On uses of energy in buildings: Extracting influencing factors of occupant behaviour by means of a questionnaire survey

On Uses of Energy in Buildings: Extracting influencing Factors of Occupant Behaviour by Means of a Questionnaire Survey

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Abstract

In order to reduce the energy consumption in buildings, more and more energy efficient technologies for the building-HVAC system have been developed. Several studies showed that occupant behaviour has a much larger influence on the energy performance of a building than the thermal process within the building façade. This underlines the need to investigate the influence of occupant behaviour on building performance. This paper presents the results of a questionnaire survey related to occupant behaviour and preferences in residential buildings. Multivariate regression analyses are conducted to outline main patterns and correlations between energy use, building characteristics and occupant behaviour. Results show a strong relationship between occupants' actions and characteristics of the built environment – in particular the construction year of the building. Furthermore, occupants have a notable impact on building performance: the chosen set point temperature and the total hours of heating system utilization, which both increase with the age of the building, lead to an increase of the fuel consumption. In conclusion, occupant behavior is affected by the characteristics of the building, which requires additional studies to increase our understanding of occupant behavioral patterns in existing and modern (e.g. NZE) buildings.

Keywords: Occupant behaviour; Energy saving; Data collection; Questionnaire survey; Multivariate regression analysis.

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1. Introduction

In last decades, in response to the high impact of buildings on global energy consumption and on greenhouse gases emission, recent international directives [1] and researches have focused on the physical aspects of buildings, such as the building envelope and the management of Heating, Ventilation and Air Conditioning (HVAC) systems [2-8]. However, there is often a significant discrepancy between the designed and the real total energy use in buildings. Indeed, monitoring studies for identical dwellings having the same type of installations have shown great variation in energy use [9-14]. Among others, this discrepancy is due to the operation of the building systems by the occupants. In order to get more consistent energy consumption predictions, there is a need to investigate further the impact of occupant behaviours [2]. Understanding the occupant behaviour is a key issue for building design optimization, energy diagnosis, performance evaluation, and building energy simulation.

Degelman [3] notes that occupant behaviour has a much larger influence on the energy performance of a building than the thermal process within the building facade. Occupants may influence the indoor environment by their presence in the building, but above all by the actions that occupants take (or not). Degelman states that building simulation is only capable of accurate predictions if the use of a building is predictable and routine. In the same line, Schweiker [4] found that the influence on the energy consumption of occupant behaviour is higher compared to building envelope improvements especially in cases, where the difference between indoor and outdoor conditions is small.

Several surveys in different case studies [21], [22] showed that occupants have a natural tendency to adapt to the mutable conditions of the external environment. The theoretical basis of the previous analysis is the so-called ‘adaptive approach’, which states that ‘if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort’ [23]. Occupants have three means of interacting with the indoor environment [24], [25]:

(1) they can interact with the given built environment directly with the objective of controlling the physical properties of the indoor environment (e.g. adjusting thermostats, operating windows or shadings);

(2) they can affect it unintentionally (e.g. by appliances and equipment usage);

(3) they can adjust themselves to the existing environmental conditions (e.g. changing their level of clothing or activity level) [26].

As concerning the thermal comfort theory in buildings, occupant behaviour (e.g. changes in clothing level or the activity level) has a major impact on the level of comfort, represented e.g. by the Predicted Mean Vote (PMV) [27], [28].

The behaviours of occupants inside the buildings are influenced by a variety of "driving forces": internal (e.g. lifestyle, age, gender, attitudes, preferences, etc.) and external (e.g., air temperature, wind speed, building properties, etc.) [29], [4].

Nowadays the implementation of occupant behaviour in building performance simulation is inappropriate and oversimplified, leading to inaccurate expectations of building energy performance and large discrepancies between the predicted and the real energy consumptions [5], [6], [7]. Rijal et al. [8] state that the application of occupant behaviour models with higher resolution and higher complexity will improve the understanding of the relation between building, occupant and building performance.

In Hargreaves [9], Smart Energy Monitoring (SEM) is used to make energy visible to occupants and Faruqui [10] described how this knowledge affects occupant behaviours, by describing its impact on energy consumption saving. In Galvin [11] a detailed investigation of sensor data from 60 retrofitted apartments served as a testing ground to analyse occupant behaviour rules. The research investigated real occupant habits, by defining consumption patterns as ‘light’, ‘medium’ and ‘heavy’ consumers.

While some scientists use energy consumption comparison to infer the effects of occupant behaviour on building performance, others adopt questionnaire surveys to investigate the determinant for energy consumptions [12], [13]. Following the approach presented by other studies [14], [15], [16], which are using questionnaire surveys, this paper put in relation the building-HVAC information (i.e. building construction period, set-point temperature, etc) with information on the occupant (preferences, adaptive behaviour, etc) in order to define the tie between the occupant behaviour and the built environment. The goal of this paper is to extract influencing factors on the building performance, taking into account the occupant’s behaviour and attitudes by means of a questionnaire survey.

Statistical analyses are conducted to identify prevalent population characteristics and to outline the main patterns and correlations between several data points provided by the surveyed.

The paper is organized as follows. Section 2 describes the materials and methodology of this study and Section 3 the multivariate analysis applied. Then, Section 4 and 5 present the results and their discussion and Section 6 draws the conclusions.

2. Materials and Methodology

This paper is based on data of an online questionnaire conducted between 2012 and 2015 by the "Department of Architecture and Urban Planning" of the Polytechnic University of Bari (Italy) inside the Strategic Plan (PS_047) "*ECOURB: Analysis and Models of Air Pollution and Thermal Systems for Urban Ecolabelling*" financed by Apulia Region [17], [18], [19]. In detail, this project aimed at building up hybrid scenarios for the management of urban microclimates in the area of Bari, Italy, trying to work out how occupants with different roles and behaviours could affect urban microclimate while performing their single and/or collective activities. The analysis presented in this paper concentrates on the data related to the building-HVAC system and occupants data affecting the energy consumptions are extrapolated and used for the statistical analysis.

The data derived from an Internet-based investigation, which was announced by electronic mail to 495 students of Polytechnic University of Bari. In total 450 students completed the whole questionnaire, i.e. the response rate was very high (91%). All buildings in which the respondents were living are located in the Mediterranean climatic context of south Italy (Puglia region). The climatic conditions of this region are characterized by heating degree days (h.d.d.) between 901 and 2100. Each participant followed an online guide that was designed to engage the respondents for questions about key comfort, behaviour, and energy use issues. Some questions were "open questions" (i.e. questions 1-3-9-10-12) and the others were "closed questions" where the participants needed to choose among fixed options.

The survey included the following sections (see Table1):

- **Background Information of Buildings**: this section regarded questions about the type of building the residents lived in and the characteristics of the building (e.g. year of construction, type of window glazing, heat source, and apartment size). The categories of the question concerning the *building typology* have been chosen according to typical Italian typologies for residential buildings:

a. multi-family building;
b. detached house;
c. terraced house.

These building typologies are the most common Italian macro-typologies. For example the multifamily building includes subcategories like the tower buildings, the block buildings or apartment dwellings. In addition, it should be noted that the question “construction year” allows drawing conclusions regarding characteristics and technological solutions of the “building-HVAC” system typical of that certain period.

- **Family General Information**: this section included general questions regarding the respondents.
- **Behaviours and Preferences**: in this section, respondents stated when they used their heating and cooling system in the house, or the actions to adapt to indoor conditions. It should be noted that occupants' were not asked about their individual behaviour but referred to the common attitudes and behaviours of the whole family.
- **Fuel Consumptions**: this last section included questions about the total fuel consumption for domestic hot water, heating and cooking. The responses are based on the invoices of energy vectors and not the result of simulations. For the analysis, the total fuel consumptions (m^3) of the buildings were normalized by dividing the fuel consumption by the dwelling size. This led to an index (m3/m2) approximatively independent from the building size and the number of family member.

Table 1. Questionnaire structure.

BUILDING-HVAC SYSTEM

Background Information

1. Construction year of the building.
2. Building typology:
   - ☐ multifamily building
   - ☐ detached house
   - ☐ terraced house
3. Apartment size (m^2).
4. Heat source type:
   - ☐ biomass boiler
   - ☐ condensing boiler
   - ☐ high efficiency boiler
   - ☐ traditional boiler
5. Cooling system presence:
   - ☐ yes
   - ☐ not
6. Window glazing type:
   - ☐ double glazed (low e-coating)
   - ☐ double glazed (no low e-coating)
   - ☐ single glazed
7. Heating (cooling) system management:
   - ☐ on/off
   - ☐ climatic thermoregulation
   - ☐ chronotermostat
8. Refurbishment actions on building-HVAC system:
   - ☐ yes
   - ☐ not

Fuel consumptions

9. Annual fuel consumption (m^3/ m^2)

OCCUPANT

Family General Information

10. Number of family members.
11. Number of occupants in the dwelling:
    - from 8 a.m. to 1 p.m.
    - from 1 p.m. to 3 p.m.
    - from 3 p.m. to 8 p.m.
    - from 8 p.m. to 11 p.m.
    - from 11 p.m. to 8 a.m.
12. Family monthly income (€).

Behaviours & Attitudes

13. Daily hours of heating system activation:
    - ☐ less than 2 hours
    - ☐ from 2 to 4 hours
    - ☐ from 4 to 8 hours
    - ☐ more than 8 hours
14. Daily time slot of heating system activation:
    - ☐ from 6 p.m. to 12 a.m.
    - ☐ from 6 a.m. to 9 a.m. and from 6 p.m. to 12 a.m.
    - ☐ from 12 a.m. to 9 a.m.
    - ☐ from 12 a.m. to 6 a.m. and from 8 p.m. to 12 a.m.
    - ☐ whole day
15. Set point temperature for heating system.
16. Occupant behaviours during situations of thermal discomfort in winter:
    - ☐ drinking hot drink
    - ☐ reducing opening windows
    - ☐ wearing heavy clothes
    - ☐ closing shielding system nighttime
    - ☐ turning on heating system
17. Occupant behaviours during situations of thermal discomfort in summer:
    - ☐ drinking cold drink
    - ☐ opening windows
    - ☐ wearing light clothes
    - ☐ closing shielding systems
    - ☐ turning on cooling system
18. Occupant preferences:
    I prefer coming into a too-heated (cooled) room when outside it's cold (hot):
    - ☐ agree
    - ☐ indifferent
    - ☐ not agree

3. Statistical analysis

In order to identify and quantify the main characteristics of the examined buildings and the main attitudes and behaviours of the occupants, the following statistical analysis were conducted using the R software [20]. First, frequency and density estimation analyses are performed. Frequency density is a measure of the number of statistical units having a certain type of character within a given class in relation to the size of that class. The frequency density f_j is defined as follows:

$$f_j = {}^{F_j}\!/_{\Delta_j}$$

where:

- F_j is the absolute frequency;
- Δ_j is the class size.

Second, multivariate linear regression analyses were conducted taking into account the effects of one or more independent variables (IV) on the responses variable or dependent variable (DV) of interest. Multivariate regression analyses were performed in order to determine the function that best expressed the relationship between the IVs $\mathrm{X_1, X_2, \dots X_k}$ and the DV Y.

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k$$

where:

- $\mathrm{b_0}$ is the intercept;
- $\mathrm{b_1, b_2, \dots, b_k}$ are the regression coefficient;

The sign and the values of the regression coefficient represent the partial effect of each variable $(\mathrm{e.g.\ X_1})$ on the variable $\mathrm{Y,}$ keeping constant the other variables $(\mathrm{X_2, \dots X_k})$. That is if the sign of the independent variable is positive, it leads to an increase of the dependent variable. For the models analysed, the coefficient of linear regression, the p-value, the adjusted R^2, and the β standardized values are calculated.

Regarding the p-value it is possible to determine if an independent variable has a statistically significant effect on the dependent variable. For this study, the significance level is set to 0.05, as conventionally defined in statistical analysis. In case the p-value is lower than this limit, the variable is significant and it cannot be excluded. In order to analyse which variables affected the dependent variable most, the comparison between the regression coefficients is only possible when they have the same measurement units. In order to realize this, partial regression coefficients are exploited, which were obtained from the multivariate linear regression equations by means of standardized variables (β values).

In this paper, multivariate regression analyses were carried out in order to define and evaluate those IVs that affect the DVs fuel consumption and heating set point. As IVs $(\mathrm{X_1, X_2, \dots X_k})$ for the DV *fuel* *consumption* (Y) the following variables included in the questionnaire are selected based on introductory literature review and the findings presented in the previous section:

- *the construction period of the building;*
- *the set-point temperature of heating system;*
- *the family monthly income;*
- *the total daily total hours of heating system utilization;*
- *the occupant behaviour in thermal discomfort situations.*

The second multivariate linear regression analysis is conducted in order to determine the most significant variables influencing the *set-point temperature* of the heating system (Y). The following data points provided by the questionnaire are considered as IVs $(X_1, X_2, \dots X_k)$:

- *the construction period of the building;*
- *the monthly family income;*
- *the daily total hours of heating system utilization;*
- *the adaptive behaviour in thermally discomfortable situations*.

4. Results of the frequency and density analyses

4.1. Frequencies and densities of the building characteristics

In this section the results of the frequency density analysis of the building characteristics are reported.

As shown in Fig. 1, the reported *construction years* include buildings built after the 60s, with the most prevailing construction years being between 1980 and 2010. Furthermore, the majority of respondents were living in multi-family buildings followed by detached houses and then terraced houses.

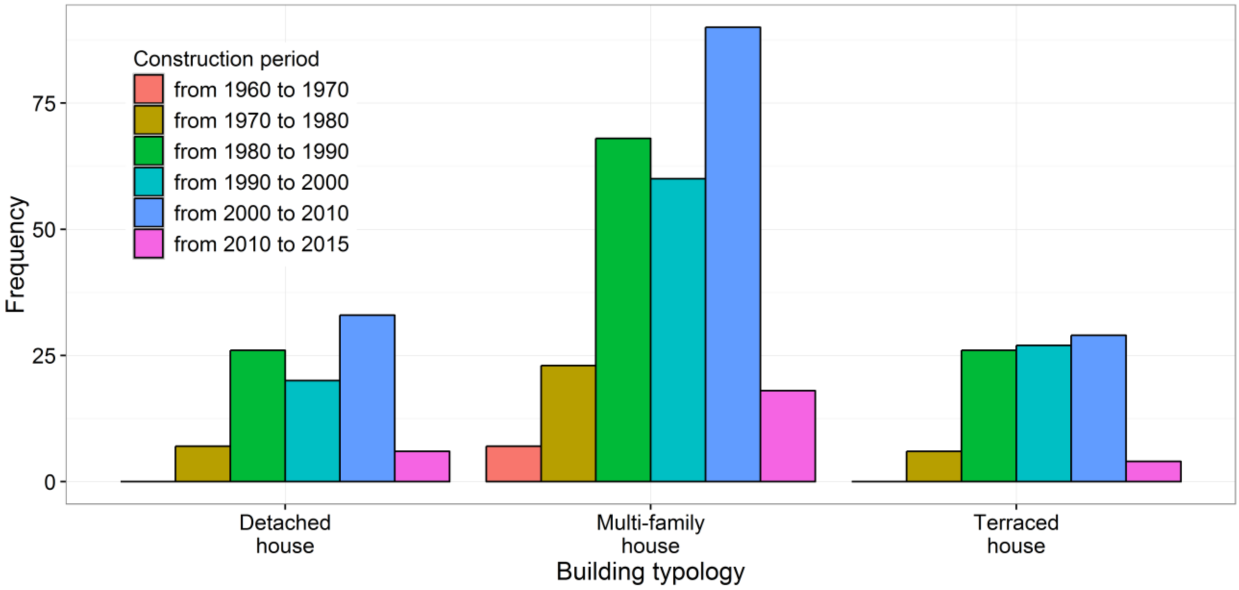

Fig.1 Absolute frequency of building typologies in function of the construction period.

Figs. 2 shows the frequency density of the *building typology* in relation to the *apartment size*. The *apartment size* is between 50 m^2 and 200 m^2, with the most frequent value around 100 m^2 for all building typologies. The *apartment size* is also related to the *number of family members* (r_s=.0.68, $p < 0.001$). Based on this relationship between the *apartment size* and the *number of family members*, the most frequent *apartment size* of 100 m^2 corresponds to a family with 4-5 members.

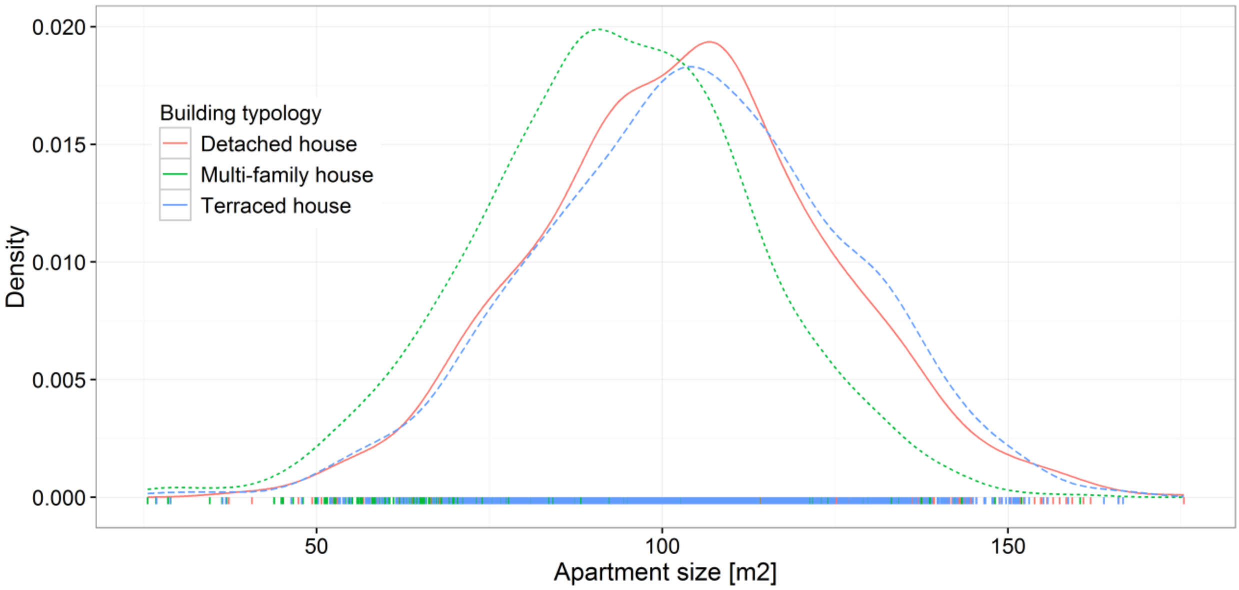

Fig.2 Frequency density of apartment size of the several building typologies.

Figs. 3 and 4 show the variation of *window glazing* type and type of *heat source* in relation to the *building construction year*. As expected, both the variation of the *glazing* type and *heat source* change according to the history of Italian regulations. Between the years 1976 and 2005 requirements concerning energy efficiency of buildings increased (law n.373/1976, law n.10/1990 and legislative decree n.192/2005). Consequently, single glazed windows are typical for the oldest[2] buildings built before 1990 and since then are substituted by double glazed and later by more efficient glazing types such as the double glazing with low-e coating (r_s=.0.83, p < .0.001). In addition, the type of heat source have changed from traditional boilers, typical for buildings constructed in the 1980s and 1990s, to high efficiency boilers and recently to condensing boilers.

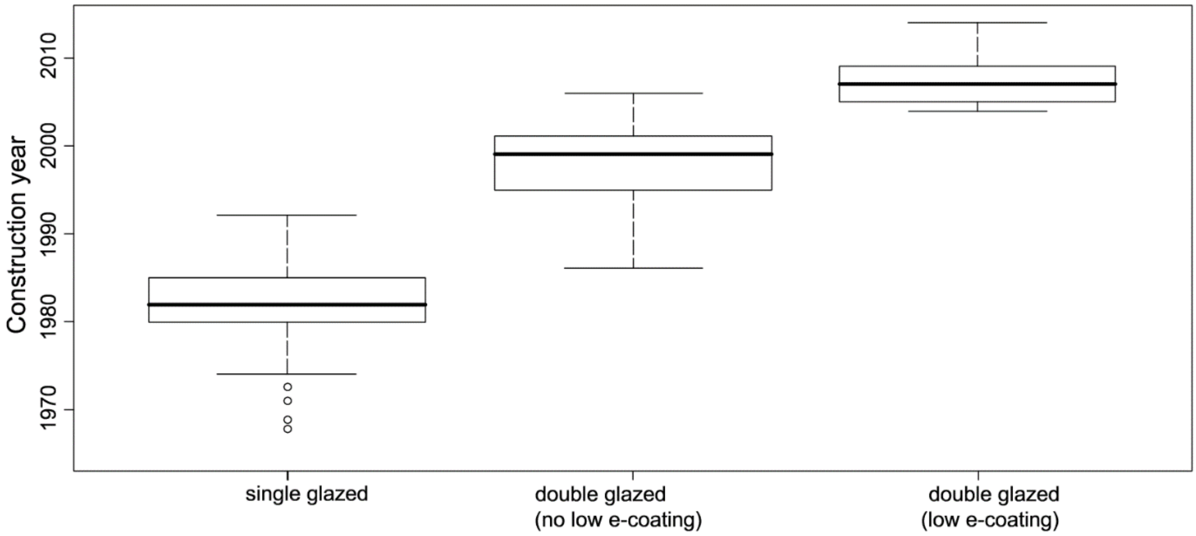

Fig.3 Window glazing type in function of the construction year.

[2] In this paper the term "old" refers to those buildings constructed before 1985, which are the oldest buildings of the analyzed sample.

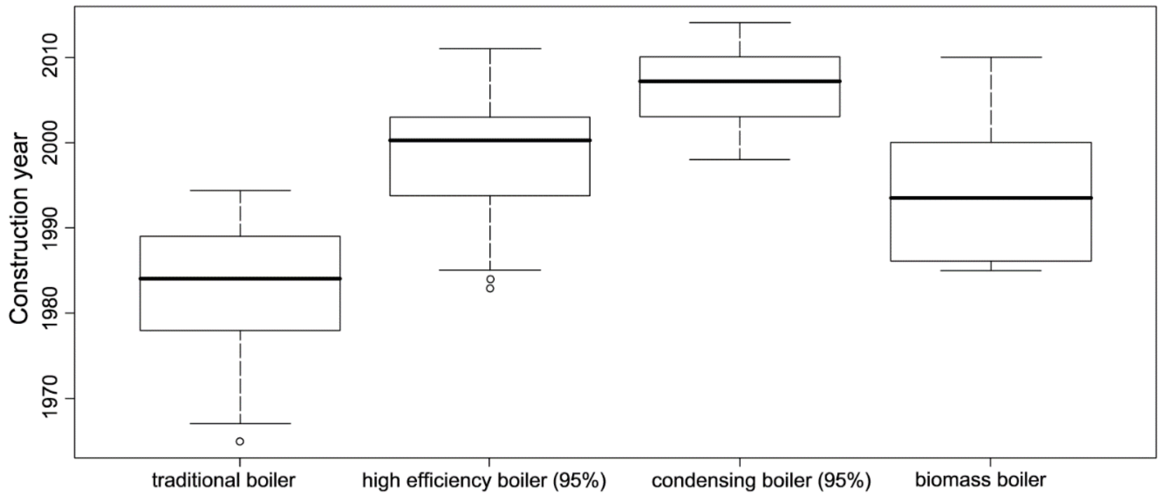

Fig.4 Heat source type in relation to the construction year.

As concerning the *management system*, it results that in 93% of cases the occupants control the activation of the heating and cooling system through ON/OFF systems and by setting the desired set-point temperature; in other cases a climatic temperature control is used for indoor climate control.

4.2. Occupant attitudes and preferences

Fig. 5 shows the *daily occupancy schedule* in relation to the occupancy ratio for each family. In order to homogenize the data and to obtain the occupancy ratio, the number of occupants present in the dwelling during daytime was divided by the total number of family members. The occupancy ratio is the highest from 11 p.m. to 8 a.m., which corresponds to the hours of sleeping. At dinner (from 8 p.m. to 11 p.m.) the number of occupants of each family present in the apartment is higher than during lunch time (from 1 p.m. to 3 p.m.). In the morning hours, the occupancy ratio is at its minimum, likely due to most of the family members being at work or school.

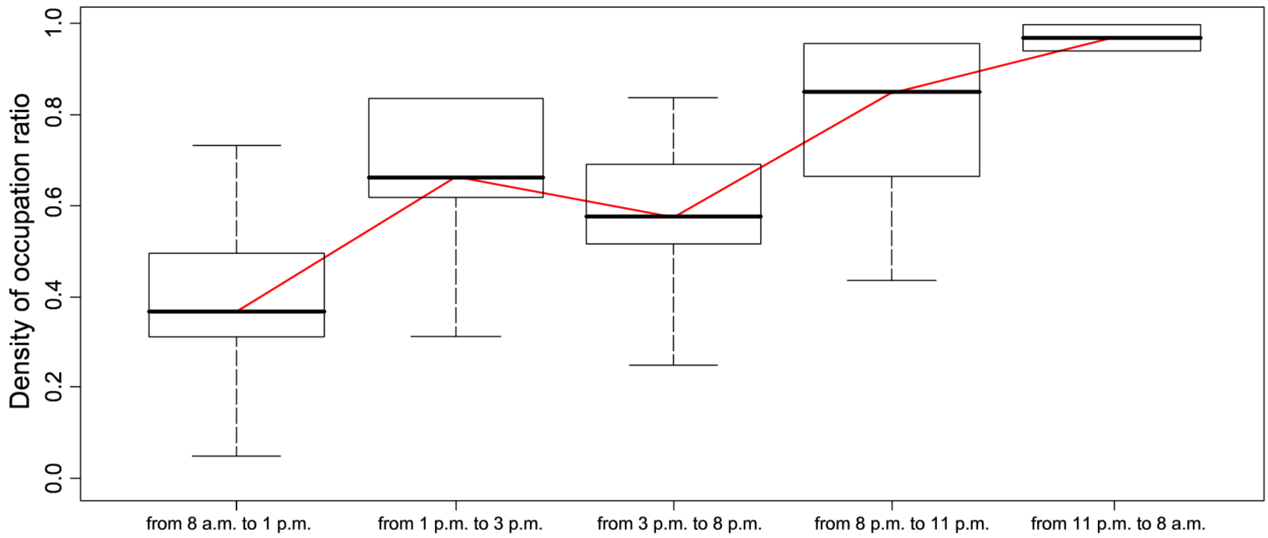

Fig.5 Daily occupancy schedule

Fig. 6 shows the *daily hours of heating system activation* in relation to the *construction year* of the building (r_s= - 0.71, $p < 0.001$). In most cases (43%), the daily total hours of heating system activation are between 4 and 8 hours. Furthermore, it results that by considering the median values (the thick line), the buildings before 1985 are related to longer periods of heating system activation (more than 8 hours), while recent buildings (after 2005) are related to only few activation hours (less than 4 hours).

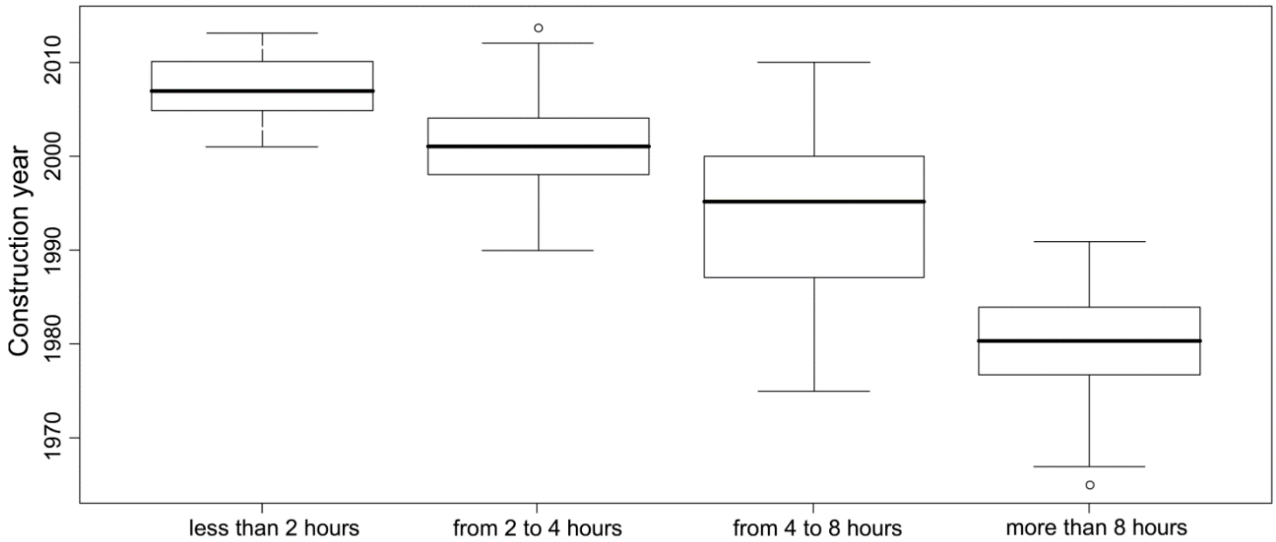

Fig.6 Daily hours of heating system utilization in relation to the construction year.

As presented in Fig. 7, also the *set-point temperature of heating system* change with the *construction year* of the buildings (r_s= - 0.72, $p < 0.001$). By considering the median values, the occupants adopt lower set-point temperatures (< 20°C) in the most recent buildings (after the 2000). In contrast, the occupants in the oldest buildings use higher set-point temperatures (> 20°C).

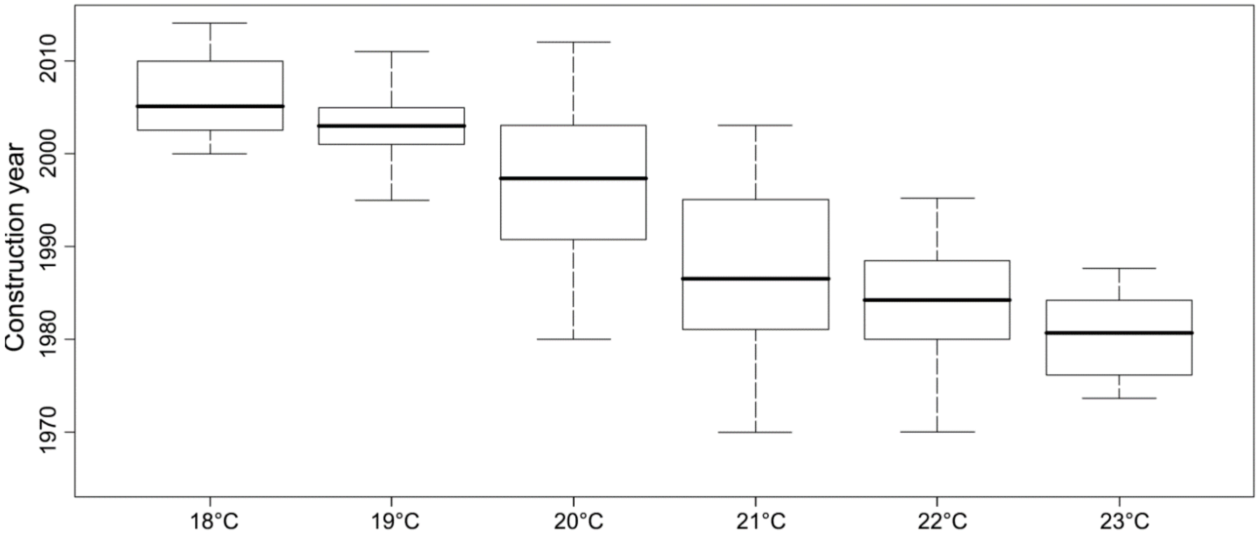

Fig.7 Set-point temperature of heating system in relation to the construction year

4.3. Adaptive behaviours in winter and summer

Related to adaptive behaviours in winter, participant were asked: "*What do you do in winter, in order to reduce thermally discomfortable situations*?" (see also Table 1). As shown in Fig. 8 the most frequent action during situations of thermal discomfort is wearing heavy clothes. Furthermore, in the oldest buildings, the occupants usually turn on the heating system to satisfy their thermal comfort requirements. It should be stressed that the little variability is justified by the low number of buildings before 1980. On the contrary, in recent buildings, the adaptive behaviours performed most often by the occupants are actions like wearing heavy clothes, drinking hot drink, or reducing the opening of windows.

As shown in Fig. 9 the most frequent action to reduce thermally discomfortable situations in summer (see Table 1, question 17) is opening windows. Setting these answers in relation to the construction year of the buildings, it results that in the oldest buildings, the occupants turn on the cooling system to satisfy own thermal comfort more often. On the contrary, in recent buildings, adaptive behaviours adopted by the majority of participants are wearing light clothes, drinking cold drinks, or increasing window openings.

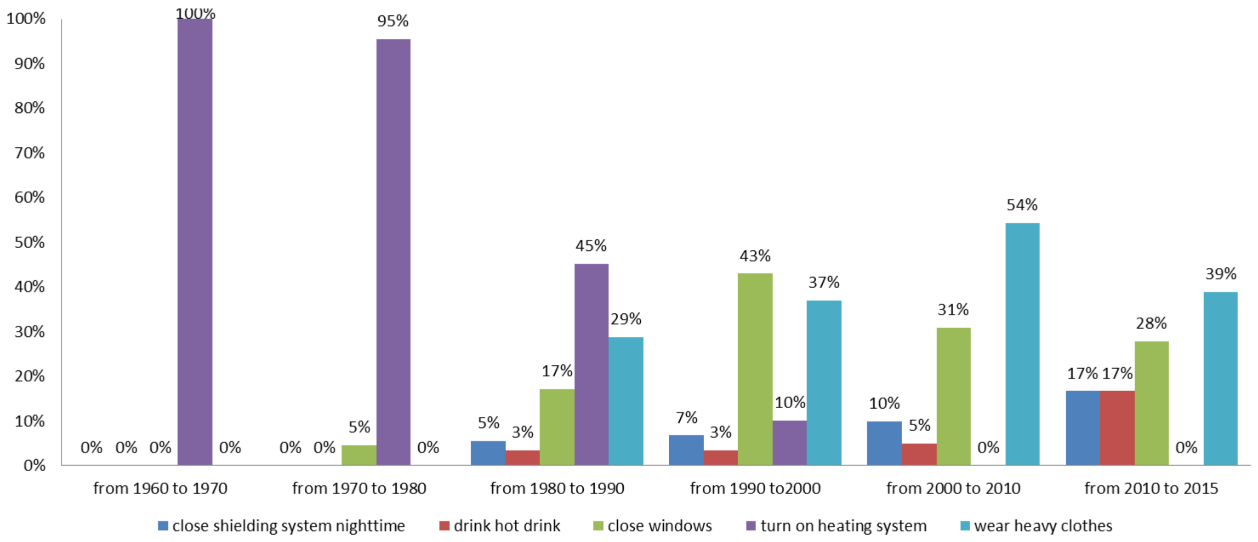

Fig.8 Percentage of occupant behaviours for thermal discomfort in winter in function of the construction year.

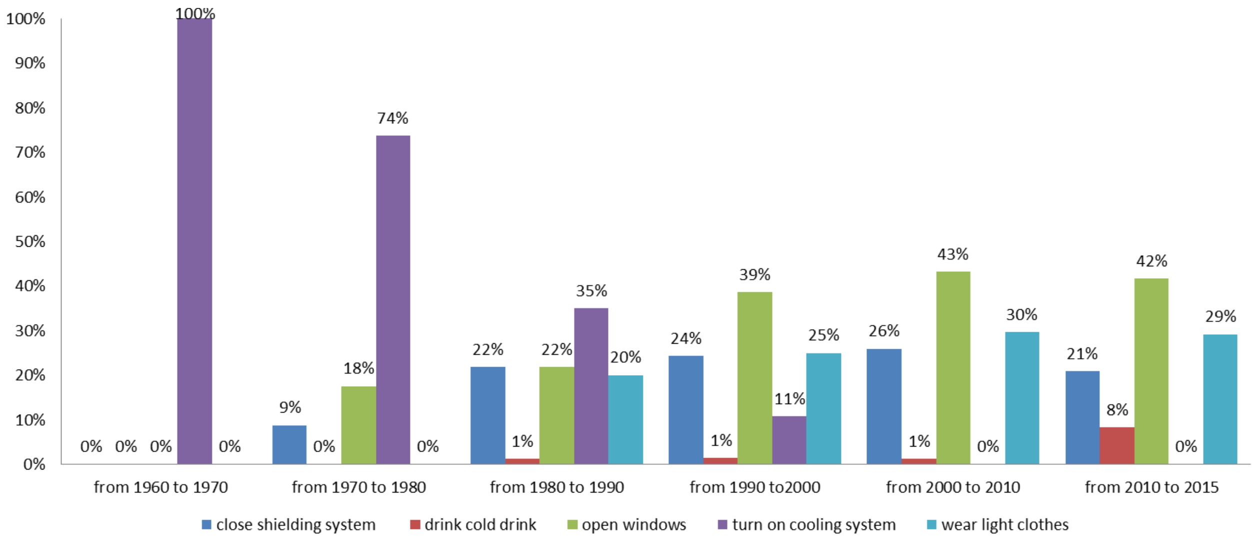

Fig.9 Percentage of occupant behaviours for thermal discomfort in summer in function of the construction year.

4.4. Fuel consumption, construction year, and adaptive behaviours

In this section, the occupant behaviours and preferences, building construction, are correlated with the fuel consumptions (m^3/m^2). The relation between the construction period of buildings and the fuel consumptions shows that the fuel consumptions are the highest for the oldest buildings (Fig. 10). The fuel consumption almost linearly depended on the construction year of the building ($r= -0.83$, $p < 0.001$): by considering the median values, the most recent buildings have the lowest fuel consumption (< $5m^3/m^2$), while the oldest buildings have a much higher fuel consumption (> 20 m^3/m^2).

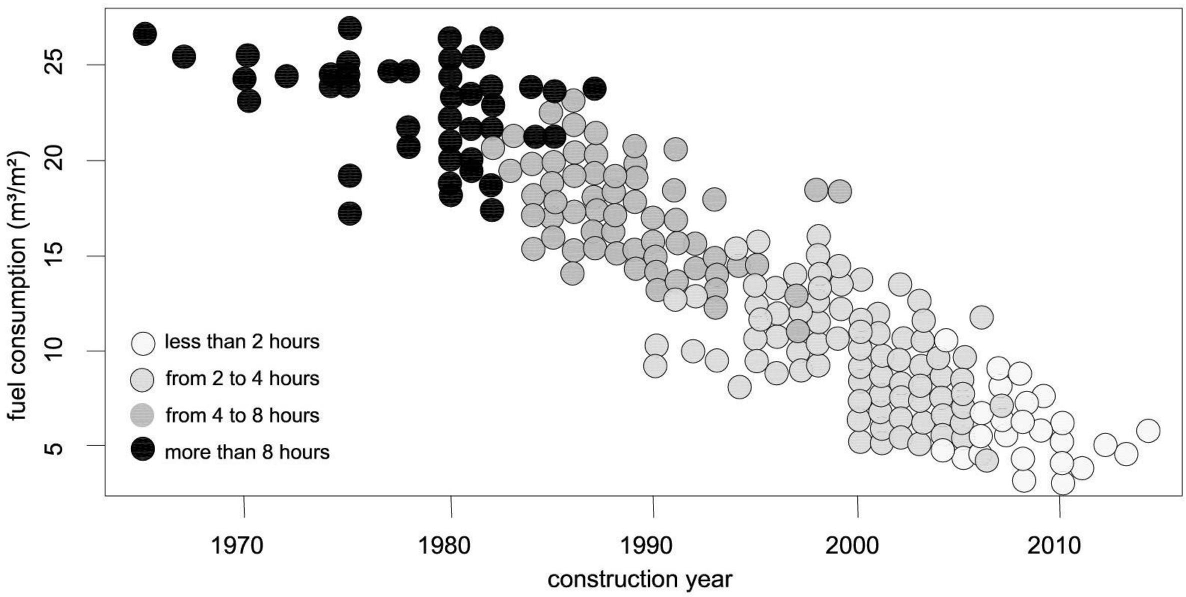

Fig.10 Fuel consumption in relation to the construction year and the daily total hours of heating system utilization.

Fig. 10 also shows that the occupants use the heating system for more hours (more than 8 hours) in the oldest buildings.

In Fig.11, it is possible to notice a positive relationship between the set-point temperature and the fuel consumption, i.e. that high values of the set-point temperature (22°C, 23°C) correspond to an increase of fuel consumption (r_s=.0.68, p <0.001).

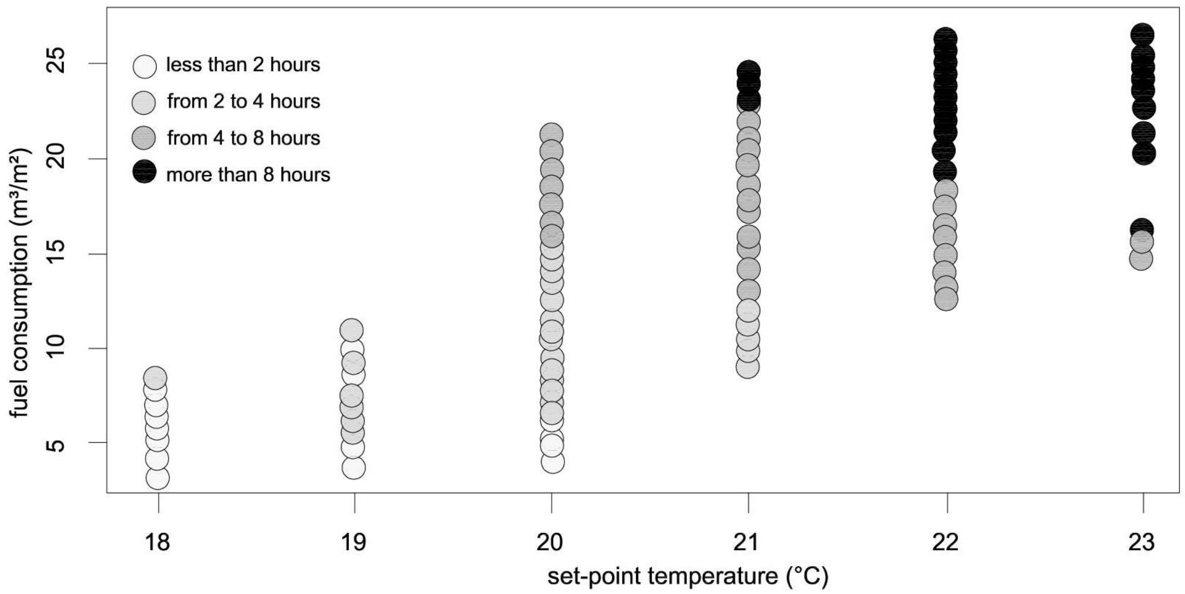

Fig.11 Fuel consumption in relation to the setpoint temperature and the daily total hours of heating system utilization.

Fig.12 shows the main adaptive behaviours in relation to the construction year and the fuel consumption. Especially the action of turning on the heating system is typical for the oldest buildings, while in recent buildings actions like wearing heavy clothes or closing windows are more frequent.

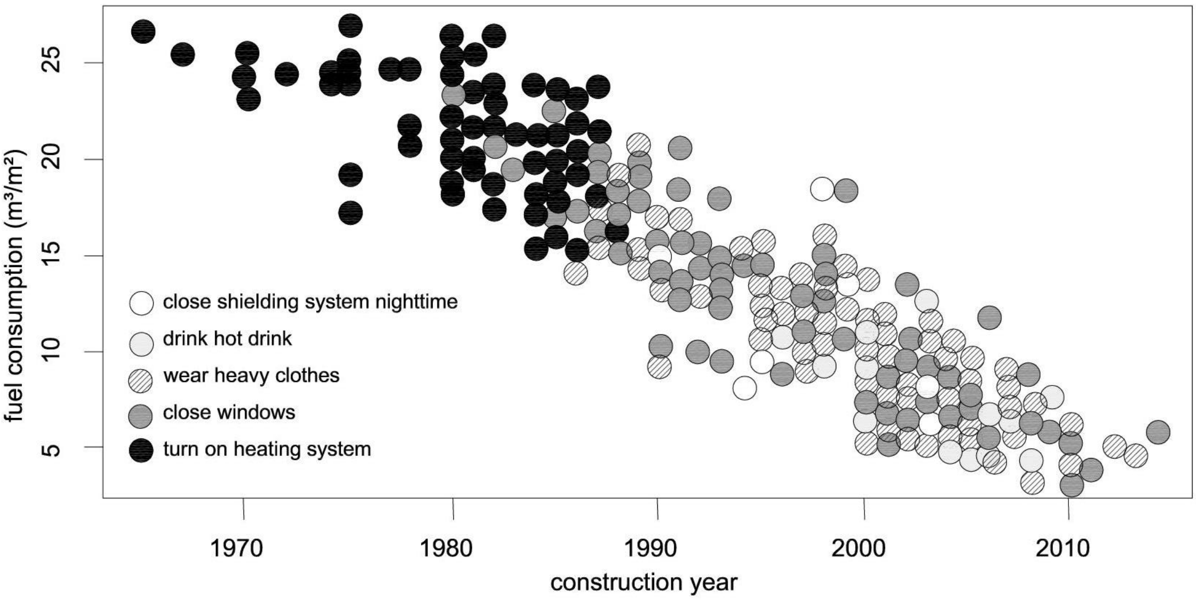

Fig.12 Fuel consumption in relation to the construction year and the adaptive behaviour of occupants.

5. Results of the multivariate regression analysis

In the previous section, the data has been described in a descriptive way and first insights into relationships between variables have been shown. This section focusses on the results of the multivariate regression analysis in order to extract influencing factors on fuel consumption and thermostat settings.

5.1. Results of multivariate regression analysis related to the fuel consumption

The main results of the linear regression analysis with fuel consumption as DV are reported in Table 2. The first column reports the independent variables, the second the estimated values of regression coefficient, the third the p-values and the last column the significance of the independent variables on the dependent variable. The findings can be summarized as follows:

- the fuel consumption increases with the set-point temperature and the total hours of heating system utilization;
- as regarding the family monthly income, fuel consumption increases with the family monthly

income;

- as regarding the construction period of the building, the buildings built after the 2000s have a negative coefficient and hence have lower fuel consumptions compared to the older buildings;
- among the adaptive behaviours, only turning on the heating system has a significant influence on the fuel consumption and leads to an increase of the consumptions.;
- the adjusted R^2 for the model is equal to 0.948 (p-value <0.001): almost the 95% of the data is explained by the variables considered.

The β standardized values allow a comparison between the influence of individual independent variables on the fuel consumption. This comparison shows that the explanatory variables mostly influencing the fuel consumption are the construction period of the building, the set-point temperature adopted by the occupants, and the total hours of heating system utilization. Leaving the other variables unchanged, passing from a set point temperature of 19°C to 23°C or increasing the hours of heating system utilization (from 2 to more than 8 hours) leads to an increase of fuel consumption of 5 times. This proves that the occupant behaviour significantly affects the building performance and so the energy consumption. For these reasons, it is important to investigate further the factors influencing the occupant behaviour.

Table 2. Multivariate analysis results for the fuel consumption.

		Estimate	**p- value**	**Signif. code**[3]	β
Set-point temperature	19°C	0.832	0.033	*	0.35
	20°C	2.013	1.01 e^{-7}	***	0.39
	21°C	3.738	1.59 e^{-15}	***	0.49
	22°C	4.831	< 2 e^{-16}	***	0.82
	23°C	5.489	< 2 e^{-16}	***	0.87
Family monthly income	less than 1000 €	-1.163	0.001	**	-0.15
	from 1500 € to 2000 €	1.189	2.04 e^{-5}	***	0.22
	from 2000 € to 2500 €	2.053	2.38 e^{-8}	***	0.40
	more than 2500 €	3.233	7.29 e^{-11}	***	0.55

[3] Significance code: "***" if 0 ≤ p-value ≤ 0.001; "**" if 0.001 ≤ p-value ≤0.01; "*" if 0.01 ≤ p-value ≤ 0.05; "-" if 0.05≤ p-value ≤0.1; " " if 0.1 ≤ p-value ≤ 1;

Hours of heating system utilization	from 2 to 4 hours	0.993	0.008	*	0.16
	from 4 to 8 hours	2.682	1.26 e^{-10}	***	0.85
	more than 8 hours	5.779	< 2 e^{-16}	***	1.13
Construction period	from 1970 to 1980	-1.190	0.260		-0.16
	from 1980 to 1990	-2.216	0.035	*	-0.37
	from 1990 to 2000	-5.184	2.91 e^{-6}	***	-0.83
	from 2000 to 2010	-7.085	6.35 e^{-10}	***	-1.23
	from 2010 to 2015	-7.940	3.09 e^{-10}	***	-1.52
Adaptive behaviour	reducing opening windows	0.192	0.582		-0.15
	turning on heating system	0.668	0.004	*	0.65
	wearing heavy clothes	-0.087	0.796		-0.12
	closing shielding system	0.063	0.905		-0.13
Adjusted R^2		**0.948**			

5.1.1. Results of multivariate regression analysis related to the set-point temperature

The estimates for the coefficients, their p-values, significance level and their β standardized values for the linear regression with set-point temperature as DV are reported in Table 3. The findings can be summarized as follows:

- family income has a significant influence on set-point temperature, a higher income category predicts a higher set-point temperature;
- even though the total hours of heating system utilization load positively on the set-point temperature, this effect is not significant;
- related to the construction periods of the building, the buildings built after the 2000s had a significant negative coefficient, i.e. the set-point temperature is lower, and hence the most recent buildings have lower consumption;
- among the adaptive behaviours, only turning on the heating system has a significant influence on the set-point temperature.

The a*djusted* R^2 of the model was equal to 0.684 (p-value <0.001): more than 68% of the data is explained by the considered variables.

Comparing the β standardized values, it results that the explicative variables mostly influencing the set-point temperature are the construction period of the building and the family monthly income.

Table 3. Multivariate analysis results for the set-point temperature.

		Estimate	p-value	Signif. code	β
Family monthly income	less than 1000 €	-0.117	0.519		-0.12
	from 1500 € to 2000 €	0.218	0.015	*	0.32
	from 2000 € to 2500 €	0.456	0.239		0.09
	more than 2500 €	1.00	2.35 e^{-5}	***	0.69
Hours of heating system utilization	from 2 to 4 hours	-0.467	0.065		0.01
	from 4 to 8 hours	-0.196	0.321		-0.12
	more than 8 hours	0.009	0.956		-0.20
Construction period	from 1970 to 1980	-0.025	0.962		0.12
	from 1980 to 1990	-0.044	0.931		-0.03
	from 1990 to 2000	-0.207	0.695		-0.18
	from 2000 to 2010	-0.607	0.249		-0.62
	from 2010 to 2015	-1.554	0.008	**	-0.65
Adaptive behaviour	reducing opening windows	0.042	0.860		0.01
	turning on heating system	0.579	0.024	*	0.59
	wearing heavy clothes	-0.185	0.412		-0.11
	drinking hot drink	0.022	0.929		0.01
Adjusted R^2		**0.684**			

6. Discussion

6.1. Discussion of results

While most of the studies, that have investigated the influence of occupant behaviour on the energy performance of buildings, have compared energy consumptions of identical buildings [30], [31], [32], [33], [34], the originality of this work lies in the quantification of behavioural patterns and the influencing factors of occupant actions related to different characteristics of residential buildings.

In contrast to the studies by Humphreys [23] where no data regarding the building-HVAC system was provided and only occupant's adaptive behaviours were analysed, the novelty of this paper is to correlate occupant behaviours with building characteristics (e.g. glazing type, heat source typology, envelope properties, construction period, etc.) in order to extract influencing factors on the fuel consumptions and set-point temperature. Although some results and trends are easily deducible (e.g. the occupants using high values of set point temperature for heating system corresponded high fuel consumptions) this work quantifies the tie between the buildings characteristics and occupant actions by multivariate linear regression analyses.

The high correlations found between occupant behaviour (here set-point temperature and number of adaptive behaviours) and characteristics of the built environment (especially the construction year) suggest difficulties in adapting to discomfortable conditions in the oldest building without energy- and cost-intensive measures such as switching on the heating device for long hours.

With respect to the order of adaptive behaviours, Langevin et al. [35] found that clothing adjustment was the first action both in winter and summer. To some extent in contrast, Schweiker et al. [14] reported that clothing adjustments are the first action only in winter. The results presented in this paper are in line with Schweiker [14]. Clothing is adjusted first, followed by other adjustments in the winter season. However, clothing is not as frequently adjusted when people are feeling warm in summer. A reason might be that people already dress in as few layers as possible in summer in expectation of warm conditions and that they are therefore constrained to adjust their clothing level any further. In addition to findings presented in the literature, this study showed that the order of actions depends also on the construction year of the building;

Differently by the results presented by Langevin et al. [35], who found that windows were not used in the heat of the summer because they could make conditions worse, in this study in summer during discomfort conditions the first action performed by the occupant is opening windows. This is again in line with the findings by Schweiker et al. [14]. The difference between these results can also be explained by the different climatic conditions of the considered cities in the three questionnaire studies

As already shown by Sardianou [36], this study supports the findings that the socioeconomic status (family size, monthly income) has an impact on the behavioural patterns of occupants: wealthier families seem to have a lower tendency to adapt to the environmental conditions and are more likely to use energy- and cost-intensive active conditioning system.

6.2. Limitations of case study

In contrast to Andersen et al. [37] who carried out a field monitoring campaign in parallel to repeated surveys of occupant control of the indoor environment, this cross sectional survey identified associations between variables but cannot establish the cause-and-effect relationships. This is because cross sectional studies offer a snapshot of a single moment in time; they do not consider what happens before or after such snapshot is taken. In addition, no evaluation of thermal comfort assessments were conducted in the presented study.

Although the age/sex/clothing have a big impact on comfort, this study is based on a questionnaire survey whose main goal is to define the common attitudes and behaviours of the family in order to set these behaviours into relation with the energy consumptions of the apartment. Hence, many data (set-point temperature, hours of heating system utilization etc) are referred to the family and not to the single person, and this study does not have the goal to identify individual differences in occupant's behaviours but only the impact of these behaviours on building performance.

Another limitation of this work is identified in the limited slice of the analysed building stock as result of the young families that had been subjected to this questionnaire. In particular, most of buildings analysed are constructed after the 1980. This range of *construction period* represents only a limited slice of the entire Italian building stock. This result is due to the fact that the questionnaire is subjected to university students, whereby most of the families are young and they do not live in the oldest buildings. Consequently, because of these buildings regarded only a limited slice time (after the 1980) only a minimum percentage of these buildings (< 7%) had been subjected to retrofitting actions. Hence, the results of this study on the relationship found between the occupant behaviours, the construction period of buildings and its energy performance is only representative for the analysed building sample.

Furthermore, it is worth noting that in order to have a more accurate prediction of the fuel consumption for heating, the fuel consumption for domestic hot water (DHW) and for cooking have to be curtailed through a more accurate evaluation. Indeed while the consumptions for heating depend on the building-HVAC characteristics and occupant behaviour, the consumptions for DHW and cooking depend above all on the number of the family members and they do not reflect the building performance and the occupant behaviours related to thermal aspects.

Another issue is tied to the reliability of setpoint temperatures reported by occupants. The questionnaire asked for a single set-point temperature, so that the participants could not state when they activated or changed it. With this respect, it should be remarked that this study is based on data provided by the questionnaire and cannot monitor when the occupants used the heating system in reality.

7. Conclusions

This paper underlines that occupants have a notable impact on the building performance and hence on the energy consumptions. High values of the set-point temperature and of the total hours of heating system utilization by occupants cause more energy consumptions. In this context, it was shown that especially the construction period of the building affected the occupants' behaviours: in the oldest buildings, the occupants use the heating system for more hours and with higher set-point temperature values, and therefore cause a high fuel consumption. Hence, the common practice of designers to assume fixed set-point temperature and occupants' action independent of the building characteristics, leads to discrepancies between predicted energy consumptions and observed ones. This is an important and new finding, showing that models of occupant behaviour ~~for NZEB buildings~~ cannot be the same for buildings of different construction periods.

To analyse the relationship between the building-HVAC system and the occupants behaviour in more detail, future studies need to conduct in-depth studies using a representative sample of buildings where data regarding the building characteristics (e.g. U-value, thermal capacity, orientation, etc) will be related to occupants actions. In addition some occupant's behavioural factors, (e.g. lifestyle, tendencies etc) have to be included to improve adaptive behaviours analysis. In this way, it will be possible to obtain a more comprehensive understanding of the mechanisms driving adaptive occupant behaviours in the built environment.

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