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Freezing the poor—Indoor environmental quality in low and very low income households during the winter period in Athens

M. Santamouris [a,*], S.M. Alevizos [b], L. Aslanoglou [b], D. Mantzios [b], P. Milonas [b], I. Sarelli [b], S. Karatasou [b], K. Cartalis [b], J.A. Paravantis [c]

[a] Cyprus Institute, Nicosia Cyprus and Group Building Environmental Studies, Physics Department, University of Athens, Athens, Greece
[b] Group Building Environmental Studies, Physics Department, University of Athens, Athens, Greece
[c] University of Pireas, 18534 Pireas, Greece

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ABSTRACT

Previous research has shown that the economic crisis has a very serious impact to the indoor environmental quality of the low income households. Indoor temperature as well as energy, environmental, social and health related data are collected during the winter 2012–2013 from 50 low and very low income dwellings in the major Athens area in Greece in order to assess the influence of the serious economic situation in the country on the energy and environmental quality of poor families. Results show that indoor temperatures are much below the accepted standards and in many cases place in risk the health and even the life of the residents. The energy consumption for heating is found to be minimum and much below the country's threshold while a high fraction of households is not using heating energy at all. Strong correlations are found between the minimum indoor temperatures and the level of thermal losses of the dwellings. In addition, a strong association of the income level to various environmental and energy parameters is found. Finally, a high fraction of the very low income population is diagnosed to suffer from mental problems and in particular depression.

1. Introduction

Reaching proper indoor temperatures in buildings is a necessary requirement to satisfy thermal comfort conditions, protect human health and improve the quality of life. Very low or very high indoor temperatures have a serious impact to indoor environmental quality, a severe influence on the social attainment of households and result in a very important seasonal increase of mortality and morbidity [1]. Although it is generally believed that improper indoor environmental quality is primarily a problem of developing countries, there are almost 80 million people in European Union, or 16.4% of the global population living below the poverty line, residing in dwellings of pure thermal quality due to inadequate indoor environmental conditions [2]. Official statistics in Europe show that the percentage of the population living in low income houses in the various European countries varies between 10% and 25% [3].

The construction, energy and environmental standards of the low income housing in Europe is of much lower quality than the average building stock [4,5]. In parallel, a high part of the low income population cannot cover the housing energy needs and lives in temperature conditions heavily outside the comfort limits [6]. According to Ref. [7], almost 20–55% of the low income households in Southern and Eastern Europe lives in housing with leaking windows. In addition, about 15–25% of the low income population in Southern Europe and Ireland cannot afford the expenses for heating while in Portugal the corresponding figure is close to 73% [7]. It is believed that the above figures may have dramatically increased because of the serious economic crisis in Southern Europe. Low construction and energy related standards in low income housing oblige households to spend a much higher share of their income to satisfy general housing needs. According to Ref. [8], the average running housing cost in the 27 EU countries is close to 11% of the actual household income, while for the low income population the figure increases to 40%.

To maintain adequate indoor temperatures during the winter period, heating is necessary in almost all areas of Europe. Several national and international standards define the threshold indoor temperatures to maintain comfortable conditions in buildings [9–11]. Proposed indoor temperatures are in the range of 18 to 21 °C, varying as a function of many parameters regulating thermal comfort. Almost similar thresholds are proposed as adequate temperatures for health reasons. The World Health Organisation [6] proposes 20 °C for vulnerable population while 18 °C is proposed in Ref. [12]. Various medical sources propose 21 °C as a minimum temperature for the more vulnerable population and 18 °C for sedentary activities and able health people [13], while the UK

* Corresponding author. Tel.: +30 2107276847; fax: +30 2107295282.
E-mail address: msantam@phys.uoa.gr (M. Santamouris).

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Department of Environment proposes as minimum temperatures for health reasons 16 °C in bedrooms and 18 °C in living rooms [14].

Cold homes are a serious problem in many European countries. Most of the existing data are available from UK, Ireland and other Northern countries where several studies have been carried out and many policies to improve the problem have been applied. Most of the experimental studies carried out in Northern Europe and UK found that indoor temperatures in low income houses were quite low and in most of the cases non adequate for humans, while problems of internal condensation, mold and damp were found in a high part of the buildings [15–26]. In some cases temperatures were found very low placing the health of humans in risk [7]. Recent medical research has associated low indoor temperatures to various illnesses like pneumonia, increased blood pressure, asthma, bronchitis, influenza arthritis, heart deceases, and migraine [7]. In parallel, medical problems associated to social pathologies like depression, anxiety, constraints of mobility and isolation are diagnosed at a high score in low income households [7,27].

Low indoor temperatures have a serious impact on mortality. According to Ref. [28], there are almost 30,000–60,000 excess winter deaths in UK and 1500–2000 in Ireland because of the low indoor temperatures in dwellings, while an important association between the housing quality and seasonal mortality is found [29]. As shown in Refs. [30,31] less insulated houses in UK, are associated with excess winter mortality. The continuous improvement of the energy quality of the building stock has permitted to improve indoor environmental conditions and decrease cold related mortality [32–35]. In fact, as mentioned in Ref. [36], during the last 40 years the average indoor temperature of houses in UK with central heating has increased by 3.6 K from 13.7 °C to 17.3 °C, while in non centrally heated buildings temperatures have increased from 11.2 °C to 14.8 °C.

Energy poverty in Greece is a serious problem. The specific percentage of energy poor varies as a function of the parameters and criteria used to calculate energy poverty. According to the estimations given in Ref. [37], fuel poverty in the country varies between 24.6% and 36% as a function of the weighting factor for each of the indicators used. Furthermore and based on the criteria proposed in Ref. [1], the percentage of energy poverty in Greece is close to 36%, while according to Ref. [27], is between 16% and 17%. According to Ref. [2], almost 20% of the population lives in low income housing while in Ref. [7] it is reported that almost 28% of the population lives in houses with leaking windows and 26% of the low income population in Greece cannot afford to cover the expenses for heating while the national average is close to 8%.

Specific information on the social and energy characteristics of the low income population in Greece is given in Ref. [38]. As reported, only 8% of the low income households live in insulated houses with double glazing while the corresponding figure for the high income group is close to 60%. In parallel, because of the housing inappropriate quality, low income people had to spend almost the double energy quantity for heating and cooling per square meter and inhabitant, to satisfy the basic energy needs of the houses. These specific data were collected much before the economic crisis hit the country. A recent study on the heating energy consumption in the country performed during the period of the crisis [39] reported that the energy consumption in the low income group has decreased significantly because of the increased prices of fuel and the serious decrease of the family income. The study found that most of the low income households have used for a minimum period or have not used at all their heating system.

The lack of resources to satisfy the heating and cooling demands has a serious impact on the indoor environmental quality of the low income houses in the country. Measurements of the indoor temperature performed during the summer period in 50 low income houses in Athens [40] showed that indoor environmental quality was very low and indoor conditions were completely out of the comfort zone. For almost 85% of the heat waves period indoor temperatures exceeded 30 °C, while spells of about 216 continuous hours above 30 °C were measured. In very low income houses, spells of six continuous days above 33 °C were also recorded.

Table 1
General characteristics of the households participating in the study.

No of households	43
Average persons per household	1.72
Average age	47
Percentage of employed people	38.30%
Percentage of unemployed or non-active people	28.70%
Percentage of retired people	22%
Percentage of students	11%
Average annual income (€)	8158.00
Average annual income per person (€)	4721.20
Average education score (0–3), 0 = compulsory education, 1 = low school, 2 = upper secondary school, 3 = tertiary	2.11
Percentage of population with tertiary education	33%
Percentage of population with upper secondary education	53.00%
Percentage of population with compulsory education	14%

The present paper aims to present specific measurements and analysis on the indoor temperature in low and very low income households in Athens, Greece. Fifty houses were selected and monitored continuously during the winter period of 2012–2013. Data on the energy consumption, housing and neighbourhood quality, social and economic status as well as the health level of the people were also collected and analysed.

2. Description of the study

In order to assess the environmental quality of low income households in Athens, Greece, fifty low and very low income households were selected for monitoring. The criteria applied for the selection were the declared household annual income that had to be lower or around 15,000 € and the willingness of the family to participate in the study. Almost all houses selected are located in dense areas of the city characterised by significant social economic and environmental problems [41]. In each house a miniature temperature sensor was placed measuring indoor temperature at 15 min intervals. Sensors were placed in a well-ventilated and heat protected part of each house, whereas all sensors were properly calibrated, with their accuracy being better than 0.5 K. Measurements were performed for the period between December 2012 and April 2013. All houses were regularly visited by trained surveyors to download the recorded data and get a report on the actual problems and the applied conditions in the households. All data were subjected to quality control and measurements not satisfying the requirements were rejected. During the initial period of monitoring, 12 of the initially selected houses were replaced by others as a result of observed problems. The final number of households used in the present paper was 43 and the total number of people participating in the survey was 74.

All information about the main characteristics defining the energy, environmental, economic, social and health indicators in the households was collected using a specific questionnaire similar to the one employed in the LARES study of WHO [7]. Specific information on the consumed energy was collected through inspection of the relevant fuel and electricity bills. All information collected through the surveys was doubled checked through specific phone calls to the participating families.

The main characteristics of the households which participated in the survey are given in Table 1. As shown, the average persons per household was close to 1.7 persons while the country's average is much higher [2.73]. In parallel, the mean age of the persons participating in the survey was 47 years while the country's average is

Table 2
Characteristics of the dwellings participating in the study.

Average surface of the dwellings, (m^2)	77.2
Average year of construction	1983
Percentage of detached or Semi detached houses	21%
Percentage of apartments	79%
Average number of exposed facades to the outside environment	2.6
Percentage of rented dwellings	32.5%
Percentage of insulated dwellings	54%
Percentage of dwellings with double windows	66%
Percentage of insulated dwellings with double glazing	44%
Percentage of dwellings with a central heating system	69.70%
Percentage of dwellings with an installed A/C	55.80%
Percentage of dwellings with an other auxiliary heating systems (mobile)	39.50%

close to 43 years. As expected, the percentage of employed people was quite low (38.3%) while 28.7% were unemployed and non active people. Also, 22% were retired persons against the 27.3% which is the national average. The mean annual income of the households was 8150 € against 20,202 € which is the average in the country. Almost 33% of the participants have a tertiary education against 25% of the national average, while 14% of the population has compulsory education.

The specific characteristics of the dwellings participating in the study are given in Table 2. The average surface of the dwellings was 77 m^2, while the corresponding average in the country is close to 85 m^2 [42]. The mean age of the dwellings is 30 years, (1983), while official statistics of the country give that 43.7% of the buildings had been built in the 1960s and 1970s and 18.6% after 2000 [42]. Almost 79% of the dwellings are apartments and 21% are detached or semidetached houses. In average, almost 55% of the population in Greece lives in flats however the percentage is much higher in urban areas. The average number of the facades of the selected dwellings exposed to the ambient environment is 2.6, while 32.5% of the dwellings are hired and 67.5% are privately owned, against 73.2% which is the national average. In terms of the thermal quality of the envelope almost 54% of the dwellings are insulated while the national average is 50%. Also, 66% of the selected dwellings have double glazing and 44% are insulated with double glazing. Regarding the heating system used, almost 69.7% has a central heating system using oil, 55.8% an air conditioning unit while 39.5% are also using an auxiliary secondary heating equipment. The average figures in the country give that 98.9% of the dwellings have a central system, 63.8% have a central heating system using oil, and almost 30% have an auxiliary heating system [42].

3. Results of the study—Indoor temperatures, energy, economic, social and health characteristics

3.1. Levels of indoor temperature

For the whole period of the study, climatic data on the outdoor environment are provided by the National Observatory of Athens. The minimum temperatures were recorded during January 2013, (0.9 °C), while the corresponding minimum for December was 5.6 °C. The average temperatures for December and January were 11.1 °C and 10.5 °C, respectively. Finally the absolute maximum temperatures recorded in December and January were 19.8 °C and 19 °C, respectively. For the rest of the months ambient temperature was quite higher. The specific winter was characterized as a very mild one. Only two days of very low ambient temperature were recorded, (8th and 9th of January). During the two days, the minimum temperature was around to 0.9–1.0 °C, while the average temperature was 2.5 °C and 3.9 °C for the first and second day, respectively. Given the above, the specific analysis is concentrated on the data collected during the month of January in full, as it represents the more severe period from a climatic point of view.

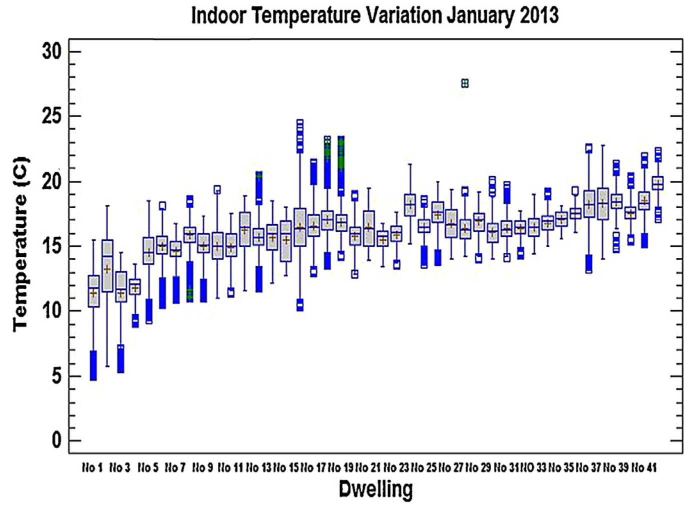

Fig. 1. Variation of the indoor temperature in the surveyed buildings during January 2013.

The average minimum indoor temperature for all the 43 dwellings in January was 12.6 °C while the mean average temperature was 15.9 °C. In addition, the average maximum was close to 19.1 °C. The variation of the indoor temperature for each of the houses during the whole January 2013 is presented in Fig. 1. As shown for most of the dwellings indoor temperatures where low or very low and certainly far beyond the comfort zone. The average temperature in the dwellings varies between 11.4 °C and 19 °C, while the corresponding minimum temperature varies between 5 °C and 16.2 °C. It is apparent that several patterns of indoor temperature conditions can be recognized among the studied dwellings. While significant differences occur between various buildings, the thermal behavior of the selected dwellings presents almost identical characteristics.

3.2. Classifying the households

In order to classify buildings according to the specific indoor temperature characteristics, clustering techniques are used. Using as inputs the minimum, average and maximum indoor temperature for each dwelling, k clustering techniques are applied. Given the limited number of available dwellings, the results of the clustering analysis offer more of a qualitative grouping of the dwellings than a robust mathematical definition of classes. Five groups of dwellings are identified presenting significant similarities on the characteristics of the indoor temperature. The main features of the dwellings belonging in the five groups are given in Table 3. The characteristics of the indoor temperature in the specific dwellings belonging in the five defined groups as well as of the ambient temperature recorded by two meteorological stations in Athens are given in Fig. 2; the density distribution of the indoor temperatures in the five groups is given in Fig. 3. The five groups may be defined and analysed as follows:

3.2.1. Group A: The group of very high deprivation

Indoor temperatures in the four dwellings of the specific group are very low. The average indoor temperatures is 12.2 °C, while the minimum and the maximum ones are 6.5 °C and 15.5 °C, respectively. The group is composed by people of rather high age, (average age close to 55 years). The percentage of employed people is very low reaching 17%, whereas the group involves small families (one or two persons), and the average annual income is 4750 €. Most of

Table 3
Characteristics of the dwellings in the five defined groups.

	Group A	Group B	Group C	Group D	Group E
General identity of households					
No of households	4	12	4	17	6
Average persons per household	1.5	1.75	1.75	1.47	2.5
Average age	55	39.5	43.5	50.9	46.8
Percentage of employed people	17%	45%	43%	42%	33%
Percentage of unemployed or non active people	33%	40%	14%	11%	47%
Percentage of retired	17%	5%	29%	39%	13%
Percentage of students	33%	10%	14%	8%	7%
Average annual income (€)	4750.00	6250.00	11500.00	8282.00	11667.00
Annual income per person (€)	3166.00	3571.00	6571.00	5632.00	4666.00
Average education score (0–3), 0 = compulsory education, 1 = low school 2 = upper secondary education 3: tertiary	2.33	2.60	2.14	1.92	1.93
Percentage of population with tertiary education	33.00	62.00	14.00	24.00	33.00
Percentage of population with upper secondary education	67.00	33.00	86.00	60.00	47.00
Percentage of population with compulsory education	0.00	0.00	0.00	16.00	20.00
Characteristics of the dwellings					
Average surface of housing (m^2)	50	89	63	76	83
Average year of construction	1972	1987	1991	1978	1989
Percentage of detached or semi detached houses	50%	25%	25%	18%	0%
Percentage of apartments	50%	75%	75%	82%	100%
Average number of exposed facades to the ambient environment	4	3.2	3	1.7	2.3
Percentage of rented dwellings	25	58	0	35	0

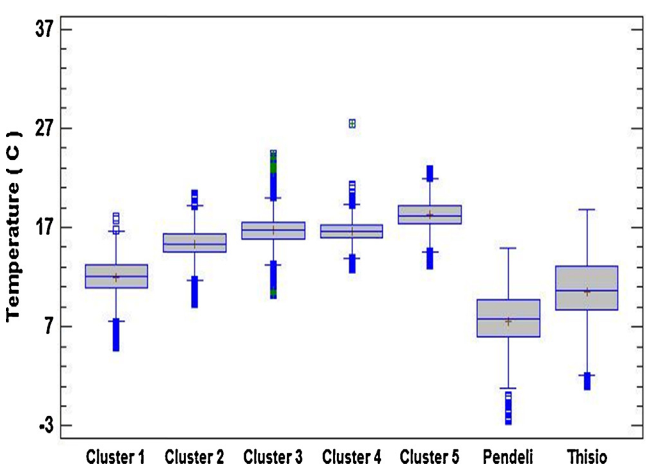

Fig. 2. Variation of the indoor temperature in the five defined clusters of dwellings as well as the variation of the ambient temperature in two meteorological stations of Athens.

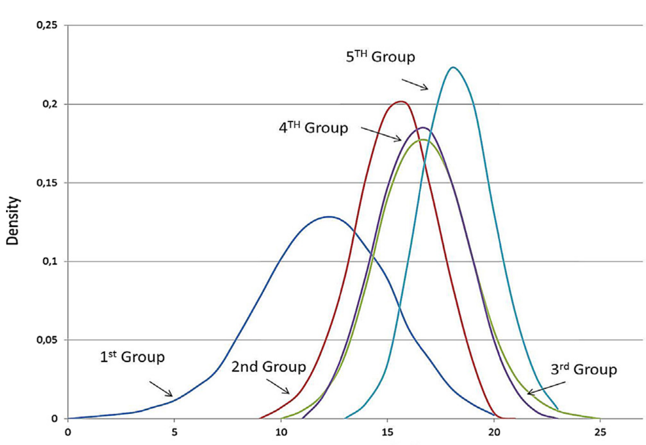

Fig. 3. Density distribution of indoor temperature for the five defined groups.

the people have an upper secondary school education and few of them have a tertiary education. The age of the dwellings is the highest among the various groups and the average age of the buildings is close to 41 years. The group involves dwellings of small surface, 50 m^2, which is the smallest among the groups. The thermal quality of the envelope is low and the group is presenting the highest degree of convective losses through the envelope, (UA = 244 W/K), not including ventilation losses. Finally most of the dwellings are privately owned buildings.

3.2.2. *Group B: The group of high deprivation*

The group is composed by 12 dwellings. Indoor temperatures are low with an average close to 15.1 °C, and a minimum and maximum one around to 11.2 °C and 18.1 °C, respectively. It is composed by relatively young people, (average age 39.5 years), which is the lower among the groups. The percentage of employed people in absolute terms is low, (45%), but considering the very high unemployment rate among the low income population in the country, it may be considered as acceptable. Families in the groups are composed by one or two persons, (1.75 persons/household). The average annual income is 6250 €. The group is the more educated one as almost 62% of the people have tertiary education. Most of the dwellings are apartments, (75%). The average surface of the dwellings is the highest among the groups, 89 m^2, and the average age is 26 years. Almost 58% of the dwellings are rented. The thermal quality of the envelope is not adequate with an average UA value close to 116 W/K.

3.2.3. *Group C: The group of people in partial deprivation*

Indoor temperatures in the four dwellings of the present group are higher than in the previous groups, but for almost 60% of the time are lower than the minimum threshold of the comfort zone. The average temperature is 16.2 °C, while the minimum and maximum temperatures are 12.9 °C and 22.9 °C. The average age of the people in the group is 43.5 years, while the unemployment rate is quite low (14%). Families are composed of one to three members and the average annual income is 11,500 €. Most of the people have an upper secondary school education. The dwellings in the group are quite new (20 years), while their mean surface is close to 63 m^2. All are privately owned buildings and 75% are apartments. The thermal quality of the envelope is medium, UA = 74 W/K.

Table 4
Characteristics of the heating system and energy consumption.

Energy consumption characteristics	Group A	Group B	Group C	Group D	Group E
Cost of fuel consumption for heating (€/m^2)	0	1.4	1.66	2.28	3.1
Cost of electricity consumption for heating (€/m^2)	0.31	0.41	0.43	0.46	0.49
Total cost of fuel and electricity (€/m^2)	0.31	1.81	2.09	2.74	3.59
Cost of energy for heating per person and m^2	0.2	1.03	1.19	1.86	1.44
Percentage of dwellings with a central heating system	25%	75%	100	59%	100%
Percentage of dwellings with an installed A/C	50%	75%	100	24%	83%
Percentage of dwellings with other auxiliary heating systems (mobile)	0	25%	25%	65%	33%
Percentage of dwellings using fuel for heating	0	50	25	23	33
Percentage of dwellings using electricity for heating	25	75	75	82	66
Percentage of dwellings using both fuel and electricity for heating	0	50	25	17	17
Percentage of dwellings not using any source of energy	75	25	25	6	17
Average heating hours per day	0.75	2.40	3.00	2.60	3.00
Percentage of dwellings non using thermostatic control	50%	33%	0	35%	0%
Set point of thermostat, (°C)	21.00	20.50	20.00	18.50	18.70
Vote on thermal sensation, −2 = very bad, −1 = bad, 0 = acceptable, 1 = good, 2 = very good	−0.75	0.50	0.5	0.11	0.17

3.2.4. Group D: The group of average deprivation

This group is the biggest one and is composed of 17 dwellings. Indoor temperatures are for almost 60% of the time below the threshold of the comfort zone. The average temperature is 16.6 °C a bit higher than in the previous group. The lower temperature is 14.1 °C, which is by 1.2 K higher than in the Group C, while the maximum temperature is 19 °C, much lower than in the previous group. It is composed by a mixture of young and aged people. The percentage of retired people in the group is high, 39%, while the unemployment rate is very low (11%). Almost 65% of the families are composed by just one person. It is the group with the minimum education score, as the percentage of people with compulsory education is quite high, (14%). The average annual income is 8282 €. The age of the dwellings is quite high, 35 years, while their surface is close to the average in the study, (76 m^2), and 65% of them are privately owned. Most of the dwellings are internal apartments, 82%, with the lowest convective losses through the envelope, (UA = 52 W/K).

3.2.5. Group E: The group at the limits of deprivation

This group is composed by six dwellings and presents the higher temperatures in the study. Indoor temperatures are for almost 70% of the time within the comfort levels. The average temperature is 18.4 °C while the minimum and maximum temperatures are 15.1 °C and 21.4 °C. Families in the group are of a quite big size and most of them have children. The average age of people is close to 47 years but the group is also composed by children and people of higher age. Almost half of the population is not active or unemployed. The education score in the group is low because of the children, however, 33% of the people has tertiary education. The average annual income is 11,667 € which is the highest in the study. All dwellings are privately owned apartments and their surface is quite high, 83 m^2, while their average age is 24 years. The thermal losses through the envelope are quite limited, (UA = 66 W/K).

3.3. Energy consumption

The characteristics of the heating systems installed as well as the specific energy consumption for heating purposes during the winter 2012–2013 are given in Table 4 for the previously defined groups. As it concerns the existence of the various heating systems, in Group A (very high deprivation), three out of the four dwellings have a certain type of heating installed, while one dwelling is not having any system for heating. One building has an oil based central heating system which is not used, while air conditioners are installed in two other dwellings but used in only one of them. Heating is provided in the conditioned dwellings for less than an hour per day, (45 min), and the thermostat is set at 21 °C. The average vote of the residents about the thermal sensation in the dwellings during the heating period was close to 'bad' or equal to −0.75 on a scale from (−2) to (2). The group has not used any fuel for heating while the average cost of electricity used for heating purposes in the conditioned buildings was close to 0.31 €/m^2, that is almost equivalent to 4 kW h/m^2. Given that three out of the four dwellings are not using any energy, the average energy consumption for the whole group is 1 kW h/m^2.

In Group B, (High Deprivation), almost 75% of the dwellings have an installed central heating system but it is used partially and occasionally in the 50% of the dwellings. Air conditioners are installed also in the 75% of the houses and are used in all of them. Also, in almost 25% of the dwellings an auxiliary mobile system (stove) is used. About one quarter of the dwellings in the group is not using any type of heating system. Heating is provided in the conditioned buildings for about 2.4 h per day and the thermostat when used is set at 20.5 °C. About 33% of the dwellings do not use any thermostatic control. The average thermal sensation vote of the whole group was 0.5% which corresponds to an acceptable thermal indoor environment. Such a vote is quite surprising given the indoor temperatures recorded in the dwellings. The average fuel cost for heating in the so heated dwellings, was 1.4 €/m^2, which corresponds to about 10.5 kW h/m^2. In parallel, the average cost of the electricity used for heating in the corresponding dwellings was 0.41 €/m^2 which is equivalent to 5.6 kW h/m^2.

In Group C (partial deprivation), all the dwellings have a central heating system and air conditioners installed. However, only the 25% uses the central heating system, while 75% of the dwellings use the air conditioner and 25% uses in parallel an auxiliary mobile heating system. Heating is provided for three hours per day and the thermostat is set at 20 °C. The average thermal sensation vote of the whole group is 0.5 which means that residents consider their indoor thermal environment as satisfactory. The average fuel cost for heating in the so heated dwellings, is 1.66 €/m^2 which is equivalent to 12.5 kW h/m^2. In parallel, the mean cost of electricity used for heating purposes in the corresponding dwellings, is 0.43 €/m^2, which is equivalent to 6 Kw h/m^2.

In Group D (average deprivation), almost 59% of the households live in dwellings with an installed central heating system but this is in operation only in the 23% of the dwellings. There is an extensive use of mobile auxiliary heating systems, (65%), while in the 24% of the houses there is an installed air conditioner. In total 82% of the dwellings is using electricity for heating and 17% uses both fuel and electricity. Almost 6% of the dwellings are not heated at all. Heating is provided in the conditioned buildings for 2.6 h per day and the average thermostat temperature is set at 18.5 °C, while 35% of the dwellings are not using any thermostatic control. The average thermal sensation vote is 0.11, 'acceptable', which is quite reasonable for the specific indoor conditions. The mean cost of fuel used for heating purposes in the so heated dwellings is 2.28 €/m^2, which is equivalent to 17.2 kW h/m^2. The average cost of electricity in the corresponding buildings is 0.46 €/m^2, which is equivalent to 6.4 kW h/m^2.

In Group E (at the limits of deprivation), all buildings have an installed central heating system however only 33% of the dwellings is using it. In 83% of the buildings an air conditioner is installed while in the 33% of the dwellings an auxiliary mobile heating system is available. However, the fraction of households using electricity for heating is 66% while 17% are using both fuel and electricity and 17% are not heated at all. Dwellings are heated on the average for 3 h per day and the average thermostat temperature is 18.7 °C. The mean thermal sensation vote in the group is 0.17 which signifies that residents consider the indoor thermal environment as satisfactory. The average cost of fuel in the so heated dwellings is 3.1 €/m^2, which is equivalent to 23.4 kW h/m^2. In parallel, the corresponding cost of the electricity in the so heated dwellings is 0.49 €/m^2, which is equivalent to 6.8 kW h/m^2.

Based on the above the following conclusions may be drawn:

(a) People living in high deprivation, Group A, are not using almost any kind of energy for heating. Indoor temperatures are very much depending on the quality of the buildings envelope and follow the pattern of the ambient temperature.
(b) The absolute energy consumption for heating purposes in all groups is quite low and much lower than the corresponding consumption before the crisis, [38]. The mean heating consumption in all groups varies between 4 and 30 kW h/m^2, with an average close to 18 kW h/m^2 while before the crisis it was close to 110 kW h/m^2 [38,42].
(c) Although in most of the dwellings, a central heating system is installed, this is used only by a small fraction of the households. This is because the cost of oil has considerably increased during the last two years and households cannot afford to buy it.
(d) The average time of use of the heating systems is the minimum one. It varies between 0.75 and 3 h per day, while during the winter period heating is necessary for much longer depending on the occupancy of the dwellings.
(e) Given the lack of economic resources to use oil for the central heating systems, people are using auxiliary mobile heating systems like stoves etc. Such systems provide local heating and are usually transferred by the residents to the rooms they reside.
(f) The vote of people regarding the evaluation of their thermal environment, (thermal sensation vote), is higher than expected and justified from the recorded indoor temperatures. There are different reasons that may explain such a vote. First, all residents in low temperature dwellings are wearing additional clothes, while they use local sources of heating that helps to increase locally and not globally the temperature in the dwelling, while the possibility that people are adapted after a long exposure to lower temperatures should be investigated.

3.4. Households characteristics and impact on indoor temperature

Given the very low energy consumption of the dwellings, the levels of indoor temperature are mainly determined by the quality of the building envelope and less by the amount of energy used. In particular the minimum indoor temperature in the dwellings is almost completely determined by the corresponding losses to the ambient environment as they occur during the night time when the possible heating contribution or other thermal gains are almost negligible. This is clear from Fig. 4 where the minimum indoor temperature is plotted against the corresponding UA value for each dwelling. The UA value is calculated taking into account the convective and conductive losses through the envelope, while ventilation losses are not considered. As shown, there is a very good correlation, (R^2 = 0.78), that confirms the previously mentioned conclusion. Not such a good correlation is observed between the average indoor temperature and the corresponding UA values, (R^2 = 0.46), although there is a clear decreasing trend of the average indoor temperature for increasing UA values. This is because, the average indoor temperature is influenced by the energy spent for heating purposes, despite the fact that the amount of energy is small.

No relation between the average indoor temperature in all the dwellings and the corresponding heating energy consumed is found. This is because the average temperature is mainly determined by the thermal losses through the envelope and not due the energy spent. However, when the mean indoor temperature for each group is correlated against the corresponding average thermal or electrical energy spend in each group, a clear linear relation is observed (Figs. 5 and 6). This means that when the average heated dwelling in each group is considered, then energy has a clear impact on the average indoor temperatures.

The household income defines the ability of the families to buy and use energy and also to live in dwellings of better thermal

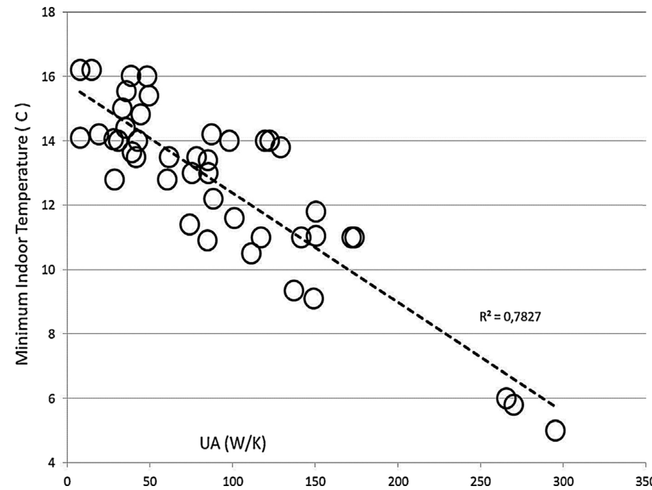

Fig. 4. Variation of the minimum indoor temperature in the dwellings, as a function of the corresponding thermal losses through the envelope, (UA).

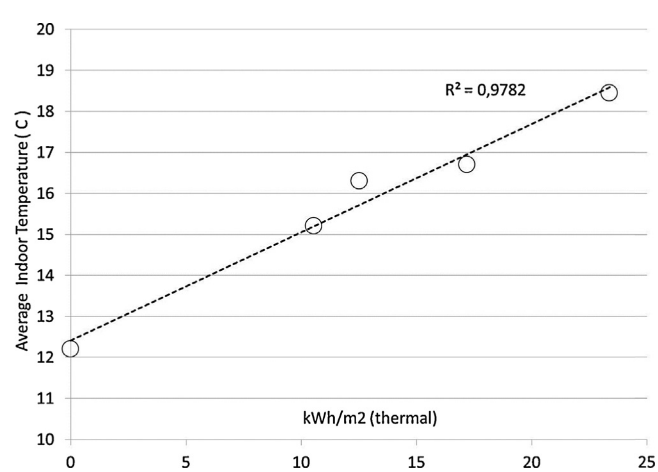

Fig. 5. Relation between the average indoor temperature in the various groups against the corresponding thermal energy spent.

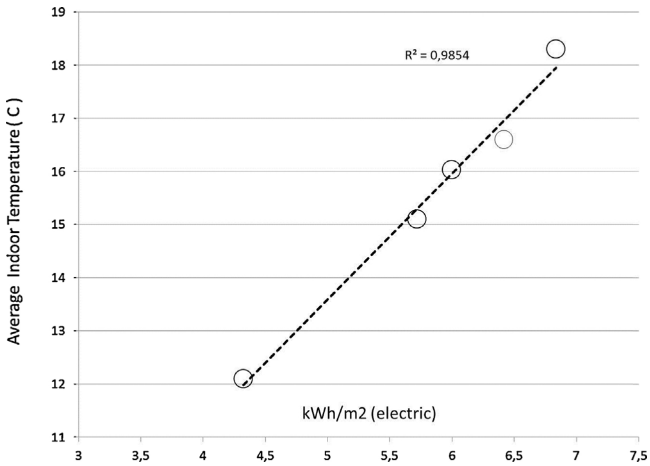

Fig. 6. Relation between the average indoor temperature in the various groups against the corresponding electric energy spent for heating.

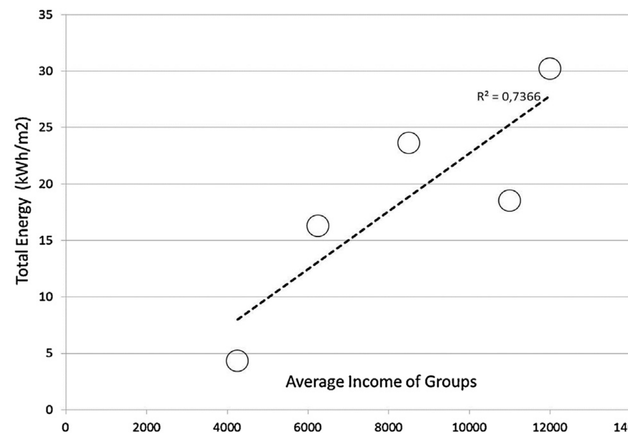

Fig. 9. Relation between the average annual income of the groups against the corresponding total energy consumption for heating.

quality. Correlation of the average income for each group against the corresponding average indoor temperature (Fig. 7), shows that the higher the income, the higher the average indoor temperature. This is an expected result given that the average group income correlates well with the corresponding mean UA value (Fig. 8), and the average total energy spent, (thermal + electric) (Fig. 9). As shown in Fig. 8, the UA value decreases rapidly for increasing incomes up to a certain level of income where it is stabilized and no further decrease of the UA is observed. This was expected as most of the dwellings in the groups of higher income are insulated apartments presenting quite similar thermal characteristics. The reasonably good relation between the income and the heating energy spent, Fig. 9, is quite evident and well expected. Higher income households have a considerably greater ability to buy and consume energy.

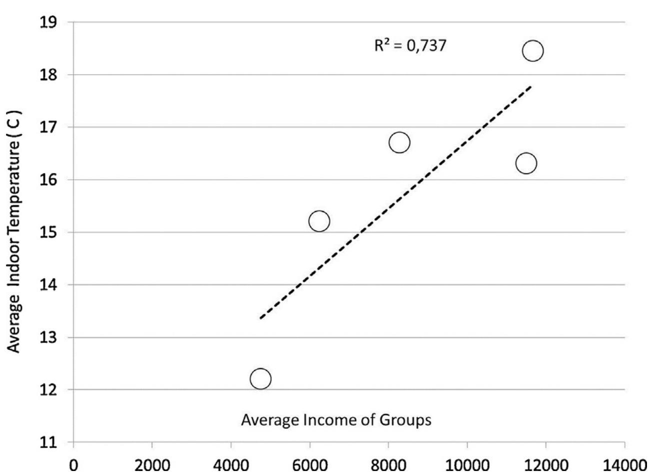

Fig. 7. Relation between the average indoor temperature in the various groups against the corresponding annual income.

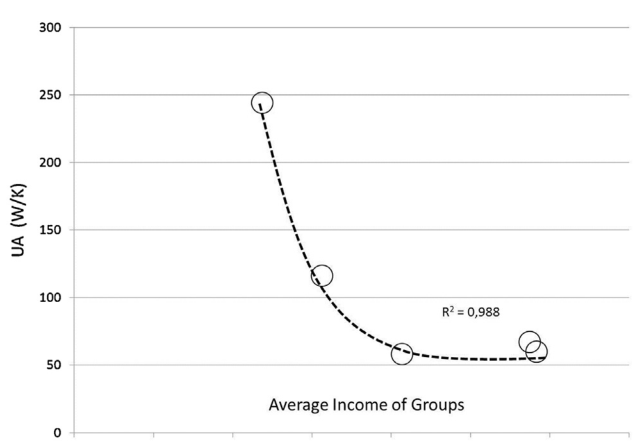

Fig. 8. Relation between the average annual income of the groups against the corresponding mean UA value.

3.5. Indoor temperatures during the very cold period

As already mentioned, the winter of 2012–2013 was quite mild and it was quite difficult to extract specific information on the behaviour of the buildings and the households under extreme weather conditions. To evaluate the performance of buildings as well as the indoor conditions during periods of very low temperature, a specific analysis is performed for the two cold days of 8th and 9th of January. As previously mentioned, the minimum temperature during the two days was around to 0.9 °C–1.0 °C, while the average temperature was 2.5 °C and 3.9 °C for the first and second day, respectively. Fig. 10 presents the variability of the indoor temperature in the dwellings of the five defined groups for the two specific days and the entire January. As shown, the average temperature for all groups has been substantially reduced. In particular in the groups of Very High Deprivation, (Group A), and High Deprivation, (Group B), the reduction of the average temperature was very high. In particular:

In Group A, the average temperature during the two cold days was 7.5 °C, while the minimum and maximum temperatures were 4.9 °C and 11.4 °C. This means that the mean indoor temperature is reduced by 4.6 °C compared to the corresponding mean temperature for the whole January while the maximum indoor temperature was reduced by 6.7 °C against the average for the whole month. The daily evolution of the indoor temperature for three out of the dwellings belonging to Group A as well as of the ambient temperature during the two cold days are given in Fig. 11. As shown, during the full duration of the two days, indoor temperature was at freezing conditions placing in risk the health and even the lives of the residents.

In Group B, the average indoor temperature is reduced by 2.5 °C down to 12.8 °C, while the mean temperature during January was 15.3 °C. For almost the whole 48 h indoor temperature in all houses was below 18 °C, and for almost 90% of the time below 15 °C, while for about 50% of the time below 13 °C.

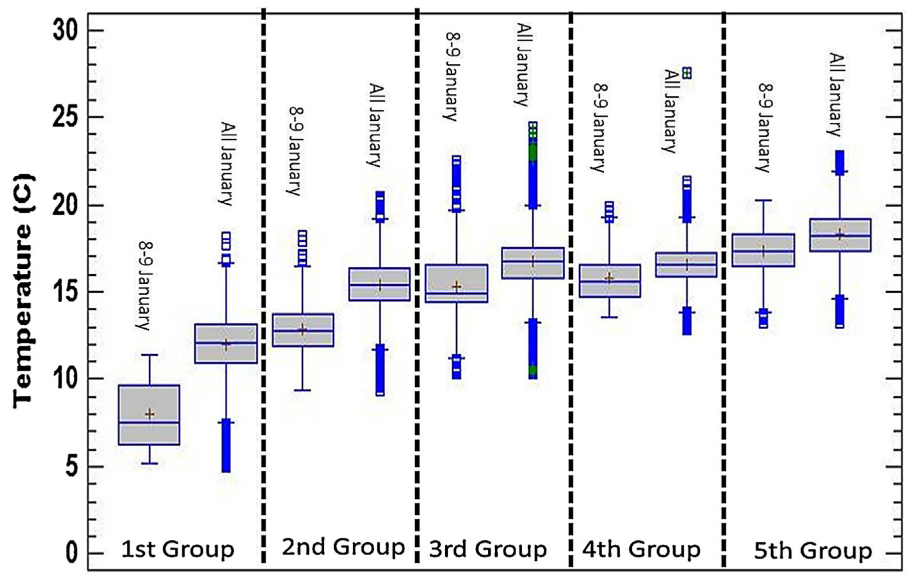

Fig. 10. Variation of the indoor temperature during the two cold days (8–9 January), and also during the whole January, for all the defined groups.

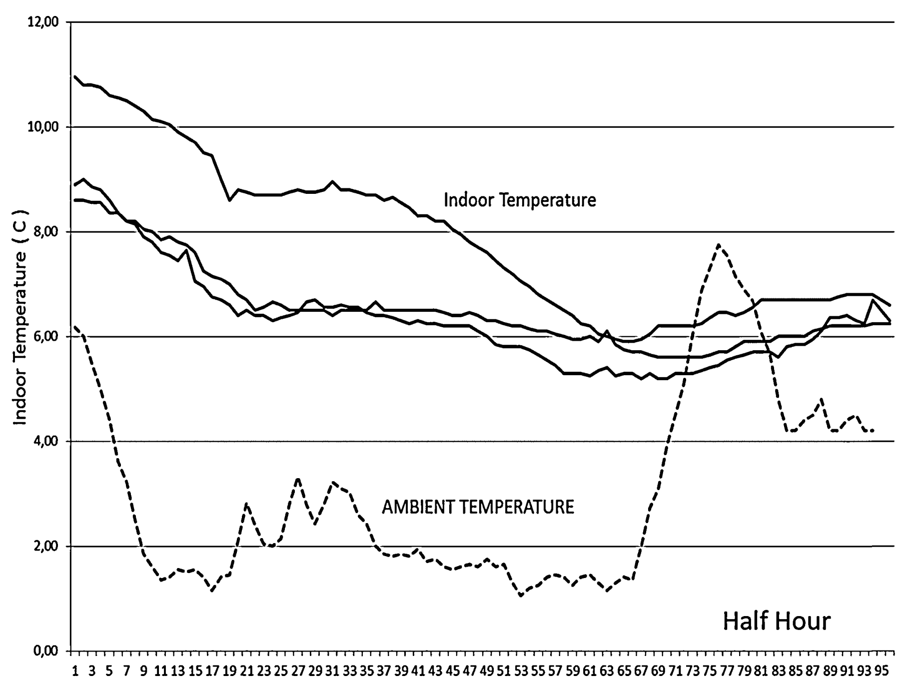

Fig. 11. Variation of the indoor Temperature in three buildings of Group A and the ambient temperature for the 8th and 9th of January.

In Group C, the average indoor temperature is reduced by 1.8 °C down to 14.9 °C, while for January it was 16.7 °C. For almost 80% of the time, indoor temperatures were below 18 °C and for 40% of the time below 15 °C. In Group D, the average indoor temperature is reduced by 0.95 °C down to 15.6 °C. Almost for 80% of the time, temperatures were below 18 °C and for 35% of the time below 15 °C. Finally, in Group E, the average indoor temperature is reduced to 17.3 °C, almost 0.9 K lower than the average for January. For 65% of the time, indoor temperatures were below 18 °C and for about 20% of the time below 15 °C.

3.6. Housing and neighborhood characteristics

Important information about the general quality of the dwellings as well of their neighborhood is collected through personal interviews with the residents. The results for each defined group are summarized in Table 5. The overall perception of the residents on the global quality of their dwellings show that people in very high deprivation (Group A) consider that the quality is 'Bad', while all other groups believe that the quality is at 'Acceptable' levels. Almost 50% of the dwellings in Group A, 12% in Group D and 8% in Group B have problems with rats. In parallel, 75% of the dwellings of Group A, 42% of Group B and 17% of Group D have problems of internal mold. It is well known that the presence of mold and damp in houses is associated to illnesses like asthma, influenza, bronchitis, migraine, etc. [43].

Noise is a serious problem for many urban areas in Athens while it is an important source of annoyance for humans. According to Ref. [44], people living in noisy environments present sleep disturbances, are stressed and become irritable. On a scale 0 to 1 (not noisy to noisy), the vote was 1 (one), for Group A, 0.5 for Group E, 0.41 for Group D, 0.25 for Group B and zero for the Group B. Thus, noise seems to be a quite important problem for a high part of the residents.

Table 5
Housing and neighborhood characteristics.

	Group A	Group B	Group C	Group D	Group E
Housing characteristics					
Levels of noise: 1 = noisy environment, 0 = not a noisy environment	1	0.25	0	0.41	0.5
Percentage of dwellings with problems of mold	75	42	0	17	0
Percentage of dwellings with problems of rats	50	8	0	12	0
Perception on the dwelling quality, −2 = very bad, −1 = bad, 0 = acceptable, 1 = good, 2 = very good	−1	0.17	0.25	0.05	0.17
Neighborhood characteristics					
Perception on the quality of the neighborhood, −2 = very bad, −1 = bad, 0 = acceptable, 1 = good, 2 = very good	0	0.42	0.75	0.23	0.33
Existence or not of Green in the neighborhood: 0 = Non existence of green, 1 = existence of green	0.25	0.58	0.75	0.35	0
Quality of the outside view from the window, −2 = very bad, −1 = bad, 0 = acceptable, 1 = good, 2 = very good	0.5	0	0.5	−0.71	−0.5

Table 6
Health problems and characteristics for the various groups.

	Group A	Group B	Group C	Group D	Group E
Self reported health levels −2 = very bad, −1 = bad, 0 = acceptable, 1 = good, 2 = very good	1	0.86	0.67	0.28	0.53
Percentage of population with at least a serious disease	0	18%	0%	29%	7%
Percentage of population with depression problems	17%	0	0	13%	7%
Percentage of population with allergies	0	12%	0%	8%	0%
Percentage of smokers	17%	18%	7%	25%	33%

As it concerns the perception of the residents on the quality of their neighborhood, people voted using a five steps scale (from −2 (very bad) to 2 (very good). The lowest score, zero or 'acceptable', is given by people in Group A, while all other groups evaluated their neighborhood on the zone between 'Acceptable' and 'Good'. The main problems raised by the residents were related to increased criminality, problems of noise and pollution and lack of open space. Regarding the existence of green spaces in their neighborhood, the vote was on a two steps scale: from zero for no green to 1 for sufficient green. Votes ranged between 0, (Group E), to 0.75 given by Group C. Finally, in terms of the evaluation of the quality of view from the windows, people in Group D voted that it is almost 'Bad', while Group 'E' voted that it is between acceptable and bad. All other groups considered that the view is between to 'Acceptable' and 'Good'. It is evident that the groups living mainly in apartments in dense areas have a non-positive opinion about their neighborhood.

3.7. Health conditions and problems

The collected specific information on the health conditions and characteristics of the residents is given in Table 6 for all the defined groups. The main important finding is that almost 8.2% of the concerned population suffers from mental problems and in particular depression. In two Groups, A and D, the corresponding percentage exceeds 10% and in Group A is 17%. Previous research has shown that low indoor temperatures have a damaging psychosocial impact including depression, stress and other [6,23,27,45]. In parallel, other studies [6] have shown that non proper levels of indoor daylight or bad window view increase the probability of depression by 60% and 40%, respectively. Finally, as reported in Ref. [6], people living in houses with mold, present a 60% higher trend for depression than residents of dwellings without mold problems. Similar conclusions are also reported in Ref. [46].

As it concerns the self-reported health levels, no specific conclusions are drawn. All groups have reported health conditions between the 'Acceptable' and 'Good' levels. Previous studies [6,47,48] concluded that self-reported health is poorer in colder homes. In Ref. [6], it is stated that in proper houses 4.7% of the residents declare in bad health while in dwellings of bad quality the corresponding percentage was 16.8%. Also, in Ref. [48], it is mentioned that residents of cold houses visited almost twice the medical doctors compared to those living in comfortable dwellings.

4. Conclusions

Low income population in Greece lives in inadequately protected houses that need a quite high energy load to heat. Previous studies have shown that low income population has to spend much higher energy quantities for heating per capita and area compared to high income population as their dwellings are improperly insulated and thermally protected. At the same time the serious decrease of the financial income caused by the economic crisis, has a serious impact on the heating energy consumed by low income population and has tremendously decreased the heating bills. This very unpleasant financial situation has a very serious impact to indoor environmental quality as lack of resources does not allow reaching the proper indoor temperatures. Monitoring of 43 low and very low income houses during the winter of 2012–2013 in Athens has shown that indoor temperatures are much lower than the minimum threshold values set for comfort and health purposes. In most of the houses, long spells of low indoor temperatures are recorded while during periods of low ambient temperatures the specific indoor conditions in selected houses were completely unacceptable and much below the internationally accepted conditions. The energy consumed is found to be minimum and much lower that the country's average. Indoor temperature levels are mainly defined by the thermal quality of the envelope and an almost linear relation between the minimum indoor temperatures and the level of thermal losses through the envelope is found. Five specific groups of low income households are defined based on the recorded levels of indoor temperature. Analysis of the exact levels of the indoor environmental quality in each group showed that they are highly associated to the environmental, energy, economic, social, and health characteristics of the households.

Given the above, an immediate priority is to improve indoor environmental quality in low and very low income households in Greece especially during the period of economic crisis as residents are exposed to very serious environmental and health risks. Programs to supply energy at low prices in order to satisfy basic heating needs together with programs to improve the thermal performance of the low income houses have to be defined and undertaken urgently. Efforts to this direction have been promoted in recent years by state authorities, yet they need to be intensified, to be modified so as to be also eligible for people in unemployment and to be also linked to a respective public awareness program. At the same time, the under revision Master Plan of Athens needs to promote urban tools and interventions so as to upgrade the overall outdoor microclimatic environment of the dwellings in a sustainable manner. Furthermore detailed spatial inventories of (a) low and very low income households per area and (b) poor thermal performance buildings need to be developed so as to assess the overall degree of the problem for the population and recognize areas in danger or of potential danger. Close adherence to the new state building and energy regulations needs to be promoted for both existing and new buildings, whereas quantitative time targets regarding the annual reduction of the number of dwellings of poor thermal performance need to be set by state and local authorities and linked to the financial provisions of the next programmatic period of the European Structural Funds (2014–2020). An urban observatory for the problem dealt in this paper, may be of considerable support for the effective monitoring of the state of the problem and the success of the undertaken measures. Finally, a paneuropean approach needs to be also developed taken that energy poverty is also met in other European countries as well.

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