to central systems can vary significantly, as can be seen in Fig. 4. This has been recognized by the market, leading to a demand for new installations, both in newly constructed and existing buildings, which in some cases exceeds the pace of the networks' expansion. According to the last census of 2001 there were 1,950,000 households in Athens and Thessaloniki [4]. In the area of Thessaloniki more than 320,000, or 42% of households, have switched to gas between 2001 and 2006, whilst the aim for 2011 is to achieve a propagation of 85% [17]. In Athens, however, the respective figure for 2006 was 110,000 households, or less than 8%, due to delays in the network's expansion, leading to some tens of thousands of contracts still pending [22].

7. Concluding remarks

The study of a typical multi family Greek building and the comparison of the three most commonly used heating systems led to some useful conclusions regarding the systems' and buildings' economic and environmental performance. Natural gas and autonomous systems are by far the cheapest and cleanest solutions available in the market. On the other hand the methodology used to determine the cost distribution of central heating has been found to favor penthouses against apartments in intermediate floors. It comes as no surprise that it is, therefore, not promoting the occupants' energy conscious behavior, since their cost benefits will not be directly proportional to any energy savings. At the same time it does not provide the incentive towards enhanced insulation of the buildings' roofs. Finally, it should be mentioned that the use of electrically driven heat pumps can, under the specific circumstances mentioned be the optimum solution as far as the heating of Greek buildings is concerned, since even now they are in some cases comparable to other fuels regarding their running costs. Furthermore, and given the increased potential of renewable energy sources in electricity generation (mainly wind power) their environmental performance will also improve. In that direction the rationalization of the electricity tariffs, in order to enable the installation of heat pumps as central heating systems will enhance their until now limited market penetration.

References

[1] A.M. Papadopoulos, S. Oxizidis, L. Papathanasiou, Developing a new library of materials and structural elements for the simulative evaluation of buildings' energy performance, Building and Environment, 2007, doi:10.1016/j.buildenv.2007.01.049.
[2] A.M. Papadopoulos, Energy cost and its impact on regulating the buildings' energy behaviour, Advances in Building Energy Research 1 (2007) 105–121.
[3] K. Papakostas, G. Tsilingiridis, N. Kyriakis, Heating degree-days for 50 Greek cities, Technika Chronika, Scientific Journal of the Technical Chamber of Greece, Section IV, in press (in Greek).
[4] Hellenic National Statistical Service, Statistical Index—Census of Buildings' Inventory, Athens, 2001.
[5] Electricity Information 2006, IEA, OECD/IEA, 2006, pp. I19–I21.
[6] G. Papandritsas, A study on the economical and environmental performance of heating systems in Greece, Diploma Thesis, Department of Mechanical Engineers, Aristotle University Thessaloniki, July 2006 (in Greek).
[7] A.M. Papadopoulos, Solar thermal technologies for buildings—the state of the art, in: M. Santamouris (Ed.), Active Solar Heating and Cooling of Buildings: Perspectives for the coming decade, James and James, London, 2003, pp. 17–35.
[8] D.B. Crawley, L.K. Lawrie, C.O. Pedersen, R.J. Liesen, D.E. Fisher, R.K. Strand, R.D. Taylor, R.C. Winkelmann, W.F. Buhl, Y.J. Huang, A.E. Erdem, ENERGYPLUS, a new-generation building energy simulation program, in: Proceedings of Building Simulation '99, vol. 1, September, (1999), pp. 81–88.
[9] G. Mihalakakou, M. Santamouris, A. Tsagrassoulis, On the energy consumption in residential buildings, Energy and Buildings 34 (7) (2002) 727–736.
[10] C.A. Balaras, K. Droutsa, A.A. Argiriou, D.N. Asimakopoulos, Potential for energy conservation in apartment buildings, Energy and Buildings 31 (2) (2000) 143–154.
[11] Hellenic Ministry of Environment, Planning and Public Works. Thermal Insulation Code for Buildings, Decree-Law 1/6/1979, The Hellenic Official Gazette, 362D, 1979 (in Greek).
[12] Lawrence Berkeley National Laboratory, EnergyPlus Manual. Engineering Reference (available from http://www.energyplus.gov), April 2006.
[13] A.M. Papadopoulos, T. Theodosiou, K. Karatzas, Feasibility of energy saving renovation measures in urban buildings: the impact of energy prices and the acceptable pay back time criterion, Energy and Buildings 34 (2002) 455–466.
[14] M. Santamouris, K. Kapsis, D. Korres, I. Livada, C. Pavlou, M.N. Assimakopoulos, On the relation between the energy and social characteristics of the residential sector, Energy and Buildings 39 (2007) 893–905.
[15] Hellenic Ministry of Environment, Planning and Public Works. Technical regulation of distributing the heating costs of central heating installations, The Hellenic Official Gazette, 631D, 1985 (in Greek).
[16] Technical Camber of Greece. Technical Directive 2427/83, Athens, 1983 (in Greek).
[17] Thessaloniki Gas Supply Company, Bulletin of December 2006, 2006, http://www.epathessalonikis.gr.
[18] Power Public Corporation, 2006, http://www.dei.gr.
[19] Greece-National Inventory Report 1990–2003, National Observatory of Athens, 2005, http://www.climate.noa.gr/Reports/Sub_2005.
[20] RAE (Regulatory Authority of Energy), Synoptic Report on the Situation of the Electricity Market, Athens, RAE, 2005.
[21] N. Moussiopoulos, I. Ossanlis, P. Barmpas, A study of heat transfer effects on air pollution dispersion in street canyons by numerical simulations, International Journal of Environment and Pollution 25 (1–4) (2005) 131–144.
[22] Attiki Gas Supply Company, Bulletin of September 2006, 2006, http://www.aerioattikis.gr/eng/index.php.