Energy and Built Environment 1 (2020) 288–295

Contents lists available at ScienceDirect

Energy and Built Environment

journal homepage: www.elsevier.com/locate/enbenv

What are the odds? On the determinants of high residential energy expenditure

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ARTICLE INFO

Key words:
Energy expenditure
Residential sector
Odd-ratio
Household variables
Determinants

ABSTRACT

A precise understanding of the relationships between the household characteristics and the residential energy consumption is needed to support the implementation of effective top-bottom energy strategies and to improve the prediction of forecasting models. This paper contributes to the present-day discussion and analyses the building factors, socio-demographic variables and appliances contributing to high-energy expenditures (viz., electrical energy expenditure, thermal energy expenditure and total energy expenditure) in the Italian households. The proposed study builds on an earlier work proposed by the authors, which identified the determinants of the household energy expenditures, based on a nationally representative survey (the "*household Budget Survey: microdata for research purposes* - 2015″ performed by the Italian National Institute of Statistics). In particular, the present paper completes and extends the previous research by applying the odds-ratio analysis to the previously identified determinants, in order to identify the factors that led to high electricity consumption (viz., electrical energy expenditure, thermal energy expenditure and total energy expenditure). In conclusion, this paper aims to providing a more precise understanding of the factors that certainly affect the energy expenditure.

1. Introduction

Energy consumption in buildings largely contributes to the energy consumption in the different countries, i.e., Brounen et al. [1] mentioned that approximately one-fifth of total global energy demand originates from the residential sector. Hence, a reduction in energy consumption at the "*household-scale*" may determine a significant reduction in the total carbon dioxide emissions of the whole country [2]. In this respect, a precise knowledge of the existing relationships between the household characteristics (i.e., building factors, socio-demographic factors and appliances variables) and the energy consumption/energy expenditure may serve as basis for policymakers when planning investments aiming to reduce the energy consumption in the residential sector, by also taking also into account the changes that continuously affect the "*household-scale*" [3]. In particular, this knowledge is requested, by policy-maker when designing effective top-bottom long-term energy strategies: for example, unveiling the socio-demographic and geographic dimensions of the higher energy consumption in the whole country can be exploited to guide effective policy schemes. In this perspective, Khosrowpour et al. [4] concluded that "*occupants are integral elements of a building ecosystem and their behavior can have a substantial impact on energy consumption in buildings*".

However, despite its importance, the study of the relationships between the household characteristics and the energy consumption/energy expenditure has received a growing interest only in the very recent years. Brouner et al. [1] stated that, in the last decades, this field of study received less attention, with the exception of some preliminary (and mostly qualitative) discussions by Fritzsche [5], by Raaij and Verhallen [6], and by Schipper et al. [7]. In conclusion, despite the considerable amount of research activities carried out during the last decades, summarized by Besagni and Borgarello [8], an agreement regarding the methods and the relationships between the residential energy consumption/energy expenditure and the many variables describing households is far from being reached. The proposed study builds on the earlier work proposed by the authors, which identified the determinants of the household energy expenditure characteristics, based on a nationally representative sample (based on the "*household Budget Survey: microdata for research purposes*" performed by the Italian National Institute of Statistics, *ISTAT*, on the Italian population [9]). In particular, this study completes and extends the previous research by applying the odds-ratio analysis to the previously identified determinants, in order to identify the factors that led to high electricity consumption (electrical energy, thermal energy and total energy). Hence, this paper contributes in providing a more precise understanding of the factors that certainly

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https://doi.org/10.1016/j.enbenv.2020.03.001
Received 23 January 2020; Received in revised form 27 February 2020; Accepted 2 March 2020
Available online 2 April 2020

affect the energy expenditure and further unveils the high energy consumption patterns in the Italian residential sector. To the authors' best knowledge, this research, along with our previous paper, is the very first comprehensive study regarding the energy expenditure patterns, at the household level, in Italy as a whole. The paper proceeds as follows. Section 2 describes the dataset and the methods used for this analysis. Section 4 discusses the results of the odd-ratio analysis. Finally, the main conclusion, outlook and outcomes are presented and discussed.

2. Dataset, variables and methods

2.1. Dataset

The dataset used in this study is the "*Household Budget Survey: microdata for research purposes*" (reference year: 2015) obtained by Italian National Institute of Statistics (*ISTAT*) and provided to RSE Spa research center. The household budget survey, which is representative of the Italian population, focuses on consumption expenditure behaviors of households residing in Italy and it provides a large number of information. In particular, the micro-data were collected from approximately 15.015 households, in 502 different municipalities; for each household, more than 1264 variables are available concerning (a) socio-demographic information (of all household members), (b) building characteristics, (c) appliances owned and (d) monthly equivalent expenditures. The reader may refer to the statistical report provided by ISTAT for a complete descriptive analysis of the employed dataset.

2.2. Dependent variables

Given the aim of this study—describing the relationships between the energy expenditure and the many variables describing the households characteristics—three dependent variables have been selected: (a) electrical energy expenditure, (b) thermal energy expenditure, and (c) the total energy expenditure (viz. the sum of electrical energy and thermal energy expenditures). These data are provided, in the present dataset, as monthly expenditures. As the expenditure variable is already available within the dataset, all price support mechanisms and incentives, for low-income households, are intrinsically taken into account in such dependent variables and no further post-processing is needed. Future studies should be devoted to unveil the economic fluxes at the household boundaries, to clarify the effect of top-bottom policies at the household-scale. In the following of this section, further details regarding the dependent variables are provided.

In particular, the monthly electrical energy expenditure ($S_{El.Month}$) is available in the dataset as-is, whereas the monthly thermal energy expenditure ($S_{Th.Month}$) has been obtained by summing the following components: (a) gas from distribution network, (b) central heating (i.e., diesel/kerosene/other fuels…), (c) district heating, (d) butane and other liquid gases, (e) diesel/kerosene/other liquid fuels, (f) coal, (g) Wood/pellet/ Other solid fuels. Thermal energy can be related to heating energy expenditure. Finally, the monthly total energy expenditure ($S_{En.Tot.Month}$) has been obtained by summing $S_{El.Month}$ and $S_{Th.Month}$. It is worth noting that the electrical energy expenditure mainly concerns lighting, appliance and other electrical uses; of course $S_{El.Month}$ may also include the expenditure for heating purposes by the use of heat pumps. It is known that heat pump is an interesting technology for efficiency heating and cooling purposes; however, their use in the Italian framework is quite limited so far (most of the heating systems rely on non-electrical technologies) and the applied dataset does not contain any variable concerning the use of heat pumps; therefore, it was not possible for us to describe this appliance. It should be considered that every record in the dataset refer to a precise month during the year (i.e., the energy expenditure refers to the amount of money paid on the last month). Unfortunately, monthly energy expenditures cannot be directly applied to correctly relate household variables and energy expenditures, but they should be computed based on an annual point of view, to avoid a bias, as discussed in ref. [8]. Indeed, it is known that the heating and cooling energy depend of a household is highly related to the ambient conditions. In this respect, $S_{El.Month}$ does not depend on the time on the year and, thus, the annual electrical energy expenditure ($S_{El.Ann}$) can be estimate by multiplying $S_{El.Month}$ for twelve (as performed by Jones and Lomas [10]). Conversely, the thermal energy expenditure is highly related to the time of the year and, for this reason, a calibration procedure to obtain the annual thermal energy expenditure ($S_{Th.Ann}$) is needed. The procedure is detailed in the Appendix A of ref. [8]. The total annual energy expenditure ($S_{En.Tot.Ann}$) is obtained by summing $S_{El.Ann}$ and $S_{Th.Ann}$. Finally, in agreement with the previous literature [1,11,3], the annual energy expenditures are divided by the number of household components to obtain per-capita energy expenditures ($S_{El.Ann.Pc}$, $S_{Th.Ann.Pc}$, $S_{En.Tot.Ann.Pc}$), to obtain results comparable regardless of the number of occupants. It has been observed that the annual energy expenditures ($S_{El.Ann.Pc}$, $S_{Th.Ann.Pc}$, $S_{En.Tot.Ann.Pc}$) have left-skewed distributions: in this case, in order to be able to use t-tests for statistical significance it is common practice to compute the log of the dependent variable (viz. a log-linear model is used); this procedure results in a dependent variable which is closer to a normal distribution. Another advantage of using logs is that the regression coefficients refer to the relative changes rather than the absolute changes in per-capita energy expenditures. This concept has been detailed by Longhi [3], to whom the interested reader may refer, and has been widely applied in the previous literature (see refs. [1,3,11–13]).

2.3. Predictors

This section describes the variables used as predictors, accordingly with ref. [8]. Three categories of predictors have been considered: (a) socio-demographics variables (summarized in Table 1; 21 categorical variables and 1 continuous variable), (b) building variables (summarized in Table 2; 10 categorical variables and 1 continuous variable) and (c) appliances and assimilated variables (summarized in Table 3; 7 categorical variables and 1 continuous variable). In Tables 1, and –3, all variables are listed along with their frequencies or their summary statistics (viz., mean and standard deviation for the continuous variables). It should be noted that only some of these variable have been found significant determinants of the residential energy expenditure [8].

2.3. The odd-ratio (OR) method

In our previous study [8] we applied (a) the ordinary least squares method, to determine the relationship between the variables, (b) the variance inflation factor, to check for multicollinearity issues, (c) the least absolute shrinkage and selection operator, to select significant variables. Once the regression approach has been applied to determine the significant predictors, the odd-ratio (*OR*) method is used to further examine the relationships between the predictors and the energy expenditures ($S_{El.Ann.Pc}$, $S_{Th.Ann.Pc}$, $S_{En.Tot.Ann.Pc.}$). *OR* is a statistical method that compares the relative odds of the occurrence of the outcome of interest (i.e., high/low energy expenditure), given exposure to a factor of interest (e.g., the predictors found significant from the regression procedure). The application of the *OR* method requires that the dependent variable is binary (See also Jones and Lomas [14]); for this reason, a baseline expenditure is selected to split the dependent variable into two parts; the baseline value is chosen as the second tertile of $S_{El.Ann.Pc}$, $S_{Th.Ann.Pc}$, $S_{En.Tot.Ann.Pc.}$; The threshold values are as follows:

a $S_{El.Ann.Pc,Baseline} = 290.8$ [€/year,per-capita];
b $S_{Th.Ann.Pc,Baseline} = 508.2$ [€/year,per-capita];
c $S_{En.Tot.Ann.Pc,Baseline} = 794.4$ [€/year,per-capita].

Energy expenditures below above baseline values are considered "*low/medium*"; conversely, energy expenditures above the baseline values are considered "*high*". Given this splitting, the OR test can be applied

Table 1
Socio-demographic variables and their frequencies (bold = reference category) - the categories printed in bold indicates the reference category for later analyses.

Variable	Summary statistics
Absolute poverty	(a) Yes [834], **(b) No [14179]**
Age of the HRP	(a) Up to 34 years [995], (b) From 25 to 44 years [2343], **(c) From 45 to 54 years [3059]**, (d) From 55 to 64 years [2934], (e) From 65 to 74 years [2841], (f) From 75 years [2841]
Birth place of the household components	**(a) Only born in Italy [13456]**, (b) At least one born abroad [973], (c) Only born abroad [584]
Changes in economic resources compared to the previous year	(a) Much improved [30], (b) A little bit improved [512], **(c) More or less the same [8488]**, (d) A little worsened [4626], (e) Much worsened [1357]
Citizenship of the household components	**(a) Only Italian citizens [14176]**, (b) At least one foreign citizens [257], (c) Only foreign citizens [580]
Current economic resources	(a) Optimal [279], **(b) Adequate [7912]**, (c) Scarce [5651], (d) Insufficient [1171]
Enrolment in study courses	**(a) No members enrolled in a course [[10930]**, (b) At least one in no title school [419], (c At least one in elementary school [747], (d) At least one in junior high school [584], (e) At least one in high school [1244], (f) At least one in a degree or post-degree course [1089]
Entrepreneurs and freelancer workers	**(a) No one [13696]**, (b) One [1172], (c) More than one [145]
Expenditure for elderly/disabled people	(a) Yes [100], **(b) No [14913]**
Household structure	(a) Single person 18–34 years [391], (b) Single person 35–64 years [1817], (c) Single person 65 years and more [2240], (d) Couple without children with *HRP* 18–34 years [178], (e) Couple without children with *HRP* 35–64 years [1350], (f) Couple without children with *HRP* 65 years and more [2164], **(g) Couple with 1 child [2276]**, (h) Couple with 2 children [2184], (i) Couple with 3 children or more [495], (l) Mono parent family [1033], (m) Others [885]
Number of managers and employees	**(a) No one [8227]**, (b) One [4739], (c) More than one [2047]
Marital status of the HRP	(a) Unmarried [2551], **(b) Married or cohabitant [8252]**, (c) Married but not cohabitant [355], (d) Legally separated [625], (e)) Divorced [698], (f) Widow or widower [2532]
Qualification of the occupants	(a) No member has a qualification [377], (b) At least one member with elementary school [1978], (c) At least one member with junior high school [3108], **(d) At least one member with high school [6483]**, (e) At least one member with a degree [3067]
Self-employed workers	**(a) No one [11876]**, (b) One [2583], (c) More than one [554]
Sex of the HRP	**(a) Male [10193]**, (b) Female [4820]
Source of income of the occupants	(a) There is no income [83], (b) At least one maintained [413], (c) At least one pension [4911], **(d) At least one income [9606]**
Transportation expenditures	**Continuous variable** [Mean = 130 / Variance = 18,725]
Work contract of the occupants	**(a) There is neither temporary job nor permanent job [7536]**, (b) At least one temporary job [1125], (c) At least one permanent job [6352]
Workers and similar	**(a) No one [8166]**, (b) One [4741], (c) More than one [2106]
Number of workers in the primary sector	**(a) No one [13622]**, (b) One [1100], (c) More than one [291]
Number of workers in the secondary sector	**(a) No one [9766]**, (b) One [4098], (c) More than one [1149]
Number of workers in the tertiary sector	(a) No one [4577], **(b) One [6195]**, (c) More than one [4241]

*HRP = Household Representative Person, which is the individual that is taken to represent the household. In this study it describes the highest income earner in the household.
**Summary statistics evaluated on the whole data-set.
***Reference Categories highlighted in bold.

to every category as follows:

$$OR = \frac{ES_{high} \times NES_{low/medium}}{NES_{high} \times ES_{low/medium}} \quad (1)$$

Where ES_{high} is the number of households with certain condition and "*high*" energy expenditure; $ES_{low/medium}$ the number of households with certain condition and "*low/medium*" energy expenditure; NES_{high} is the number of households without certain condition and "*high*" energy expenditure; $NES_{low/medium}$ the number of households without certain condition and "*low/medium*" energy expenditure. If OR =1, it follows that households with a certain condition are just as likely to have energy expenditures as the households in the reference group; $OR > 1$ indicates a higher probability to have higher energy expenditures compared to the reference group (the higher the *OR* value, the higher the probability); $OR < 1$ indicates that the probability is lower than for the reference group. To obtain more precise information, the confidence interval at 95% (95%-CI) can be computed as described by Jones and Lomas [14]; the 95% confidence interval associated with each *OR* describes the uncertainty in the estimate. The narrower is the confidence interval, the more precisely the effect is known; conversely, a wider interval indicates that the uncertainty is greater. Instead, a *CI* spanning the value 1 indicates that the influence of the factor on the energy consumption is unclear.

3. Results of the odd-ratio analysis

The results of the *OR* analysis, for the three dependent variables (for the so-called "*aggregate regression models*" in ref. [8] and the different classes of predictors are presented in Table 4 ($S_{El.Ann.Pc}$), Table 5 ($S_{Th.Ann.Pc}$) and Table 6 ($S_{En.Tot.Ann.Pc}$). This table also presents the 95% confidence intervals (*CI*-95%): they indicate the range of values that the *OR* could be if a different sample of households were used (see ref. [14]). If the confidence interval is narrow, the effect of the condition on energy expenditure is known more precisely and there is high confidence in the result observed; conversely, if the confidence interval span the value 1, it indicates that the effect of the condition on energy expenditure is less clear. In Tables 4–IV, *OR* values in bold indicate that the factor increases the likelihood that a household has high energy expenditure; *OR* values in italic indicate that the factor increases the likelihood that a household has low energy expenditure; *OR* in plain text indicates that the

Table 2
Building variables and their frequencies (bold = reference category) - the categories printed in bold indicates the reference category for later analyses.

Variable	Summary statistics
Domestic hot water system	(a) Electric boiler [2009], (b) Gas boiler [3603], **(c Heating system [9135]**, (d) Other [24], (e) Solar panel [199], (f) No hot water system [43]
Natural gas from network	(a) Yes [12359], (b) No [2645]
Gas/Electricity cooking	(a) Yes [14940], (b) No [73]
Geographic location	(a) northwest [3284], (b) northeast [3382], **(c) center [2791]**, (d) South [4385], (e) Sicily [753], (f) Sardinia [418]
Number of rooms	(a) 1 [443], (b) 2 [2876], **(c) 3 [5912]**, (d) 4 [4044], (e) 5 [1212], (f) 6 [333], (g) 7 and more [193]
Occupation title	(a) Rent or sublease [2358], **(b) Property [11169]**, (c) Usufruct [352], (d) Free use [1134]
Period of construction	(a) After 2009 [190], (b) Between 2000 and 2009 [1222], (c) 1990s [1411], (d) 1980s [2326], **(e)** 1970s **[3426]**, (f) 1960s [2724], (g) 1950s [1481], (h) Between 1900 and 1949 [1404], (i) Before 1900 [829]
Floor area	**Continuous variable** [Mean = 98 / Variance = 1342]
Type of heating system and fuel	(a) Central heating - Natural gas from network [1381], (b) Central heating – Gas oil/kerosene/other liquid fuels [264], **(c) Autonomous heating - Natural gas from network [9443]**, (d) Autonomous heating – Gas oil/kerosene/other liquid fuels [270], (e) Autonomous - Gas cylinder[483], (f) Autonomous - Wood/pellet/ Other solid [964], (g) District heating [109], (h)) Individual devices - Wood/pellet/ Other solid [841], (i) Individual devices - Other not solid fuels [396], (l) Other [101], (m) No heating system [761]
Type of dwelling	(a) Single family villa [2738], (b) Multifamily villa [4587], **(c) Apartments in building with less than 10 apartments [3733]**, (d) Apartments in building with 10 or more apartments [3939], (e) Other [16]
Type of municipalities	(a) center of metropolitan area [1889], (b) Periphery of metropolitan area and municipalities with 50.001 inhabitants and more [4032], **(c) Other municipalities until 50.000 inhabitants [9092]**

*HRP = Household Representative Person, which is the individual that is taken to represent the household. In this study it describes the highest income earner in the household.
**Summary statistics evaluated on the whole data-set.
***Reference Categories highlighted in bold.

Table 3
Appliances and assimilated variable and their frequencies. (bold = reference category) - the categories printed in bold indicates the reference category for later analyses.

Variable	Summary statistics
Expenses for appliances and electric tools	***Continuous variable*** [Mean = 22 / Variance = 1650]
Number of cars	(a) No car [2761], **(b) One car [7324],** (c) Two cars [4226], (d) Three or more cars [702]
Number of computers	(a) No pc [5607], **(b) One pc [6771],** (c) Two pc [2087], (d) Three or more pc [548]
Number of mobile phones	(a) No mobile phones [1565], **(b) One mobile phones [4373]**, (c) Two mobile phones [5225], (d) Three or more mobile phones [3850]
Number of televisions	(a) No TV [648], **(b) One TV [6600],** (c) Two TVs [5785], (d) Three or more TVs [1980]
Ownership of air conditioner	(a) Yes [5043], **(b) No [9970]**
Ownership of a dishwasher	(a) Yes [7220], **(b) No [7793]**
Ownership of fridge	(a) Yes [14982], (b) No [31]
Ownership of washing machine	(a) Yes [14750], (b) No [263]
Self-consumption	(a) Yes [2029], **(b) No [12984]**

*HRP = Household Representative Person, which is the individual that is taken to represent the household. In this study it describes the highest income earner in the household.
**Summary statistics evaluated on the whole data-set.
***Reference Categories highlighted in bold.

confidence interval span the value 1-It is worth noting that the *OD* test can be applied only for categorical variables and, for this reason, continuous variables are excluded from the analysis. Dependent variables are transformed in binary variables (viz. "low-*medium energy expenditure*" and "*high energy expenditure*" as suggested by Jones and Lomas [14].

3.1. Electrical energy expenditure ($S_{El.Ann.Pc}$)

The results for $S_{El.Ann.Pc}$ "*aggregate regression model*" are presented in Table 4. Concerning appliances and assimilated variables, contrarily to what observed by Jones and Lomas [14], dish washer ownership is not a factor that increases the likelihood that a household has either low or high electrical energy expenditure (as *CI*-95% spans the value of 1); conversely, air-conditioning ownership increases the likelihood that a household has high electrical energy expenditure (*OR* = 1.14, with a low CI-95% variation). Concerning building variables, households not connected to the natural gas network are significantly more likely to be high electricity consumers (*OR* = 1.14), owing to the likely use of electricity-based heating and cooking systems. Similarly with Jones and Lomas [14], families living either in single family villas (*OR* = 1.43) or in multifamily villas (*OR* = 1.32) are more likely to have higher electrical energy expenditures compared with families living in small (reference category) or large condominiums (*OR* = 0.80). Concerning the type of municipalities, it is found that households in the center of metropolitan area are likely to exhibit lower electrical energy expenditure compared with small municipalities; on the contrary, a straightforward result concerning households in periphery of metropolitan areas or municipalities with more than 50.000 inhabitants is not found (as *CI*-95% spans the value of 1). As far as the macro-geographic location is concerned, it is observed that the electrical energy expenditures in Sardinia are considerably higher compared with the other cases (*OR* = 2.63); indeed, as stated above, there is not natural gas network in Sardinia. Concerning socio-demographic variables, the absolute poverty condition results in a significant decreases of the electrical energy expenditures (*OR* = 0.39). The enrollment in study courses determines a reduction in the electrical energy expenditures (*OR* in the range of 0.21 – 0.39). As far as the household structure is concerned, the odd-ratio analysis results support the discussion reports in [8]: taking couples with 1 child as the reference category, it is observed that, couples with more than 1 child exhibit lower electrical energy expenders (2 children, *OR* = 0.53; 3 children, *OR* = 0.42); conversely, couples without children (*OR* in the range of 1.69 – 1.73) and single person (*OR* in the range of 4.20 – 5.61) have higher electrical energy expenditure. Instead, a clear results concerning mono-parent families is not found (as *CI*-95% spans the value of 1). Finally, the presence of self-employed workers determine an increase in the electrical energy expenditure (*OR* = 1.21), whereas the effect of the presence of self-employed workers is not clear.

3.2. Thermal energy expenditure ($S_{Th.Ann.Pc}$)

The results for $S_{Th.Ann.Pc}$ "*aggregate regression model*" are presented in Table 5. Concerning appliances and assimilated variables, it is observed

Table 4
Odd Ratio and 95%-CI for the variables in the $S_{El.Ann.Pc}$.

Variable	Categories	OR	CI-95%	CI+95%
Ownership of a dishwasher	Yes	0.96	0.90	1.03
	No		Reference	
Ownership of air conditioner	Yes	1.14	1.06	1.23
	No		Reference	
Natural gas from network	Yes		Reference	
	No	1.59	1.46	1.73
Type of dwelling	Single family villa	1.48	1.33	1.64
	Multifamily villa	1.32	1.21	1.45
	Apartments in building with < 10 apartments		Reference	
	Apartments in building with ≥ 10 apartments	0.80	0.73	0.89
	Other case	0.56	0.12	2.63
type of municipalities	center of metropolitan area	0.70	0.63	0.78
	Town with > 50,000 inhabitants	1.02	0.95	1.11
	Town with <= 50,000 inhabitants		Reference	
Geographic location	North Ovest	0.96	0.86	1.06
	North Est	0.82	0.74	0.91
	Centro		Reference	
	South	0.67	0.60	0.74
	Sicily	1.01	0.86	1.20
	Sardinia	2.63	2.12	3.26
Absolute poverty	Yes	0.39	0.32	0.47
	No		Reference	
Enrolment in study courses	No members enrolled in a course		Reference	
	At least one in no title school	0.21	0.15	0.28
	At least one in elementary school	0.21	0.16	0.26
	At least one in junior high school	0.20	0.16	0.26
	At least one in high school	0.29	0.25	0.34
	At least one in a degree or post-degree course	0.39	0.33	0.45
Household structure	Single person 18–34 years	4.20	3.32	5.32
	Single person 35–64 years	4.68	4.08	5.37
	Single person ≥ 65 years	5.61	4.92	6.41
	Couple without children with *HRP* 18–34 years	0.82	0.55	1.22
	Couple without children with *HRP* 35–64 years	1.69	1.45	1.97
	Couple without children with *HRP* ≥ 65 years	1.73	1.52	1.98
	Couple with 2 child		Reference	
	Couple with 2 children	0.53	0.45	0.62
	Couple with 3 children or more	0.42	0.31	0.57
	Mono parent family	1.14	0.96	1.36
	Other case	0.80	0.66	0.98
Entrepreneurs and freelancers	No one		Reference	
	One	1.21	1.07	1.37
	More than one	1.05	0.74	1.49

*Reference represents the reference category. Bold OR indicate that the factor increases the likelihood of having high expenses, OR in italics indicate that the factor reduces the likelihood of high expenditures.

that the number of mobile phones owned is related to the likelihood that a household has either low (three of more mobile phones, *OR* = 0.48) or high (no or one mobile phones, *OR* = 2.56 −2.82) thermal energy expenditures. Concerning building variables, using as reference a three-room dwelling, it is observant that a dwelling with one (OR= 1.54), two (*OR* = 1.25), six (*OR* = 1.79) or more (*OR* = 2.18) rooms are more likely to have higher thermal energy expenditures; conversely, there is not a significant difference with a four or five rooms dwelling. This result may appear surprisingly; however, it is worth noting that, dependent variables are per-capita energy expenditures and not the total energy expenditures. As previously, households not connected to the natural gas network are significantly more likely to be high electricity consumers and, thus, lower thermal energy expenditures (*OR* = 0.73). The OR results for the dwelling type are similar to the results obtained for the electrical energy expenditure: families living in single family villas (*OR* = 1.30) or in multifamily villas (*OR* = 1.25) are more likely to have higher energy expenditures compared with families living in small (reference category) or large condominiums (*OR* = 0.77). Using as reference a dwelling using an autonomous heating system with natural gas from network, it is observed that dwelling is likely to have higher thermal energy expenditure when using a central heating system with natural gas from network (*OR* = 1.02,) central heating system with liquid fuels (*OR* = 1.80), an autonomous system with liquid fuels (*OR* = 2.57), an autonomous system with liquid fuels (*OR* = 1.57); conversely, is likely to have lower thermal energy expenditure in the case of individual devices (*OR* in the range of 0.23 – 0.84) and, of course, when there is no heating systems (*OR* = 0.14); in the other cases, a non-straightforward relationship is found. As far as the macro-geographic location, using as reference the center of Italy, it is observed that the thermal energy expenditures in Sardinia (*OR* = 0.37), in Sicily (*OR* = 0.24) and in the South of Italy (*OR* = 0.52) are lower; conversely, the north west (*OR* = 1.87) and the north east (*OR* = 1.32) are likely to have higher thermal energy expenditure. The results can be interpreted by considering the relationship between heating/cooling degrees and the thermal energy consumption [15]. Concerning socio-demographic variables, it is observed that the absolute poverty condition results in a significant decreases of the thermal energy expenditures (*OR* = 0.31). The enrollment in study courses determines a reduction in the thermal energy expenditures (*OR* in the range of 0.17 – 0.35). As far as the household structure is concerned, the results support the discussion reports in [8]: taking couples with 1 child as the reference category, it is observed that, couples with more than 1 child exhibit (2 children, *OR* = 1.91; 3 children, *OR* = 2.30) are likely to have lower thermal energy expenditure; conversely, couples without children, *if HRP* is older than 34 years old (*OR* in the range of 1.91 – 2.30), single person (OR in the range of 3.81 – 5.08) and mono-parent families (*OR* = 1.51)

Table 5
Odd Ratio and 95%-CI for the variables in the $S_{Th.Ann.Pc}$.

Variable	Categories	OR	CI-95%	CI+95%
Number of mobile phones	No mobile phones	2,82	2,50	3,18
	One mobile phone	2,56	2,34	2,79
	Two mobile phones		Reference	
	Three or more mobile phones	0,48	0,43	0,53
Number of rooms	1	1,54	1,25	1,90
	2	1,25	1,14	1,38
	3		Reference	
	4	0,98	0,90	1,07
	5	1,11	0,97	1,27
	6	1,79	1,43	2,25
	7 or more	2,18	1,63	2,91
Natural gas from network	Yes		Reference	
	No	0,73	0,66	0,81
Type of dwelling	Single family villa	1,30	1,17	1,45
	Multifamily villa	1,25	1,14	1,37
	Apartments in building with < 10 apartments		Reference	
	Apartments in building with ≥ 10 apartments	0,77	0,70	0,86
	Other case	3,53	0,84	14,80
Type of heating system and fuel	Central heating - Natural gas from network	1,02	0,90	1,15
	Central heating - Gas oil/kerosene/other liquid fuels	1,80	1,35	2,39
	Autonomous heating - Natural gas from network		Reference	
	Autonomous heating - Gas oil/kerosene/other liquid fuels	2,57	1,99	3,30
	Autonomous - Gas cylinder	1,57	1,31	1,90
	Autonomous heating - Wood/pellet/ Other solid	0,99	0,85	1,14
	District heating	1,45	0,98	2,13
	Individual devices - Wood/pellet/ Other solid	0,84	0,72	0,99
	Individual devices - Other cases	0,23	0,17	0,32
	Other cases	0,79	0,47	1,33
	No heating system	0,14	0,10	0,19
Geographic location	North Ovest	1,87	1,68	2,07
	North Est	1,32	1,19	1,47
	Centro		Reference	
	South	0,52	0,47	0,58
	Sicily	0,24	0,18	0,31
	Sardinia	0,37	0,27	0,49
Sex of the HRP	Male		Reference	
	Female	1,87	1,74	2,02
Absolute poverty	Yes	0,31	0,25	0,39
	No		Reference	
Enrolment in study courses	No members enrolled in a course		Reference	
	At least one in no title school	0,17	0,12	0,23
	At least one in elementary school	0,16	0,12	0,20
	At least one in junior high school	0,24	0,19	0,30
	At least one in high school	0,20	0,17	0,24
	At least one in a degree or post-degree course	0,35	0,30	0,41
Household structure	Single person 18–34 years	3,81	2,97	4,87
	Single person 35–64 years	4,93	4,28	5,68
	Single person ≥ 65 years	5,08	4,44	5,81
	Couple without children with *HRP* 18–34 years	1,35	0,94	1,93
	Couple without children with *HRP* 35–64 years	1,91	1,64	2,23
	Couple without children with *HRP* ≥ 65 years	2,30	2,01	2,63
	Couple with 1 child		Reference	
	Couple with 2 children	0,40	0,34	0,48
	Couple with 3 children or more	0,27	0,19	0,39
	Mono parent family	1,51	1,27	1,79
	Other case	0,71	0,58	0,88

*Reference represents the reference category. Bold OR indicate that the factor increases the likelihood of having high expenses, OR in italics indicate that the factor reduces the likelihood of high expenditures.

are likely to have higher thermal energy expenditures. Finally, the presence of female HPR workers determine an increase in the thermal energy expenditure (OR = 1.87), compared with male HRP.

3.3. Total energy expenditure ($S_{En.Tot.Ann.Pc}$)

The results for $S_{En.Tot.Ann.Pc}$ "*aggregate regression model*" are presented in Table 6. Concerning appliances and assimilated variables, dish washer ownership is not a factor that increases the likelihood that a household has low or high total energy expenditure (as *CI*-95% spans the value of 1). Concerning building variables, households not connected to the natural gas network are significantly more likely to be lower total energy expenditures (*OR* = 0.80). Families living in single family villas (*OR* = 1.45) or in multifamily villas (*OR* = 1.33) are more likely to have higher total energy expenditures compares with families living in small (reference category) or large condominiums (*OR* = 0.75). Using as reference a dwelling using a autonomous heating system with natural gas from network, it is observed that dwelling is likely to have higher total energy expenditure when using a central heating system with liquid fuels (*OR* = 1.39), an autonomous system with liquid fuels (*OR* = 2.46), an autonomous system with liquid fuels (*OR* = 1.55); conversely, is likely to have lower total energy expenditure in the case of individual devices with non-solid fuels (*OR* = 0.44) and, of course, when there is no heating systems (*OR* = 0.27); in the other cases, a non-straightforward

Table 6
Odd Ratio and 95%-CI for the variables in the $S_{En.Tot.Ann.Pc}$.

Variable	Categories	OR	CI-95%	CI+95%
Ownership of a dishwasher	Yes	0.99	0.93	1.06
	No		Reference	
Natural gas from network	Yes		Reference	
	No	0.80	0.73	0.88
Type of dwelling	Single family villa	1.45	1.31	1.61
	Multifamily villa	1.33	1.21	1.46
	Apartments in building with < 10 apartments		Reference	
	Apartments in building with ≥ 10 apartments	0.75	0.68	0.83
	Other case	2.19	0.63	7.58
Type of heating system and fuel	Central heating - Natural gas from network	0.91	0.81	1.03
	Gas oil/kerosene/other liquid fuels	1.39	1.08	1.78
	Auntonomous, Natural gas from network		Reference	
	Auntonomous, Gas oil/kerosene/other liquid fuels	2.46	1.92	3.15
	Autonomous - Gas cylinder	1.55	1.29	1.87
	Auntonomous, Wood/pellet/ Other solid	0.96	0.84	1.11
	District heating	0.87	0.58	1.30
	Single appliances, Wood/pellet/ Other solid	0.91	0.78	1.06
	Individual devices - Other cases	0.44	0.34	0.57
	Other case	0.87	0.56	1.34
	No heating system	0.27	0.22	0.34
Geographic location	North Ovest	1.58	1.42	1.76
	North Est	1.14	1.03	1.27
	Centro		Reference	
	South	0.50	0.45	0.56
	Sicily	0.39	0.32	0.48
	Sardinia	0.88	0.70	1.10
Sex of the HRP	Maschio		Reference	
	Female	1.84	1.71	1.98
Absolute poverty	Yes	0.24	0.19	0.30
	No		Reference	
Source of income of the components	There is no income	0.53	0.28	0.98
	At least one maintained	1.08	0.86	1.37
	At least one pension	2.50	2.32	2.68
	At least an income		Reference	
Enrolment in study courses	No one		Reference	
	At least one in no title school	0.12	0.09	0.17
	At least one in elementary school	0.13	0.10	0.16
	At least one in junior high school	0.16	0.12	0.21
	At least one in high school	0.18	0.15	0.22
	At least one in a degree or post-degree course	0.31	0.27	0.37
Household structure	Single person 18–34 years	3.76	2.97	4.75
	Single person 35–64 years	5.94	5.16	6.84
	Single person ≥ 65 years	6.49	5.67	7.43
	Coppia no con figli 18–34 anni	1.23	0.85	1.78
	Couple without children with *HRP* 35–64 years	2.18	1.87	2.54
	Couple without children with *HRP* ≥ 65 years	2.67	2.33	3.05
	Couple with 1 child		Reference	
	Couple with 2 children	0.36	0.30	0.43
	Couple with 3 children or more	0.28	0.19	0.40
	Mono parent family	1.47	1.24	1.75
	Other case	0.72	0.58	0.89

*Reference represents the reference category. Bold OR indicate that the factor increases the likelihood of having high expenses, OR in italics indicate that the factor reduces the likelihood of high expenditures.

relationship is observed. As far as the macro-geographic location, using as reference the center of Italy, it is observed that the total energy expenditures in Sicily (*OR* = 0.39) and in the South of Italy (*OR* = 0.50) are lower; conversely, the north west (*OR* = 1.58) and the north east (*OR* = 1.14) are likely to have higher total energy expenditure. Concerning socio-demographic variables, the absolute poverty condition results in a significant decreases of the total energy expenditures (*OR* = 0.24). The enrollment in study courses determines a reduction in the total energy expenditures (*OR* in the range of 0.12 – 0.31). Taking couples with 1 child as the reference category, it is observed that, couples with more than 1 child exhibit (2 children, *OR* = 0.36; 3 children, *OR* = 0.28) are likely to have lower total energy expenditure; conversely, couples without children, if *HRP* is older than 34 years old (*OR* in the range of 2.18 – 2.67), single person (*OR* in the range of 3.76 - 6.49) and mono-parent families (*OR* = 1.47) are likely to have higher total energy expenditures. It is also observed that, compared with a family with, at least, a source of income, the absence of income sources are likely to determine lower total energy expenditures (*OR* = 0.53); conversely, if at least a pension is included, the household is likely to be subject to higher total energy expenditures (*OR* = 2.50).

4. Conclusions

Using a large, nationally representative sample Italian households, this paper contributes to the existing concerning the relationships between residential energy expenditure and building factors, socio-demographic and appliances. The results obtained in this paper complete and extends our previous study, by applying the odd-ratio method to identify the factors that led to high electricity consumption (electrical energy, thermal energy and total energy). In particular, the

results further support our previous findings: it appear that socioeconomic characteristics have a higher explanation power compared with dwelling characteristics and appliances, with respect to the electrical energy expenditures. Conversely, building variables are particularly important in determine the thermal energy expenditures. The results are of practical relevance for policy-maker when designing effective top-bottom energy policies as they clearly provide a raking for variables determining the high energy consumption patterns in Italy. In particular, highly significant predictors in Tables 4–6 can be used as input criteria, for highly effective policy-schemes.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Giorgio Besagni: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Marco Borgarello:** Resources, Data curation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Acknoledgements

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development - General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency stipulated on July 29, 2009 in compliance with the Decree of March 19, 2009. Authors are grateful to ISTAT, for providing the dataset.

References

[1] D. Brounen, N. Kok, J.M. Quigley, Residential energy use and conservation: economics and demographics, Eur. Econ. Rev. 56 (2012) 931–945 ISSN: 00142921.
[2] Q. Ding, et al., The relationships between household consumption activities and energy consumption in china— an input-output analysis from the lifestyle perspective, Appl. Energy 207 (2017) 520–532 Transformative Innovations for a Sustainable Future – Part II. ISSN: 0306-2619.
[3] S. Longhi, Residential energy expenditures and the relevance of changes in household circumstances, Energy Econ. 49 (2015) 440–450 ISSN: 0140-9883.
[4] Ardalan, et al., A review of occupant energy feedback research: opportunities for methodological fusion at the intersection of experimentation, analytics, surveys and simulation. Khosrowpour, Appl. Energy 218 (2018) 304–316 ISSN: 0306-2619.
[5] D.J. Fritzsche, An analysis of energy consumption patterns by stage of family life cycle. american marketing association, J. Mark. Res. 18 (1981) 227–232 ISSN: 00222437.
[6] W.F.Van Raaij, T.M.M. Verhallen, A behavioral model of residential energy use, J. Econ. Psychol. 3 (1983) 39–63 ISSN: 0167-4870.
[7] L. Schipper, et al., Linking life-styles and energy use: a matter of time? Ann. Rev. Energy 14 (1989) 273–320.
[8] G. Besagni, M. Borgarello, The determinants of residential energy expenditure in Italy, Energy 165 (2018) 369–386 ISSN: 0360-5442.
[9] Istat, Household Budget Survey: Microdata For Research Purposes (reference year: 2015), Italian National Institute of Statistics (ISTAT), 2017 Istat. s.l.Statistiche report.
[10] R.V. Jones, K.J. Lomas, Determinants of high electrical energy demand in uk homes: socio-economic and dwelling characteristics, Energy Build. 101 (2015) 24–34 ISSN: 0378-7788.
[11] D. Wiesmann, et al., Residential electricity consumption in Portugal: findings from top-down and bottom-up models, Energy Policy 39 (2011) 2772–2779 ISSN: 0301-4215.
[12] M. Filippini, S. Pachauri, Elasticities of electricity demand in urban Indian households, Energy Policy 32 (2004) 429–436 ISSN: 0301-4215.
[13] M. Salari, R.J. Javid, Modeling household energy expenditure in the United States, Renew. Sustain. Energy Rev. 69 (2017) 822–832 ISSN: 1364-0321.
[14] R.V. Jones, K.J. Lomas, Determinants of high electrical energy demand in UK homes: appliance ownership and use, Energy Build. 117 (2016) 71–82 ISSN: 0378-7788.
[15] M.De Rosa, et al., Historical trends and current state of heating and cooling degree days in Italy, Energy Convers. Manag. 90 (2015) 323–335 ISSN: 0196-8904.
[16] L. Lutzenhiser, Social and behavioral aspects of energy use, Annu. Rev. Energy Environ. 18 (1993) 247–289.