Electric Energy Consumption in Greece: A study based on socio-economic features

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Abstract

Data Collection

The initial data was collected through an anonymous online survey that was distributed among colleagues at several universities and other public fora in Greece and weather data provided by the National Observatory of Athens. The survey contained 26 questions that can be organized into four main categories.

Household Data

This category contains questions about construction variables that play an important role in energy consumption according to various studies. These variables are outlined in Table 1.

- **Dwelling Type**. This is a categorical variable with four discrete values: a) Single family home (detached house), b) semi-detached house (a house sharing one common wall with another residence), c) townhome (a house sharing two common walls with other residences) and d) apartment (a single or multi floor residence in a block of flats)
- **Household m^2**. This is a numerical variable referring to the total area of the house in square meters.
- The number of **bedrooms** in the house
- **Age**. The year of construction or major renovation of the house. This is an ordinal variable with four discrete values: a) 0 – 5 years (a new house or a recently renovated one), b) 6 – 15 years (a fairly recent one), c) 16 – 30 years (an old house) and d) at least 31 years ago (a very old construction).
- **Electric Heating**. This is an ordinal variable referring to whether the main source of heating for the house is electricity or not.
- **Household area code**. The area code of the house is recorded in order to specify the approximate location of the house and link its electricity consumption with the corresponding weather data.

Variable	Type	Measurement Unit
Dwelling Type	Categorical	1. Single family home 2. Semi-Detached Home 3. Townhome 4. Appartment
Household m^2	Numerical	
Bedrooms	Numerical	
Age	Ordinal	1. 0 - 5 2. 6 - 15

		3. 16 – 30 4. 31 -
Electric Heating	Categoric al	1. Yes 2. No
Area code	Numerical	

Table 1 Household Properties

An excerpt from the household data is presented in Table 2. The data have been augmented by additional fields in order to replace the categorical variables with ordinal ones:

1. **Dwelling Grade** has 4 possible values depending on the dwelling type of the house (Appartment – 0, Townhome – 0.4, Semidetached – 0.7, Single Family - 1).
2. **Size Grade** has 5 possible values depending on the m^2 of the house (0: 0 m^2 – 60 m^2, 0.2: 61 m^2 – 80 m^2, 0.4: 81 m^2 – 100 m^2, 0.6: 101 m^2 – 140 m^2, 0.8: 141 m^2 – 200 m^2, 1.0: >200+ m^2).
3. **Old Grade** has 4 possible values depending on the construction age of the house (0: 0 – 5, 0.33: 6 – 15, 0.66: 16 – 30, 1.0: 30+).

Dwelling	Dw. Grade	Household m2	Size Grade	Bedrooms	Age	Old Grade	Electric Heating	Area Code
Single Family	1	117	0.6	3	6 - 15	0,33	No	57003
Semidetached	0.7	100	0.4	2	6 - 15	0,33	Yes	54634
Townhome	0.4	25	0	1	30+	1	Yes	54640
Appartment	0	142	0.8	3	30+	1	No	54248
Appartment	0	75	0.2	2	16 - 30	0,66	Yes	54636
Appartment	0	35	0	2	0 - 5	0	Ναι	54636

Table 2 Augmented Household Data

Occupants' socio-economic features

The second category consists of social and economic features about the residents of the house and are outlined in Table 3.

1. **Occupants**. A numerical variable representing the total numbers of occupants.
2. **Children**. A numerical variable representing the number of children (ages between 0 and 10) living in the house.
3. **Teenagers**. A numerical variable representing the number of teenagers (ages between 11 and 18) living in the house.
4. **Adults**. A numerical variable representing the number of adults (ages between 19 and 69) living in the house.
5. **Elders**. A numerical variable representing the number of elders (70 years old and older) living in the house.
6. **Full Timers**. Number of occupants working in full time status.
7. **Part Timers**. Number of occupants working in part time status.
8. **Grads**. Number of occupants that have graduated from a university.
9. **Post Grads**. Number of occupants that received a post-graduate degree (Masters or PhD)
10. **Income**. The total annual income of the family in euros. This is an ordinal variable with five discrete values: a) 0€ - 10,000€, b) 10,001€ - 20,000€, c) 20,001€ - 40,000€, d) 40,001€ - 60,000€ and e) more than 60,000€.

Variable	Type	Measurement Unit
Occupants	Numerical	
Children (0 – 10 years old)	Numerical	
Teenagers (11 – 18 years old)	Numerical	
Adults (19 – 69 years old)	Numerical	
Elders (70 - years old)	Numerical	
Full timers	Numerical	
Part timers	Numerical	
Grads	Numerical	
Post grads	Numerical	
Income	Ordinal	1) 0€ - 10,000€ 2) 10,001€ - 20,000€ 3) 20,001€ - 40,000€ 4) 40,001€ - 60,000€ 5) > 60,000€

Table 3 Occupants' socio-economic features

An excerpt from the socio economic data is presented in Table 4. The data have been augmented by additional fields in order to replace the categorical variables with ordinal ones:

1. $\mathbf{A_{inc}}$ is a way to quantify the ages of the people living in the house, following the assumption that an individual consumes more energy as it grows. The formula used is $\boldsymbol{A_{inc}} = 0.5 * Children + 0.75 * Teenagers + 0.9 * Adults + 1.0 * Elders$
2. $\mathbf{A_{dec}}$ is a way to quantify the ages of the people living in the house, following the assumption that an individual consumes less energy as it grows. The formula used is $\boldsymbol{A_{dec}} = 1.0 * Children + 0.9 * Teenagers + 0.75 * Adults + 0.5 * Elders$
3. $\mathbf{A_{gauge}}$ is a way to quantify the ages of the people living in the house, following the assumption that adults and teenagers consume more energy than children and elders. The formula used is $\boldsymbol{A_{gauge}} = 0.5 * Children + 0.75 * Teenagers + 1.0 * Adults + 0.5 * Elders$
4. Education Index (**EI**) is a index that aims at measuring the educational attainment of a group of people. The formula is based on two factors: Mean Years of Schooling (**MYS**) for adults and elders and Expected Years of Schooling (**EYS**) for children and teenagers. The EYS in Greece in 2019 was 17.91 (UNDP 2019) and this value was used in our calculations. The MYS was calculated under the assumptions that the average duration of studies in University is 4 years for the first degree and 2 years for a masters or a PhD. The formula for calculating Educational Index was based on (Priemyshev, Arysheva and Lavrova 2015) and is the following:

$$EI = \frac{\frac{EYS}{18} + \frac{MYS}{18}}{2}$$

Occupants	Children	Teenagers	Adults	Elders	Ainc	Adec	Agauge	Fulltimers	Parttimers	Grads	PostGrads	EI
3	1	0	2	0	2,3	2,5	2,5	2	0	2	1	0,97
2	0	0	2	0	1,8	1,5	2	2	0	2	2	1,00
4	2	0	2	0	2,8	3,5	3	2	0	2	2	1,00
4	0	2	2	0	3,3	3,3	3,5	2	0	0	0	0,83

5	3	2	2	0	4,8	6,3	5	1	1	0	0	0,83
4	2	0	2	0	2,8	3,5	3	1	0	2	2	1,00

Table 4 Augmented Socio Economic Data

Energy related occupants' behaviour

This category consists of questions aiming to quantify the awareness of the occupants about their energy fingerprint. The variables associated with these questions are outlined in Table 5.

1. **Usage**. An ordinal variable representing how often is the house occupied. There are three discrete values: a) there is at least one person in the house throughout the day, b) the house remains unoccupied for approximately 1/3 of the day and c) the house is used as a second house and it is occasionally occupied.
2. **Recycling**. An ordinal variable representing how often the occupants recycle their waste. This is related to the eco-consciousness of the family. There are three discrete values: a) rarely, b) sometimes and c) often or always.
3. **Energy Class**. An ordinal variable representing how often the occupants check the energy class when they buy new electric devices. This question is also related to the eco-consciousness of the family. There are three discrete values: a) rarely, b) sometimes and c) often or always.
4. **Thermostats**. An ordinal variable representing how often the occupants lower the desired temperature in the thermostats when they leave the house (e.g. for work or weekends). This question is also related to the eco-consciousness of the family. There are three discrete values: a) rarely, b) sometimes and c) often or always.
5. **Water heater**. A categorical variable representing if the house is equipped with a solar water heater. There are two discrete values: a) yes and b) no.
6. **Smart plugs**. An ordinal variable representing how often the occupants use smart plugs in order to monitor the energy consumption of energy demanding devices (e.g. washer dryers). This is one more question about the eco-consciousness of the family. There are three discrete values: a) rarely, b) sometimes and c) often or always.
7. **Awareness**. A variable representing how often the occupants compare their electric energy consumption against the ones by neighbours, family members and friends. This is a question about the energy awareness of the family that plays a significant role in the proper use of electric energy. The variable is an ordinal on and there are three discrete values: a) rarely, b) sometimes and c) often or always.

Variable	Type	Measurement Unit
Usage	Ordinal	1. There is always someone in the house 2. People are in the house except for working hours 3. The house is used occasionally
Recycling	Ordinal	1. Never or seldom 2. Occasionally 3. Frequently
Energy Class	Ordinal	1. Never or seldom 2. Occasionally 3. Frequently

Thermostats	Ordinal	1. Never or seldom 2. Occasionally 3. Frequently
Water heater	Categorical	1. Yes 2. No
Smart plugs	Ordinal	1. Never or seldom 2. Occasionally 3. Frequently
Awareness	Ordinal	1. Never or seldom 2. Occasionally 3. Frequently

Table 5 Energy related occupants' behaviour

Weather Data

Each entry in the questionnaire recorded the area code of the household. We used the area code for each house in order to find the closest weather station from the National Observatory of Athens stations network. Through this process the 113 houses from the questionnaire were categorized into 24 clusters. Each cluster was directly linked with a specific weather station from which we obtained hourly recordings of temperature and humidity in a period of 3 years to cover the consumption periods of all the provided electric company bills. An excerpt from the weather data from the central station located in the city of Thessaloniki is presented in

Date	Time	Temperature (°C)	Humidity
…			
2019-05-11	7:00	13.9	0.86
2019-05-11	8:00	14.9	0.84
2019-05-11	9:00	15.6	0.74
2019-05-11	10:00	19.4	0.62
2019-05-11	11:00	20.9	0.55
2019-05-11	12:00	21.9	0.45
2019-05-11	13:00	22.4	0.5
2019-05-11	14:00	23.4	0.45
…			

Table 6.

Date	Time	Temperature (°C)	Humidity
…			
2019-05-11	7:00	13.9	0.86
2019-05-11	8:00	14.9	0.84
2019-05-11	9:00	15.6	0.74
2019-05-11	10:00	19.4	0.62
2019-05-11	11:00	20.9	0.55
2019-05-11	12:00	21.9	0.45
2019-05-11	13:00	22.4	0.5
2019-05-11	14:00	23.4	0.45
…			

Table 6 Initial Weather Data for the central station of Thessaloniki, Greece

For each weather station and for each hourly record we calculated various additional variables that relate to the energy consumption of buildings as shown in Table 7. The first two additional variables are Heating Degree Hours (HDH) and Cooling Degree Hours (CDH) that give a rough indication of Heating and Cooling loads of a residence (McGarity and Gorski 1984). HDH and CDH are calculated by subtracting the actual hourly temperature from base heating and cooling temperatures as shown in Equation 1 and Equation 2. The base temperatures for heating (T_{HB}) and cooling (T_{CB}) may vary

depending on the location, type, year of construction and energy class of the building but for simplicity reasons we used the following values: $T_{HB} = 15.5°C, T_{CB} = 22°C$.

$$HDH = \begin{cases} 0, & T > T_{HB} \\ T_{HB} - T, & T \leq T_{HB} \end{cases}$$

Equation 1. HDH formula

$$CDH = \begin{cases} 0, & T < T_{CB} \\ T - T_{CB}, & T \geq T_{CB} \end{cases}$$

Equation 2. CDH formula

Date	Time	Temperature (°C)	Humidity	HDH	CDH	HI	HIDH
…							
2019-05-11	7:00	13.9	0.86	0.07	0.00	13.9	0.00
2019-05-11	8:00	14.9	0.84	0.03	0.00	14.9	0.00
2019-05-11	9:00	15.6	0.74	0.00	0.00	15.6	0.00
2019-05-11	10:00	19.4	0.62	0.00	0.00	19.4	0.00
2019-05-11	11:00	20.9	0.55	0.00	0.00	20.9	0.00
2019-05-11	12:00	21.9	0.45	0.00	0.00	21.9	0.00
2019-05-11	13:00	22.4	0.5	0.00	0.02	21,2	0.00
2019-05-11	14:00	23.4	0.45	0.00	0.06	22,2	0.01
…							

Table 7 Augmented Weather Data for the central station of Thessaloniki, Greece

Energy Consumption

People participating in the survey had to fill in some details from one or more electric company bills. The data from collected from the bills are outlined in Table 8.

1. **Start**. The start date of the consumption period.
2. **End**. The end date of the consumption period. The start and end dates were used in order to calculate the number of days in the period and also connect the consumption with weather data for the specific period and area (obtained from the area code).
3. **Kwhs**. The total consumption in Kwhs in the specified time period.

Variable	Type
Start	Date
End	Date
Kwhs	Numerical

Table 8 Energy Consumption

An excerpt from the energy consumption data is presented in Table 9. The data have been augmented by three additional fields:

1. **Days** the total number of days in the consumption period (End - Start)
2. **Kwhs/day** Electric Consumption per day
3. **Kwhs/day/m2** Electric Consumption per day per square meter

Start (dd/mm/yyyy)	End (dd/mm/yyyy)	Days	Kwhs	Kwhs/day	Kwhs/day/m2	HDD	CDD	HID
01/09/2021	02/01/2022	123	2081	16,92	0,14	429,52	63,89	45,63
01/01/2022	31/01/2022	30	350	11,67	0,12	269,00	0,00	0,00
23/08/2021	21/12/2021	120	872	7,27	0,29	248,46	93,06	64,73
02/08/2021	01/12/2021	121	1674	13,83	0,10	106,91	288,42	219,22
23/10/2021	23/02/2022	123	1696	13,79	0,12	790,41	0,00	0,00

02/08/2021	01/12/2021	121	538	4,45	0,04	2,32	299,49	215,61
10/07/2021	10/09/2021	62	1200	19,35	0,18	0,00	358,74	426,55

Table 9 Energy Consumption Data

Conclusions and Future Work

References

Arthur E. McGarity, Anthony I. Gorski, Passive Generation and Storage of Winter Ice for Summer Cooling Applications, in Energy Developments: New Forms, Renewables, Conservation, 1984

R. G. Steadman, The Assessment of Sultriness. Part I: A Temperature-Humidity Index Based on Human Physiology and Clothing Science, Journal of Applied Meteorology. 18 (7): 861–873, 1979

A. A. Priemyshev, M. V. Arysheva, Z. I. Lavrova, Analysis of the human development index calculation - Comparison of the old and the new methods. St. Petersburg State Polytechnical University Journal. Economics, 216(2), 85–93. 2015

UNDP, Education in Greece - Expected years of schooling, 2019