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Application of survey on energy consumption and occupancy in residential buildings. An experience in Southern Italy

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Abstract

The aim of the study was to create and administer a questionnaire to collect data and obtain typical occupancy profiles of residential buildings. The survey was developed by considering previous experiences conducted in the University of Calabria since 2012, and it was distributed among 80 families via email, face-to-face and through social network. Different levels of occupancy (high, medium and low) and different sub-categories of high occupancy (morning, afternoon, and intermediate) were individuated by processing the gathered data. Buildings energy consumption was investigated with regard to occupancy categories, and correlations were found.

Keywords: Occupant behavior, survey, residential buildings, energy consumption, occupancy profiles, thermal storage

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1. Introduction

To address the challenges of climate changes, the three main sectors (buildings, transport, and industry) need to develop effective strategies to reduce their share of fossil fuel use for energy supply. The built environment consumes a great amount of the produced energy, 40% of total final energy consumption, in Europe, comes from buildings [1]. In the last decades, governments worldwide have implemented energy requirements in their building regulations to reduce levels of energy consumed by buildings and to promote more energy-efficient edifices [2]. Improvements have been registered due to the development of new materials, more efficient heating systems (e.g., boilers and heat pumps) and low energy appliances (e.g., labels A+ and A++). In parallel, the use of advanced simulation tools is encouraged. On the other hand, the recent literature demonstrates that frequently the expected building performance does not meet real consumption, and the gap is due to the influence of human factors [3].

Table 1. Summary of the literature review about the use of questionnaire in residential buildings.

Location	Survey Distributed	Distribution	Valid data sets	% response	Data Analysis
Hokkaido, Tohoku, Hokuriku, Kanto, Kansai, and Kyushu District. Japan [4]	80 buildings	Not specified	67	83%	Correlation analysis
Hangzhou. China [5]	124 households	Reports	71	57%	Correlation analysis
Chongqing. China [6]	201	Interviews face to face	182	90%	Descriptive
Hangzhou. China [7]	2000	Not specified	642 winter surveys 838 summer surveys	74%	Not specified
Changsha. China [8]	73	Face to face	73	100%	Descriptive
Seoul. Korea [9]	200	Self-administered questionnaire	139	69%	Correlation analysis
Suita. Japan [10]	10000 in 2009 4000 in 2013	Mailed	4448 in 2009 1245 in 2013	40%	Regression Analysis
China [11]	75 families	Reports for 1 year	60	80%	Confidence intervals
Chengdu. China [12]	Large scale 287 districts	Non- specified	1426		Descriptive
Shanghai, Chongqing and Changsha. China [13]	27 households	Selected sample for time recording of heating operation	27	100%	Descriptive
Sichuan, Chongqing, Hunan, Hubei, Jiangxi, Anhui, Jiangsu, Shanghai, and Zhejiang. China [14]	1800 households	Online questionnaire	1625	90%	Descriptive
Northern Ireland [15]	27 households	Non- Specified	27	100%	Correlation analysis
Netherlands [16]	7000 households	Mail	313	(5%)	Correlation analysis
Cameroon [17]	1750	Distributed twice a day: from 8:00 to 12:00 PM and from 14:00 to 18:00.	1750		Descriptive (time reports)

Generally, standardized occupant behavior is used as input into most common Building Simulation Software (BSS) but, the complex nature of occupant behavior makes the results far from reality. Hence, contextual occupancy schedules instead of standardized schedule are needed with the end to bridge the gap between theoretical models and real building performance. Several studies, such as [18,19], analysed the influence of occupant behavior on Thermal Activated Building System (TABS) and showed that the knowledge of real occupancy profiles also let to develop an efficient control of thermal storage technologies in terms of operation time. The occupant monitoring approaches can be divided into three categories [20]: surveys and interviews, observational studies, laboratory studies. The first one is the most common technique used for residential buildings. The value of surveys is not immediately apparent upon the availability of a rich dataset, but they can be used to develop a greater understanding of the predominant behavioral characteristics or motivating factors for interacting with building systems [21]. A review of previous experiences is presented in Table 1 with the aim of understanding the common ways to distribute the questionnaire, the samples size, the response rate and the techniques for data elaboration. The aim of this work is to create and deliver a questionnaire to collect data for obtaining typical occupancy profiles trends to be compared with related buildings energy consumption. Occupancy profiles can be individuated through some regularities in occupant actions and lifestyle. In fact, occupancy includes features of time and space, and occupants usually maintain a specific schedule in each room of the house.

2. Methodology

2.1 Survey preparation

The survey results consider previous experiences. The first study is a Chinese study made in the Tsinghua University [22]. This study was conducted twice: first in 2006-2007 and then in 2015, covering in total a sample size of more than 7000 households. The questionnaire translation process from Chinese to English and then to Italian language took a long time, because it was necessary to adapt the questionnaire to the Italian context, including habits and heating/cooling/DHW systems used in the considered Mediterranean region. The new questionnaire was used in researches conducted in the University of Calabria, from 2012 to 2018 [23–26]. The results showed that the questions with the lowest answer ratio were those regarding total annual income, presence of air-conditioning systems and thermal sensation (especially in cooling). The authors conducted further research about Italian experiences, and the collected information which is summarised in Figure 1.

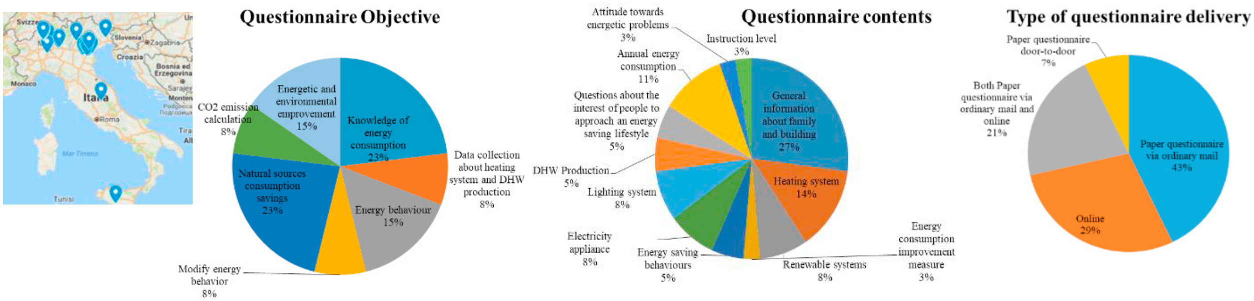

Fig. 1. Location, objective, contents and type of questionnaire delivery.

The questionnaire proposed in this work is obtained by combining the previous Chinese and Italian models. An intermediate step, however, consisted of a further improvement by means of comparison with Mediterranean [27] and Northern European [1] investigations. The long process of elaboration of previous experiences in the world led to the definitive version of the questionnaire. The survey consists of 80 questions grouped into four sections (see Figure 2). The repartition in sections was dictated by the aim of collecting information about physical, socio-demographic and behavioral variables. Physical parameters allow to define the climatic context, the construction typology, the heating/cooling/DHW systems, and equipment. Socio-demographic parameters are collected in order to describe composition, education, and income of families. Occupant's behavior is detected by means of detailed schedules in which people indicate, for every hour of the day, the presence in each room of the house. Similar schedules are applied to collect the operation of heating, cooling, lighting, DHW, and electrical devices. Furthermore, windows opening and curtains usage are detected both for winter and summer.

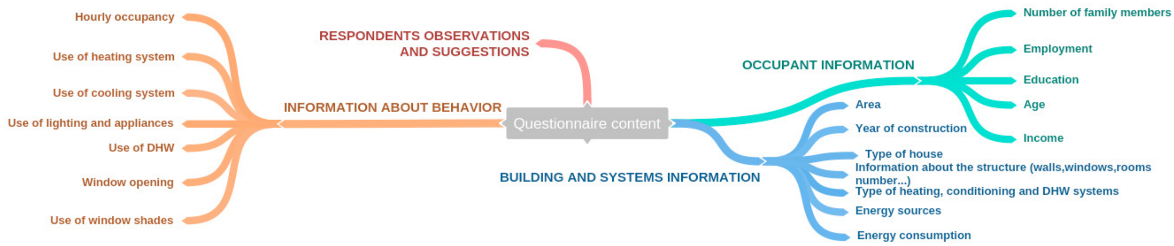

Fig. 2. Questionnaire content grouped into four sections.

2.2 Survey distribution

The questionnaire was distributed between September 19th and October 3rd, 2017 to a sample of 80 families residing in Calabria (Southern Italy). The distribution took place in three different ways: via email, face-to-face and through social network. Among the 80 questionnaires distributed, the percentage of valid answers used in the study was 65%.

3. Results

The different distribution methods were analyzed in order to understand which one was the most efficient. The comparison is shown in Figure 3.

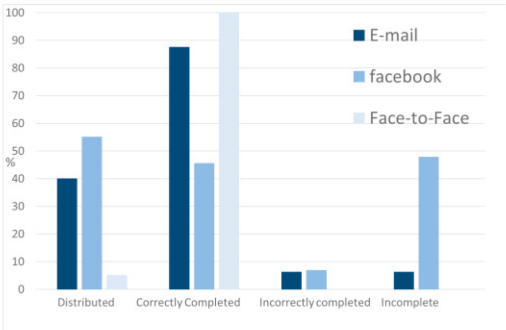

Fig. 3. Breakdown of the methods used for the questionnaire distribution and their effectiveness.

Only four questionnaires (5%) were completed through face-to-face interview. Even if this sample is smaller than the others, it is immediate understanding that this method is the most effective. By contrast, it is also the most time consuming, requiring 45 minutes per interview. Facebook guarantees a greater number of respondents, but most of the returned questionnaires were not fully completed (48%). E-mail delivering is probably the best compromise, because most of the respondents fully completed the questionnaire (88%).

3.1. Description of the sample and energy consumption

The first section of the questionnaire is aimed at gathering information to characterize the respondents' families and their houses. On average, the sample consists of 44% of men and 56% of women, and 50% of people belong to the age group between 18 and 40 years old. About 35% of households have average annual income less than € 15000. 53.8% of the respondents live in apartments and the majority of the investigated buildings were built between 1973 and 1991. The type of heating system was widely investigated by considering several options. Almost 86% of respondents have a heating system and, among them, 89% have an independent system. 60% of respondents use traditional gas boilers and the most common energy source is methane (44.2%). Among households not provided with a heating system, 42.9% use fireplace and electric heaters. 61.5% of respondents use the same system for heating and DHW production, and electricity is the most used energy source in the remaining part. 48.1% of the investigated dwellings are equipped with a cooling system. Regarding artificial lighting, 90.4% of respondents use low energy consumption bulbs. About electric appliances, 80% of respondents own high efficiency appliances. Only 7.7% of respondents have a photovoltaic system, while solar thermal collectors are present in 5.8% of the analyzed cases. Energy consumption data are collected by bills: the range of variation of electricity consumption is wide (from 475 to 4775 kWh/year), and has average annual value of 2139 kWh; annual consumption of primary energy for heating and DHW varies from 7 to 375 kWh/m^2 with an average value of 99.07 kWh/m^2. Higher consumption is registered when wood is used as a fuel. In fact, fireplaces are commonly applied in cold areas (climatic zone D and E [28]) and present low thermal efficiency [29].

3.2. Occupancy profiles

Data gathered through questions aimed at exploring the presence of the occupants at home are used to obtain occupancy trends. In the first phase, the percentage of daily hours in which at least one person is present in the house is calculated for each surveyed family. This allows obtaining of three occupancy classes characterized by high occupancy, medium occupancy and low occupancy, as described in Table 2.

Table 2. Occupancy classes.

	Low occupancy	Medium occupancy	High occupancy
Occupancy hours range (%)	0-60	60-80	80-100
Buildings in the class (%)	7.7	7.7	84.6

In the second phase of the analysis, for each family in the sample, a specific occupancy profile was built by calculating the percentage of people present at home compared to the total number of family members, for each hour of the day. Typical profiles for each class were successively determined by calculating the average of all the profiles of the households belonging to the same occupancy class. Figure 4 shows how the percentage values of people in the house as well as the extent of the time intervals in which people are present at home, progressively increase moving from the low to the high occupancy class.

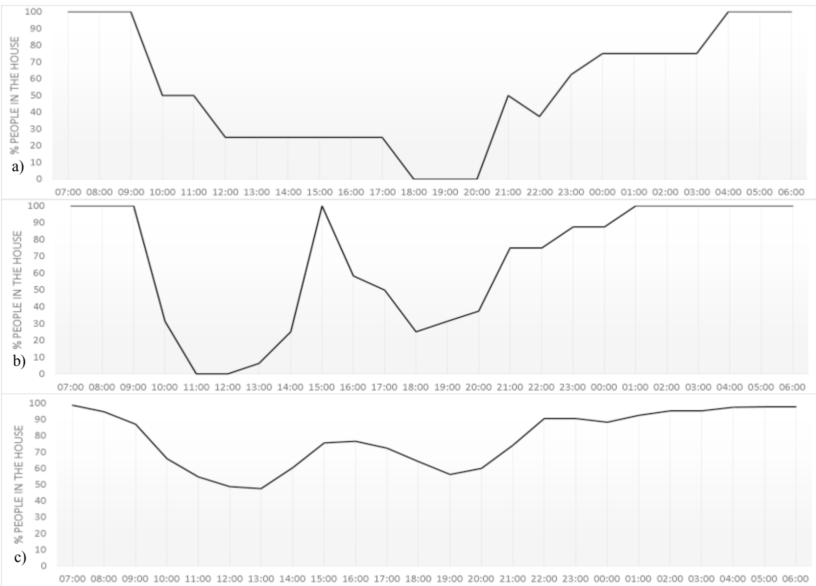

Fig. 4. Average profile for a) low occupancy class, b) medium occupancy class and c) high occupancy class.

In particular, the low occupancy class (Figure 4 a) is characterized by 100% occupancy only during the night hours. For the medium occupancy average trend (Figure 4 b), 100% occupancy also appears during lunch hours. For the high occupancy class, a continuous presence throughout the day is highlighted (Figure 4 c), with two minimum levels in the morning and afternoon. It is immediately clear that the house is always occupied in the latter case. Moreover, the percentage of people at home never drops down 50% in the high occupancy profile, while wide time ranges in which the percentage of people at home is lower than 50% are displayed in low and medium occupancy profiles. For example, only a fraction of 20% of the family is on average present at home between 12:00 and 17:00 in the low occupancy profile.

Within the high occupancy class, due to the large number of families ranked in this category, a further classification was done, in order to explore in more detail how the percentage of people present at home during the day evolves. The classification criterion is based on the distinction between the category of families characterized by a prevalent occupancy during the morning, and the families class with a predominant occupancy in the afternoon hours. An intermediate category is represented by the buildings in which the difference, between the occupancy in the morning and in the afternoon, is lower than 10%. The resulting average trends are illustrated in Figure 5.

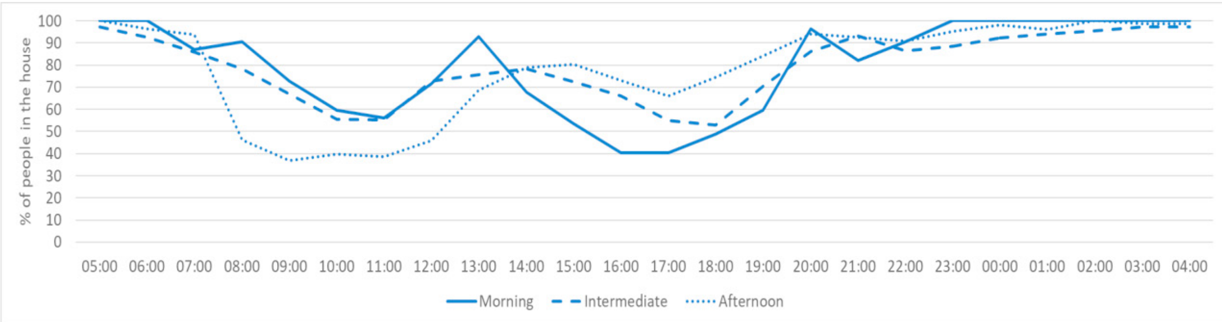

Fig. 5. Average profiles for the three sub-categories of families within the high occupancy class: prevalent occupancy in the morning, in the afternoon and intermediate.

The profile with prevalent occupancy in the morning shows higher occupancy rates (ranging from 55% to 93%) between 8:00 and 14:00 and exhibits a minimum corresponding to 40% of occupancy in the afternoon hours. By contrast, the profile with predominant occupancy in the afternoon reports higher occupancy rates (varying from 66% to 94%) between 14:00 and 20:00 and shows a decrease in the morning hours, reaching a minimum at 9:00, equal to 37% occupancy rate. In the intermediate sub-category, it was not possible to identify a strong difference in house occupancy between morning and afternoon. The obtained average profile reveals a symmetrical trend, with occupancy rates never below 50% and maximum occupancy during the night.

Further analyses were carried out with the aim of identifying possible relations between occupancy classes and the variables investigated in the questionnaire. In particular, a significant relationship was found for both households' income and energy consumption, which present a diverse distribution among the different occupancy classes.

Data presented in Figure 6 and Figure 7 disclose that high occupancy class is characterized by the lowest income families and by the highest average value of electricity (generally equipment and cooling) and primary energy consumption for heating and DHW. Instead, within the low occupancy class, 40% of the families have an income between € 15000 and 28000 and show the lowest average value of energy consumption. Information about income and heating/DHW energy consumption were not provided by 50% of the households classified in the medium occupancy class.

With regard to sub-classes of high occupancy class, it can be inferred that the families in this class have almost the same annual income. On the other hand, some differences can be highlighted among the values of primary energy consumption. The highest value was found in the class "afternoon", this is reasonable because the most used fuel in this class is wood that, as already said, is the fuel for which the highest primary energy values are registered.

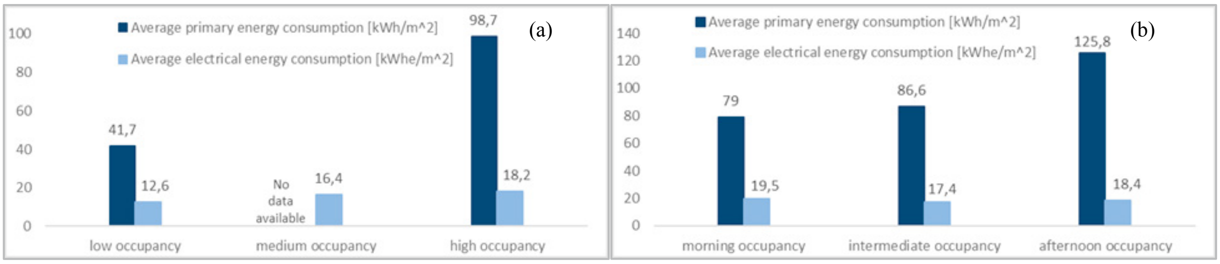

Fig. 6. Annual values of average energy consumption as a function of occupancy classes (a) and of high occupancy sub-categories (b).

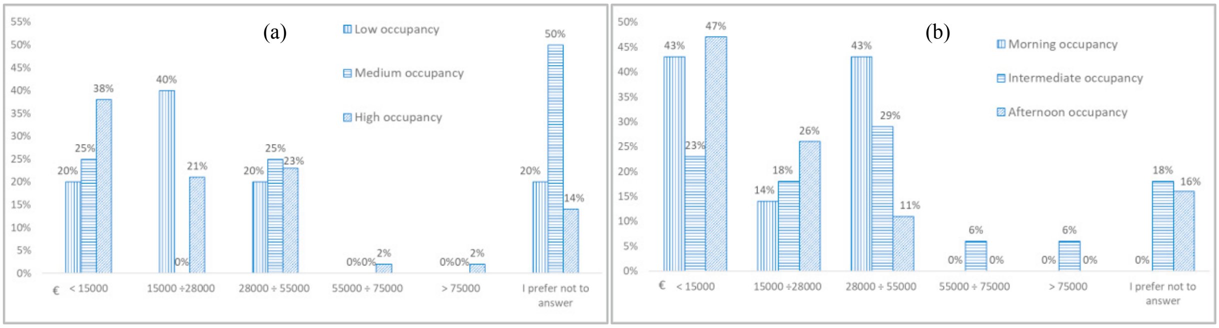

Fig. 7. Income distribution for each occupancy class (a) and for each high occupancy sub-category (b).

4. Conclusions

This work is a pilot study. For this reason, the first aim was to understand how much efficient is the use of the questionnaire and what are the most critical issues in using this investigation method. Moreover, it has been a useful experience to understand what kind of data can be gained. In fact, it has to be considered that in order to make energy consumption forecast the most possible precise, a lot of information is needed. When this information involves occupant behavior, it is almost impossible to establish standard values. The possibility to have an average trend of occupancy profiles makes easier and more precise working on energy simulations. Only using as average occupancy trends as starting point in energy simulation, it is possible to obtain reliable building energy consumption estimation usable in thermal storage systems dimensioning and renewable energy applications.

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