On the relation between the energy and social characteristics of the residential sector

M. Santamouris, K. Kapsis, D. Korres, I. Livada, C. Pavlou, M. N. Assimakopoulos

University of Athens, Greece

KEYWORDS
Fuel Poverty, Energy Consumption of Residential Buildings

ABSTRACT
Social, financial, energy and technical data from about 1110 households have been collected during 2004 in the major Athens area. The sample has been divided in seven income groups and a detailed analysis has been performed. Important conclusions have been drawn regarding the quality of households, the operational conditions and the energy spent per income group. Low income people are more likely to be living in old buildings with poor envelope conditions. The cost per person and unit area is much higher for the low income group for both heating and electricity. Fuel poverty is quite high, especially when the actual oil prices are considered.


1. INTRODUCTION

Energy in the residential sector is used for heating and cooling, lighting, hot water and in electric appliances. The physical size of the residence, the climatic zone, the design characteristics of the building, the income level of the household and the available energy infrastructure are key factors in determining the energy consumption in residences.

Knowledge of the energy and social characteristics of the households is a key element for design policies for the residential sector. Some relevant studies have been recently carried out aiming to identify the relations between energy consumption, income and the social and technical characteristics of the residential sector, (1-3). Energy consumption of households is strongly related to the family income. Earlier research has shown that the higher the income, the higher the energy consumption of the household. The specific relation between the household income and the energy consumption of homes varies from country to country as a function of their economic and technical characteristics.

Important research has been carried out regarding energy expenditure in low income households. Fuel poverty is defined by the UK government as the number of households who need to spend in excess of 10% of income on energy services in order to achieve a specified heating standard. When expenditure exceeds 20 per cent of the income, the family is defined as suffering ‘severe energy poverty’. Statistical data around Europe has shown that fuel poverty reaches high levels in the South of Europe and according to moderate calculations accounts for about 12 % of the households in Italy, 30 % in Greece, 26 % in Spain and 44 % in Portugal, (4). In parallel, fuel poverty in England alone totals between 2.8 million and 3.9 million households, (5).

Fuel poverty has important effects, mainly on human health. There is increasing evidence that lack of heating and poor indoor environmental conditions in low income households cause serious health problems and increase mortality. Low outdoor temperatures during the winter season are associated with an annual average of 40,000 excess winter deaths in the UK.

The residential sector in Greece accounts for about 24.5 % of the total final consumption in the country and presents a high increasing trend. In the period 1990-2002, the energy consumption of the residential sector increased by 54 %, while the total energy consumption increased by 35 % in the same period. In parallel, the energy consumption for space heating, electrical appliances and lighting increased by 65% since 1990, while space heating accounts for almost 72 % of the total energy consumption, (34.3 Mtoe). Given that the number of residential buildings has considerably increased during the same period, it is calculated that the unit consumption per dwelling has increased by 33 %, with an annual growth rate of 2.6%, and has risen from 0.98 toe/dwelling in 1990 to almost 1.32 toe/dwelling in 2002. The corresponding increase for space heating per unit, has been 30 % while the corresponding consumption of appliances and lighting has almost doubled, and has risen from 0.37 Mtoe in 1990 to 0.80 Mtoe in 2002, presenting an annual increase rate close to 6.6 %.

The present study aims to analyse the main characteristics of the residential sector in Athens, Greece, and investigate the inter-relations between the energy consumption, income of households and the technical and
social structure of the housing sector. Data from about 1110 households have been collected during 2004 in the greater Athens area and analysed. The methodology followed as well as the main results of the study, are discussed in the following section.

2. DATA COLLECTION AND ORGANISATION OF THE STUDY

Information and data have been collected through interviews with the members of the selected families and corresponding inspections of each building. The information collected has been organized into five main groups: Group 1. General Information, involving data about the location of the building, its floor area, the number of occupants, the year of construction, the type of residence, the number of storeys, and some other information about the neighboring buildings. Group 2. Information on the annual income of each family. Group 3. Information on the operational schedules of the building. In particular, on the set point temperature, the heated and non heated part of the building, and on the mean daily hours of heating. Group 4. Information on the energy consumption and the type of fuels used; in particular, on the energy consumption for heating and electricity uses, the type of fuel used for heating, the heating system, the number and type of air conditioners installed in the house and, finally, information on the maintenance of the heating system. Electricity consumption has been obtained directly from the bi-monthly electricity bills, while oil consumption for the apartment buildings has been obtained from the monthly invoices issued for each apartment by the managers of the buildings. Finally, for the detached buildings, the oil purchase invoices have been checked. Group 5. Information on the quality of the envelope and in particular: on the type of glazing and the existence and type of insulation.

Based on the distribution of the annual income, seven income classes have been defined, and specific analysis has been performed for each income class in a comparative way. Income classes have been defined using intelligent clustering analysis.

3. RESULTS OF THE STUDY

3.1 Quality of the Building Envelope
The quality of the building envelope of dwellings is determined by many parameters. However, two are the most important ones that mainly determine heat flux through the envelope: the insulation of the opaque elements and the type of installed glazing. Insulation has become mandatory in Greece after 1979 and thus all buildings built before this are not insulated. In parallel, the rate of retrofitting of buildings to add insulation is quite low. According to the National Statistical Service of Greece, the number of refurbished dwellings per year is close to 250. Installation of double glazing in residential buildings has started in reality at the late 80’s. There are many statistics about the number of insulated residential buildings or the number of buildings with single or double glazing but there is no information linking the quality of the envelope to the available income of households. As already mentioned information on the use of insulation in the buildings as well as on the installation of double glazing was collected during the inspections of the buildings. The results of the analysis are discussed below.

3.2 Use of Insulation
Almost 52 % of the households in the sample are living in fully or partly insulated buildings. The study has not investigated problems concerning the quality of insulation placing. The percentage of insulated buildings per income group is given in Table 1. As shown there is a very clear relation between the income level and the percentage of non insulated dwellings. The higher the income the higher the percentage of insulated buildings. It is characteristic that only 28 % of people of the poorest group live in insulated buildings, while the corresponding figure for the richest group is close to 70 %. A statistical significant correlation between the percentage of households living in insulated buildings and the logarithm of the income is observed. The increasing trend is much higher for the low and medium income groups.

<table>
<thead>
<tr>
<th>Income Group</th>
<th>Percentage of Households living in insulated Buildings</th>
<th>Percentage of Households living in buildings with double glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>A : &lt; 9000 Euros / y</td>
<td>38.0</td>
<td>8.0</td>
</tr>
<tr>
<td>B : 9000-13000 Euros / y</td>
<td>39.0</td>
<td>23.2</td>
</tr>
<tr>
<td>C : 13000 – 24000 Euros / y</td>
<td>43.0</td>
<td>27.3</td>
</tr>
<tr>
<td>D : 24000 – 36000 Euros / y</td>
<td>54.0</td>
<td>37.6</td>
</tr>
<tr>
<td>E : 36000 – 63000 Euros / y</td>
<td>68.0</td>
<td>51.3</td>
</tr>
<tr>
<td>F : 63000 – 100000 Euros / y</td>
<td>73.0</td>
<td>63.2</td>
</tr>
<tr>
<td>G : &gt; 100000 Euros / y</td>
<td>70.0</td>
<td>60.0</td>
</tr>
</tbody>
</table>

3.3 Use of Double Glazing
The percentage of buildings with double glazing in the sample is close to 45 %. The percentage of buildings with double glazing is given in Table 1. As in the case of insulation, there is a very clear relation between the per-
percentage of buildings with double glazing and the income levels. The higher the income the higher the percentage of buildings with double glazing. The differences between the income groups are quite high. For the poorest group the percentage of double glazed buildings is 24% while for the richest group the corresponding figure is 67%. It is found that the correlation between the percentage of buildings with double glazing and the logarithm of the income level is statistically significant. This correlation presents a statistically significant increasing trend for the lower and medium income groups. Finally, insulated buildings with double glazing are quite rare for the lower income groups, (8 %), Table 1, while the corresponding percentage increases to 60% for the highest income group. As before, the higher the income the higher the percentage of buildings with insulation and double glazing. As previously, it is found that the correlation between the percentage of buildings with double glazing and insulation and the logarithm of the income level is statistically significant.

3.4 Energy Consumption Characteristics

3.4.1 Energy Consumption for Heating

The mean and median energy consumption per square metre for heating purposes for each income group is given in Figure 1. The distribution has a U type shape with high consumption at the two limits. High energy consumption per square meter is observed for both the low and high income groups. Higher energy consumption of the lower income group can be explained by the poor quality of the envelope. In parallel, the high energy consumption of the upper income group can be explained by the longer hours of operation of the heating system and the higher set point temperature. In parallel, high income people live predominantly in single detached houses that have a much higher energy consumption than apartments (see below).

In absolute values, the mean energy consumption for heating varies between 154 kWh/m2/year and 200 kWh/m2/year, while the corresponding median values vary between 107 to 130 kWh/m2/year. Such a level of consumption is verified by much detailed monitoring performed by the University of Athens, and is quite high given the climatic conditions of Athens. In particular, the level of consumption per square meter is quite similar to mean consumption of the residential sector in Austria. Thus there is a very high potential for energy conservation.

A very similar pattern is found when the mean and median heating energy consumption per person is calculated. At the same time when the mean heating energy consumption per person and area unit is calculated (figure 2) it is evident that the lower the income the higher the cost of heating per person and unit of surface. As shown the cost per person and m2 for the lower income group is to about 127% higher that the corresponding cost of heating for the richest group.

![Figure 1](image1.png)

**Figure 1.** Mean and median primary energy consumption for heating, (lt oil/m2/year), for all income groups.

![Figure 2](image2.png)

**Figure 2.** Mean and median primary energy consumption for heating, (lt oil/person/m2/year), for different income groups.

4. FUEL POVERTY

Analysis of the data has shown that the mean income fraction spent for heating and electricity is close to 2.4 and 3.1% respectively, (2004 values). Thus, almost 5.5% of the annual income is spent on energy. The annual heating expenditures represent almost 6.2% of the total income of the poorest people the corresponding figure for the upper income group is close to 0.6%.

Annual expenditures for electricity represent almost the 5.9% of the income of the poorest group, while for the richest group the corresponding value is close to 1.1%. Thus, the total annual expenses for energy represents almost the 12.1% of the income of the poorest group, while for the richest group the corresponding value it is close to 1.4%.

As already mentioned, fuel poverty is defined in the UK as the number of households needing to spend in excess of 10% of income on energy services, and if expenditure exceeds 20 per cent of the income, the family is characterized as in 'severe energy poverty'. Analysis of the data has shown that 1.63% of the households suffer from fuel poverty and 0.35% from severe fuel poverty, (2004 values). Fuel poverty in low income groups, is
close to 16%. Fuel poverty conditions are not found for incomes higher than 24000 Euros per year. Severe fuel poverty, in the low income group, is calculated close to 4%. Severe fuel poverty is found only in income groups with less than 13000 Euros per year. All this data is based on what households are actually spending for heating purposes. Based on the UK definition of fuel poverty, data have to be based on what households they need to spend in order to achieve a specified comfortable and healthy heating standard. Such an evaluation requires knowledge of the indoor temperature during the winter period. During the study, specific measurements of indoor temperature have been performed in 50 dwellings belonging to the low income groups. Measurements have been performed during the cold period. It has been found that almost all dwelling are adequately heated. During the occupation period, average indoor temperatures were found close to 18-19 C. Thus, it is considered that the actual data based on what households are actually spending are very similar to the corresponding figures based on what they need to spend to achieve a comfortable indoor environment. When both heating and electricity expenditures are considered, the average percentage of households spending more than 10% of their income for energy is increased to 11.3%, while 2% spends more than 20%, (2004 values). The percentage of families per income group spending more than 10% or 20% of their income for energy is almost 40% of the low income group spends more than 10% of their income for energy, (energy poor), while almost one fifth of the poor households spends more than 20% of their income for energy, (severe energy poor).

Given that this data was collected during 2004, and since the price of fuel has almost doubled, figures on fuel and energy poverty have been adjusted to the current situation, assuming that the levels of energy consumption remain the same. The actual prices of oil and electricity, as well as the annual increase of GDP for 2004 and 2005 have been considered. New fuel prices have contributed to the increase the mean income fraction spent for heating from 2.4% to 4.5%. In parallel, the average percentage spent on energy has increased from 5.5% to 7.4%. The average income fraction spent for heating has increased from 6.2% to 11.6% for the low income group. In parallel, the total expenses for energy of the same group have increased from 12.1% to 17.6%. For the upper income group, the fraction of the income spent for heating has been increased from 0.6 to 1.1%, while total energy expenses now represent 1.9% of the total income compared to 1.4% in 2004.

New fuel prices have increased the average percentage of households suffering from fuel poverty from 1.6% to 8.4%. For the lower income group, fuel poverty has been increased from 16% to 36%, while fuel poverty is now observed in the next richest income group, (24000-36000 Euros). Average severe fuel poverty has been increased from 0.35% to 1.5%. The percentage of severe poor in the lower income group has been increased from 4 to 12%, while severe fuel poverty is observed in the three poorest income groups instead of the two in 2004. The average percentage of households suffering from energy poverty, i.e. their total expenses for energy exceeds 10% of their income, has increased from 11.3% to 21.1%. It is characteristic that energy poverty in the low income groups has been increased from 40 to 60%. In parallel, the mean percentage of severe energy poor, has increased from 2 to 3.7%. The distribution of severe energy poor per income group is given in Figure 15f, (line). Severe energy poverty in low income groups has increased from 20% to 32%.

5. MAIN RESULTS AND CONCLUSIONS

Social, financial, energy and technical data from about 1110 households have been collected during 2004 in the greater Athens area. The sample has been divided into seven income groups and a detailed analysis has been performed. The main conclusions are:

a) There is an almost a linear relation between income and occupied space per household. The mean occupied area for the richest income group is about 115% higher than the corresponding area for the poorest group.

b) The mean occupied surface per person is close to 37 m². The number of inhabitants per household increases as a function of income. The median value of the occupied area per person does not present important differences between the various income groups and only for the richest group the occupied surface per person is much higher.

c) As it concerns the distribution of the age of the households per income group, it is found that the higher the income the lower the age of the buildings. The mean age of households of the lower income group is 29 years while for the richest group is 19 years.

d) As it concerns the type of households per income group, it found that as the income increases the number of households living in apartment decreases. Almost 64% of the families in the lower income group live in apartments, while the corresponding number for the richest group is 48%. In parallel, low income families live mostly in the lower part of multistory buildings while high income households live mainly in the higher part of the buildings. Also, the analysis has shown that high income households prefer to live in smaller size multistory buildings, while low income families...
live mainly in buildings with a much higher number of apartments per floor.

e) There is a very clear relation between the income level and the percentage of non insulated dwellings. The higher the income the higher the percentage of insulated buildings. Only 28% of people of the poorest group lives in insulated buildings, while the corresponding figure for the richest group is close to 70%. In parallel, the higher the income the higher the percentage of buildings with double glazing. For the poorest group the percentage of double glazed buildings is 24% while for the richest group the corresponding figure is 67%. Insulated buildings with double glazing are quite rare for the lower income groups, (8%), while the corresponding percentage increases to 60% for the high income group.

f) The mean daily duration of heating is close to 7.5 hours per day. The heating period increases considerably, up to 8.5 h per day, in the richest groups. The average set point temperature for the heating period is close to 18.4 C. The difference in the set point temperature between the poorest and the richest groups is about 1 C.

A very high increase of the installed a/c per household is observed as a function of income. The mean value for the lower income group is close to 0.6 air conditioners per household, while the corresponding value for the upper income class is close to 2.15. However, the density of installed air conditioners per square meter is much higher for the lower income people that for all other groups. Although middle and high income people use more air conditioning, the relative cost of comfort during the summer period is much higher for the lower income people.

h) The distribution of the energy consumption for heating presents a U type shape with high consumption at the two limits. High energy consumption per square meter is observed for both the low and high income groups. As it concerns the mean heating energy consumption per person and area it is found that the lower the income the higher the cost of heating per person and unit of surface. The cost per person and m2 for the lower income group is about 127% higher than the corresponding cost of heating for the richest group.

i) As it concerns the heating energy consumption per type of dwelling it is found that the energy consumption of detached houses is about 50% higher than that for apartments.

j) There is a considerable decreasing trend of the heating energy consumption as a function of age of the buildings. The calculated decreasing trend of the heating consumption is close to 0.8 kwh/m2/year.

k) For detached houses, the combined impact of insulation and double glazing decreases the mean heating energy consumption of the building stock to about 40 kwh/m2/y compared to a single glazed non insulated dwelling. For apartments, the corresponding reduction is much lower, 8 kwh/m2/y.

l) There is almost a linear relation between the annual expenses for electricity and the family income. High income families pay almost 160% higher annual cost than the low income ones. As it concerns the annual electricity cost per unit of area and person it is found that the lower the income the higher the cost of electricity per person and unit of area. Low income people pay almost 67% higher electricity cost per person and square meter than high income people.

m) The use of air conditioning increases considerably the annual electricity expenses especially in the low income groups. As a mean value, the use of air conditioning increases the annual expenses to about 100 Euros per household, or 0.6 Euros/m2, or 12.5 Euros per person. The increase is much higher for the low income groups, where the relative increase of the cost because of the air conditioning use is close to 195 Euros/household, or 1.2 Euros/m2, or 87 Euros/person.

n) The mean income fraction spent for heating and electricity is close to 2.4 and 3.1% respectively, (2004 values). Annual heating expenditures represent almost 6.2% of the total income of the poorest people. The corresponding figure for the upper income group is close to 0.6%.

o) Almost, 1.63% of the households suffer from fuel poverty and 0.35% from severe fuel poverty, (2004 values). Fuel poverty in low income groups, is close to 16%. Severe fuel poverty, in the low income group, is calculated close to 4%, (Figure 15d).

p) As it concerns energy poverty, the average percentage of the households spending more than 10% of their income for energy is close to 11.3%, while 2% spends more than 20%, (2004 values). Almost 40% of the low income group spends more than 10% of their income for energy, (energy poor), while almost one fifth of the poor households spends more than 20% of their income for energy, (severe energy poor).

q) Considering 2006 fuel prices and increase of GDP, the mean income fraction spent for heating has increased from 2.4% to 4.5%, while the average percentage spent for energy has increased from 5.5% to 7.4%. For the low income group, the average income fraction spent for heating has increased from 6.2% to 11.6%. In parallel, the total expenses for energy of the same group have been increased from 12.1% to 17.6%.

r) New fuel prices have increased the average percentage of households suffering from fuel poverty from 1.6% to 8.4%. For the lower income group, fuel poverty has increased from 16% to 36%. Average severe fuel poverty has increased from 0.35% to 1.5%. The percentage of severe poor in the lower income group has been increased from 4 to 12%.

s) The average percentage of households suffering from
energy poverty, has risen from 11.3 % to 21.1 %. Energy poverty in the low income groups has increased from 40 to 60 %. The mean percentage of severe energy poor, has also increased from 2 to 3.7 %. Severe energy poverty in low income groups has risen from 20 % to 32 %.

REFERENCES

5. Fuel Poverty and Energy Efficiency in the UK Calouste Gulbenkian Foundation, 2004