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Statistical analysis of the heating demand in residential buildings located in Mediterranean climate and proposals for refurbishment

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Abstract

The paper deals with the investigation of the heating energy consumptions of a sample of residential buildings located in South Italy. A survey for the collection of data concerning energy performance certificates, characteristics of the building envelopes, air-conditioning plants and real consumptions, was carried out. A statistical analysis aimed at the identification of the main parameters affecting the energy requirements was developed using SPSS software. A multiple regression analysis was applied to obtain a forecasting tool that can be used to identify suitable action strategies for the retrofitting of buildings in the considered area.

Keywords: Mediterranean climate, existing buildings, energy consumption, statistical analysis, prediction model, building refurbishment

1. Introduction

The building sector is liable to be one of the widest energy consumers. In accordance with the latest addresses of the European Union [1] all Member States should adopt the necessary measures to ensure high-energy performance of new and/or retrofitted buildings, with the aim of reaching a zero or positive energy balance.

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The improvement of the energy performance of buildings accomplishes the dual purpose of reducing energy dependence on fossil fuels from other countries and of decreasing greenhouse gas emissions. In Italy, Ministerial Decree 26/06/2015[2], applying European directives, specifies the obligations to be met in constructions, with the goal of limiting energy consumption for the air conditioning. Consequently, all new edifices are built in compliance with the minimum requirements set by the Regulations. However, as a large part of the housing stock consists of existing buildings, the retrofitting of these structures to satisfy current energy efficiency and thermal comfort standards is firmly needed to concretely improve sustainability. An action spread throughout the territory is essential because, even if one single structure may not have any particular relevance, the system as a whole shows a network which constitutes the historic memory of the site [3]. Redeveloping the existing building stock represents an interesting opportunity to reach higher levels of environmental performance and reduce both energy consumption and CO_2 emissions required for its operation. As stated in Munarim and Ghisi [4], rehabilitation brings environmental and economic advantages. Also Martìnez-Molina et al. [5] confirmed the feasibility of preserving the built heritage while enhancing its energy efficiency and thermal comfort; furthermore, they claimed that Italy is leading the research in this field, thanks to the huge extent of its historical legacy. According to De Santoli [3] one of the fundamental processes of the energy upgrade of buildings is the energy audit. Several authors, e.g. Belpoliti and Bizzarri [6], Evola et al. [7], Droutsa et al. [8], propose the use of energy audits and data from energy performance certificates to briefly assess the energy consumption of entire building districts. In addition, building energy certificates should be used to produce an overview of the broad energy performance trends of buildings and drive improvements in energy performance by steering energy policy towards financial support of refurbishment strategies [9][10].

The estimate of building stock energy consumption is increasingly frequently carried out by extrapolating information from a wider database, created by assembling data collected through energy audits, but also by means of measurements, surveys, and simulations [11]. Forecasting models developed on the basis of large-scale investigations allow the prediction of the energy consumption of buildings, using few readily available parameters [12]. In Rhodes et al. [13] researchers performed a simulation model to predict the actual residential energy usage, with energy audits and surveys, under different scenarios of analysis. The combined IOA-LCA model proposed by Cellura et al. [14] aims to analyse the role of the building sector in the reduction of Italian energy consumption and CO_2 emissions. Koo and Hong [15]developed a dynamic energy performance curve for evaluating the historical trends in the energy performance of existing buildings. Recommendations on measures that can lead to a reduction in energy consumption are given in both Bojić et al. [16] and Ilić [17]; their recommendations essentially consist of different external insulation techniques, window replacement, installation of more efficient heating/cooling systems and application of renewable sources. The integration of several energy efficiency measures, if carefully planned, may even result in a Zero Energy Building after refurbishment, as shown by Corrado et al. [18] and Passer et al. [19] for residential buildings, and by Aksamija [20] for commercial buildings.

All the forecasting models are based on the strong interdependence between energy consumptions and some variables such as building shape, compactness, building age, surface area, etc. [21][22][12].

The association of the independent input variables with the dependent output variables is often performed by means of statistical analysis tools. Jang et al. [23] evaluated the characteristics in old apartment buildings that need to be considered for energy requalification. They found that, by using multiple regression analysis, three main features should be used as priorities for refurbishment schemes, namely the conditions of building envelope, the heating methods and the sizes of building units. Aranda et al. [24] and Chen et al. [25] used a regression analysis to develop analytic correlations for the prediction of energy consumptions in both the residential and the banking sectors. As asserted by Fan et al. [26], the drivers are many, varied, and complex, and involve local climate, household demographics, household behaviour, building stock and the type and number of appliances. Economical assessments conducted in several studies, e.g. Garrido-Soriano et al. [27], Ilić [17] and Pikas et al. [28], confirm that investment in energy efficiency is not only environmentally important but that it also provides economic benefits on an individual and government budget level.

This paper seeks to identify the characteristics of heating energy consumptions in a sample of residential buildings located in the region of Calabria, located in Southern Italy, typified by a Mediterranean climate. The investigation shows an overview of the energy performances of residential buildings in the interested area, obtained by the collection of energy certificates for the houses scattered throughout the territory. The study has allowed for the identification of the complex variables that can influence the energy consumptions for heating and DHW production in the considered dwellings. The parameters that greatly affect the energy consumption are identified by means of a regression analysis. Moreover, a correlation between energy consumptions and a set of multiple variables is carried out and allows to predict the energy performance of existing residential buildings with good approximation. The purpose of the study is to provide a simplified procedure, that is handy and inexpensive, and which can be used as a valuable support for designers of the building energy retrofitting process. Moreover, the same tool can be employed to determine the energy saving potential for heating applications, in order to facilitate the planning of future energy strategies for the involved territory. In particular, the research intends to promote the creation of inter-territorial databases of energy certificates, useful for monitoring the trend of energy consumption over time, and from designers can extrapolate the information necessary to plan redevelopment.

2. Methodology

Data relating to energy use in the Region were collected through a survey carried out by means of questionnaires addressed to a sample of engineering students of the University of Calabria, from 2010 to 2015. The investigation was aimed at gathering information about the actual consumptions, the characteristics of the building-plant system, and the energy certificates of their homes. Globally, 363 households located in different climatic zones were interviewed. Analysis parameters were defined in order to assess the variability of energy consumptions in the sample. Statistical analysis of the variables was carried out by using the SPSS software [29]. Before any evaluation, all data was checked to verify a normal distribution. The variables that did not meet the condition of normality were transformed by applying a square root. Following this, a bivariate correlation analysis was performed to identify the relationship between the variables. Finally, a multiple linear regression analysis was applied to assess the effect of the different variables on energy consumptions, and to identify the opportunity of requalification.

2.1. Description of the sample

The survey regarded only residential buildings and sought to collect data related to: geographical location and general characteristics of the buildings, typology of external walls and windows, characteristics of the heating and domestic hot water (DHW) production systems, monitoring of electrical and heating/DHW consumptions for three consecutive years, renewable sources and energy performance certificates of the buildings.

In particular, this study sought to evaluate the relationship between a series of typical parameters of the buildings and the informations that can be inferred from the energy certificates. The overall characteristics of the survey sample are shown below. Buildings are located in zones with different degree days [30]: 38.8% belongs to a climatic zone with degree days ranging between 900 and 1400, and 42.7% in a climatic zone with degree days varying between 1440 and 2100. Regarding the remaining part, 6.7% of the buildings are in locations characterized by degree days lower than 900 and 11.8% in a climatic zone with degree days greater than 2100. Regarding the building typology, more than half are apartments, whereas 41.3% are classified as detached houses, including single-family houses, two-family houses, and row houses (see Fig.1a). The average heated net floor area of the apartments is 107.66 m^2 (Std. deviation 32.25 m^2) while for the detached houses is 137.41 m^2 (Std. deviation 44.89 m^2). For the year of construction, four classes were provided, as depicted in Fig.1b.

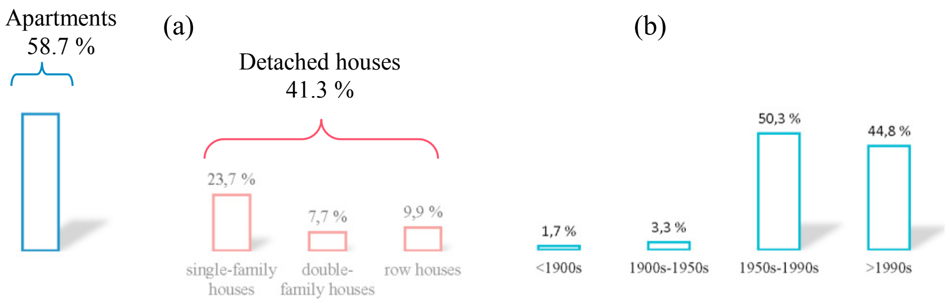

Fig. 1. (a) Building typologies in the sample; (b) year of construction of the buildings.

Technical characteristics of the windowed systems are displayed in Fig. 2a and Fig. 2b, respectively. The majority of the windows are equipped with a wooden frame and double-glazing.

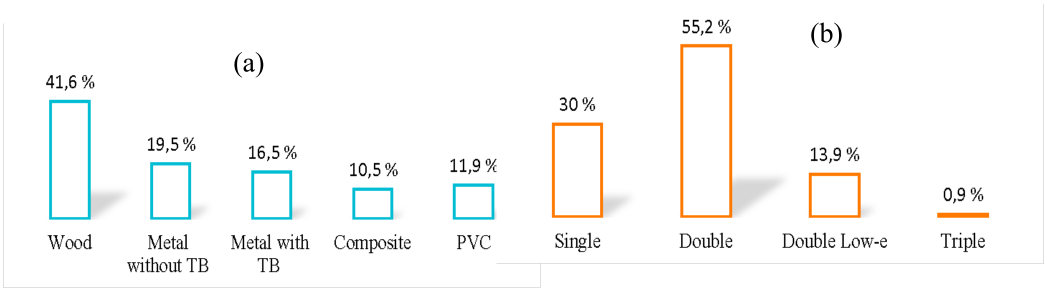

Fig. 2. (a) Typologies of windows frame; (b) Typologies of windows glass.

The correspondent average thermal transmittance value is 3.40 W/ (m^2·K) (Std. deviation 1.45 W/(m^2·K), whereas external opaque walls present a mean U-value of 0.84 W/ (m^2·K) (Std. deviation 0.39 W/(m^2·K)).

Regarding the heating plants, over 95% of the dwellings are equipped with autonomous systems. Most of them consist of independent boilers and fireplaces; a negligible percentage (about 1%) is provided with electrical heat pumps. The types of fuel employed to supply heat generators are presented in Fig. 3a, while Fig. 3b shows the typologies of emission terminals.

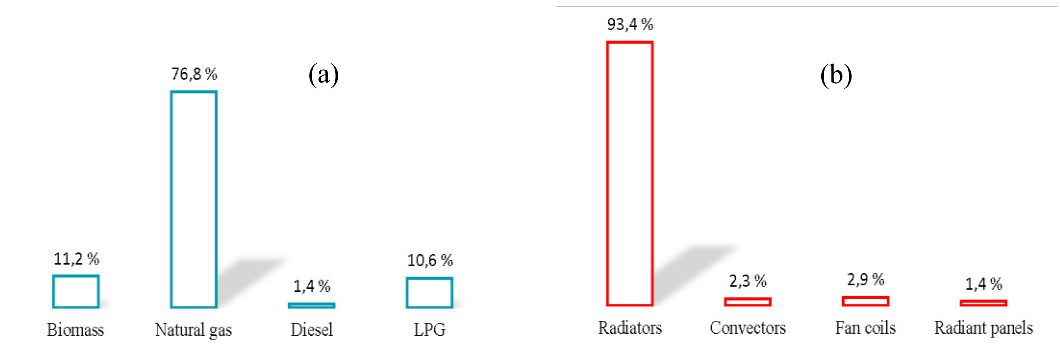

Fig. 3. (a) Fuel used by heating generators; (b) Types of emission terminals.

The most widely used control systems concern boiler thermostat (51.9%) and zone thermostat (28.1%). For 85.9% of the examined cases, the DHW production takes place through the same generator used for heating, and only 14.1% of cases have a separate DHW production system. Instead, regarding renewable energy, 5.8% of the participants interviewed have reported the presence of a photovoltaic system, 6.4% have solar collectors for DHW, and 2.8% have both photovoltaic and solar collectors.

The energy certificates of all the buildings in the sample were acquired in the survey. When the investigation was conducted, the former energy labelling system disciplined by Ministerial Decree 26 June 2009 [31] was in force in Italy, later replaced by the new Regulation [32]. Therefore, the energy labels provided for buildings ranged from “A”, the most efficient, to “G” the least efficient. Despite the regulations concerning the heating requirement provided after 1990, most of the existing buildings in the research area have a poor energetic quality, ranking in the labels E, F, and G, which generate the largest energy consumptions, as illustrated in Fig. 4.

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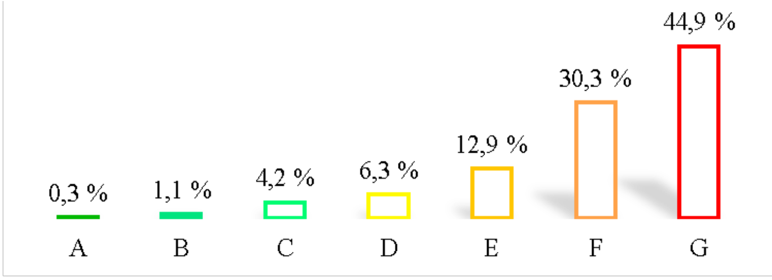

Fig. 4. Energy labels of the investigated existing buildings.

2.2. Definition of analysis variables

The study focused on the analysis of the variability of two energy performance parameters: net energy requirement for heating (Qh) and primary energy for heating and DHW (EPh), as a function of different independent variables. Three numeric variables that can potentially affect the energy consumption parameters described above were employed.

1. The S/V ratio, obtained by the Equation (1):

$$S/V = \text{dispersing gross surface} / \text{heated gross volume} \quad [m^{-1}] \tag{1}$$

The dispersing surface includes all the opaque and glazed external surfaces, as well as surfaces adjacent to unheated spaces.

2. The mean heat transfer coefficient of the building envelope normalized with respect to the net floor area of the dwelling, calculated by the Equation (2):

$$H_m = [(S_w \cdot H_w) + (S_g \cdot H_g)] / S \quad [W/(m^2 \cdot K)] \tag{2}$$

Where S_w is the area of the dispersing opaque elements [m^2], H_w is thermal transmittance of the opaque elements [$W/(m^2 \cdot K)$], S_g is the area of the dispersing glazed elements [m^2], H_g is the thermal transmittance of the glazed elements [$W/(m^2 \cdot K)$], S is the net floor area of the dwelling [m^2].

3. The solar energy transmitted through the glazed surfaces normalized with respect to the net floor area of the house, determined with the Equation (3):

$$I = (S_g \cdot \tau \cdot \Phi) / S \quad [W/m^2] \tag{3}$$

Where S_g is the area of the glazed surfaces [m^2], τ is the normal solar transmittance factor, equal to 0.85 for the single glass and 0.75 for the double glass, Φ is the global solar radiation on vertical surfaces, calculated for all the exposures using UNI 10349 [33], S is the net floor area of the dwelling [m^2].

Due to the relevant heterogeneity of the geometrical characteristics between the different typologies of buildings, in order to perform the statistical analysis, the sample was divided into two subpopulations: apartments (N=213) and detached houses (N=150). In addition, after a preliminary analysis, the observations of incomplete or inconsistent values were removed. Table 1 outlines the investigated variables.

Table 1. Mean and standard deviation of the analysed variables.

	N	Mean	Std. Deviation
APARTAMENTS			
S/V[m^{-1}]	168	0.389	0.159
H_m [W/m^2K]	206	1.243	0.563
I [W/m^2]	191	176.262	82.549
Q_h [kWh/(m^2·year)]	199	62.87	38.24
EPh [kWh/(m^2·year)]	199	131.20	64.06
DETACHED HOUSES			
S/V [m^{-1}]	77	0.493	0.182
H_m [W/m^2K]	146	1.562	0.980
I [W/m^2]	135	93.495	93.495
Q_h [kWh/(m^2·year)]	116	100.30	49.76
EPh [kWh/(m^2·year)]	116	188.73	83.28

Since energy demands vary according to the climatic zone, all the values of the energy requirements (Qh and EPh) were divided by the heating degree days (HDD) [30] of the corresponding location to eliminate the variability due to different climatic conditions, obtaining the variables Qh' and EPh', calculated with the Equation (4) and (5), respectively:

$$Qh' = Qh / HDD \qquad [kWh/(m^2 \cdot year)] \tag{4}$$

$$EPh' = EPh / HDD \qquad [kWh/(m^2 \cdot year)] \tag{5}$$

Moreover, outliers identified by means of boxplot diagrams, were removed from the data set to avoid distortions in the results, thus reducing the sample. Therefore, no anomalous values appear in the considered data set, as illustrated in Fig. 5 for some of the analysed variables. Furthermore, a square root transformation was applied to all the variables to improve normal distribution. As shown in Table 2, all the transformed variables are normally distributed. Numerical measurements of the shape of data, skewness (index of asymmetry) and kurtosis (index of "tail") vary within the acceptable range [-1; 1]. Most of them are close to zero, denoting a good approximation of the data set with the standard normal distribution, as shown in Fig. 5.

Even the quantile graphs (Q-Q plot) demonstrate that the data are normally distributed, as proved by the linearity of the observed values (Fig. 5).

Table 2. Mean and standard deviation of the analysed variables.

	N	Mean	Std. Deviation	Skewness	Kurtosis
APARTMENTS					
S/V_SQRT	165	0.605	0.124	-0.030	0.440
H_m_SQRT	203	1.076	0.225	-0.045	-0.342
I_SQRT	187	12.750	2.568	-0.310	0.040
Q_h'_SQRT	193	0.194	0.052	0.342	-0.434
EP_h'_SQRT	192	0.285	0.060	0.268	-0.454
DETACHED HOUSES					
S/V_SQRT	76	0.685	0.127	-0.112	0.308
H_m_SQRT	139	1.150	0.297	0.261	-0.465
I_SQRT	130	12.396	2.675	-0.333	-0.010
Q_h'_SQRT	113	0.245	0.065	0.183	-0.772
EP_h'_SQRT	113	0.340	0.080	0.236	-0.765

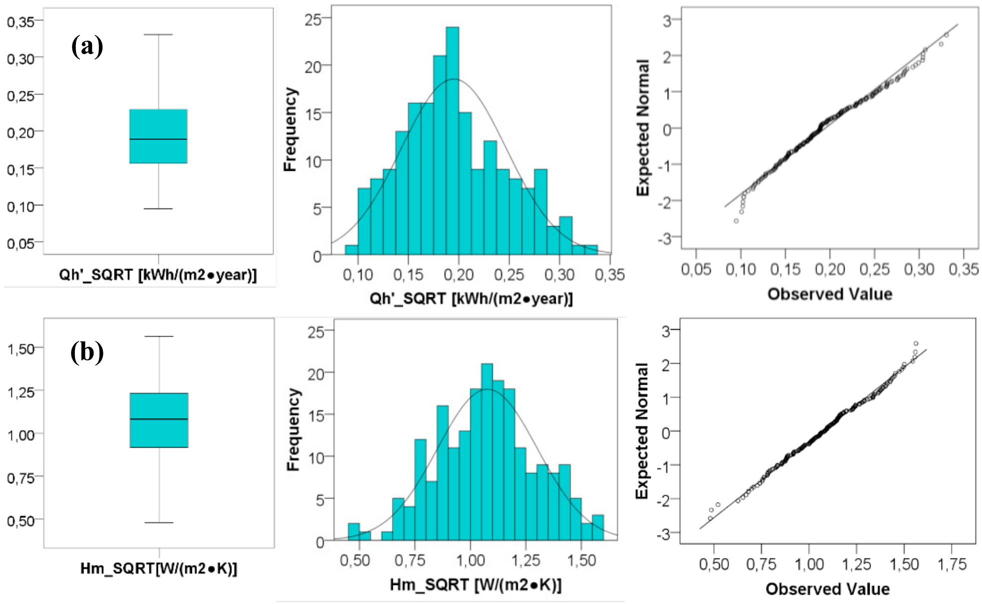

Fig. 5. Box plot, histogram, and Q-Q plot of the variables Qh'_SQRT (a) and Hm_SQRT (b) for the apartments dataset.

3. Results

First, a simple regression analysis was performed in order to evaluate the degree of correlation between the thermal energy requirement (Qh'_SQRT) and the previously presented numerical variables. The Pearson correlation coefficient was determined to measure the strength of linear dependence between two variables, with values ranging from -1 to 1. The proportion of variability in one variable accounted for by another variable was assessed through the coefficient of determination R^2 with values from 0 to 1. The p-value is a measure of the probability of obtaining a result at least as extreme as the one that is actually observed. Thus, the lower the value (usually below 0.05 or 0.01), the more significant the results. Subsequently, a multivariate regression analysis was carried out by evolving in three phases. The first model analysed the variability of the square root of net energy requirements for heating (Qh'_SQRT) as a function of the numerical variables (S/V_SQRT, Hm_SQRT, I_SQRT). The second model was still related to the variability of (Qh'_SQRT), but additional categorical variables were introduced in the analysis. The third model analysed the variability in the Primary Energy for heating and DHW (EPh'_SQRT) considering all the variables of previous steps, and by adding further variables that characterize the heating system.

3.1. Simple regression analysis

In the first instance, a bivariate correlation analysis was performed in order to examine the strength of the relationship between the net energy demand for heating and the independent variables previously described. The Pearson coefficient and its level of significance were determined for each correlation between the independent variables (S/V_SQRT, Hm_SQRT, I_SQRT) and the dependent variable (Qh'_SQRT). Table 3 contains the results of the simple regression analysis for the separate data set of apartments and detached houses.

Table 3. Correlations between Qh'_SQRT and the variables S/V_SQRT, Hm_SQRT, I_SQRT.

		S/V_SQRT	H_m_SQRT	I_SQRT
APARTEMENTS				
Q_h'_SQRT	Pearson	0.256**	0.235**	-0.040
	p Value (2-tailed)	0.001	0.001	0.308
	R^2	0.065	0.055	0.002
	N	152	182	158
DETACHED HOUSES				
Q_h'_SQRT	Pearson	0.368**	0.394**	-0.088
	p Value (2-tailed)	0.003	0.000	0.197
	R^2	0.135	0.155	0.008
	N	64	105	95

** Correlation is significant at the 0.01 level (2-tailed)

The square root of the net energy requirement for heating (Qh'_SQRT) is significantly correlated with the square root of S/V ratio (Pearson=0.256, $p < 0.01$ for apartments and Pearson = 0.368, $p < 0.01$ for detached houses) and with the mean heat transfer coefficient of the envelope (Pearson = 0.235 $p < 0.01$ for apartments and Pearson = 0.394 $p < 0.01$ for detached houses). In particular, in the apartment dataset, the variable S/V_SQRT has the largest correlation with the net heating demand; conversely, the variable Hm_SQRT has the highest correlation with the net energy heating need for detached houses. This is due to the greater dispersant surface that, generally, detached houses have compared to the apartments. A weak correlation was found between Qh'_SQRT and I_SQRT. However, although the solar energy transmitted through the glazed surfaces does not have a significant correlation with the energy thermal requirements, an indirect correlation cannot be excluded. The variables S/V_SQRT and Hm_SQRT are positively correlated to the net energy demand for heating, meaning that the greater extent of surface and its U-value, the greater net energy for heating is required (Fig. 6a and Fig. 6b). Instead, the relationship between I_SQRT and Qh'_SQRT is negative (Fig. 6c), thus the higher the value of I_SQRT, the lower amount of net energy for heating is needed. S/V_SQRT accounts for 6.5% of the variation in thermal heating requirements of apartments, and for 13.5% of the variation in detached houses. The variable Hm_SQRT explains 5.5% of the variation in Qh'_SQRT for apartments and 15.5% for detached houses.

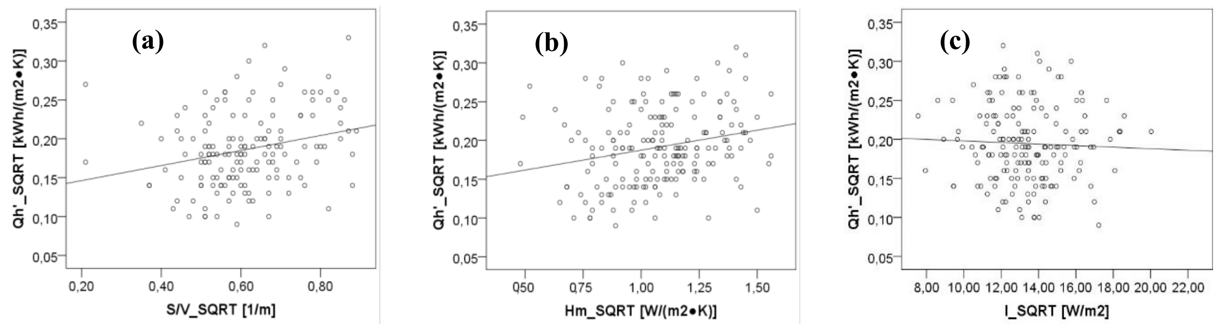

Fig. 6. Scatter plot of Qh'_SQRT and S/V_SQRT (a), Qh'_SQRT and Hm_SQRT (b), Qh'_SQRT and I_SQRT (c).

3.2. Multiple regression analysis

First regression model

A multiple regression analysis was performed to explore the potential causal relationship between the net energy requirement for heating and all the variables, in order to obtain a model based on the Equation (6):

$$Y = B_0 + B_1 X_1 + B_2 X_2 + \ldots\ldots\ldots\ldots + B_n X_n + e \quad (6)$$

able to explain the variation in the dependent variable Y according to the variation of the independent variables X. The first analysed multiple regression model assumed as dependent variable Y = Qh'_SQRT and as independent variables: X_1= S/V_SQRT, X_2 = Hm_SQRT, X_3 = I_SQRT, resulting in the Equation (7) for apartments and Equation (8) for detached houses.

$$Y = 0.106 + 0.020 X_1 + 0.101 X_2 - 0.003 X_3 \quad (R^2=0.293) \quad (7)$$

$$Y = 0.071 + 0.099 X_1 + 0.108 X_2 - 0.002 X_3 \quad (R^2=0.213) \quad (8)$$

By applying the obtained equations in all the units of the two separate samples, and by comparing the calculated results with the observed data, a medium relative error of 29.32% is achieved for the apartments, and of 16.63% for detached houses. Numerical variables alone are not able to explain the phenomenon, therefore the analysis was enhanced to make the model more accurate, and additional categorical variables were introduced in the study.

Second regression model

The second multiple regression model considered the variables illustrated in Table 4. For the categorical parameters, dummy variables were created and the "mode" (the class with the maximum frequency) was used as reference.

Table 4. Numerical and categorical variables used in the second regression model exploring the variation in Qh'_SQRT.

DEPENDENT VARIABLE					
Net energy requirement for heating				Q_h'_SQRT	Y
INDEPENDENT VARIABLES					
Square root of S/V ratio	S/V_SQRT	X_1	Window frame	Wood	X_8
Square root of mean heat transfer coefficient of the envelope	H_m_SQRT	X_2		Metal without TB	X_9
				Metal with TB	X_{10}
Square root of the solar energy transmitted through glasses	I_SQRT	X_3		Composite	X_{11}
				PVC	X_{12}
Year of construction of the building	<1900s	X_4	Window glass	Single	X_{13}
	1900s-1950s	X_5		Double	X_{14}
	1950s-1990s	X_6		Double Low-e	X_{15}
	>1990s	X_7		Triple	X_{16}

The relations obtained with the second regression model are represented by the Equation (9) for apartments and Equation (10) for detached houses:

$$Y = 0.072 + 0.040 X_1 + 0.088 X_2 - 0.003 X_3 - 0.012 X_7 - 0.010 X_8 - 0.011 X_9 + 0.002 X_{10} + 0.004 X_{11} + \\ - 0.003X_{12} + 0.055 X_{13} + 0.042 X_{14} + 0.037 X_{15} \quad (R^2=0.291) \quad (9)$$

$$Y = 0.074 + 0.104 X_1 + 0.092 X_2 - 0.002 X_3 + 0.022 X_4 + 0.064 X_5 + 0.001 X_6 + 0.005 X_9 + 0.018 X_{10} + \\ - 0.012X_{11} + 0.015 X_{12} - 0.005 X_{13} - 0.005 X_{14} + 0.007 X_{16} \quad (R^2=0.402) \quad (10)$$

The considered parameters are able to explain about 30% of the variation in the square root of the thermal requirement of the apartments, and slightly more than 40% of the variation in detached houses. A medium relative error of 17.07% and 14.11% is obtained for apartments and detached houses, respectively.

Third regression model

The latest statistical model moves a further stride forward and analyses the variability in Primary Energy for heating and DHW (EPh'_SQRT). All the independent variables previously listed are included in the model and further variables related to the characteristics of the plant are added, as explained in Table 5.

Table 5. Numerical and categorical variables used in the third regression model exploring the variation in EPh'_SQRT.

DEPENDENT VARIABLE					
Primary energy for heating and DHW				EP_h'_SQRT	Y
INDEPENDENT VARIABLES					
Square root of S/V ratio	S/V_SQRT	X_1	Year of installation of the heating system	<1990s	X_{17}
Square root of mean heat transfer coefficient of the envelope	H_m_SQRT	X_2		1990s – 2000s	X_{18}
				2000s – 2010s	X_{19}
Square root of the solar energy transmitted through glasses	I_SQRT	X_3		>2010s	X_{20}
Year of construction of the building	<1900s	X_4	Control system	Boiler thermostat	X_{21}
	1900s-1950s	X_5		Zone thermostat	X_{22}
	1950s-1990s	X_6		Zone thermostat plus outdoor sensor	X_{23}
	>1990s	X_7		Room thermostat	X_{24}
Window frame	Wood	X_8	Heating set point temperature in the dwelling	T	X_{25}
	Metal without TB	X_9			
	Metal with TB	X_{10}			
	Composite	X_{11}	Number of occupants	Occ	X_{26}
	PVC	X_{12}			
Window glass	Single	X_{13}	Presence of renewable sources (PV or solar collectors)	Ren	X_{27}
	Double	X_{14}			
	Double Low-e	X_{15}	No renewable sources	NRen	X_{28}
	Triple	X_{16}			

The analysis leads to the Equation (11) for apartments and Equation (12) for detached houses

$$Y = 0.066 + 0.049\,X_1 + 0.087\,X_2 - 0.002\,X_3 + 0.006\,X_7 - 0.001\,X_8 + 0.015\,X_9 - 0.018\,X_{10} + 0.025\,X_{11} + 0.010\,X_{12} + 0.019\,X_{13} - 0.02\,X_{15} - 0.099\,X_{16} + 0.030\,X_{17} + 0.017\,X_{18} - 0.022\,X_{22} + 0.016\,X_{23} + 0.008\,X_{24} + 0.002\,X_{25} - 0.001\,X_{26} + 0.079\,X_{28} \quad (R^2=0.408) \tag{11}$$

$$Y = -0.462 + 0.313\,X_1 + 0.083\,X_2 - 0.043\,X_4 + 0.006\,X_5 - 0.009\,X_6 + 0.157\,X_8 + 0.245\,X_9 + 0.253\,X_{10} + 0.278\,X_{12} - 0.204\,X_{13} - 0.162\,X_{14} - 0.191\,X_{15} - 0.056\,X_{16} - 0.060\,X_{17} - 0.039\,X_{19} + 0.105\,X_{20} + 0.112\,X_{21} + 0.022\,X_{22} + 0.106\,X_{23} - 0.002\,X_{24} + 0.024\,X_{25} - 0.003\,X_{26} - 0.123\,X_{28} \quad (R^2=0.950) \tag{12}$$

The latest models, expressing the variation in primary energy for heating and DHW, seem to be the most complete and reliable. The considered parameters are indeed able to explain 40.8% of the variation in EP_h'_SQRT in the case of apartments, and 95% of the variation in the case of detached houses. The obtained medium relative error is equal to 12.46% for the apartments dataset and 9.71% for detached houses.

Standardized regression coefficients "Beta" were calculated in order to assess the influence of the individual parameters on the variation of EP_h'_SQRT. The analysis reveals that Hm_SQRT is the variable which has the maximum weight, with an influence of 12% in the variation of EP_h'_SQRT for apartments, and an influence of about 20% in the case of detached houses. The S/V_SQRT is the second most influential variable in both samples.

4. Proposals for refurbishment

Statistical data reports that 760094 "dwellings occupied by residents" are present in the Region [34]. With reference to the distribution detected in the survey, 58.7% are apartments and 41.3% are detached houses. A typical apartment and a typical detached house were defined according to the most widespread features found in the sample. By applying the calculation models (11) and (12), it was possible to predict an average consumption of 116.44 kWh/m^{2}year for the apartment and of 194.36 kWh/m^{2}year for the detached house. The regression analysis revealed that H_m_SQRT, namely the square root of the mean global heat transfer coefficient of the building envelope, is the most influential variable among those considered. Consequently, a refurbishment scenario that provides for the reduction of this parameter was estimated, assuming for example the replacement of windows and the thermal insulation of external walls. In particular, assuming to reduce the value of the mean heat transfer coefficient by 50%, a saving of 36.33 kWh/m^{2}year and 48.44 kWh/m^{2}year could be achieved, respectively for the apartment and the detached house. Knowing the number of housing units in the Region and their medium floor area, the assessment can be extended at a territorial level, resulting in a saving of 6272 TJ/year for the refurbishment of the apartment stock and 7530 TJ/year for the intervention on detached houses. Since most dwellings are equipped with a gas boiler, and the most widely used fuel is natural gas, a saving of about 350000 tCO_2/year for apartment and of 420300 tCO_2/year for the detached houses can be estimated with the considered refurbishment interventions.

5. Conclusions

A statistical survey on heating consumptions was conducted on a sample of existing residential buildings in the region of Calabria, a typically Mediterranean Region. The survey sought to collect data on the characteristics of the buildings and plants, and energy performance certificates of the dwellings. The data set was divided into two different groups, apartments and detached house, because of the considerable differences in the characteristics of the two types of accommodation. After presenting the general features of the sample, a bivariate regression analysis allowed identification of the level of significance of the analysis variables. Subsequently, a multivariate regression analysis developed in three steps, led to the definition of two equations, which can be used to forecast the heating consumptions in existing residential buildings, to be applied according to the type of dwelling (apartment or detached house). In particular, the mean global coefficient of heat transfer was found to be the variable with the highest weight on heating consumption variation. Therefore, the primarily recommended refurbishment strategy consists in the improvement of the building envelope and should seek to reduce the heat losses through the external surfaces. For example, the replacement of existing windows with other more performant (using low energy glass and isolated frames) and the thermal insulation of external walls, could be subsidized. A broad assessment of the existing residential stock in the Region showed that through the implementation of refurbishments, it could be possible to halve the mean global heat transfer coefficient, resulting in the achievement of an overall saving of 770392 tCO_2/year. In particular, since the highest saving is given by the energy renovation of detached houses, decision makers should plan and encourage this action.

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