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ScienceDirect

Energy Procedia 78 (2015) 603 – 608

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Behavioral and physical factors influencing energy building performances in Mediterranean climate

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Abstract

The residential sector is used to test the relative roles of socioeconomic and behavioral variables of occupants as compared with the climate and physical building characteristics. The study is carried out considering a housing stock in Mediterranean area. Energy consumptions are investigated by using surveys, the data are collected in the University of Calabria (Italy). The analysis is developed by means a statistical approach, regression models are used to determine the significance of parameters and their interrelations. The results are useful to individuate important aspects influencing final energy uses with reference to the specific context.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

*Keywords:*Occupant behavior; Residential buildings; Energy use; Statistical approach.

1. Introduction

It is widely recognized that residential energy consumption is determined by interaction of many factors: apart from physical characteristics, such as the climate, heating type, age and size of the house, occupant behavioral and socio-economic aspects are critical.

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.033

Previous studies in the USA and the Netherlands have determined that building characteristics explain from only 40 to 54% of variation in energy use [1,2]. Researchers have agreed that as the thermal properties of buildings improve, the role of building characteristics will decrease, thus making occupant behavior more important. Furthermore, the relative impact of occupant characteristics and behavior seems to differ in various studies confirming the importance of contextual analysis.

The papers available in literature evidence no less than 27 possible factors have been evaluated as drivers for space-heating behavior, but with varying conclusions regarding their causal effect. Within these factors, some have been studied more frequently than others and the considerations on the importance of individual factors are varied [3]. Generally the following factors are considered significant: outdoor climate, dwelling type, house insulation, indoor temperature control, age and income of family members, time of day and occupancy. In many cases statistical methods were used to predict energy use and regression equations are indicated as a faster and easier tool than simulation models to have indication about energy consumption in a large sample of dwellings. Regression analysis has been used to understand behavior in different climate conditions and to forecast energy demand.

Studies conducted in China [4] show that occupant age is a more significant factor than income. Contrary to other existing research, a negative correlation between occupant age and energy consumption was found. In addition, this investigation reveals that household socio-economic and behavior variables are able to explain 28.8% of the variation in heating and cooling energy consumption.

For the major Athens area, Santamouris et al. [5] found that household income is an important determinant which indirectly influences energy consumption. Low income people are more likely to be living in old buildings with poor envelope conditions. In the Netherlands [6] results showed that the number of usage hours for the heating system has a stronger effect on energy consumption than temperature setting. The analysis presented in [7] exploits existing building stock data for US housing to gain insight into the key parameters related to energy use for heating and cooling. The most significant parameter that determines energy use is the climate, less important are some physical characteristics of the dwellings (age, type and area), primarily because a large portion of the existing building stock was not designed to respond to meet current comfort standards through energy-efficient design. Another insight is that income is indirectly correlated with energy demand, via floor area and house form.

On the bases of the available studies, the purpose of this paper is to evaluate the main factors affecting the energy performance of a housing stock in Mediterranean climatic conditions. Energy consumptions are investigated by using a survey, the data are collected in the University of Calabria (Southern Italy). The data set consists of information about the annual energy consumption (electricity, heating and DHW) and characteristics of dwellings and their occupants. The investigation is carried out in order to test the importance of physical and occupancy variables by means a statistical approach.

2. Data presentation

The statistical analysis is carried out by means of surveys. Data collection started in 2012 and involved the families of engineering students. The data set comprises the energy consumptions, the characteristics of dwellings and their occupants obtained from energy bills and questions. The investigated area is the Calabria region with about 2 million of people. Overall 111 households were interviewed obtaining 98 usable cases. The collected information was compared with the data provided by the National Institute of Statistics[8] to check its representativeness. The average age of interviewees is 36.9 years coherently with the average age of the population of 42.9 years. In particular, 46.3% of the respondents are males and 53.7% females, in accordance with the regional gender distribution(48.7% males and 51.3% females). The average annual household electricity consumption is 2723 kWh and consistent with the regional average value of 2509 kWh. The average annual household income resulting by the surveys is below 30000 € in accordance with the regional value of 23995 €.

The investigated variables were classified into three main categories: physical characteristics, occupants, energy.

Physical characteristics, shown in the first section of table 1, include building parameters, heating system, lighting and climate. The most common type of dwelling is the apartment (56.3%) followed by single house (24.1%). The majority of the constructions was built after 1990 (43.8%). The average area of dwellings is 141 m^2, a large percentage of buildings has reinforced concrete structure (77.7%), exhibits uninsulated external walls (44.6 %) and has double-glazed windows (59.8%). In regard to heating, 83% of the houses is equipped with autonomous heating system, 54.4% of the respondents has a wall mounted gas boiler as generation system and methane is the most used fuel both for heating and domestic hot water; 13.4 % of houses are heated by fireplaces. The 54.5% of dwellings is equipped with “some energy saving” lamps. The majority of buildings is located in C and D climatic zones (25.0% and 34.8% respectively).

The second section of table 1 contains occupant’s variables, that is information about household composition and social conditions. On the average families count 3.7 members. Most of the interviewed subjects (46.3%) is aged in the class 19 - 30 years. The gender composition of families was determined, in 38.4% of the cases prevails the female gender. The average annual income is less than 30000 € (38.4 %) or between 30000 € and 70000 € (29.5%), many interviewees did not answer this question due to the privacy.

Behavioral characteristics are given in terms of thermal sensation and habits in the use of DHW. The 39.3% of occupants is satisfied with the internal comfort and the majority of them uses to have shower with an average duration of 10-20 minutes. Shower frequency is higher during the summer.

Generally electricity consumption refers to equipment and lighting, the 21% of the cases includes air conditioning. Different types of heating system are used in the considered area. Figure 1 illustrates the distribution of fuels for heating and DHW production resulting from the surveys compared with national data [9]. The percentages of methane and LPG are comparable, differences emerge for diesel and biomass: in the sample diesel consumption is lower than the national value while biomass seems clearly higher in accordance with the local tradition that adopts firewood for domestic use. The percentage of “other fuels” is negligible. Since methane is the most used fuel, it has been considered this consumption for the processing relating to heating and DHW. Furthermore, these data are more reliable as directly determined by bills.

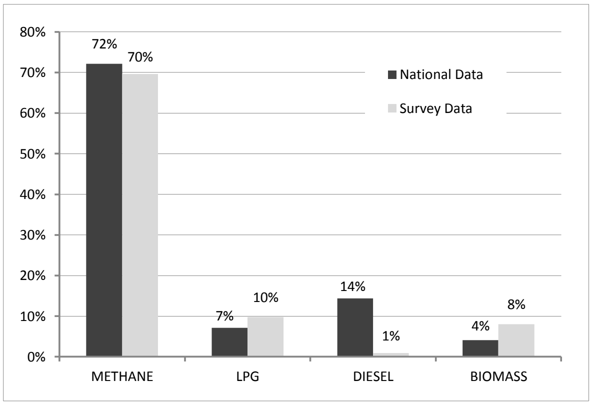

Fig.1. Fuel types for heating resulting from the surveys compared with National data for the civil sector.

3. Data analysis

The survey responses are presented as categorical and continuous variables. All the parameters were checked for normality and outliers. Normality was verified by the analysis of skewness and kurtosis. Skewness is a measure of symmetry and kurtosis is a measure whether the data are peaked or flat relative to the normal distribution, value of zero represents a Gaussian distribution. Variables with a value larger than 1 for these parameters were transformed in order to improve the normality.

Table 2 reports the descriptive statistics for continuous parameters. Three variables did not meet the criteria for normality and, for statistical elaborations, electricity consumption was transformed into its square root and heating degree days and floor area were transformed into logarithm 10.

Figure 2 shows a graphical representation of the mentioned parameters and the average age of families.

Table 1. Physical and Behavioral variables collected by the surveys.

			Responses	*N*	*%*			*Responses*	*N*	*%*
PHYSICAL CARACTERISTICS	**BUILDING**									
	Type of house	1.	Single house	27	24.1	**Structure**	1.	Reinforced concrete	87	77.7
		2.	Apartment	63	56.3		2.	Stone	7	6.3
		3.	Double house	8	7.1		3.	Wood	0	0
		4.	Other	1	0.9		4.	Other	4	3.6
		5.	Don't answer	13	11.6		5.	Don't answer	14	12.5
	Year of construction	1.	Before 1980	32	28.6	**Type of windows**	1.	Double glass	67	59.8
		2.	1980 - 1990	18	16.1		2.	Single glass	28	25.0
		3.	After 1990	49	43.8		3.	Other	3	2.7
		4.	Don't know	0	0		4.	Don't know	0	0
		5.	Don't answer	13	11.6		5.	Don't answer	14	12.5
	Floor area (m^2)	1.	Less than 70	9	8.0	**Type of external walls**	1.	With thermal insulation	45	40.2
		2.	70-150	62	55.4		2.	Without thermal insulation	50	44.6
		3.	More than 150	27	24.1					
		4.	Don't answer	14	12.5		3.	Don't answer	17	15.2
	HEATING					**DHW SYSTEM**				
	Typology	1.	District heating	3	2.7	**Energy source**	1.	Methane	68	60.7
		2.	Building Centralized system	0	0		2.	LPG	4	3.6
		3.	Autonomous system	93	83.0		3.	Methane + Solar	1	0.9
		4.	Don't answer	16	14.3		4.	LPG + Solar	0	0
	Generation system	1.	Air source heat pump	2	1.8		5.	Electricity	7	6.3
		2.	Electricity	8	7.1		6.	Pellet	0	0
		3.	Wall mounted gas boiler	62	55.4		7.	Electricity + Solar	0	0
		4.	Fireplace	15	13.4		8.	Other	16	14.3
		5.	Pellet	0	0		9.	Don't answer	16	14.3
		6.	Other	11	9.8					
		7.	Don't answer	14	12.5	**LIGHTING**				
	Fuel	1.	Methane	77	68.8	**Energy savings lamps**	1.	All are energy saving	29	25.9
		2.	LPG	10	8.9		2.	Some are energy saving	61	54.5
		3.	Diesel	1	0.9		3.	No energy saving lamps	8	7.1
		4.	Biomass	9	8.0		4.	Don't answer	14	12.5
		5.	Other	2	1.8					
		6.	Don't answer	13	11.6					
	WEATHER									
	Climate zone / Heating degree day	1.	A (less than 600)	0	0					
		2.	B (601-900)	8	7.1					
		3.	C (901-1400)	28	25.0					
		4.	D (1401-2100)	39	34.8					
		5.	E (2101-3000)	10	8.9					
		6.	F (more than 3000)	0	0					
		7.	Don't answer	27	24.1					
OCCUPANTS	**HOUSEHOLD**									
	Age of household members	1.	Less than 19	22	6.1	**Gender**	1.	Female	181	53.7
		2.	19 – 30	167	46.3		2.	Male	156	46.3
		3.	30 – 50	33	9.1	**Prevalence of gender**	1.	Male	24	21.4
		4.	50 – 65	117	32.4		2.	Female	43	38.4
		5.	More than 65	7	1.9		3.	Equality	25	22.3
		6.	Don't answer	15	4.2		4.	Don't answer	20	17.9
	Number of household members	1.	1	1	0.9	**Total annual income (€)**	1.	Less than 30000	43	38.4
		2.	2	13	11.6		2.	30000-70000	33	29.5
		3.	3	23	20.5		3.	70000-10000	2	1.8
		4.	4	41	36.6		4.	More than 100000	1	0.9
		5.	5	19	17.0		5.	Don't answer	33	29.5
		6.	6	1	0.9					
		7.	Don't answer	14	12.5					
	BEHAVIOR									
	Thermal sensation	1.	Very satisfied	22	19.6	**Frequency of shower during winter**	1.	Almost every day	32	28.6
		2.	It doesn't matter	11	9.8		2.	3-5 times/week	43	38.4
		3.	Satisfied	44	39.3		3.	1-2 times/week	15	13.4
		4.	Not satisfied	19	17.0		4.	Other	7	6.3
		5.	Don't answer	16	14.3		5.	Don't answer	15	13.4
	Kind of shower	1.	Only shower	67	59.8	**Average shower time**	1.	More than 2 hours	0	0
		2.	Shower + bath in a tub	31	27.7		2.	1 hour	6	5.4
		3.	Bath in a tub	0	0		3.	Half a hour	11	9.8
		4.	Other	0	0		4.	10-20 minutes	64	57.1
		5.	Don't answer	14	12.5		5.	Less than 10 minutes	14	12.5
	Frequency of shower during summer	1.	Almost every day	80	71.4		6.	Other	3	2.7
		2.	3-5 times/week	9	8.0		7.	Don't answer	14	12.5
		3.	1-2 times/week	0	0					
		4.	Other	9	8.0					
		5.	Don't answer	14	12.5					

Table 2. Descriptive statistics of continuous variables.

	Variables	Mean	Standard Deviation	Number of cases	Skewness	Kurtosis
Energy	Electricity Consumption (kWh)	2719	1325	103	0.777	0.996
	Energy for Heating and DHW (kWh)	7668	3299	70	0.189	-0.022
Household	Average Age of the family	35.8	8.2	95	0.202	0.462
	Age of the household head	51.9	14.0	95	-0.892	0.491
	Number of household members	3.7	1.0	98	-0.332	-0.390
Building	Floor area (m^2)	141.3	75.6	98	2.062	5.780
	Heating degree-days	1551.2	487.4	84	0.885	1.073

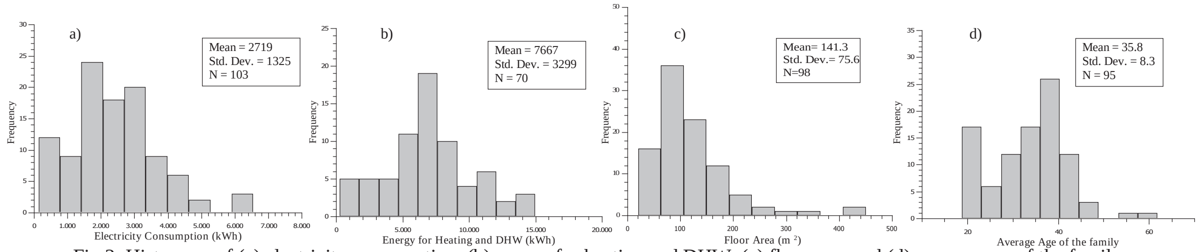

Fig.2. Histogram of (a) electricity consumption, (b) energy for heating and DHW, (c) floor area and (d) average age of the family.

4. Correlation analysis

In order to describe the relations between household energy consumptions and the physical and behavioral variables the General Linear Model was used. Regression analyses are used for continuous variables, a one-way analysis of variance (ANOVA) is applied for categorical variables and independent-samples t-tests were performed for dichotomous variables. Statistics of electricity consumption are shown in table 3.The F-statistic provides a measure of probability that energy consumption and the variable have the same variance, where its value is near 1 the null hypothesis is correct. The p-value is a measure of the probability of obtaining a result at least as extreme as the one that is actually observed, so the lower the value (usually below 0.05 or 0.01) the more significant the result. The coefficient of determination (R^2) represents the proportion of variability in one variable that is accounted for by another variable, it indicates how well data fit a statistical model. The Pearson's correlation coefficient (r) is a measure of linear dependence between two variables with a value between -1 and +1 inclusive. The t-statistic aims to analyze the differences between the means of two groups, if t-statistic is less than the significance level (or error), the null hypothesis is rejected.

Table 3.Correlation between physical and occupant's variables and electricity energy consumption (kWh).

Variables	Statistic	*p*-value	R^2	Pearson(r)
Type of house	$F_{(3,83)}=1.18$	>.05	0.040	
Year of construction	$F_{(2,84)}=0.647$	>.05	0.015	
Log10 floor area (m^2)	$F_{(1,86)}=13.19$	<.05	0.133	0.365
Structure	$F_{(2,84)}=0.299$	>.05	0.007	
Type of windows	$F_{(2,84)}=2.386$	>.05	0.053	
Prevalence of gender	$F_{(2,78)}=1.012$	>.05	0.025	
Income (€)	$F_{(3,66)}=2.916$	<.05	0.117	
Average Age	$F_{(1,82)}=9.864$	<.05	0.107	0.328
Age of the household head	$F_{(1,82)}=8.251$	<.05	0.091	0.302
Number of household members	$F_{(1,85)}=5.944$	<.05	0.065	0.256
Heating degree-days	$F_{(3,74)}=3.194$	<.05	0.115	
Energy saving lamps	$F_{(2,83)}=0.787$	>.05	.018	
Type of external wall	t(78.60)=0.427	>.05		

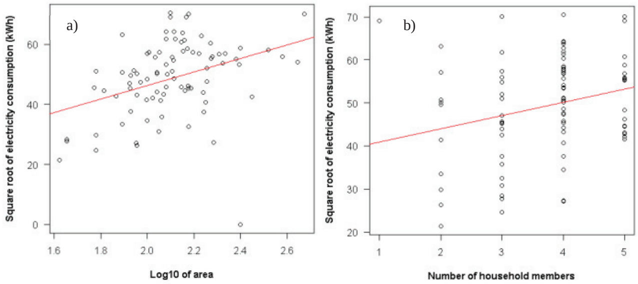

Fig.3. Scatter plot of electricity energy consumption (square rooted) and (a) Log10 of area, (b) family size.

In regard to the variables that have significant relations with electricity consumption (p<0.05 based on F-tests of all variables), four of them can be mentioned concerning the occupants: average age, age of the household head, number of family members and annual income. Two parameters are related to physical characteristics, the floor area and the heating degree-days. The relation with the climatic variable can be explained because of the use of electricity is also associated with the air conditioning. Besides, Log10 floor area is the most significant variable influencing electricity energy consumption (r=0.37 and p<0.05). The square root of electricity consumption has a direct connection with Log10 floor area, average age, age of household head and number of family members, with a Pearson's correlation coefficient positive. Figure 3 shows the dependence from floor area and family size.

The correlation analysis between physical and occupant variables and the heating and DHW energy consumption demonstrated that individual predictors are not significant. This study in the investigated region presents complexity due to the double use of the fuel. The results suggest that the formulation of the questions in the survey has to be improved in order to describe better lifestyle and types of heating system.

A multiple linear regression analysis was employed to determine the effect of physical characteristics and occupant variables on electricity energy consumption, taking into consideration the six variables described above (all with p<0.05), see table 5, and introducing only physical characteristics as reported in table 6.

The first model determines that the selected physical factors and occupant variables explain 48.7% of variation in the square root of electricity energy consumption and the second model shows that physical characteristics can explain 32.7% of variation. Even if both the models are significant overall ($p<0.001$), most of the individual predictors do not seem to be significant. The insufficient number of samples in some categories could also cause the non-significance of the independent variables. To evaluate multicolinearity the variance inflation factor (VIF) was calculated, leading to a value lower than 10 for both the models (1.94 and 1.49 respectively). Significant predictors are floor area and number of members per household. The families with income category 70000-100000€ do not consume more energy than the families with income between 30000-70000€, indicating that the relation between income and energy consumption is not linear.

Table 5. Regression model for the electricity energy consumption (sqrt of kWh).

Coefficient	b_i	Standard error	*p*-value	t-value
R^2= 0.4865, p<0.001				
Constant	-9.205	14.501	0.529	-0.635
Log 10 of floor area	-23.846	7.351	0.002	3.244
Heating degree days- C vs B	-4.505	5.114	0.383	-0.881
Heating degree days-D vs B	-7.213	4.985	0.155	-1.447
Heating degree days-E vs B	-9.461	6.585	0.158	-1.437
Average age	0.504	0.418	0.134	1.207
Age of the household head	-0.285	0.264	0.287	-1.079
Number of household members	3.661	1.896	0.060	1.931
Income- 30000€-70000€ vs Income < 30000€	-3.643	2.647	0.176	-1.376
Income- 70000€-100000€ vs Income < 30000€	5.363	7.474	0.477	0.718
Income- more than 100000€ vs Income < 30000€	-28.150	9.192	0.004	-3.062

Table 6. Regression model for the electricity energy consumption (sqrt of kWh) and physical variables.

Coefficient	b_i	Standard error	*p*-value	t-value
R^2= 0.3268, p<0.001				
Constant	-4.804	12.525	0.703	-0.384
Log 10 of floor area	28.287	5.906	0.000	4.790
Heating degree days- C vs B	-2.301	4.991	0.646	-0.461
Heating degree days-D vs B	-7.64	4.777	0.115	-1.599
Heating degree days-E vs B	-1.335	5.806	0.819	-0.230

5. Conclusions

The aim of the study was to determine the influence of physical and behavioral selected factors in energy buildings performance in Mediterranean climate. By means data collection and processing the main characteristics of the building stock were identified. The variables were classified into three categories: physical, occupants and energy. Electricity, heating and DHW consumptions were investigated statistically. The results reveal that floor area and climate are the most significant physical parameters for electricity consumption; age, number of household members and income can be mentioned concerning the occupants. Physical factors and occupant parameters explain 48.7% of variation in electricity energy consumption, the only physical factors can explain 32.7% of the variation. Otherwise, the analysis on heating and DHW energy consumption shows critical aspects because it is related to a specific use by the consumers. As a consequence more detailed investigation methodologies will be applied in the continuation of the study.

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