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# Energy Use in Residential Buildings: Characterisation for Identifying Flexible Loads by Means of a Questionnaire Survey

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**Abstract:** This work shows the outcomes of a research activity aimed at the energy characterization of residential users. Specifically, by data analysis related to the real energy consumption of sample buildings, the flexible loads amount has been identified so as to investigate on the opportunity to implement a demand/response (DR) program. The most meaningful input data have been collected by an on-line questionnaire created within an Excel spreadsheet allowing one to simulate and compare the calculations with the actual dwellings' consumption; 412 questionnaires have been used as statistical sample and simulations have been performed based on single-zone dynamic model. Additionally, once the energy consumptions have been sorted by the different services, reference key performance indicators (KPIs) have been also calculated normalising those ones by people and house floor surface. From data analysis, it emerges how the Italian residential users are not very electrified. Furthermore, the flexible loads are low and, implementing minor maintenance interventions, the potential of flexibility can decrease up to 20%. For that reason, the current research can be further developed by investigating on suitable flexibility extensions as well as on the automation system requirements which is needed managing the flexible loads.

**Keywords:** demand response; residential users; questionnaire; flexible electricity demand

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## 1. Introduction

It is well known how renewable energy sources (RES) are playing a key role in getting better energy and environmental performance out of existing electrical infrastructures. Even though they are characterized by high intermittency, they have low marginal costs [1] and for that reason they can be also considered as one of the main pillars for the energy transition [2].

In the last decade, several research projects were focused on the assessment of technical and safety issues associated to a growing RES share in current energy systems. To implement the different potential strategies, the comparisons are made very often between historical data and future scenarios [3,4].

Extending the forecasting horizon to 2050 and increasing the targets value, the wider RES integration become crucial for all those countries that really want to head towards a total decarbonization of their energy consumptions [5,6]. To do so, significant changes in national grids monitoring and managing, have to be accounted for and have to be funded as well [7]. Referring to the recent IEA/Irena scenario, it is possible to note that the two third of world's energy consumption will be met by renewables by 2050, where 70% of electricity production will hail from RES [8].

Thus, the European Commission call for achieving a RES share equal to 32% of the whole final energy consumption by 2030. In detail, looking at the electric sector, that ambitious target entails that

50% of EU members electricity demand will be met by renewables, at least. In so doing, new national energy and environmental policies are basically mandatory and have to be effectively implemented by each member state [9].

With the deployment of distributed energy generation and introduction of variable energy sources in the supply mix, it is necessary to be focused on the demand management (DSM) and flexible electrical loads to improve efficiency and to stabilize the grid [10,11]. Demand management includes all activities aimed at influencing consumer electricity demand, in order to match it better with the offer [12]. Among those, the demand/response (DR) activity offers good opportunities; it is defined as “changes in electric usage by demand-side resources from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” [13].

The main goal of a DR program is to improve the grid efficiency and security by shifting some peak loads in off-peak hours. The interest in DR program application to dwellings is quite recent and it is a consequence of the high value of energy consumption in the building sector. Indeed, in Europe, the real estate consumption accounted for 41.7% of total consumption; more specifically, consumption in the residential sector alone accounted for 27.2% of total consumption, based on data from 2017 [14].

It is important to point out that part of residential consumption is electrical, and only a fraction of it can be considered flexible. A great potential for flexibility can be found in buildings equipped with electric heating systems; the impact on overall consumption depends on the climatic zone (i.e., outdoor temperature and relative humidity), on the buildings’ characteristics and on the occupancy rate [15]. Likewise, a great potential for flexibility can be noted in buildings equipped with domestic hot water preparation systems; in that case the impact on overall consumption essentially depends on the intended use and the number of occupants [16]. In addition to those consumptions, there are further deferrable loads owing to the use of washing machines, dishwashers or dryers, whose incidence is correlated to the users’ number [17].

In this framework, the present work has been focused on the energy needs of Italian residential sector, assessing what are the potential flexible loads, so as to identify the criticalities and to highlight the main tools and strategies for fostering the energy transition as well. Referring to 2017, the Italian residential sector is responsible of 29.0% of national energy consumptions, therefore it represents a significant fraction [14]. As a consequence, searching for the flexibility potential there, is strongly suggested.

By the literature survey on those topics, in [18,19] the intervention options to improve energy demand flexibility in buildings have been reviewed, including heating, ventilation, and air conditioning (HVAC) systems, energy storage, building heat capacity, appliances, and occupants behaviour. Then, Shakouri et al. [20] proposed in their study a multi-objective optimization procedure for demand side management of a residential area; under different scenarios, the advantages of using centralized energy management systems in residential buildings were demonstrated, showing the potential benefits for both consumers and service companies.

The energy consumption status and trends of the European Union (EU) residential sector was analysed in [21], paying great attention to the impact and effectiveness of implemented energy efficiency policies for this sector.

Gaglia et al. [22], Vogiatzi et al. [23] and Chang et al. [24] provided in their works different methods and analyses of energy consumption in residential buildings, aimed at identifying energy saving interventions and at reducing pollutants emissions. The authors of [25–28] were focused only on residential electricity consumptions, so as to provide a model for loads profiling, while the optimal load scheduling, when RES are installed, was the main target for the research projects reported in [29–31].

Finally, the energy consumptions trend, in terms of time series and frequency, hailing from different occupants’ habits along with the definition of potential strategy for improving the building energy performance, was the object of several works published in the last two years [32–37].

Having said, on the basis of the aforementioned research projects, this work presents an energy needs analysis in the residential sector, carried out by the dissemination of a data collection questionnaire, designed to be user-friendly as much as possible, even by non-expert users. The research results can be used as a benchmark for similar evaluations. Additionally, the methodological approach could be useful for further investigations aimed at implementing new tools and strategies to foster the flexibility in the electric demand-side.

## 2. Materials and Methods

Acquiring the basic data to perform calculations is very often a difficult process. Indeed, their accuracy and reliability are crucial for the research outcomes quality. Statistical databases provided by public or private organizations [38–40] very often organize information in aggregate form (i.e., energy consumption, building properties, household characteristics, etc.) [41–43]. Unfortunately, the needed data are sometimes not retrievable easily and their elaboration for specific applications can be a very demanding assignment.

In this paper, the data collection to investigate on the energy consumptions in residential buildings [44,45] have been done by means of a questionnaire surveys.

By the gathered data, the most common statistical approach [7,46–48] based on the multivariate linear regressive analysis has been used in order to establish the on-line simulation tool reliability, in terms of error on data forecasting.

In order to identify and quantify the main characteristics of dwellings consumptions, the aforementioned statistical analysis has been carried out by the Excel Data Analysis Tool. To do so, floor surface and the occupants' number have been assumed as the main variables for the regression. Thereafter, the linear model outputs have been compared to those hailing from the online questionnaire/simulation tool.

The questionnaire structure has been optimized to facilitate the compiling by non-expert users as well, in order to assure the results accuracy; in a preliminary test phase the questionnaire was submitted to both common users and to a selection of expert users, to understand their different availability in providing the requested data; in its final form the questionnaire has the structure reported in Table 1. It is possible to note how some questions are “open questions” and the others are “closed questions”, where the participants have to choose among fixed options. Moreover, for some input values, suggestions for compiling have been indicated [46,49].

From a technical point of view, the questionnaire is created in the Excel environment implementing macros and functions written in Visual Basic for Applications (VBA) for a real-time simulation of energy consumptions based on the entered inputs. It is noteworthy how simulations are performed by means of an in-house developed code [50], which was used in other works [51–53] and was validated by comparison with the outcomes deriving from leading software such as TRNSYS and EnergyPlus.

With the aim of creating a simpler but still accurate tool, the code allows to run hourly single-zone dynamic simulations. The use of a self-developed code guarantees a high flexibility and allows the implementation of new tools and options if required.

The energy consumptions resulting from simulations are immediately compared with the actual ones entered by the user [54,55] and with the elaborated benchmarks. Those ones were computed on the basis of the Italian TSO report [39] and of the ISTAT survey on household energy consumption [56].

When a discrepancy between the simulation data and the actual ones occurs, warnings and potential solutions for data correction are prompted. That comparison is basically required owing to the lack of awareness that users have of their own consumption habits [57,58].

Table 1. Questionnaire structure.

<p><b>Building location</b></p> <ul style="list-style-type: none"> <li>• Province</li> <li>• Municipality</li> </ul> <p><b>Number of occupants in the dwelling over the day</b></p> <ul style="list-style-type: none"> <li>• from 8 a.m. to 1 p.m.</li> <li>• from 1 p.m. to 7 p.m.</li> <li>• from 7 p.m. to 12 p.m.</li> <li>• from 12 p.m. to 8 a.m.</li> </ul> <p><b>Architectural characteristics</b></p> <ul style="list-style-type: none"> <li>• Building Construction year</li> <li>• Apartment dimensions and boundary surfaces Vertical Walls and roof external colour</li> <li>• Shading</li> <li>• Refurbishment actions on building           <ul style="list-style-type: none"> <li>- Walls</li> <li>- Roof</li> <li>- Ground</li> <li>- Windows</li> </ul> </li> </ul> <p><b>Building services system</b></p> <ul style="list-style-type: none"> <li>• Heating system           <ul style="list-style-type: none"> <li>- Centralised/autonomous</li> <li>- Heat source type (traditional boiler, condensing boiler, heat pump)</li> <li>- Control (on/of, climatic thermoregulation, chrono-thermostat)</li> <li>- Emission system (radiators, fan-coils, radiant floor)</li> </ul> </li> <li>• Cooling system           <ul style="list-style-type: none"> <li>- Electric air conditioner               <ul style="list-style-type: none"> <li>○ Energy Class</li> <li>○ Number of served rooms</li> </ul> </li> <li>- Other devices               <ul style="list-style-type: none"> <li>○ Fans (number of hours switched-on)</li> <li>○ Dehumidifiers (number of hours switched-on)</li> </ul> </li> </ul> </li> <li>• Domestic Hot Water (DHW) plant           <ul style="list-style-type: none"> <li>- Traditional boiler/condensing boiler/heat pump water heater/electric water heater storage device (yes/no)</li> </ul> </li> <li>• Solar collectors           <ul style="list-style-type: none"> <li>- Flat solar collectors/Vacuum solar collectors</li> <li>- Number of modules</li> <li>- Slope</li> <li>- Orientation</li> </ul> </li> <li>• PV array           <ul style="list-style-type: none"> <li>- Plant peak power</li> <li>- Slope</li> <li>- Orientation</li> <li>- Self-consumption</li> </ul> </li> </ul>	<p><b>Kitchen</b></p> <ul style="list-style-type: none"> <li>• Cooking plane (type, minutes per day switched-on)</li> <li>• Oven (type, minutes per day switched-on)</li> <li>• Microwaves oven (type, minutes per day switched-on)</li> <li>• Grill (minutes per day switched-on)</li> <li>• Steak grill pan/electric stove (minutes per day switched-on)</li> <li>• Toaster (minutes per day switched-on)</li> <li>• Electric coffee maker for espresso (minutes per day switched-on)</li> <li>• Electric coffee maker mocha (minutes per day switched-on)</li> <li>• Blender (minutes per day switched-on)</li> <li>• Food processor (minutes per day switched-on)</li> </ul> <p><b>Refrigeration</b></p> <ul style="list-style-type: none"> <li>• Refrigerator (type, capacity, energy class)</li> </ul> <p><b>Washing</b></p> <ul style="list-style-type: none"> <li>• Washing machine (capacity, weekly cycles, energy class)</li> <li>• Tumble dryer (capacity, weekly cycles, energy class)</li> <li>• Dishwasher (capacity, weekly cycles, energy class)</li> </ul> <p><b>Cleaning and ironing</b></p> <ul style="list-style-type: none"> <li>• Vacuum cleaner (minutes per day switched-on)</li> <li>• Electric broom (minutes per day switched-on)</li> <li>• Iron without water boiler (minutes per day switched-on)</li> <li>• Iron with built-in water boiler (minutes per day switched-on)</li> </ul> <p><b>Lighting</b></p> <ul style="list-style-type: none"> <li>• Filament Lamps (number)</li> <li>• Halogen Lamps (number)</li> <li>• Fluorescent Lamps (number)</li> <li>• LED Lamps (number)</li> </ul> <p><b>Audio/Video</b></p> <ul style="list-style-type: none"> <li>• TV, monitor (size, quantity, energy class, hours per day switched-on)</li> <li>• decoder (quantity, daily use in hours)</li> <li>• Videorecorder (quantity, daily use in hours)</li> <li>• DVD reader (quantity, daily use in hours)</li> <li>• Radio, stereo (quantity, daily use in hours)</li> <li>• Hi-fi/home theatre (quantity, daily use in hours)</li> <li>• <b>Computer/Internet</b></li> <li>• Desktop PC (quantity, daily use in hours)</li> <li>• Notebook (quantity, daily use in hours)</li> <li>• Modem (quantity, daily use in hours)</li> <li>• Inkjet printer (quantity, copies per day)</li> <li>• Laser printer (quantity, copies per day)</li> </ul> <p><b>Personal Care</b></p> <ul style="list-style-type: none"> <li>• Hairdryer (daily use in hours)</li> <li>• Hair straightener (daily use in hours)</li> </ul> <p><b>Other equipment</b></p> <ul style="list-style-type: none"> <li>• Other equipment (quantity, electric power, daily use in minutes)</li> </ul>
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To provide a complete energy characterization of domestic users, the electrical and thermal users’ analysis has been carried out, assessing their peculiarities in terms of management flexibility, specific energy consumptions, power commitments and time. Thus, for that purpose, a preliminary classification has been drawn up (see Figure 1) according to [59], distinguishing four load typologies and the self-generation, which are defined as follows:

- (1) Storable load: the power consumption and the end-use service are decoupled by storage devices such as batteries (electrochemical) or thermal inertia.
- (2) Shiftable load: power consumption can be moved over the time period unaffected the end-use service. Shiftable load often involves non-interruptible processes such as the laundry cycle and thus involves some planning.
- (3) Curtailable load: power consumption cannot be shifted unaffected the end-use service, but that service can be interrupted instantly.
- (4) Non-curtailable load (Base load): the end-use service needs instant power and cannot be interrupted or shifted over the time period.
- (5) Self-generation: on-site power generation at consumer residence, reducing the net electric load. Dispatchable self-generation can be used as back-up power system.

Self-generation	Load mix			
	Non-storable load			Storable load
	Non-shiftable load		Shiftable load	
	Non-curtailable load (Base load)	Curtailable load		
Solar-PV, solar-boiler, micro-chp, small biomass, small wind power, etc.	Burglary alarm, automation, freezer, refrigerator, etc.	Lighting, TV, handyman tools, computer, etc.	Laundry, dishwasher, tumble dryer, vacuum cleaner, stove, etc.	Electric vehicle, heating, cooling, DHW, battery, etc.

Figure 1. General loads mix and self-generation.

According to that classification, the users’ characterization for the domestic sector has been developed to evaluate the potentially storable loads, potentially shiftable loads and the remaining ones. The outcomes of this work derive from gathered data which have been collected by the online questionnaire starting from September 2018. The statistic sample consists of 412 households which fully compiled the online questionnaire by means of students attending the Faculty of Architecture of Sapienza University of Rome (Italy).

### 3. Results and Discussion

#### 3.1. Dwellings Description and General Analysis on Consumptions Typology

In this section the frequency analysis related to the building characteristics is presented. Specifically, Figure 2a shows the buildings subdivision according to the construction year, following the official classification used in the Italian population censuses [38]. From data it emerges that a large part of the sample buildings was built before 1976, the year in which the first Italian law on energy saving was issued. In addition, Figure 2b depicts the buildings frequency as a function of their size once five different dimensional classes have been identified (i.e., small < 50 m<sup>2</sup>; small-medium 50–85 m<sup>2</sup>; medium 85–115 m<sup>2</sup>; medium-large 115–145 m<sup>2</sup>; large > 145 m<sup>2</sup>). The apartments’ average size is equal to 112.4 m<sup>2</sup> and the most common class is the middle one.

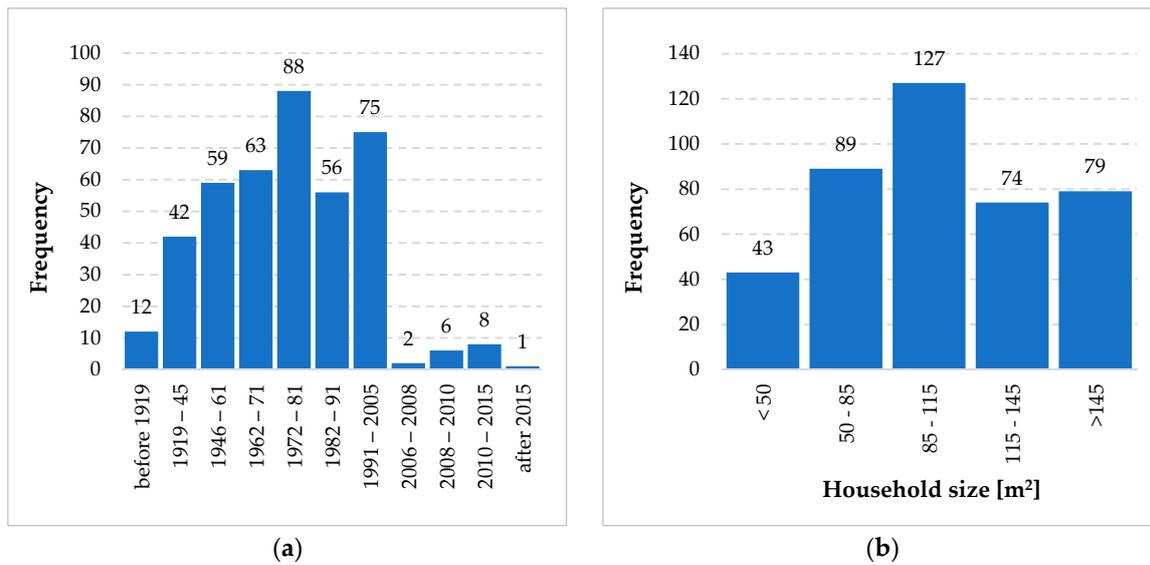


Figure 2. Buildings' subdivision. (a) Year of Construction; (b) Surface.

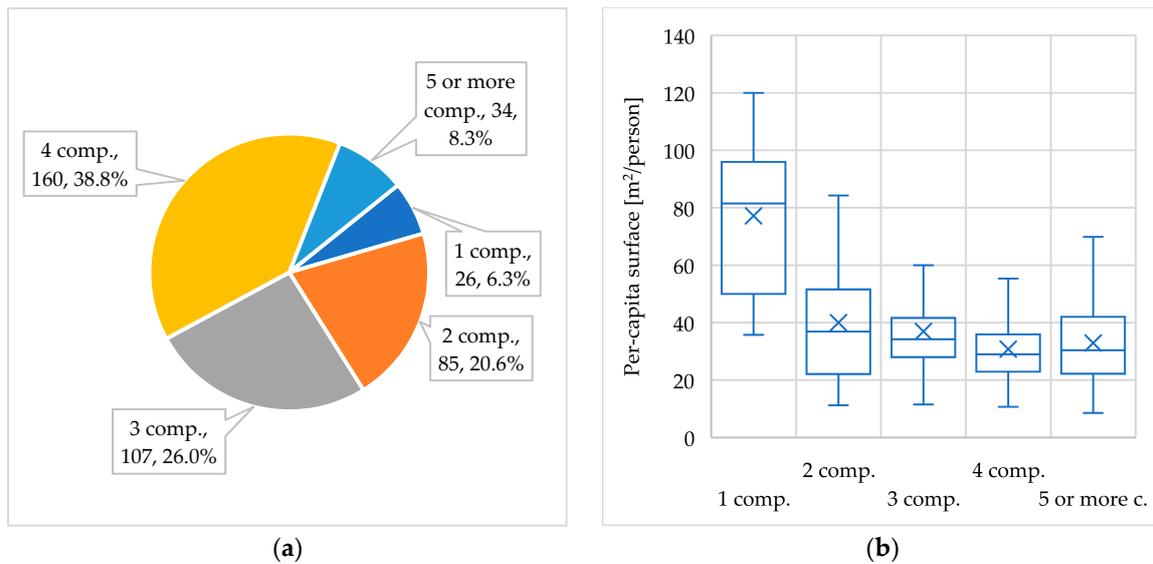
Table 2 outlines in a systemic overview the homes number that undergone refurbishments, sorted by the construction year and type of intervention; the most frequent measure is the windows replacement with a share equal to 46.6% (i.e., 192 sample apartments).

Table 2. Refurbishment actions on building.

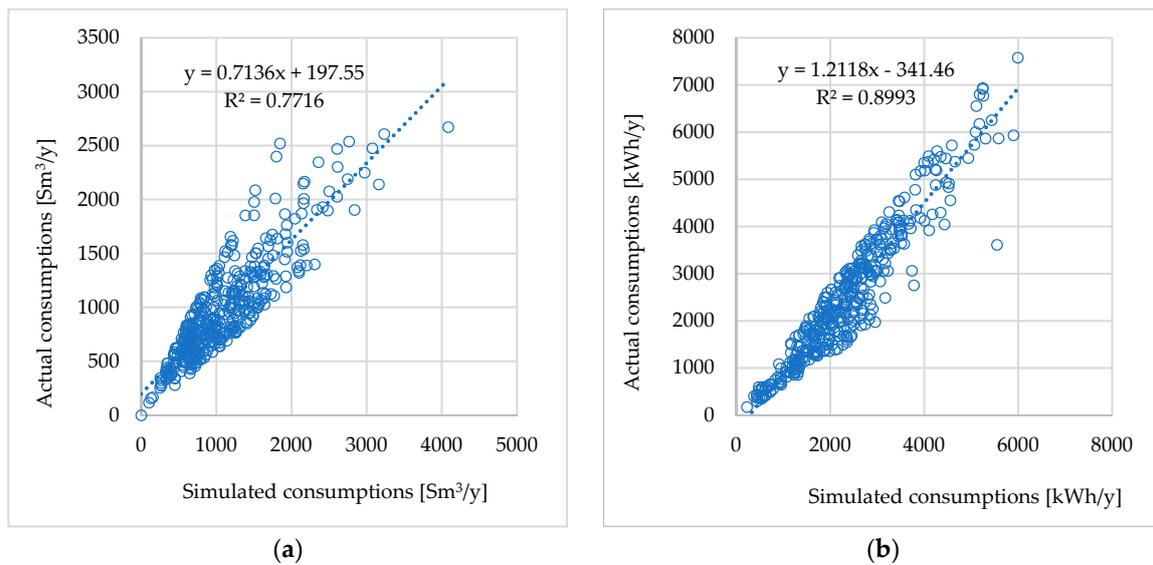
Building Construction Year	Refurbishment Actions on Building			
	Walls	Roofs	Floors	Windows
before 1919	0 (0%)	0 (0%)	0 (0%)	5 (41.7%)
1919–1945	2 (4.8%)	2 (4.8%)	3 (7.1%)	29 (69%)
1946–1961	6 (10.2%)	8 (13.6%)	1 (1.7%)	46 (78%)
1962–1971	8 (12.7%)	7 (11.1%)	3 (4.8%)	29 (46%)
1972–1981	13 (14.8%)	13 (14.8%)	5 (5.7%)	44 (50%)
1982–1991	5 (8.9%)	5 (8.9%)	3 (5.4%)	22 (39.3%)
1991–2005	16 (21.3%)	14 (18.7%)	9 (12%)	13 (17.3%)
2006–2008	0 (0%)	0 (0%)	0 (0%)	0 (0%)
2008–2010	2 (33.3%)	1 (16.7%)	0 (0%)	2 (33.3%)
2010–2015	4 (50%)	4 (50%)	3 (37.5%)	2 (25%)
after 2015	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Total	56 (13.6%)	54 (13.1%)	27 (6.6%)	192 (46.6%)

Figure 3a shows the apartments' subdivision by the number of family members; the most recurrent classes consist of three people households and four people households, with shares equal to 26.0% and 38.8%, respectively. The per capita surface decreases as the number of family members increases (see Figure 3b), ranging from an average value of 77 m<sup>2</sup>/person for single-core households up to 31 m<sup>2</sup>/person for all those families consisting of four components.

The questionnaire for data collection also includes a comparison between the simulated consumptions and the real ones which were entered by the user. Figure 4 shows the dispersions related to the natural gas (NG) volumes and the electricity needs; the predictive model for the electricity needs is characterised by a higher correlation coefficient than the NG one and they are equal to 0.8993 and 0.7716, respectively.



**Figure 3.** Buildings' subdivision. (a) Household vs. family components; (b) Per-capita surface vs. family components.



**Figure 4.** Actual consumptions vs. simulated consumptions (a) Natural Gas; (b) Electricity.

On the contrary, when the linear regressive analysis is used for both NG and electricity consumptions, the outcomes from the data forecasting model are characterized by large standard errors. The yearly NG consumptions equation (expressed by  $\text{Sm}^3/\text{y}$ ) reads as follows:

$$NGC = 326.59 + 5.3671 \cdot S_{\text{floor}} + 53.451 \cdot N \tag{1}$$

where  $S_{\text{floor}}$  denotes the dwelling floor surface and  $N$  is the number of occupants.

Similarly, for the yearly electricity consumptions ( $\text{kWh}/\text{y}$ ) the analytical function is:

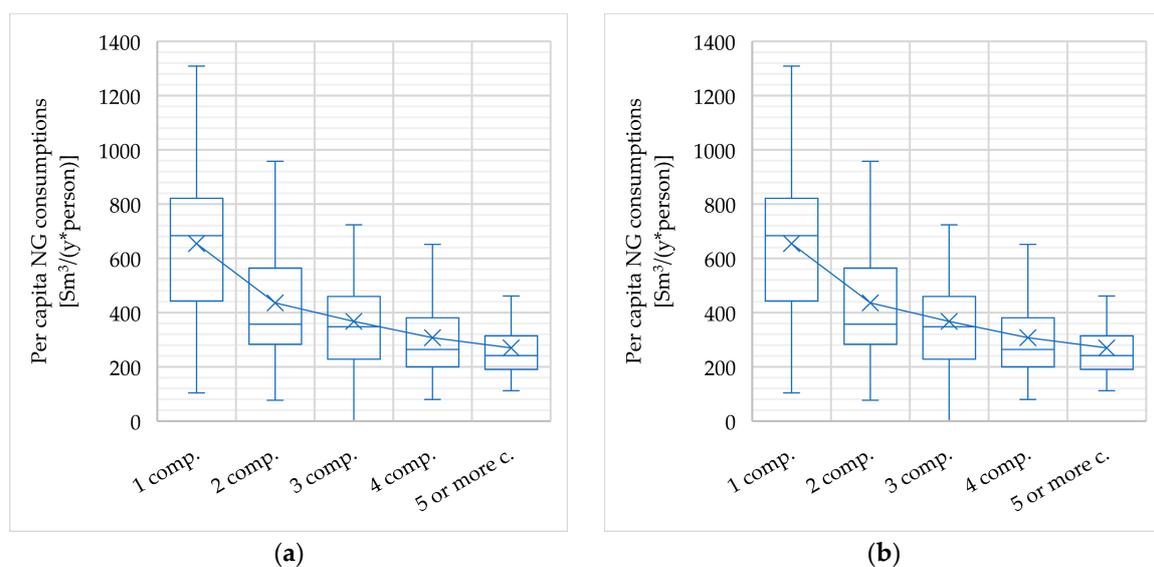
$$ELC = 664.29 + 3.7492 \cdot S_{\text{floor}} + 395.12 \cdot N \tag{2}$$

In addition, the  $R^2$  values and the standard errors are  $R^2 = 0.3453$ ,  $STDE = 475.01$  and  $R^2 = 0.2815$ ,  $STDE = 924.86$ , respectively.

Looking at those values, it is possible to note how the traditional statistic method is less reliable than the developed calculation code within the Excel spreadsheet.

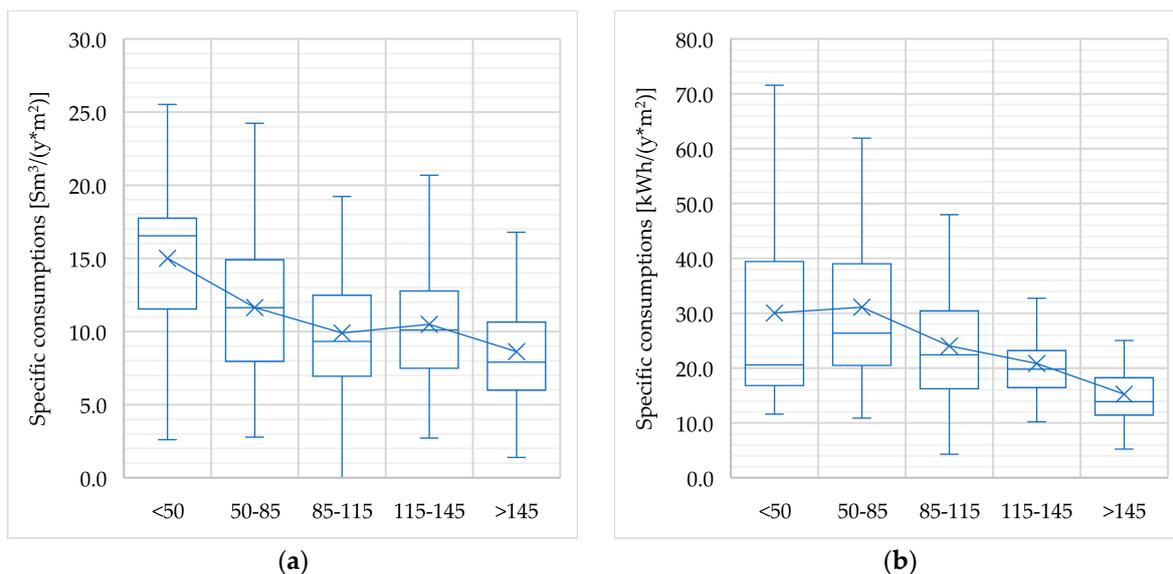
Finally, a parametric assessment of electricity and gas consumptions was carried out, normalising all data by the number of components and the building floor surface. In detail, the per capita consumptions have been correlated to the number of components while the specific consumptions by unit of surface have been plotted as a function of building size classes. Those KPIs have been built in accordance with the current Italian building energy certification system, providing technical information related to the building characteristics and the occupants' behaviour. Anyway, by rearranging those values it is possible to calculate the most common environmental and economic KPIs as reported in literature [60].

The average value of per capita NG consumption is equal to  $368 \text{ Sm}^3/(\text{y}\cdot\text{person})$ ; as the family members increase (Figure 5), the NG per capita consumption lessens from  $654 \text{ Sm}^3/(\text{y}\cdot\text{person})$  (one component) to  $269 \text{ Sm}^3/(\text{y}\cdot\text{person})$  (five or more components). As regards the average value of per capita electricity consumption, it is equal to  $772 \text{ kWh}/(\text{y}\cdot\text{person})$ ; similarly, it decreases as the number of components increases, from  $1184 \text{ kWh}/(\text{y}\cdot\text{person})$  (one component) to  $617 \text{ kWh}/(\text{y}\cdot\text{person})$  (five or more components). Having said this, comparing Italy with other countries, it emerges that in the domestic sector, per capita electricity consumption is quite low. Indeed, the European average value is  $1566 \text{ kWh}/(\text{y}\cdot\text{person})$ , while in the United States and Finland it exceeds  $4000 \text{ kWh}/(\text{y}\cdot\text{person})$  [14,61]. That demonstrates how the Italian residential sector is poorly electrified reflecting its dependence on fossil fuel -based technologies, especially for the heating purpose.



**Figure 5.** Per capita consumptions; (a) Natural Gas; (b) Electricity.

Referring to the normalised data by surface the curves trend are quite different as shown in Figure 6. Likewise, as the apartments size increases the NG specific consumption shrinks less rapidly from  $15.0 \text{ Sm}^3/(\text{y}\cdot\text{m}^2)$  (small households) up to  $8.6 \text{ Sm}^3/(\text{y}\cdot\text{m}^2)$  (large households); on the contrary, for the electric specific consumption it is possible to note that the first two classes show very close values, thereafter as the surface increases more, they goes down almost linearly. However, the highest specific electricity consumption is equal to  $30.1 \text{ kWh}/(\text{y}\cdot\text{m}^2)$  (small households) while the lowest is  $15.2 \text{ kWh}/(\text{y}\cdot\text{m}^2)$  (large households).



**Figure 6.** Specific consumptions by unit of surface vs. dwelling size: (a) Natural Gas; (b) Electricity.

### 3.2. Consumption Breakdown by Services

The code used to perform simulations allows to subdivide the energy consumption by the home services (i.e., Heating, Cooling, DHW, Cooking, Refrigeration, Washing, Cleaning and Ironing, Lighting, Audio/Video, Computer/Internet, Personal Care, Other equipment).

The same peculiarities are not available in the recent literature [14], exception for outdated publications [62]. Yet, quite similar results are based on estimation methods associated to the potential demand calculation [63].

Table 3 shows the services widespread within the reference homes; some of those services are present in all homes (i.e., Heating, DHW, Cooking, Refrigeration, Lighting); other services are present only 95% of samples (i.e., Washing, Cleaning and ironing, Audio/Video, Computer/Internet, Personal Care); equipment for cooling purpose are installed only in 275 homes (68.8%).

As regards the heating systems, they are mainly autonomous (72.8%). Furthermore, the NG is the most widely used energy carrier in heating (98.8%) and in domestic hot water preparation (85.2%) as well, given that very often the same heat generator supplies both services. The hobs are generally gas-fired (98.1%), while the ovens are largely electric (92.7%).

The services share in the overall home consumption are based on the primary energy values and it has been reported in Figures 7 and 8. Heating is the service characterised by the highest share (on average it is equal to 43.5%), showing a wide variability, due to the different climatic conditions, to the geometric and physical characteristics of buildings envelope. Among the other services, only DHW (14.1%) and Cooking (12.4%) exceed the thresholds of 10%, while for the washing service the average is limited to 5.6%; all other services have a share less than 5%.

In the use of the questionnaire several difficulties arose, mainly due to the number of required inputs. That issue discouraged the user to proceed with the compilation in many cases.

Hence, a questionnaire reformulation is to be studied, aimed at eliminating the redundant information which weakly affects the results, according to what is emerged by the previous analysis.

Table 3. Services spread within homes.

Service	Number (Share)	Type	Number (Share)
Heating	412 (100%)	Traditional boiler	318 (77.2%)
		Condensing boiler	89 (21.6%)
		Heat pump	5 (1.2%)
Cooling	284 (68.9%)		
DHW	412 (100%)	Instantaneous Boiler	321 (77.9%)
		Boiler with storage	30 (7.3%)
		Electric water heater	53 (12.9%)
		Heat Pump water heater	8 (1.9%)
Cooking	412 (100%)	-	-
Refrigeration	412 (100%)	-	-
Washing	408 (99.0%)	Washing machine	408 (99.0%)
		Tumble dryer	65 (15.8%)
		Dishwasher	247 (60.0%)
Cleaning and ironing	397 (96.4%)	-	-
Lighting	412 (100%)	-	-
Video audio	410 (99.5%)	-	-
Internet computer	400 (97.1%)	-	-
Care person	404 (98.1%)	-	-
Other equipment	45 (10.9%)	-	-

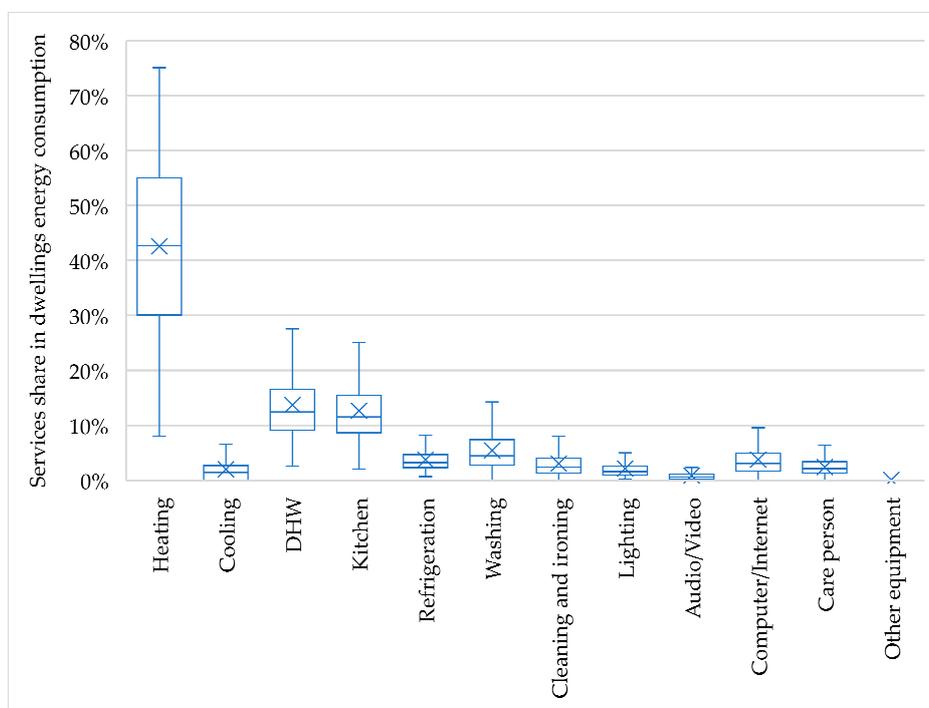


Figure 7. Services share in dwellings energy consumption.

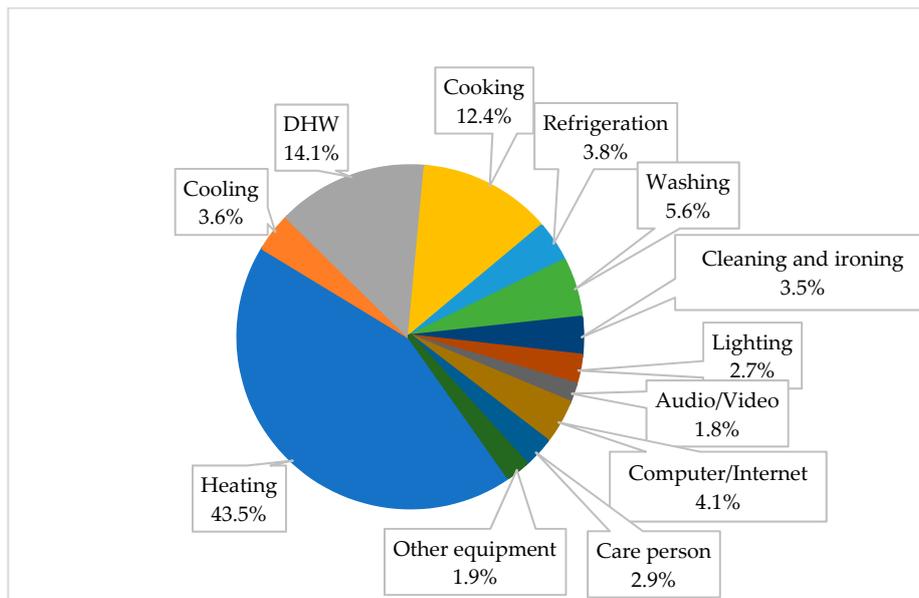


Figure 8. Average values of services share in dwellings energy consumption.

### 3.3. Potential of Flexibility for the End-Users

Starting from the simulation outputs, the potential of flexibility associated to the domestic users has been evaluated, searching for the storable loads and the shiftable loads within the typical households' energy uses.

In Italy, the percentage of electricity consumption in domestic sector is equal to 26.1%; in other countries that indicator can get higher values, such as 64% in Finland and 52.5% in France [14,61].

The collected data by the online questionnaires confirm the low electrification degree of Italian residential users (see Figure 9). Nevertheless, referring to the analysed statistical sample, the average electrification degree is equal to 36.5%, resulting therefore greater than the aforementioned value. Moreover, only 14.8% of those dwellings exceed that average value showing an electrification degree higher than 50%, while only one home gets the 100%.

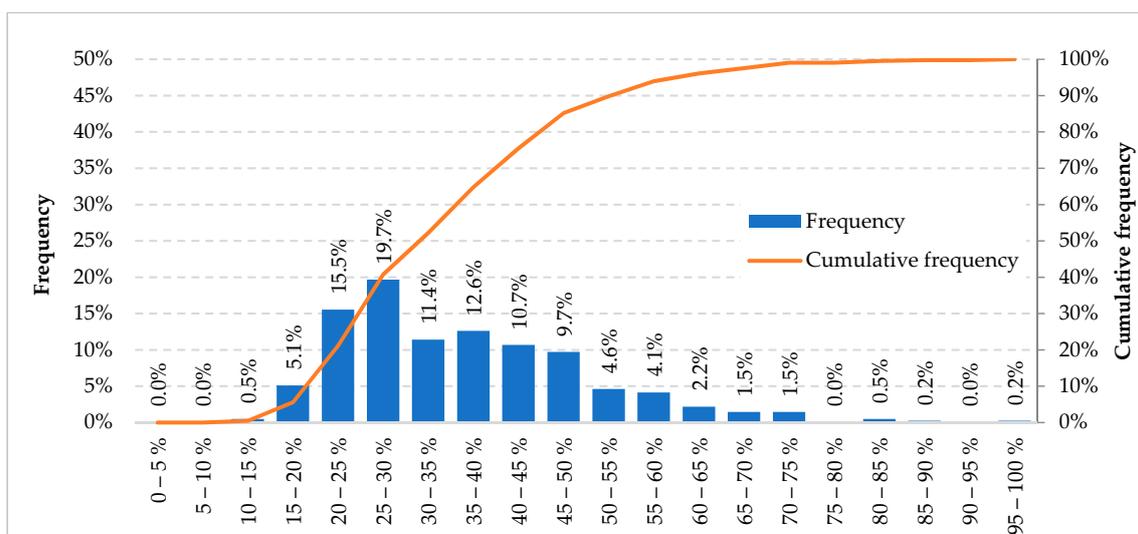


Figure 9. Dwellings electrification degree.

According to the electrical loads' classification in Section 2, both storable and shiftable loads have been estimated. Figure 10 depicts the frequency analysis related to the storable loads associated to

the statistical sample. On average, storable loads of 381 kWh/y can be identified; most homes (84.0%) are characterised by storable loads less than 400 kWh/y, while 67.0% shows storable loads lower than 200 kWh/y. It is important to highlight how the larger storable loads value can be found in all of those dwellings where the DHW is produced by electric water heater or where the equipment for summer air conditioning are mostly used.

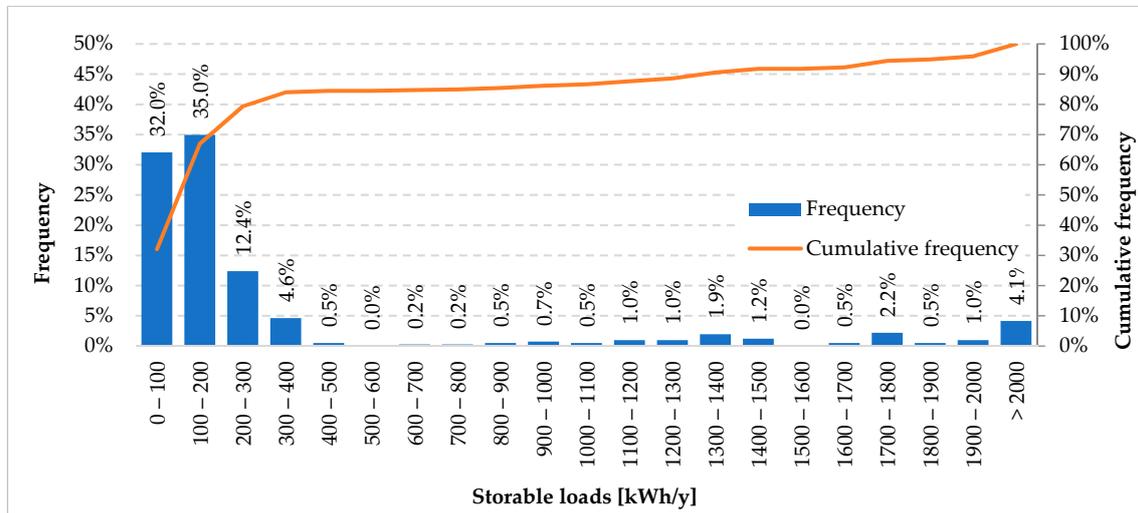


Figure 10. Storable loads.

By the same analytical approach Figure 11 shows the frequency analysis related to the deferrable loads. From data, it emerges that statistical sample is characterised by a shiftable loads average value equal 669 kWh/y. Specifically, most homes (50.7%) present a shiftable loads amount less than 600 kWh/year; in addition, where washing machines, dishwashers, tumble dryers are widely used, the higher shiftable loads value can be registered.

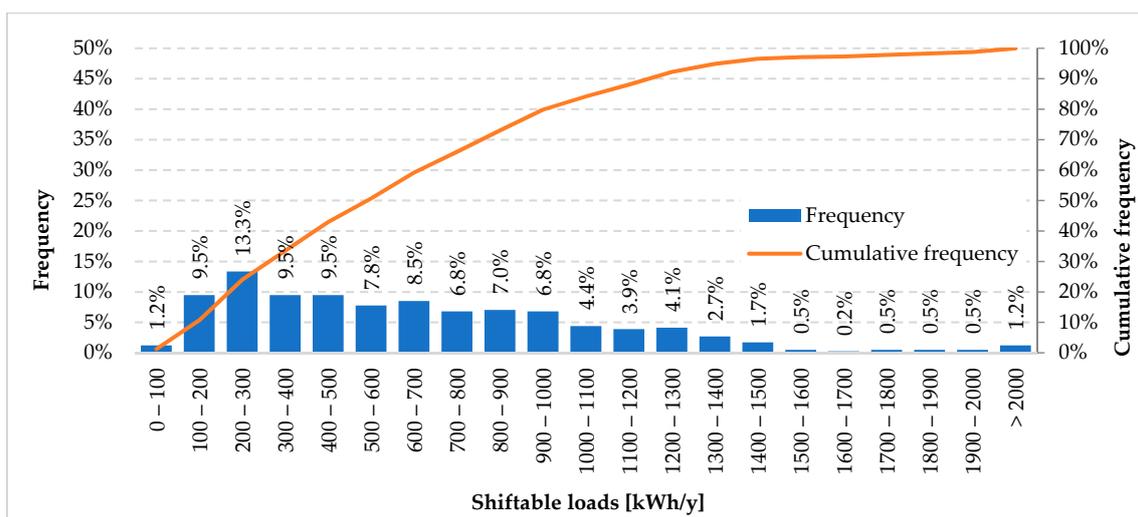


Figure 11. Shiftable loads.

Finally, Figure 12 reports the so-called flexible loads, by adding up the storable loads and the shiftable ones. Therefore, it basically represents the dwellings potential of flexibility showing an average value equal to 1042 kWh/y. Notwithstanding, only 31.6% of homes have the flexible loads value just below 600 kWh/y; 57.3% of homes have the flexible loads lower than 1000 kWh/y, whereas only 12.1% can get amounts higher than 2000 kWh/y.

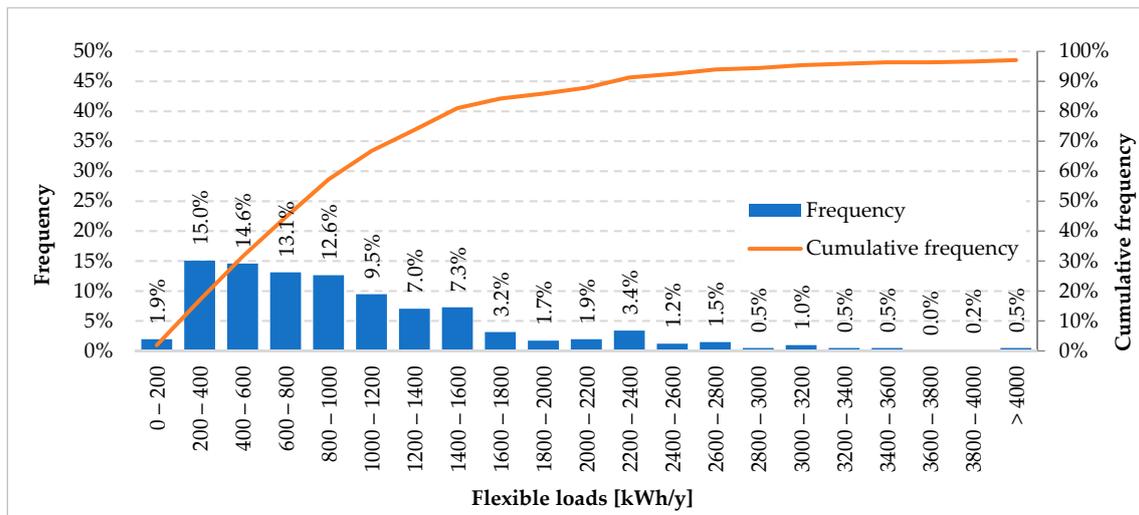


Figure 12. Flexible loads.

### 3.4. Evolutionary Scenarios Hailing from Small Maintenance Interventions

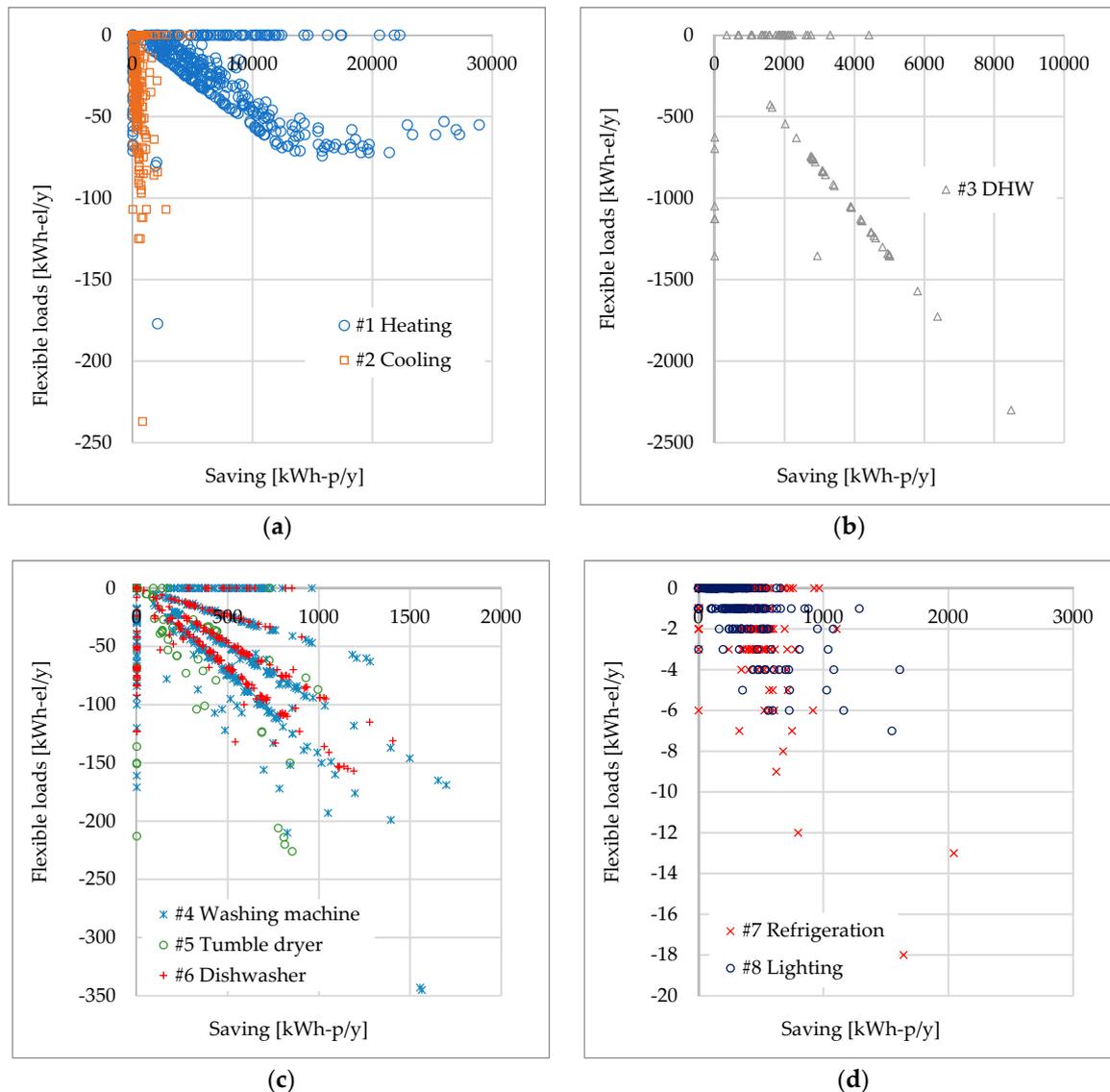
In order to verify the flexible loads temporal stability in the residential sector, eight different evolutionary scenarios have been presented and simulated. Those scenarios take into account multiple small maintenance interventions characterised by low capital expenditure (i.e., lower than 2000 €). In detail, each intervention can be motivated either by the normal equipment change at the end of technical life or by the will to adopt a non-invasive energy requalification. Table 4 summarises all actions that have been accounted for. In all cases, the existing equipment replacement have been simulated having considered the identical ones characterised by enhanced energy performance.

Table 4. Evolutionary Scenarios.

#	Service	Reference Scenario	New Scenario
#1	Heating	Traditional boiler	Condensing boiler
		Condensing boiler	Condensing boiler
		Heat pump	Heat pump–A+++ Class
#2	Cooling	Electric air conditioner	Electric air conditioner–A+++ Class
#3	DHW	Instantaneous water heater	Instantaneous condensing boiler
		Water heater with storage	Condensing boiler with storage
		Electric water heater	Heat Pump water heater
		Heat Pump water heater	Heat Pump water heater
#4	Washing	Washing machine	Washing machine–Same size–A+++ Class
Tumble dryer		Tumble dryer–Same size–A+++ Class	
Dishwasher		Dishwasher–Same size–A+++ Class	
#7	Refrigeration	Existing refrigerator	Refrigerator–Same size–A+++ Class
#8	Lighting	Existing Lamps	LED Lamps

The outcomes of those simulations have been plotted in Figure 13 where the accomplished energy savings are assessed in terms of primary energy, whereas the potential for flexibility in terms of electricity. The graphs show separately the results so as to provide more reading clarity by sorting them in accordance with the loads subdivision presented previously (i.e., storable loads: Heating & Cooling, DHW; shiftable loads: washing; non-shiftable loads: Refrigeration & Lighting). In all cases, it

can be noticed how an energy saving and a reduction in the potential of flexibility occur. Indeed, the application of such interventions leads to the lessening of services energy consumption. That is mainly due to the energy lower needs for heating and cooling services which are also caused by the reduction of internal contributions extent.



**Figure 13.** Changes in potential of flexibility vs. energy savings (as a function of primary energy) related to the evolutionary scenarios: (a) Heating & Cooling; (b) DHW; (c) Washing; (d) Refrigeration & Lighting.

On the basis of those outputs, the average values of energy saving and changes in the potential of flexibility are reported in Table 5. For this latter, the greatest variation occurs for the DHW service (−130 kWh/y), owing to the electric heater replacement by new heat pump water heaters. Similarly, for the washing service high reduction can be achieved (−503 kWh/y), once washing machines, tumble dryers and dishwashers are substituted by their latest versions.

**Table 5.** Energy saving and changes in potential of flexibility: average values.

#	Service	Energy Saving [kWh-p]	Potential of Flexibility Variation [kWh-e]
#1	Heating	6979	−28
#2	Cooling	325	−19
#3	DHW	1927	−130
#4	Washing machine	456	−50
#5	Tumble dryer	60	−14
#6	Dishwasher	262	−32
#7	Refrigeration	417	−1
#8	Lighting	302	0

Essentially, by summing all the reported reductions the overall potential of flexibility difference shrinks up to 273 kWh/y. Indeed, starting from the current value of 1.042 kWh/y, the average value declines to 769 kWh/y.

#### 4. Conclusions

The growing RES share in the Italian electricity system entailed higher balancing features due to the renewables non-programmability. In order to level off as much as possible the demand and production curves, The demand/response program can be beneficial for the electric system by enhancing load flexibility. The application of DR programs to residential users can allow to increase the demand flexibility, facilitating the penetration of renewable energies; however, it shows significant implementation complexities which are mainly represented by the strong loads' fragmentation. Indeed, the Italian building stock consists approximately of 24 millions of dwellings which are poorly electrified in terms of energy carriers. Hence, the flexible loads amount remains generally low for each single unit.

In any case, before proceeding with any DR program application, a data collection phase is needed to characterize the most common user.

This work proposes the use of a data collection questionnaire based on the Excel platform, allowing to estimate the dwelling energy consumption by a real-time simulation. In such a way, the information gathering can be very effective by an immediate data check and by a comparison between simulated outputs, real consumption data and the reference benchmarks.

Compared to other research projects on the same topic, the use of this calculation tool allows to reduce the data uncertainty and reliability. That is the typical drawback which often occurs when the information is provided by non-expert users.

Having said this, from simulations results and the real data analysis the main findings can be summarized as follows:

- the average value of per capita NG consumption is equal to  $368 \text{ Sm}^3/(\text{y} \cdot \text{person})$ ;
- the average value of per capita electricity consumption is equal to  $772 \text{ kWh}/(\text{y} \cdot \text{person})$ ;
- the larger the family members, the lower the per capita NG and electricity consumptions are;
- the average value of NG consumption by floor surface is equal to  $10.6 \text{ Sm}^3/(\text{y} \cdot \text{m}^2)$ ;
- the average value of electricity consumption by floor surface is equal to  $23.9 \text{ kWh}/(\text{y} \cdot \text{m}^2)$ ;
- the specific NG and electricity consumptions by floor surface tend to decline not linearly as the apartment size is larger;
- heating, DHW and cooking services represent the highest fraction in dwellings primary energy consumption which is equal to 70%, approximately;
- the average electrification degree of the statistic sample is limited to 36.5%;

- the flexible loads average value is equal to 1000 kWh/y, whereas only 12.1% of households shows flexible loads higher than 2000 kWh/y;
- minor maintenance interventions lead to lower energy consumptions lessening the potential of flexibility to values beneath 800 kWh/y;

The DR program application to residential users is certainly to be further investigated. On the one hand, the benefits that the electrical system can achieve are evident; on the other hand, the only demand flexibility implementation entails small economic benefits for the individual users, and they should be not interested in participating, thereby.

Yet, investigating on the temporal stability related to the potential of flexibility is recommended, given that the present analysis has shown how it tends to decrease when the most common maintenance interventions are adopted. Additionally, evaluating changes in the potential of flexibility related to residential users it might be interesting once more invasive and expensive refurbishment interventions are adopted. To do so, building envelope, power and heating plants and DHW production systems have to be deeply modified.

In the end, further developments for managing properly the new flexible users consist of studying and testing an affordable and reliable automation device able to communicate rapidly and effectively with the energy spot market as well as with the utilities.

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## References

1. McDonagh, S.; Wall, D.M.; Deane, P.; Murphy, J.D. The effect of electricity markets, and renewable electricity penetration, on the levelised cost of energy of an advanced electro-fuel system incorporating carbon capture and utilisation. *Renew. Energy* **2019**, *131*, 364–371. [[CrossRef](#)]
2. Meza, C.G.; Zuluaga Rodríguez, C.; D’Aquino, C.A.; Amado, N.B.; Rodrigues, A.; Sauer, I.L. Toward a 100% renewable island: A case study of Ometepe’s energy mix. *Renew. Energy* **2019**, *132*, 628–648. [[CrossRef](#)]
3. Paraschiv, F.; Erni, D.; Pietsch, R. The impact of renewable energies on EEX day-ahead electricity prices. *Energy Policy* **2014**, *73*, 196–210. [[CrossRef](#)]
4. Clò, S.; Cataldi, A.; Zoppoli, P. The merit-order effect in the Italian power market: The impact of solar and wind generation on national wholesale electricity prices. *Energy Policy* **2015**, *77*, 79–88. [[CrossRef](#)]
5. Zappa, W.; Junginger, M.; van den Broek, M. Is a 100% renewable European power system feasible by 2050? *Appl. Energy* **2019**, *233–234*, 1027–1050. [[CrossRef](#)]
6. De Santoli, L.; Mancini, F.; Astiaso Garcia, D. A GIS-based model to assess electric energy consumptions and usable renewable energy potential in Lazio region at municipality scale. *Sustain. Cities Soc.* **2019**, *46*, 101413. [[CrossRef](#)]
7. Noussan, M.; Nastasi, B. Data analysis of heating systems for buildings—A tool for energy planning, policies and systems simulation. *Energies* **2018**, *11*, 233. [[CrossRef](#)]
8. IEA. IRENA Perspectives for the Energy Transition: Investment Needs for A Low-Carbon Energy System. Available online: <https://www.irena.org/publications/2017/Mar/Perspectives-for-the-energy-transition-Investment-needs-for-a-low-carbon-energy-system> (accessed on 4 April 2019).

9. Simoes, S.G.; Dias, L.; Gouveia, J.P.; Seixas, J.; De Miglio, R.; Chiodi, A.; Gargiulo, M.; Long, G.; Giannakidis, G. INSMART—Insights on integrated modelling of EU cities energy system transition. *Energy Strategy Rev.* **2018**, *20*, 150–155. [CrossRef]
10. Strbac, G. Demand side management: Benefits and challenges. *Energy Policy* **2008**, *36*, 4419–4426. [CrossRef]
11. Palensky, P.; Dietrich, D. Demand Side Management: Demand Response, Intelligent Energy Systems, and Smart Loads. *IEEE Trans. Ind. Inform.* **2011**, *7*, 381–388. [CrossRef]
12. Mohsenian-Rad, A.-H.; Wong, V.W.S.; Jatskevich, J.; Schober, R.; Leon-Garcia, A. Autonomous Demand-Side Management Based on Game-Theoretic Energy Consumption Scheduling for the Future Smart Grid. *IEEE Trans. Smart Grid* **2010**, *1*, 320–331. [CrossRef]
13. Earle, T.C. Trust, confidence, and the 2008 global financial crisis. *Risk Anal.* **2009**, *29*, 785–792. [CrossRef]
14. Eurostat Database—Eurostat. Available online: <https://ec.europa.eu/eurostat/data/database> (accessed on 4 April 2019).
15. Foteinaki, K.; Li, R.; Heller, A.; Rode, C. Heating system energy flexibility of low-energy residential buildings. *Energy Build.* **2018**, *180*, 95–108. [CrossRef]
16. Balint, A.; Kazmi, H. Determinants of energy flexibility in residential hot water systems. *Energy Build.* **2019**, *188–189*, 286–296. [CrossRef]
17. Issi, F.; Kaplan, O. The determination of load profiles and power consumptions of home appliances. *Energies* **2018**, *11*, 607. [CrossRef]
18. Chen, Y.; Xu, P.; Gu, J.; Schmidt, F.; Li, W. Measures to improve energy demand flexibility in buildings for demand response (DR): A review. *Energy Build.* **2018**, *177*, 125–139. [CrossRef]
19. Castellani, B.; Morini, E.; Nastasi, B.; Nicolini, A.; Rossi, F.; Castellani, B.; Morini, E.; Nastasi, B.; Nicolini, A.; Rossi, F. Small-Scale Compressed Air Energy Storage Application for Renewable Energy Integration in a Listed Building. *Energies* **2018**, *11*, 1921. [CrossRef]
20. Shakouri, G.H.; Kazemi, A. Multi-objective cost-load optimization for demand side management of a residential area in smart grids. *Sustain. Cities Soc.* **2017**, *32*, 171–180. [CrossRef]
21. Tsemekidi Tzeiranaki, S.; Bertoldi, P.; Diluiso, F.; Castellazzi, L.; Economidou, M.; Labanca, N.; Ribeiro Serrenho, T.; Zangheri, P. Analysis of the EU Residential Energy Consumption: Trends and Determinants. *Energies* **2019**, *12*, 1065. [CrossRef]
22. Gaglia, A.G.; Dialynas, E.N.; Argiriou, A.A.; Kostopoulou, E.; Tsiamitros, D.; Stimoniaris, D.; Laskos, K.M. Energy performance of European residential buildings: Energy use, technical and environmental characteristics of the Greek residential sector—Energy conservation and CO<sub>2</sub> reduction. *Energy Build.* **2019**, *183*, 86–104. [CrossRef]
23. Vogiatzi, C.; Gemenetzi, G.; Massou, L.; Pouloupoulos, S.; Papaefthimiou, S.; Zervas, E. Energy use and saving in residential sector and occupant behavior: A case study in Athens. *Energy Build.* **2018**, *181*, 1–9. [CrossRef]
24. Chang, C.; Zhu, N.; Yang, K.; Yang, F. Data and analytics for heating energy consumption of residential buildings: The case of a severe cold climate region of China. *Energy Build.* **2018**, *172*, 104–115. [CrossRef]
25. Sepehr, M.; Eghtedaei, R.; Toolabimoghadam, A.; Noorollahi, Y.; Mohammadi, M. Modeling the electrical energy consumption profile for residential buildings in Iran. *Sustain. Cities Soc.* **2018**, *41*, 481–489. [CrossRef]
26. Laicane, I.; Blumberga, D.; Blumberga, A.; Rosa, M. Evaluation of Household Electricity Savings. Analysis of Household Electricity Demand Profile and User Activities. *Energy Procedia* **2015**, *72*, 285–292. [CrossRef]
27. Shiraki, H.; Nakamura, S.; Ashina, S.; Honjo, K. Estimating the hourly electricity profile of Japanese households—Coupling of engineering and statistical methods. *Energy* **2016**, *114*, 478–491. [CrossRef]
28. Chuan, L.; Ukil, A. Modeling and Validation of Electrical Load Profiling in Residential Buildings in Singapore. *IEEE Trans. Power Syst.* **2015**, *30*, 2800–2809. [CrossRef]
29. Hafeez, G.; Javaid, N.; Iqbal, S.; Khan, F.A. Optimal residential load scheduling under utility and rooftop photovoltaic units. *Energies* **2018**, *11*, 611. [CrossRef]
30. Shirazi, E.; Zakariazadeh, A.; Jadid, S. Optimal joint scheduling of electrical and thermal appliances in a smart home environment. *Energy Convers. Manag.* **2015**, *106*, 181–193. [CrossRef]
31. Ahmad, A.; Khan, A.; Javaid, N.; Hussain, H.M.; Abdul, W.; Almogren, A.; Alamri, A.; Azim Niaz, I.; Ahmad, A.; Khan, A.; et al. An Optimized Home Energy Management System with Integrated Renewable Energy and Storage Resources. *Energies* **2017**, *10*, 549. [CrossRef]
32. Balvedi, B.F.; Ghisi, E.; Lamberts, R. A review of occupant behaviour in residential buildings. *Energy Build.* **2018**, *174*, 495–505. [CrossRef]

33. D'Oca, S.; Hong, T.; Langevin, J. The human dimensions of energy use in buildings: A review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 731–742. [CrossRef]
34. Cali, D.; Andersen, R.K.; Müller, D.; Olesen, B.W. Analysis of occupants' behavior related to the use of windows in German households. *Build. Environ.* **2016**, *103*, 54–69. [CrossRef]
35. Andersen, R.K.; Fabi, V.; Corgnati, S.P. Predicted and actual indoor environmental quality: Verification of occupants' behaviour models in residential buildings. *Energy Build.* **2016**, *127*, 105–115. [CrossRef]
36. Zhao, D.; McCoy, A.P.; Du, J.; Agee, P.; Lu, Y. Interaction effects of building technology and resident behavior on energy consumption in residential buildings. *Energy Build.* **2017**, *134*, 223–233. [CrossRef]
37. Chen, S.; Yang, W.; Yoshino, H.; Levine, M.D.; Newhouse, K.; Hinge, A. Definition of occupant behavior in residential buildings and its application to behavior analysis in case studies. *Energy Build.* **2015**, *104*, 1–13. [CrossRef]
38. ISTAT Italian National Institute of Statistics Edifici Residenziali. Available online: [http://dati-censimentopopolazione.istat.it/Index.aspx?DataSetCode=DICA\\_EDIFICIRES](http://dati-censimentopopolazione.istat.it/Index.aspx?DataSetCode=DICA_EDIFICIRES) (accessed on 4 April 2019).
39. Terna, S.P.A. Consumi Energia Elettrica per Settore Merceologico. Available online: [http://www.terna.it/default/Home/SISTEMA\\_ELETRICO/statistiche/consumi\\_settore\\_merceologico.aspx](http://www.terna.it/default/Home/SISTEMA_ELETRICO/statistiche/consumi_settore_merceologico.aspx) (accessed on 4 April 2019).
40. ENEA-Italian National Agency for Energy Efficiency. Analysis and Results of Energy Efficiency Policies in Italy Energy Efficiency Annual Report. Available online: [www.energiaenergetica.enea.it](http://www.energiaenergetica.enea.it). (accessed on 4 April 2019).
41. Zheng, X.; Wei, C.; Qin, P.; Guo, J.; Yu, Y.; Song, F.; Chen, Z. Characteristics of residential energy consumption in China: Findings from a household survey. *Energy Policy* **2014**, *75*, 126–135. [CrossRef]
42. Shipworth, M. Thermostat settings in English houses: No evidence of change between 1984 and 2007. *Build. Environ.* **2011**, *46*, 635–642. [CrossRef]
43. Guerra Santin, O.; Itard, L.; Visscher, H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy Build.* **2009**, *41*, 1223–1232. [CrossRef]
44. Carpino, C.; Mora, D.; De Simone, M. On the use of questionnaire in residential buildings. A review of collected data, methodologies and objectives. *Energy Build.* **2019**, *186*, 297–318. [CrossRef]
45. Fabbri, K. How to use online surveys to understand human behaviour concerning window opening in terms of building energy performance. *Adv. Build. Energy Res.* **2016**, *10*, 213–239. [CrossRef]
46. Rinaldi, A.; Schweiker, M.; Iannone, F. On uses of energy in buildings: Extracting influencing factors of occupant behaviour by means of a questionnaire survey. *Energy Build.* **2018**, *168*, 298–308. [CrossRef]
47. Ruggieri, G.; Zangheri, P.; Bulgarelli, M.; Pistochini, P.; Ruggieri, G.; Zangheri, P.; Bulgarelli, M.; Pistochini, P. Monitoring a Sample of Main Televisions and Connected Entertainment Systems in Northern Italy. *Energies* **2019**, *12*, 1741. [CrossRef]
48. Divina, F.; Torres, M.G.; Gómez Vela, F.A.; Vázquez Noguera, J.L.V.; Divina, F.; García Torres, M.; Gómez Vela, F.A.; Vázquez Noguera, J.L. A Comparative Study of Time Series Forecasting Methods for Short Term Electric Energy Consumption Prediction in Smart Buildings. *Energies* **2019**, *12*, 1934. [CrossRef]
49. Hu, S.; Yan, D.; Guo, S.; Cui, Y.; Dong, B. A survey on energy consumption and energy usage behavior of households and residential building in urban China. *Energy Build.* **2017**, *148*, 366–378. [CrossRef]
50. Bianco, V.; De Rosa, M.; Scarpa, F.; Tagliafico, L.A. Analysis of energy demand in residential buildings for different climates by means of dynamic simulation. *Int. J. Ambient Energy* **2016**, *37*, 108–120. [CrossRef]
51. Mancini, F.; Cecconi, M.; De Sanctis, F.; Beltotto, A. Energy Retrofit of a Historic Building Using Simplified Dynamic Energy Modeling. *Energy Procedia* **2016**, *101*, 1119–1126. [CrossRef]
52. De Santoli, L.; Mancini, F.; Clemente, C.; Lucci, S. Energy and technological refurbishment of the School of Architecture Valle Giulia, Rome. *Energy Procedia* **2017**, *133*, 382–391. [CrossRef]
53. Mancini, F.; Clemente, C.; Carbonara, E.; Fraioli, S. Energy and environmental retrofitting of the university building of Orthopaedic and Traumatological Clinic within Sapienza Città Universitaria. *Energy Procedia* **2017**, *126*, 195–202. [CrossRef]
54. Suomalainen, K.; Eyers, D.; Ford, R.; Stephenson, J.; Anderson, B.; Jack, M. Detailed comparison of energy-related time-use diaries and monitored residential electricity demand. *Energy Build.* **2019**, *183*, 418–427. [CrossRef]
55. Martinez Soto, A.; Jentsch, M.F. Comparison of prediction models for determining energy demand in the residential sector of a country. *Energy Build.* **2016**, *128*, 38–55. [CrossRef]

56. ISTAT Italian National Institute of Statistics. I consumi energetici delle famiglie. Available online: <https://www.istat.it/it/archivio/142173> (accessed on 4 April 2019).
57. Schweiker, M.; Shukuya, M. Comparison of theoretical and statistical models of air-conditioning-unit usage behaviour in a residential setting under Japanese climatic conditions. *Build. Environ.* **2009**, *44*, 2137–2149. [[CrossRef](#)]
58. Ren, X.; Yan, D.; Wang, C. Air-conditioning usage conditional probability model for residential buildings. *Build. Environ.* **2014**, *81*, 172–182. [[CrossRef](#)]
59. He, X.; Keyaerts, N.; Azevedo, I.; Meeus, L.; Hancher, L.; Glachant, J.M. How to engage consumers in demand response: A contract perspective. *Util. Policy* **2013**, *27*, 108–122. [[CrossRef](#)]
60. Kylili, A.; Fokaides, P.A.; Lopez Jimenez, P.A. Key Performance Indicators (KPIs) approach in buildings renovation for the sustainability of the built environment: A review. *Renew. Sustain. Energy Rev.* **2016**, *56*, 906–915. [[CrossRef](#)]
61. Lanati, F.; Gelmini, A.R. Impatti del dynamic pricing applicato ai consumatori elettrici residenziali. Available online: [http://www.energy-home.it/Documents/2016-MayDynamicPricingBook/160508DynamicPricingBook\\_ExecSummary.pdf](http://www.energy-home.it/Documents/2016-MayDynamicPricingBook/160508DynamicPricingBook_ExecSummary.pdf) (accessed on 4 April 2019).
62. Cicero, F.; Di Gaetano, N.; Speziale, L. I comportamenti di consumo elettrico delle famiglie italiane. *Energ Elettr.* **2010**, *87*, 57–63.
63. Gelmini, A.; Lanati, F.; Polidoro, F.; Vitale, S. Scenari elettro-energetici. Available online: [http://www.rse-web.it/temi.page?docIdType=1&typeDesc=Report&docType\\_1=yes&resultList=yes&RSE\\_manipulatePath=yes&objId=1&RSE\\_originalURI=/temi/sottotema/documenti/2&country=ita](http://www.rse-web.it/temi.page?docIdType=1&typeDesc=Report&docType_1=yes&resultList=yes&RSE_manipulatePath=yes&objId=1&RSE_originalURI=/temi/sottotema/documenti/2&country=ita) (accessed on 4 April 2019).



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