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How Climate Change Affects the Building Energy Consumptions Due to Cooling, Heating, and Electricity Demands of Italian Residential Sector

Francesco Mancini [1,*] **and Gianluigi Lo Basso** [2]

[1] Department of Planning, Design and Technology of Architecture, Sapienza University of Rome, 00197 Rome, Italy

[2] Department of Astronautics, Electrical Energy Engineering, Sapienza University of Rome, 00184 Rome, Italy; gianluigi.lobasso@uniroma1.it

* Correspondence: francesco.mancini@uniroma1.it; Tel.: +39-06-4991-9172

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Abstract: Climate change affects the buildings' performance, significantly influencing energy consumption, as well as the indoor thermal comfort. As a consequence, the growing outdoor environmental temperatures entail a slight reduction in heating consumption and an increase in cooling consumption, with different overall effects depending on the latitudes. This document focuses attention on the Italian residential sector, considering the current and reduced meteorological data, in anticipation of future climate scenarios. According to a sample of 419 buildings, referring to the climatic conditions of Milan, Florence, Rome, and Naples, the heating and cooling needs are calculated by a simplified dynamic model, in current and future conditions. The effects of the simplest climate adaptation measure, represented by the introduction of new air conditioners, have been also evaluated. The simulations results show an important reduction in complex energy consumption (Milan −6%, Florence −22%, Rome −25%, Naples −30%), due to the greater incidence of heating demand in the Italian context. However, the increase in air conditioning electrical consumption over the hot season (Milan +11%, Florence +20%, Rome +19%, Naples +16%) can play a critical role for the electrical system; for that reason, the introduction of photovoltaic arrays as a compensatory measure have been analysed.

Keywords: climate change; residential buildings; cooling demand; heating demand; energy community; sustainable buildings

1. Introduction

Mitigation and adaptation to climate change are key challenges of the 21st century. For this reason the European Union has undertaken numerous initiatives intended to contain its effects in the medium and long term [1–3], highlighting the role of energy saving and RES energy production. Within the Paris Agreement document [4] the role of stakeholders in coping with the climate change is strongly recognised, highlighting also the necessary participation of cities, subnational authorities, civil society, and the private sector as well; all these entities are invited to increase their efforts for supporting several initiatives so as to shrink the pollutants emissions along with the vulnerability to the adverse effects of climate change. To do so, regional and international cooperation have to be promoted as much as possible.

Indeed, the global warming is strongly affecting our environment, enhancing both the frequency and the intensity of the unexpected extreme weather events. In accordance with the IPCC [5] the anthropic activities have already induced an average temperature increase of 1 °C more, compared with those related to the pre-industrial period. As a matter of fact, an almost linear enhancement of 0.2 °C per decade, approximately, has been detected. For that reason, the built environment will face very different climatic conditions from those previously known, which will have a significant impact both on the energy performance of buildings and on human comfort [6].

The correlation between the buildings energy demand and the climate change effects emerged as a crucial research topic in the early 1990s, taking also a run-up over the past two decades; in [7] the impact of climate change in different climate zones was assessed; the authors in [8] explored how the different energy retrofitting interventions have to be effectively identified according to the future climate conditions in Sweden. A statistical survey was used to select the most representative buildings typology to take into account as a reference sample for the investigation purpose. Additionally, the building stock of three different large Swedish cities (i.e., Stockholm, Lund, and Gothenburg) were considered for carrying out the analysis. Thus, the authors in [9] investigated on the suitability of passive climate adaptation measures for reducing the building energy demand associated to both heating and cooling purposes in the residential sector. In that work, a representative terraced house in the Netherlands was used for all the assessments.

Generally, the real estate energy consumption share, over Europe, is equal to 41.7%; specifically, according to data related to 2017 [10], the residential sector alone represents almost 27.2% of total energy consumption; therefore, implementing decarbonisation strategies for that sector could be foreseeable so as to mitigate climate change issues. Indeed, in cold and temperate regions the energy use in buildings is mainly dedicated to supply heat for the inner space.

A general agreement was reached over the past few years. However, mitigation measures are not enough, so that adaptation will be required to offset the global warming impacts which are already inevitable [11]. As far as the construction sector is concerned, these adaptation measures must aim to ensure comfortable indoor conditions despite the increase in outdoor temperatures; nevertheless, one of the greatest challenge consists of progressively reducing the building energy needs, as well as the associated greenhouse gas emissions [12].

Several studies tried to predict the impact of climate change both with reference to the change in consumption and to the need for adaptation. By the use of global climate models (GCM), based on statistical downsizing, it was possible to state that 10% less of energy consumption could be achieved in cold regions due to climate change issues; while 20% more could be registered in the tropical areas, as reported in [13]. Moreover, at mid-latitudes, the primary energy consumption would undergo an inversion, shifting from heating towards cooling purpose. The outcomes reported in [14], dealing with the Icelandic climate, indicated that a 1 °C increase in the average temperatures corresponded to 1.80% less in the annual energy need (compared to the current value for the inner space heating); in [15] the authors assessed the risks of summer overheating in British homes in the form of probability curves by combining a large database of climate projections. With reference to the Dutch climatic conditions [16], even if adaptation measures were foreseen, the simulations outcomes indicated that the total energy demand could decrease by 8%. That is due to a decrease in heating demand greater than the increase in cooling demand. Very different is the situation that could be outlined in a warmer climate such as in Greece; in a very long-term forecast (year 2100), in [17] it was estimated that the demand for energy for heating in the construction sector in Greece could decrease by about 50%, while the respective demand for energy for cooling could increase by 248% up to 2100.

Following the indications of the aforementioned research, this work presents an analysis of the effects of the environmental conditions change on energy consumption in the Italian residential sector. Specifically, a sample of 419 dwellings for residential use has been accounted for, by a survey among the students of the Faculty of Architecture of the Sapienza University of Rome. The analysis has been carried out referring to the climatic data of four Italian cities (Milan, Florence, Rome, Naples) representing the different Italian climatic areas and being significant due to the number of inhabitants.

The work is divided into several phases, starting with a preliminary step where the energy characterization of the sample dwellings is carried out. A second phase of the work is aimed at comparing the energy consumptions related to a standard year with the energy consumption when higher outdoor temperatures occur, considering the existing equipment in the homes; the third phase is aimed at assessing energy consumption taking into account the most immediate adaptation measure, represented by the introduction of additional summer cooling systems.

The fourth conclusive work phase has been developed in a proactive way, proposing a potential solution to figure out the issues emerging from the previous phases. This solution essentially consists of the introduction of a photovoltaic system for the self-generation of the electrical energy necessary for driving the air conditioning systems; as well as the introduction of new air conditioners, in a residential area, the installation of a photovoltaic system appears as one of the easiest measure to implement, due to relatively low costs, short execution times, and the fact that it can be installed without interfering with normal home use. In addition, the modularity of the photovoltaic systems and the widespread nature of the solar resource allows the interventions planning on a vast territorial scale, exceeding either the single dwelling size or the single building one [18–20].

The photovoltaic systems deployment can have very limited impacts, identifying the most suitable places through clear methodologies [21] and promoting the installation on already built areas [22,23], or in any case not suitable for other uses. Furthermore, TPO (third party ownership) or community-shared (CS) business models are spreading, transforming rooftop solar systems into a simple service [24–26].

In terms of energy planning, an extremely interesting role is played by the cooperatives. The overview of energy cooperatives in terms of organization, financing, and participation is broad, and German cooperatives can be an interesting reference [27,28]; local cooperatives can also be designed for the use of new technologies to combine heating and electricity [29]; in general, statistical analyses on the European cooperatives [30] show a good effectiveness of energy efficiency interventions carried out in a REScoop, with a significant reduction (>20%) in energy consumption and harmful gas emissions.

On a wider territorial scale, the fundamental role of cities is widely recognized in the literature; in [31] it was found that on an urban scale, problems can be tackled more effectively by the easier communication with local decision makers; in [32–34] the problem of energy self-sufficiency at municipal level was addressed, identifying solutions to increase the RES share on the electricity consumption; in [35] the possibility of using municipal waste was evaluated, for building envelopes for nZEB; in [36] a methodology was proposed for the preparation of an urban action plan based on carbon footprint assessment related to a city in southern Italy; in other works, the field of study was more limited and reached the neighbourhood scale [37,38].

The main aim of this work is to identify an easy adaptation solution, or rather, a combination of different options, from both technical and economic point of views, for figuring out the main issues associated to the climate change. Moreover, the reported overview by the authors, on the Italian building stock, could represent a useful benchmark for further analyses and comparison with other countries. Yet, the authors believe that their contribution to the knowledge in this field is represented by the application of a new hybrid tool, able to collect the buildings actual consumptions and simulate them at the same time. More specifically, by the use of that online tool, it has been possible to characterise properly a huge number of inhomogeneous buildings. So that, the climate change potential effects on the Italian building sector can be evaluated more accurately, instead of using unlikely data, which very often overestimate the results.

The main findings can be used to make investment decisions for future refurbishment of the building heritage more aware, indicating the priority adaptation measures according to the changed climatic conditions.

The results of this work cannot be generalized to a wider area, since different climates and places will differently affect the energy demand. Thus, it is clear that climate change will have several impacts even within Europe, not to mention the whole world. Therefore, it is the methodology implemented here that can be generalized and applied to different environments and places.

2. Materials and Methods

The future projections of building stock energy consumption, in general, do not provide for an explicit distinction between existing and new buildings; taking into account the buildings average life span, it is clear that the current building stock will have to face the medium-term impacts of climate change in the future.

For that reason, this document analyses the implications of climate change on very large and varied sample buildings, both in terms of size and construction features. The sample consists of 419 dwellings and has been created by the collaboration of the students of the Faculty of Architecture of Sapienza University of Rome (Italy).

Useful information for energy characterization has been collected by the online questionnaire, from September 2018. The survey takes into account the following building parameters: (i) The envelope peculiarities in terms of geographic location, surfaces orientation, envelope components U-value, shading devices and ventilation rate; (ii) plants typology (i.e., heating system, cooling system, domestic hot water (DHW) systems, PV modules, solar collectors); (iii) the most common electric devices along with their typical use time-scheduling (i.e., ovens, cooking planes, refrigerators, washing machines, cleaning and ironing, lighting systems, audio/video, personal care, and other equipment); (iv) the occupants number in terms of times and attendance; finally, the actual electricity and natural gas consumptions data hailing from bills.

The same building sample was used in other recent works of the authors so as to identify what are the flexible loads [39], to analyse the energy retrofitting effects on the potential of flexibility on the grid [40], and to evaluate the impact of building automation control systems on energy performance [41]; Section 3.1 provides a more extensive description of the sample characteristics.

The sample dwellings energy performance can be simulated through the same data collection questionnaire, created in an Excel tool by implementing macros and functions written in VBA (Visual Basic for Applications).

Analysing the literature on that topic, it was observed that generally the energy performance of buildings, aimed at the future projection of energy consumption was carried out using dynamic simulation. In many papers [6,9,16] the simulation was performed using leading software (e.g., TRNSYS, EnergyPlus); in other projects the simulation was performed by calculation procedures developed in-house, [7,42–44] validating those outcomes by a direct comparison with the aforementioned tools.

In that work, the authors used their own calculation code for carrying out their analysis. That simulation tool is based on the single thermal zone modelling and it is able to dynamically analyse the building characteristics and performance. More in detail, the heat balance method (HBM) together with a solver algorithm, conduction finite differences-based (CondFD) [45], have been implemented for figuring out the calculations. The self-developed code allows to get a higher flexibility, as well as the easy way to implement additional tools and calculation options if needed.

To examine the sample buildings behaviour in different climatic conditions, it has been assumed as it was located in four different cities, such as Milan, Florence, Rome, Naples (Figure 1).

In these cities about 9% of the Italian population lives. The four cities are located at different latitudes in Italy (i.e., 45.4774; 43.7874; 41.9109; 40.863, respectively) and have different climatic conditions (i.e., degree days 2.404; 1.821; 1.415; 1.034); these climatic conditions are representative of a large part of the inhabited Italian territory (divided into six climatic zones, according to the number of degree days; Zone A: $DD \leq 600$; Zone B: $600 < DD \leq 900$; Zone C: $900 < DD \leq 1400$; Zone D: $1400 < DD \leq 2100$; Zone E: $2100 < DD \leq 3000$; Zone F: $DD > 3000$).

In the first phase, the buildings energy simulation has been performed considering the standard climate data related to the reference cities [46] in order to provide a preliminary energy characterization.

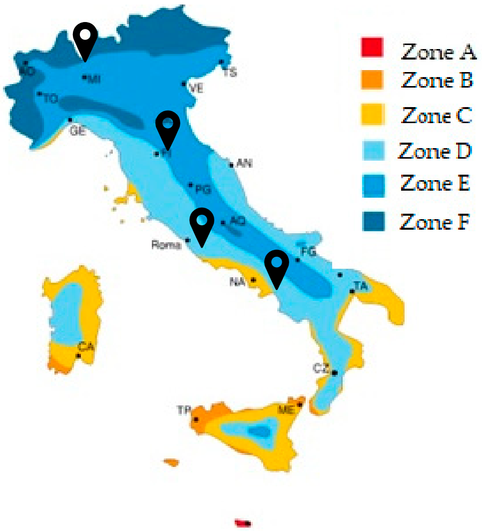


Figure 1. Italian territory climatic areas and the reference cities.

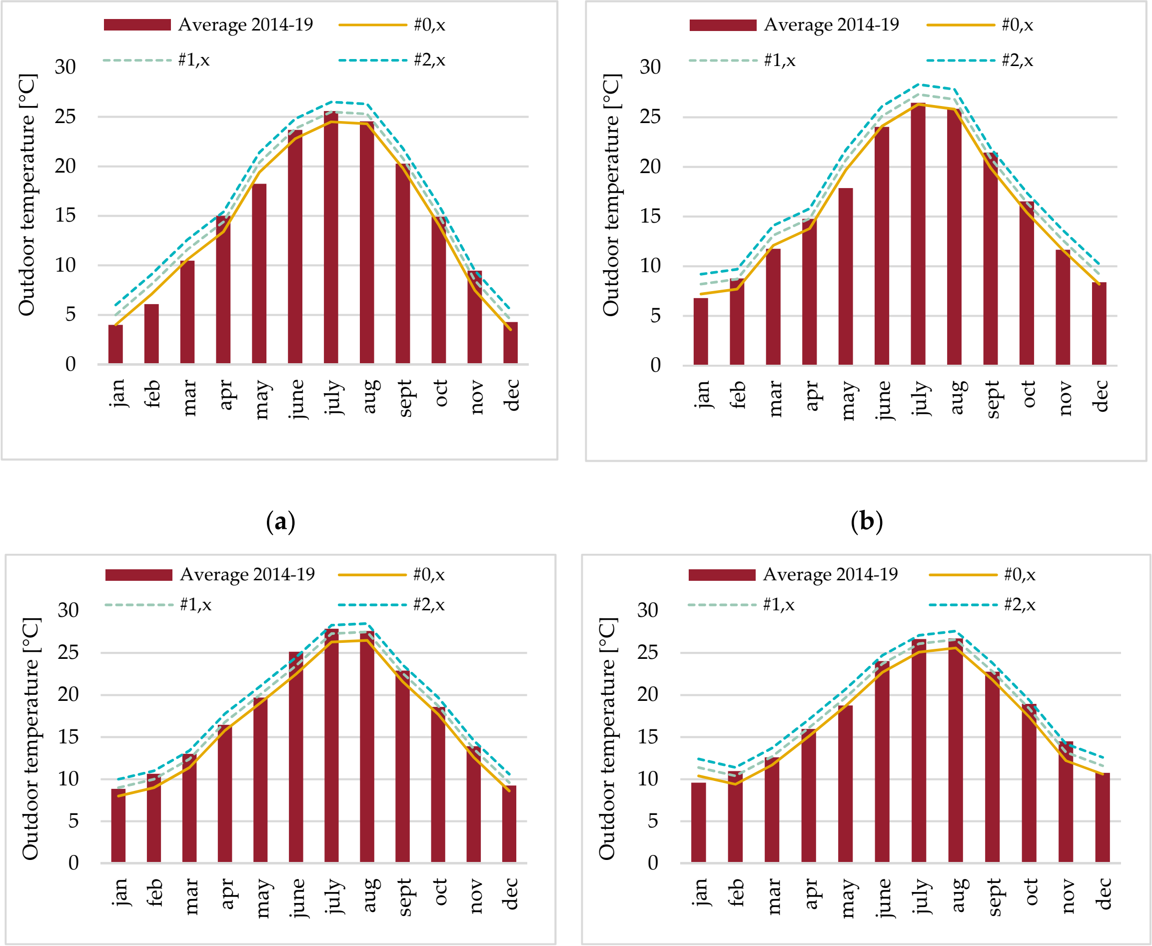
In the second phase, the simulation has been carried out by increasing uniformly the average monthly temperature for all months (+1.0 °C; +2.0 °C), in order to evaluate the effects of these variations on heating and cooling consumptions; those temperature increases have been chosen accounting for the average temperature registered in the last five years in the four sample cities. It is important to highlight that all of simulations consider only the outdoor temperature changes neglecting the relative humidity modifications. These latter, in some cases, can lead to passive solar gains lessening due to the potential fog formation. Anyway, that issue has to be considered depending on the location latitude.

Figure 2 shows the average monthly temperature related to the reference cities, comparing the simulated values with the monthly average values registered in the time span of 2014–2019 [47].

Although the Italian standards are very recent (2016) [46] in the last five years, for all cities, the outdoor temperatures, on average, were higher than the reported ones (i.e., Milan: +0.5 °C; Florence: +0.2 °C; Rome: +1.2 °C; Naples: +1.0 °C). Moreover, what is relevant pertain to the summer average values (June, July, August) of Milan (+0.7 °C), Rome (+1.8 °C), and Naples (+1.2 °C), while for Florence there are no differences referring to the standard values (indeed it being the smallest of the examined cities and it is likely less affected by the heat island effects).

In the third phase, the effects (on cooling consumption) of the simplest and the most widespread adaptation measure, aimed at accomplishing the summer comfort, has been considered. To do so, the installation of small air-to-air cooling systems have been assumed (energy label A++). In detail, the introduction of further new air conditioners (i.e., +1; +2) have been fixed, in addition to the existing ones; furthermore, an upper limit has been assumed for the total number of air conditioners, having considered one unit for each 20 m^2 of floor surface. It is worth noticing how in this work the small retrofitting interventions have been considered. Such measures consist of technical options entailing a capital expenditure less than 2000 €. For that reason, other refurbishment interventions on older buildings have not been accounted for (i.e., reduction of U-value of building envelope and roof). Moreover, for the same economic reason, the new cooling system installation along with a ventilation one for the whole flat have been neglected and, consequently, they have not been analysed.

Table 1 shows a summary of the simulated scenarios.



(**a**) (**b**)

(**c**) (**d**)

Figure 2. Comparison between simulated data and the climate average data related to years 2014–2019; (**a**) Milan; (**b**) Florence; (**c**) Rome; (**d**) Naples.

Table 1. Simulated scenarios.

#	Climate Data	System Equipment
#0.0 #0.1 #0.2	Italian Standard UNI 10349	Existing equipment Existing equipment + 1 air conditioner Existing equipment + 2 air conditioners
#1.0 #1.1 #1.2	Italian Standard UNI 10349 + 1.0 °C	Existing equipment Existing equipment + 1 air conditioner Existing equipment + 2 air conditioners
#2.0 #2.1 #2.2	Italian Standard UNI 10349 + 2.0 °C	Existing equipment Existing equipment + 1 air conditioner Existing equipment + 2 air conditioners

The fourth phase, provides, in a proactive way, a potential solution to the problems hailing from the average outdoor temperature increase; that solution essentially consists of the installation of new photovoltaic systems to compensate the greater electricity demand over the hot season. The required gross surface on the roof for PV modules installation, including the distance to avoid the mutual shading, have been computed using the average indicator equal to 19.8 m^2/kW [48,49]. Thus, the yearly

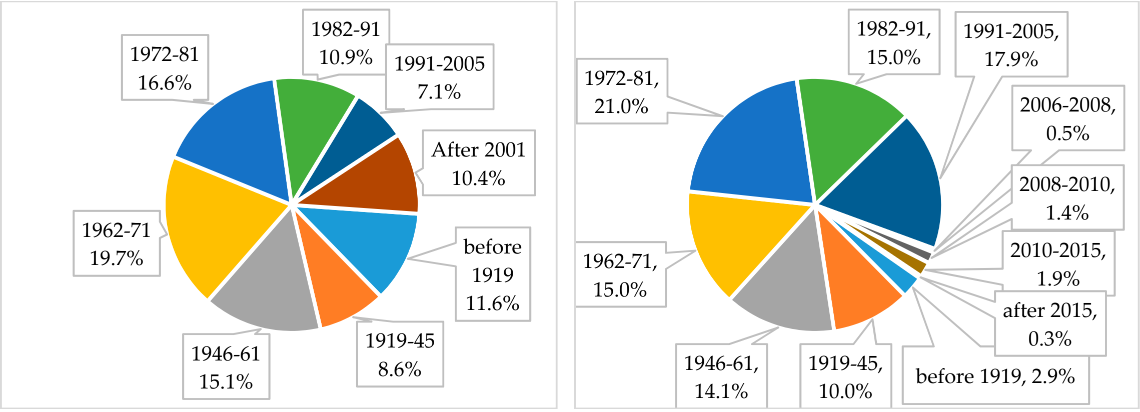
PV capability have been calculated using the online tool PVGIS developed by a previous European Commission program [50].

3. Results and Discussion

3.1. Dwellings Description and General Analysis on Consumptions Typology

The sample buildings consists of 419 dwellings with uneven characteristics in terms of construction year, size, and occupation rate [39].

Referring to the construction year classification, the sample buildings composition is basically equal to the Italian building stock one. Thus, it has been decided to subdivide all those periods after 1991 differently from what was reported by the National Institute of Statistics [51,52]; indeed, in Italy starting from 1991 several regulations dealing with energy saving in the residential sector were promoted subsequently (see Figure 3).



(**a**) (**b**)

Figure 3. Buildings' subdivision sorted by the construction age: (**a**) Italian stock; (**b**) sample buildings.

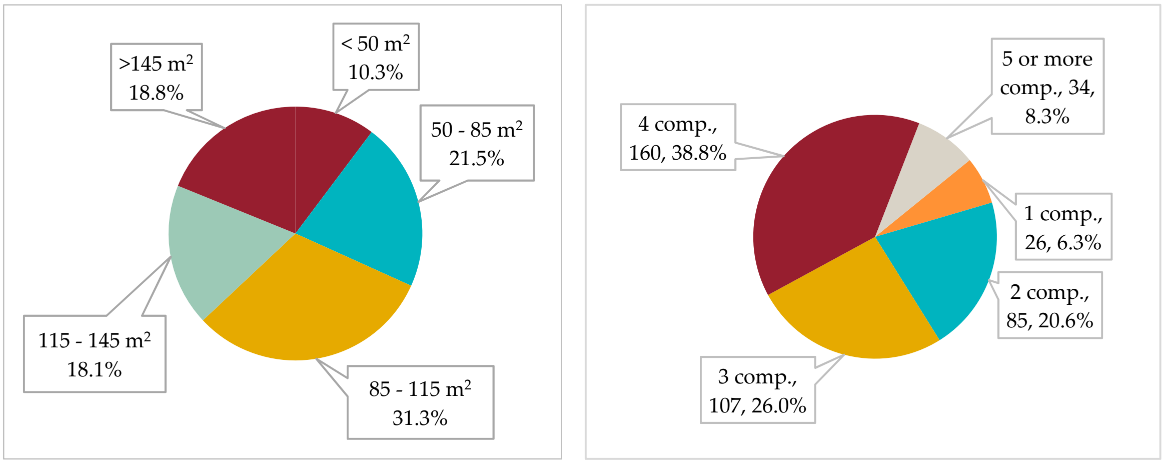
All of the dwelling's characteristics registration has been made by the use of a specific questionnaire survey dedicated to nonexpert users as well (see Appendix A, Table A1). The typical building technical parameters, such as U-value, thermal inertia, etc., have been deduced from the construction age, the climate zone, and the potential energy refurbishment interventions. Moreover, the solar gains have been evaluated taking into account the walls and roofs colour (i.e., very light colour, light colour, medium colour, dark colour, very dark colour), as well as the shading degree in terms of time periods over the day.

Additionally, Figure 3 shows how the larger part (64.1%) of the sample buildings dates back to 1976, since just in that year the Italian Government issued the first version of a technical specification for improving the buildings energy saving; only 17 flats (4.1%) were built more recently, i.e., after 2005 (Table 2). More than one half of sample buildings (55.1%) underwent light refurbishment interventions, which most frequently consisted of windows substitution (47.0%).

Table 2. The sample buildings subdivision by construction years and retrofitted building components.

Building Construction Year	N° and Fraction	Retrofitted Building Components			
		Walls	Roofs	Floors	Windows
before 1919	12 (2.9%)	0 (0%)	0 (0%)	0 (0%)	5 (41.7%)
1919–1945	42 (10%)	2 (4.8%)	2 (4.8%)	3 (7.1%)	29 (69%)
1946–1961	59 (14.1%)	6 (10.2%)	8 (13.6%)	1 (1.7%)	46 (78%)
1962–1971	63 (15%)	8 (12.7%)	7 (11.1%)	3 (4.8%)	29 (46%)
1972–1981	88 (21%)	13 (14.8%)	13 (14.8%)	5 (5.7%)	44 (50%)
1982–1991	63 (15%)	6 (9.5%)	7 (11.1%)	4 (6.3%)	27 (42.9%)
1991–2005	75 (17.9%)	16 (21.3%)	14 (18.7%)	9 (12%)	13 (17.3%)
2006–2008	2 (0.5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
2008–2010	6 (1.4%)	2 (33.3%)	1 (16.7%)	0 (0%)	2 (33.3%)
2010–2015	8 (1.9%)	4 (50%)	4 (50%)	3 (37.5%)	2 (25%)
after 2015	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Total	419 (100%)	57 (13.6%)	56 (13.4%)	28 (6.7%)	197 (47%)

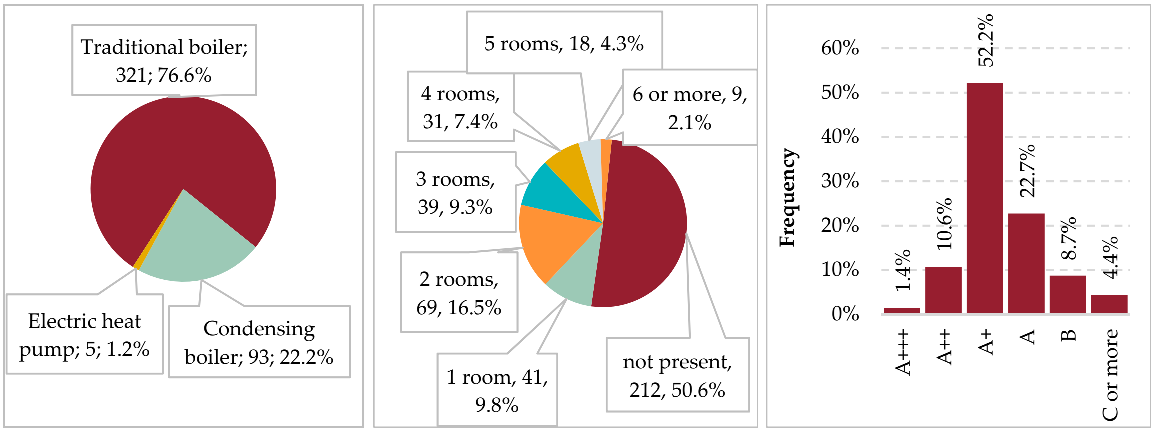
From data analysis, five building dimensional classes, in terms of floor surface, have been identified, so that Figure 4a outlines their frequency within the sample. Specifically, small dwellings are characterised by a floor surface lower than 50 m^2, the small-medium class refers to 50–85 m^2, the medium one to 85–115 m^2, while the medium-large class ranges in 115–145 m^2. Finally, all those dwellings larger than 145 m^2 have been considered the upper class. By averaging data it emerges how the most common class is the medium one since the average floor surface is equal to 112.4 m^2. Moreover, 38.8% of building sample are occupied by four people, while 26.0% by three people, and 20.6% by two people, as reported in Figure 4b. That entails an average occupants' number equal to 3.2.



(**a**) (**b**)

Figure 4. Buildings' subdivision: (**a**) Household vs. size; (**b**) household vs. family components.

The heating system along with the domestic hot water production device has been installed in all dwellings sample. The main typology consists of autonomous boilers (73.3%) which are mostly fuelled with natural gas (98.8%). With regards to domestic hot water production systems, natural gas is still the main feeding fuel (85.4%), since those devices are very often integrated within the aforementioned boilers (see Figure 5a). Then, the heat emission terminals consists typically of radiators (95.9%) while low temperature devices, such as fan-coils and radiant floors, have been registered only in a few cases, representing only 1.5% and 2.7%, respectively.



(**a**) (**b**) (**c**)

Figure 5. Equipment: (**a**) Heating systems typology; (**b**) chilled rooms; (**c**) energy label of cooling system.

In the end, fixed chillers for inner space cooling have been installed only in 207 dwellings showing that the deployment of those devices is limited to 49.4%. Specifically, only few rooms are served by split units and they are characterised also by high values in energy label, since they have been installed recently, as reported in Figure 5c. Indeed, more than 65% of them have an efficiency class equal to or greater than class A+. Thereafter, only in 77 dwellings (18.4%) there are portable equipment such as fans or dehumidifiers.

During the simulation process, the reference value for the indoor comfort temperature in the summertime has been fixed equal to 26 °C. Beyond that threshold and depending on the occupants' number, the chilling units will be switched-on. Notwithstanding, due to climate change effects, discomfort conditions will occur in a huge number of Italian dwellings, since cooling devices are not widespread as stated above. For that reason, the installation of further new air conditioners have been hypothesised, in the present analysis, as the easiest adaptation measure to overcome those features.

The spreading out of both heating and cooling systems in the sample buildings is similar to that was reported in the ISTAT survey on household energy consumption [53]; that document also reports the diffusion of system types on the Italian territory according to the area (North-West, North-East, Middle Regions, South); in regards to cooling systems, the document reported an average diffusion of 70.8%, with weak variations at territorial level (North 66.5%; South 67.8%; Middle Regions 76.0%), apparently not influenced by climatic conditions.

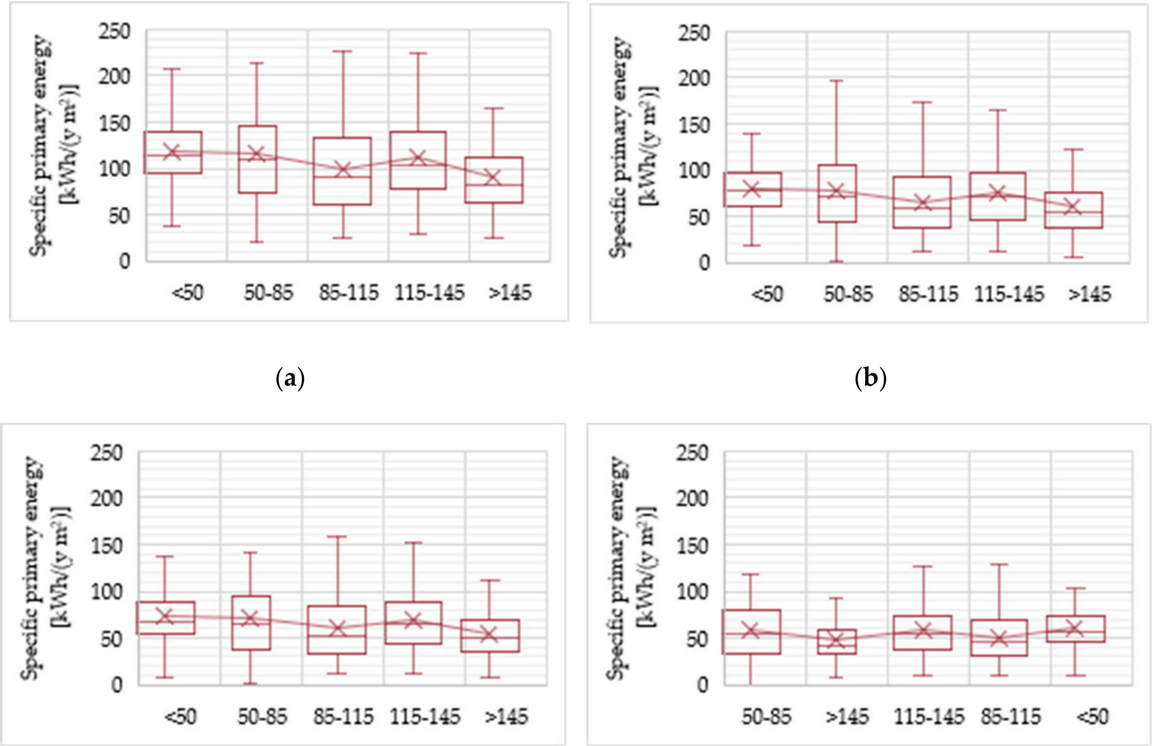
The energy characterization reported in [39] shows that energy consumption for the inner space heating is on average equal to 43.5% of the total; energy consumption for cooling, in dwellings where the service is present, is on average 3.6%; the other services have a total incidence of 52.9% characterised by relative shares equal to 14.1% for DHW, 12.4% for cooking purpose, 5.6% for washing machines, and 4.1% for computer/Internet refrigeration 3.8%; thereafter the cleaning and ironing use represents only 3.5% while the care person lighting, audio/video, and the other equipment are equal to 2.9%, 2.7%, 1.8%, and 1.9%, respectively. For more information on the building sample characteristics and its energy characterization see [39–41].

It is important to highlight that the calculation tool validation has been carried out comparing the simulation results with the real consumption data hailing from the energy bills [39]. Furthermore, the predictive model is characterised by high values of correlation coefficient R^2, i.e., 0.8993 for the electricity needs and 0.7716 for the natural gas volumes.

3.2. Energy Characterization of Dwellings in the Four Considered Cities

Considering the standard climatic data of the four cities, simulations have been performed to identify the heating consumption, cooling, and other services; in the following charts, the buildings are grouped by dimensional classes, in order to verify any differences depending on the size; the results are expressed in the form of primary energy and are normalised by the floor surface.

With regards to heating consumption (Figure 6), for the reference cities and accounting for the different size, no significant modifications are observed, except for a slightly lower specific consumption for larger flats.



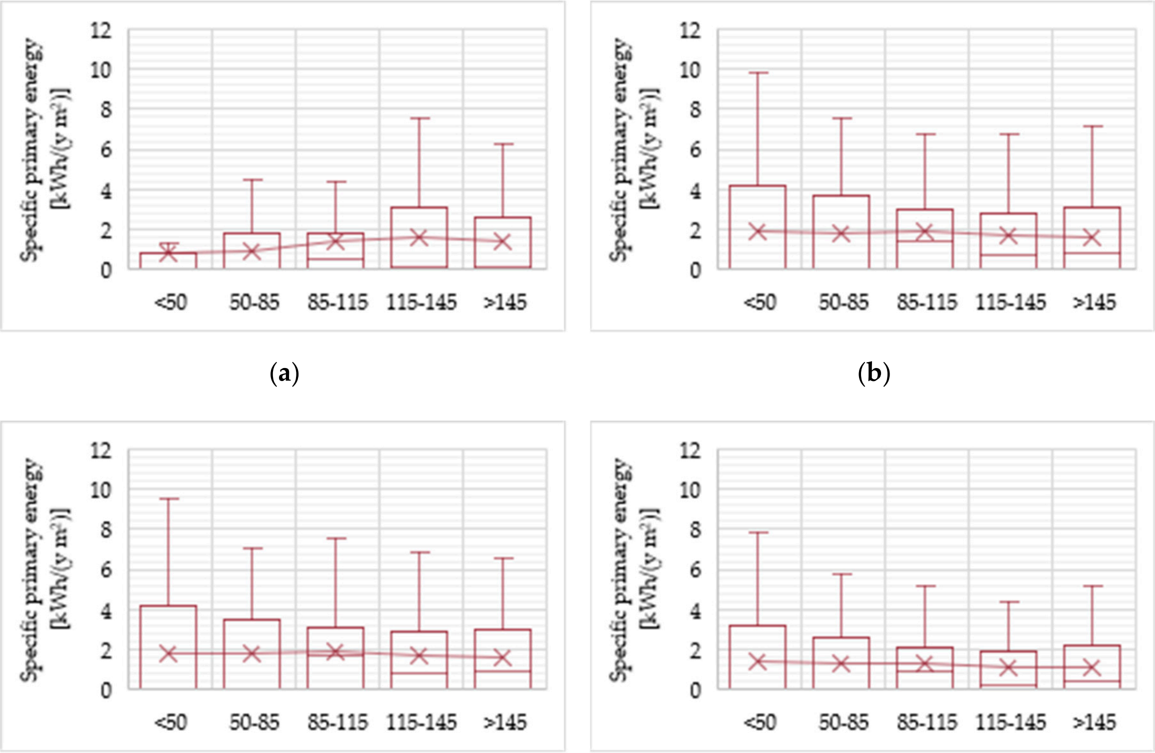
(**a**) (**b**)

(**c**) (**d**)

Figure 6. Specific consumption of primary energy for heating—Scenario #0. (**a**) Milan; (**b**) Florence; (**c**) Rome; (**d**) Naples.

Nevertheless, a noncontinuous trend has been registered. Furthermore, as it was expected, specific heating consumption is strongly influenced by the degree days; Milan has the highest consumption, on average equal to 105.0 kWh/ym^2; whilst Florence (70.5 kWh/ym^2), Rome (64.1 kWh/ym^2), Naples (54.5 kWh/ym^2).

Similarly, with reference to cooling consumption (Figure 7), having considered the different size, no significant variations are observed, except for a slightly lower specific consumption for larger flats. In that case too, a trend that is not continuous has been found, except for Milan. However, a weaker dependence of energy consumption on the cities geographical location can be noticed (Milan 1.3 kWh/ym^2; 1.8 kWh/ym^2; Rome 1.8 kWh/ym^2; Naples 1.3 kWh/ym^2).



(**a**) (**b**)

(**c**) (**d**)

Figure 7. Specific consumption of primary energy for cooling—Scenario #0. (**a**) Milan; (**b**) Florence; (**c**) Rome; (**d**) Naples.

Referring to the charts depicted in Figure 7, it is worth noticing that only 49.4% of the buildings sample are equipped with cooling systems. Moreover, the values shown there include the dwellings without a system, where consumption is necessarily equal to zero.

For the other energy consumptions (Figure 8), a decreasing trend can be noted, starting from the smaller flats (120.0 kWh/ym^2) to the larger ones (55.0 kWh/ym^2); from a geographical point of view there are no relevant variations. It is important to point out that the other energy uses, in this model, are not influenced by the climatic conditions and therefore, in this study, they have been considered constant for all the examined scenarios.

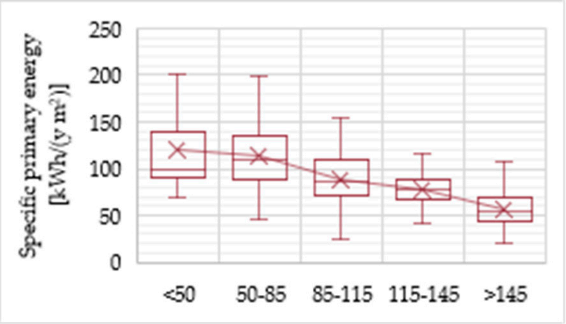


Figure 8. Specific consumption of primary energy for other services.

According to the previous statements, the impact of heating and cooling needs on the dwelling energy consumption are summarised in Figure 9; this incidence varies according to the location and the house size; the heating consumption in Milan has a variable incidence ranging between 49.4% and

61.0%; in Florence that span is limited to 40.2% and 51.1%; in Rome it is comprised between 37.9% and 48.9%; finally, in Naples, the range is equal to 34.2–45.6%. The incidence of cooling energy consumption is much lower (Milan 0.4% ÷ 1.0%; Florence 1.0 % ÷ 1.4%; Rome 1.0% ÷ 1.4%; Naples 0.8% ÷ 1.1%).

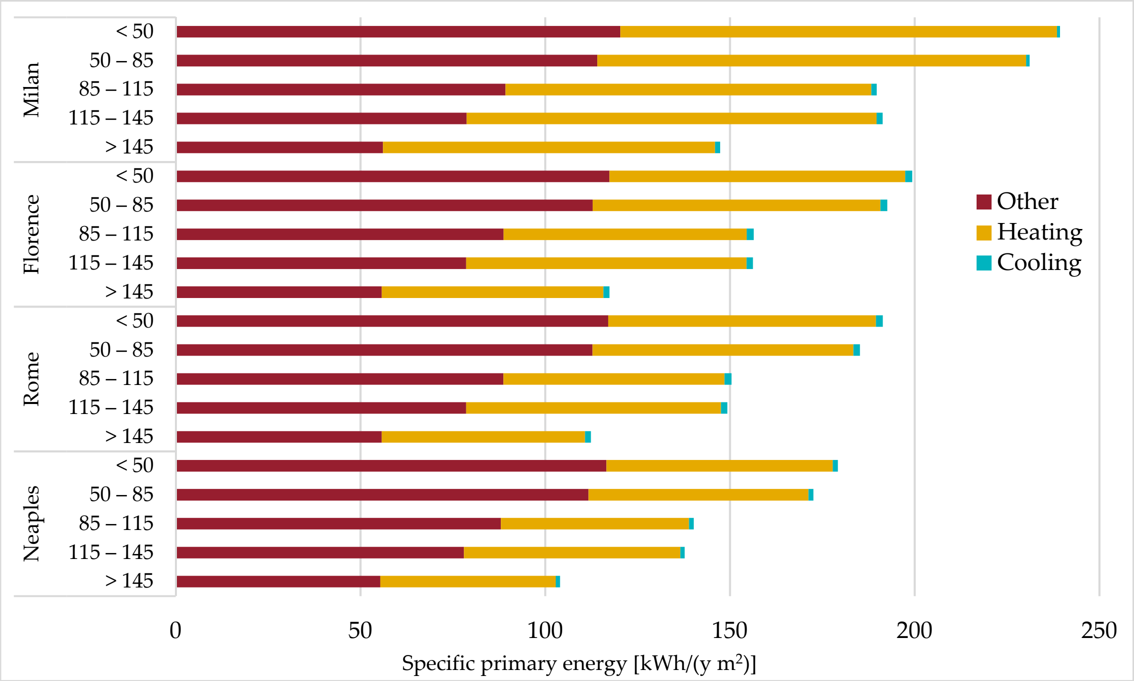


Figure 9. Specific primary energy consumption for heating, cooling, and other.

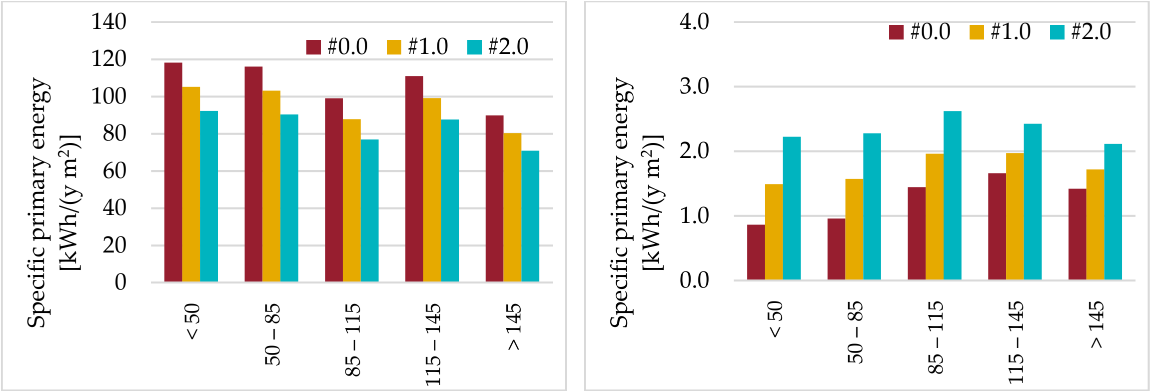
3.3. Changes in Heating and Cooling Energy Consumption Due to Temperature Enhancement

This section illustrates the simulations results to identify variations associated to heating and cooling energy consumption caused by the outdoor temperature, once average increases equal to 1 °C (scenario #1.0) and 2 °C (scenario #2.0) are assumed.

For Milan, referring to the heating consumption (Figure 10a) in scenario #1.0 there is a reduction of 11.0%, while in scenario #2.0 the reduction is equal to 21.8%; the difference related to the dwelling size are minimal. Conversely, considering the cooling consumption (Figure 10b) in scenario #1.0 there is an increase of 35.4%, while in scenario #2.0 the increase is equal to 79.9%; the enhancement is larger for small houses (scenario #1.0 + 72.8%; scenario #2.0 + 158.0%) and smaller for large houses (#1.0 + 21.0%; #2.0 + 48.9%).

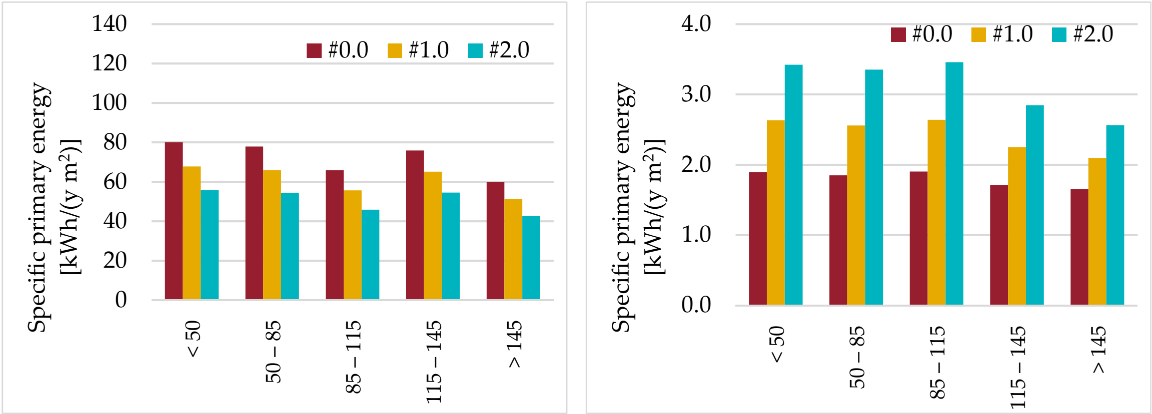
For the city of Florence, considering the heating consumption (Figure 11a) in scenario #1.0 there is a reduction of 15.0%, while in scenario #2.0 it is equal to 29.6%; the difference related to the house size are minimal. Considering the cooling consumption (Figure 11b) in scenario #1.0 there is an increase of 34.8%, while in scenario #2.0 the increase is equal to 73.6%; compared to the Milan data, smaller variations are registered depending on the floor surface; however, the increase is larger for small houses (#1.0 + 38.8%; #2.0 + 80.5%) and it is smaller for large houses (#1.0 + 26.7%; #2.0 + 54.8%).

For Rome, considering the heating consumption (Figure 12a) in scenario #1.0 there is a reduction of 15.9%, while in scenario #2.0 it is equal to 31.0%; the difference according to the dwelling size are minimal. On the contrary, referring to the cooling consumption (Figure 12b) in scenario #1.0 there is an increase of 32.1%, while 71.0% more can be achieved in scenario #2.0; furthermore, limited variations are registered when the dwelling size changes: The increase is larger for small houses (#1.0 + 35.5%; #2.0 + 78.0%) and smaller for large houses (#1.0 + 24.3%; #2.0 + 53.9%).



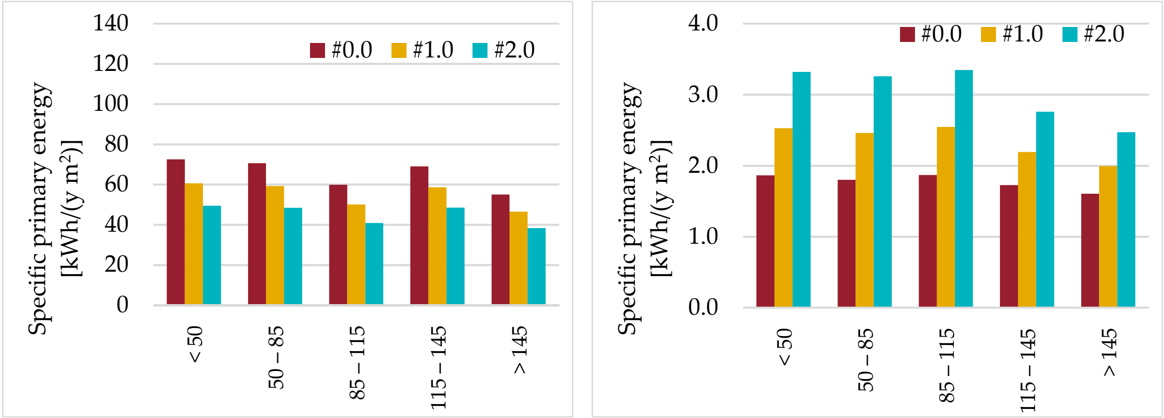
(**a**) (**b**)

Figure 10. Milan: Specific primary energy consumption. (**a**) Heating; (**b**) cooling.



(**a**) (**b**)

Figure 11. Florence: Specific primary energy consumption. (**a**) Heating; (**b**) cooling.



(**a**) (**b**)

Figure 12. Rome: Specific primary energy consumption. (**a**) Heating; (**b**) cooling.

Finally, referring to Naples, the heating consumption (Figure 13a) lessens up to 16.6% in scenario #1.0, while in scenario #2.0 that reduction is equal to 33.1%; the dwelling floor surface affects weakly the differences. With regards to the cooling consumption (Figure 13b), there is an increase of 45.2% in scenario #1.0, while 101.3% is accomplished in scenario #2.0; also in this case the floor surface values lead to limited variations: The increase is larger for small houses (#1.0 + 48.9%; #2.0 + 108.5%) and smaller for large houses (#1.0 + 33.9%; #2.0 + 76.0%).

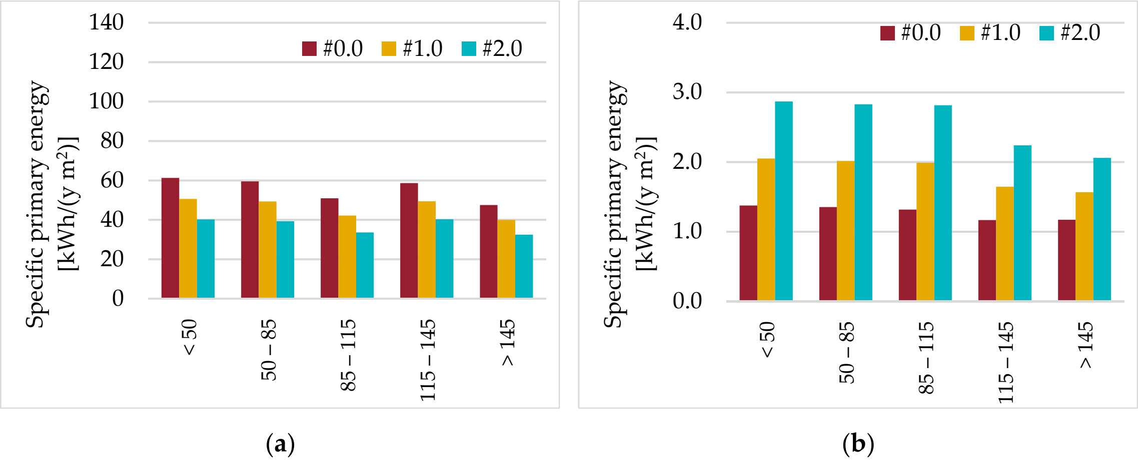


Figure 13. Naples: Specific primary energy consumption. (**a**) Heating; (**b**) cooling.

As it was expected, the simulation results show a reduction in heating consumption and an increase in cooling consumption. Basically, it is possible to state that heating consumption tends to decrease, while cooling consumption grows up, and they are not strongly influenced by floor surface. Indeed, the percentage reductions in the cold season are strictly related to the location and are smaller where the degree days are greater. More generally, the percentage reductions are very similar for all case studies except for Naples, where they are higher.

3.4. Change in Cooling Energy Consumption with the Addition of Air Conditioners

This section illustrates the simulations results to identify the enhancement of cooling energy need, when outdoor environmental conditions change. Six different scenarios have been built once average temperature increases equal to 1 and 2 °C are implemented along with an additional air conditioner (scenarios #0.1, #1.1, #2.1) or two air conditioners (scenarios #0.2, #1.2, #2.2); the variations in cooling consumption, with the existing equipment, (scenarios #0.0, #1.0, #2.0), have been already examined in the previous section and are reported here for convenience of reading (Figures 13a, 14a, 15a and 16a).

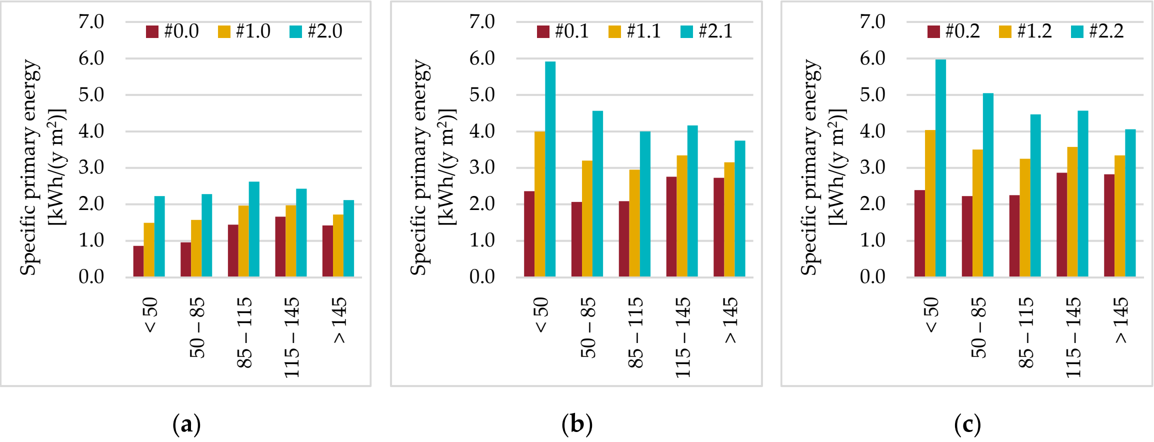
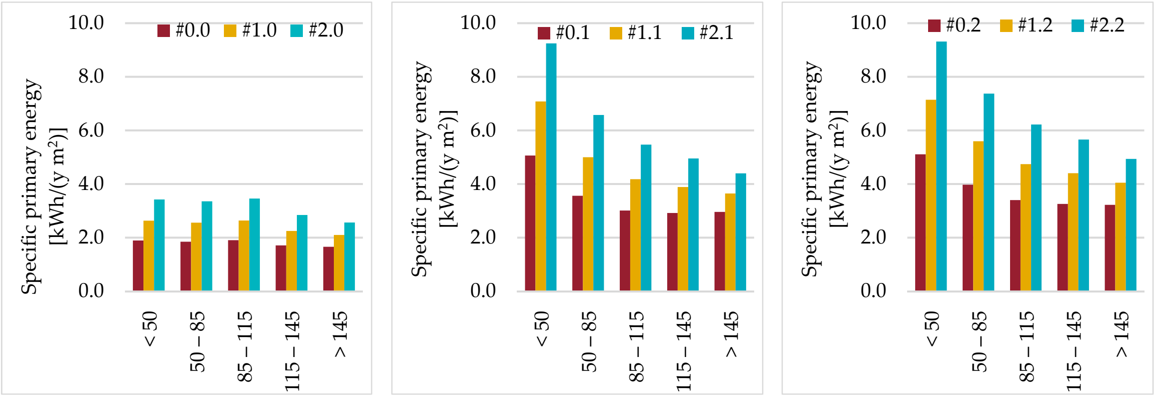
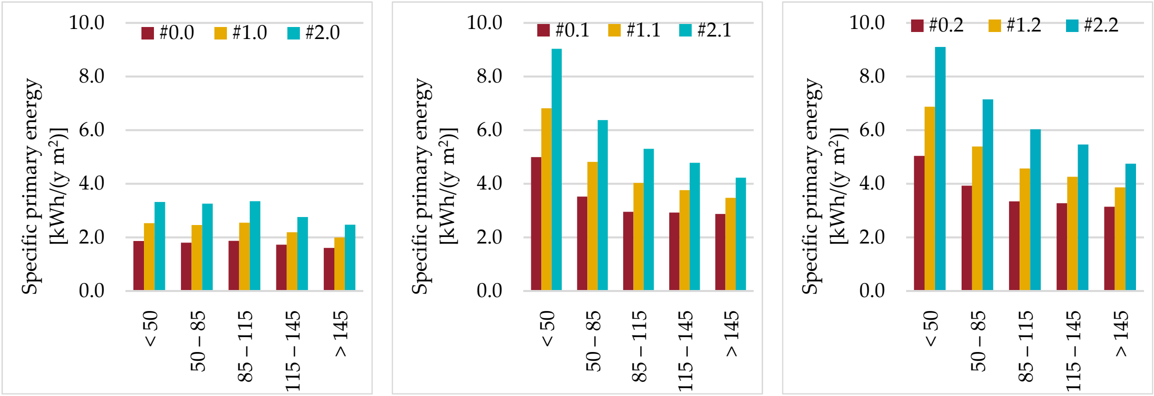


Figure 14. Milan: Specific primary energy consumption for cooling. (**a**) Existing equipment; (**b**) existing equipment + 1 air conditioner; (**c**) existing equipment + 2 air conditioners.



(**a**) (**b**) (**c**)

Figure 15. Florence: Specific primary energy consumption for cooling. (**a**) Existing equipment; (**b**) existing equipment + 1 air conditioner; (**c**) existing equipment + 2 air conditioners.



(**a**) (**b**) (**c**)

Figure 16. Rome: Specific primary energy consumption for cooling. (**a**) Existing equipment; (**b**) existing equipment + 1 air conditioner; (**c**) existing equipment + 2 air conditioners.

For Milan (Figure 14), the main findings are listed below:

- For small houses in scenario #0.0 the consumption for cooling is equal to 0.9 kWh/ym^2; in scenario #2.1 they are 5.9 kWh/ym^2; in scenario #2.2 they are 6.0 kWh/ym^2; percentage variations are equal to 556% and 567%, respectively;
- For large dwellings in scenario #0.0 the consumption for cooling is equal to 1.4 kWh/ym^2; in scenario #2.1 they are 3.7 kWh/ym^2; in scenario #2.2 they are equal to 4.1 kWh/ym^2; the percentage variations rise up to 164% and 193%, respectively;
- On average in scenario #0.0 the consumption for cooling is equal to 1.3 kWh/ym^2; in scenario #2.1 they are equal to 4.3 kWh/ym^2; in scenario #2.2 they are 4.7 kWh/ym^2; the relative variations are 231% and 262%, respectively.

For Florence case study (Figure 15):

- For small dwellings in scenario #0.0 the consumption for cooling is 1.9 kWh/ym^2; in scenario #2.1 they are equal to 9.2 kWh/ym^2; in scenario #2.2 they are equal to 9.3 kWh/ym^2; percentage variations are equal to 384% and 389%, respectively;
- For large dwellings in scenario #0.0 the consumption for cooling is equal to 1.7 kWh/ym^2; in scenario #2.1 they are 4.4 kWh/ym^2; in scenario #2.2 they are 4.9 kWh/ym^2; percentage variations rise up to 159% and 188%, respectively;

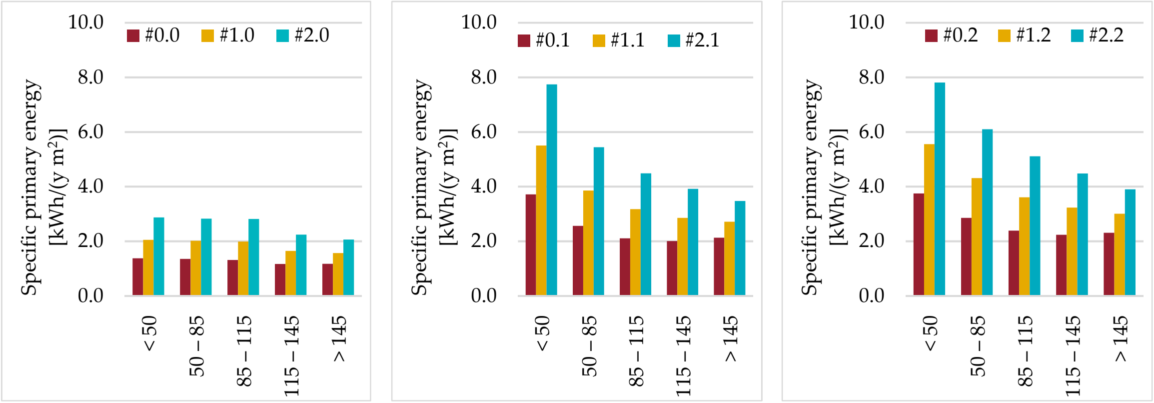
- On average in scenario #0.0 the consumption for cooling is equal to 1.8 kWh/ym^2; in scenario #2.1 they are 5.8 kWh/ym^2; in scenario #2.2 they are equal to 6.4 kWh/ym^2; relative variations are 222% and 256%.

For Rome case study (Figure 16):

- For small dwellings in scenario #0.0 the consumption for cooling is 1.9 kWh/ym^2; in scenario #2.1 they are 9.0 kWh/ym^2; in scenario #2.2 they are 9.1 kWh/ym^2; percentage variations are equal to 374% and 379%, respectively;
- For large dwellings in scenario #0.0 the consumption for cooling is 1.6 kWh/ym^2; in scenario #2.1 they are 4.2 kWh/ym^2; in scenario #2.2 they are 4.7 kWh/ym^2; percentage variations rise up to 163% and 194%, respectively;
- On average in scenario #0.0 the consumption for cooling is equal to 1.8 kWh/ym^2; in scenario #2.1 they are equal to 5.6 kWh/ym^2; in scenario #2.2 they are 6.2 kWh/ym^2; relative variations are 211% and 244%, respectively.

For Naples case study (Figure 17):

- For small houses in scenario #0.0 the consumption for cooling is 1.4 kWh/ym^2; in scenario #2.1 they are equal to 7.7 kWh/ym^2; in scenario #2.2 they are 7.8 kWh/ym^2; percentage variations are equal to 450% and 457%, respectively;
- For large dwellings in scenario #0.0 the consumption for cooling is 1.2 kWh/ym^2; in scenario #2.1 they are equal to 3.5 kWh/ym^2; in scenario #2.2 they are equal to 3.9 kWh/ym^2; percentage variations rise up to 192% and 225%;
- On average in scenario #0.0 the consumption for cooling is equal to 1.3 kWh/ym^2; in scenario #2.1 they are 4.7 kWh/ym^2; in scenario #2.2 they are equal to 5.2 kWh/ym^2; relative variations are 262% and 300%.



(**a**) (**b**) (**c**)

Figure 17. Naples: Specific primary energy consumption for cooling. (**a**) Existing equipment; (**b**) existing equipment + 1 air conditioner; (**c**) existing equipment + 2 air conditioners.

In all case studies and scenarios, the simulations outcomes show important variations in cooling consumption owing to temperature changes and to the installation of further air conditioner; this latter, entails a moderate increase in energy consumption, with significant effects only for large houses.

In percentage terms, when temperature profiles shift up of 2 °C and two additional air conditioners are considered, variation values exceed 350% for small houses and 150% for the large ones; on average such variations range between 211% and 300%. In absolute terms, the energy consumption associated to the cooling needs still remains low, showing also a modest impact on the overall consumption.

3.5. Change in Overall Energy Consumption for Simulated Scenarios

In this section a comprehensive overview of simulations results has been presented and discussed; specifically, Table 3 shows the total primary energy consumption, by summing the primary energy consumption for heating, cooling, and for other uses; for each simulated scenario, the relative change compared to the reference scenario #0.0 is reported as well.

Table 3. Summary of specific primary energy consumption for all simulated scenarios.

City	Scenario	<50 m^2		50–85 m^2		85–115 m^2		115–145 m^2		>145 m^2	
		(kWh/ym^2)	(%)	(kWh/ym^2)	(%)	(kWh/ym^2)	(%)	(kWh/ym^2)	(%)	(kWh/ym^2)	(%)
Milan	#0.0	239.4		231.1		189.7		191.4		147.4	
	#0.1	240.9	0.6%	232.2	0.5%	190.4	0.3%	192.4	0.6%	148.7	0.9%
	#0.2	240.9	0.6%	232.4	0.5%	190.5	0.4%	192.6	0.6%	148.8	1.0%
	#1.0	226.6	−5.3%	218.5	−5.5%	178.9	−5.7%	179.8	−6.0%	138.1	−6.3%
	#1.1	229.1	−4.3%	220.1	−4.8%	179.9	−5.2%	181.2	−5.3%	139.5	−5.3%
	#1.2	229.2	−4.3%	220.4	−4.6%	180.2	−5.0%	181.4	−5.2%	139.7	−5.2%
	#2.0	214.2	−10.5%	206.2	−10.8%	168.5	−11.2%	168.7	−11.9%	129.0	−12.5%
	#2.1	217.9	−9.0%	208.5	−9.8%	169.9	−10.4%	170.4	−11.0%	130.6	−11.4%
	#2.2	217.9	−9.0%	209.0	−9.6%	170.4	−10.2%	170.8	−10.7%	130.9	−11.2%
Florence	#0.0	199.3	−16.7%	192.6	−16.7%	156.5	−17.5%	156.2	−18.4%	117.4	−20.3%
	#0.1	202.5	−15.4%	194.3	−15.9%	157.6	−16.9%	157.4	−17.7%	118.7	−19.4%
	#0.2	202.5	−15.4%	194.7	−15.8%	158.0	−16.7%	157.8	−17.5%	119.0	−19.3%
	#1.0	187.5	−21.7%	181.1	−21.6%	146.8	−22.6%	145.9	−23.8%	109.0	−26.0%
	#1.1	191.9	−19.8%	183.6	−20.6%	148.4	−21.8%	147.5	−22.9%	110.6	−25.0%
	#1.2	192.0	−19.8%	184.1	−20.3%	148.9	−21.5%	148.0	−22.6%	111.0	−24.7%
	#2.0	176.0	−26.5%	170.1	−26.4%	137.6	−27.4%	135.7	−29.1%	100.7	−31.6%
	#2.1	181.8	−24.0%	173.3	−25.0%	139.7	−26.4%	137.8	−28.0%	102.6	−30.4%
	#2.2	181.9	−24.0%	174.1	−24.7%	140.4	−26.0%	138.5	−27.6%	103.1	−30.0%
Rome	#0.0	191.4	−20.0%	185.2	−19.9%	150.4	−20.7%	149.3	−22.0%	112.4	−23.8%
	#0.1	194.5	−18.7%	186.9	−19.1%	151.5	−20.1%	150.5	−21.3%	113.6	−22.9%
	#0.2	194.6	−18.7%	187.3	−18.9%	151.9	−19.9%	150.9	−21.2%	113.9	−22.7%
	#1.0	179.9	−24.8%	174.2	−24.6%	141.2	−25.6%	139.2	−27.2%	104.2	−29.3%
	#1.1	184.2	−23.1%	176.6	−23.6%	142.6	−24.8%	140.8	−26.4%	105.7	−28.3%
	#1.2	184.2	−23.0%	177.1	−23.3%	143.2	−24.5%	141.3	−26.2%	106.1	−28.0%
	#2.0	169.3	−29.3%	163.9	−29.1%	132.5	−30.1%	129.6	−32.3%	96.4	−34.6%
	#2.1	175.0	−26.9%	167.0	−27.7%	134.5	−29.1%	131.6	−31.2%	98.1	−33.4%
	#2.2	175.0	−26.9%	167.8	−27.4%	135.2	−28.7%	132.3	−30.9%	98.7	−33.1%
Naples	#0.0	179.2	−25.1%	172.6	−25.3%	140.2	−26.1%	137.8	−28.0%	104.0	−29.4%
	#0.1	181.5	−24.2%	173.8	−24.8%	141.0	−25.7%	138.6	−27.6%	105.0	−28.8%
	#0.2	181.6	−24.1%	174.1	−24.7%	141.3	−25.5%	138.8	−27.4%	105.2	−28.6%
	#1.0	168.9	−29.4%	162.8	−29.5%	132.0	−30.4%	128.9	−32.6%	96.8	−34.3%
	#1.1	172.4	−28.0%	164.7	−28.7%	133.2	−29.8%	130.1	−32.0%	97.9	−33.6%
	#1.2	172.4	−28.0%	165.1	−28.5%	133.6	−29.6%	130.5	−31.8%	98.2	−33.4%
	#2.0	159.1	−33.5%	153.4	−33.6%	124.0	−34.6%	120.2	−37.2%	89.7	−39.1%
	#2.1	164.0	−31.5%	156.0	−32.5%	125.7	−33.8%	121.9	−36.3%	91.1	−38.2%
	#2.2	164.0	−31.5%	156.6	−32.2%	126.3	−33.4%	122.5	−36.0%	91.5	−37.9%

In previous sections it has been demonstrated that an increase in the outdoor temperature leads to the lessening of consumption for heating purposes, while for the cooling ones it tends to enhance. Notwithstanding, the increase in energy consumption for cooling is greater if the addition of more air conditioners is considered. It is important to highlight how the incidence of heating consumption is higher, and therefore, adding the two variations, it is possible to get better energy gains globally. That circumstance occurs for all scenarios and for all case studies; only scenarios #0.1 and #0.2, referred to the Milan case, are the exceptions. Substantially, for the major part of simulated scenarios, reduction values beyond 20% can be accomplished anyhow.

On the basis of a yearly energy balance, it can be stated that, in the residential sector, the outdoor temperature shift-up favours the overall energy consumption diminishing. As a matter of fact, that feature is mainly caused by the conspicuous reduction in heating consumption. More specifically, referring to the Italian environmental context, it is possible to forecast a marked decrease in local polluting emissions, since the largest part of the heating systems is based on gas-fired technologies; that occurrence certainly represents an important benefit for the air quality, especially in the urban areas.

3.6. Monthly Analysis of Cooling Consumption: Criticalities and Foreseeable Solutions

The analysis over one-year period, however, does not allow to highlight properly all those issues that the growing energy consumption for cooling purposes implies on the electricity system in the summertime.

For the typical Italian climatic conditions, the cooling season lasts no longer than four months, i.e., June, July, August, and September; in these months, particularly in July and August, the electricity consumption growth for chilling the inner spaces is concentrated.

Having considered all dwellings and referring also just to the summer months, Table 4 shows accurately the relative variation of total electricity consumption. Those numerical values come out by comparing all the simulated scenarios with the reference scenario #0.0.

Table 4. Relative variations in electricity consumption compared to the base-scenario #0.0 in the summer months.

City	Scenario	June	July	August	September
Milan	#0.1	0.7%	7.2%	8.4%	0.4%
	#0.2	0.9%	9.6%	11.1%	0.4%
	#1.0	2.3%	5.3%	5.2%	0.6%
	#1.1	4.4%	16.4%	17.4%	1.4%
	#1.2	5.1%	20.1%	21.5%	1.6%
	#2.0	6.4%	10.8%	10.5%	2.5%
	#2.1	11.5%	25.8%	26.7%	4.6%
	#2.2	13.1%	30.8%	32.0%	5.2%
Florence	#0.1	3.1%	10.7%	9.0%	0.3%
	#0.2	4.1%	14.3%	12.0%	0.3%
	#1.0	4.5%	5.1%	51%	0.1%
	#1.1	10.9%	19.5%	17.9%	0.4%
	#1.2	13.0%	24.3%	22.2%	0.4%
	#2.0	10.1%	10.2%	10.4%	0.4%
	#2.1	20.4%	28.4%	27.1%	0.9%
	#2.2	23.8%	34.5%	32.6%	1.0%
Rome	#0.1	0.7%	10.3%	11.2%	0.3%
	#0.2	0.9%	13.8%	14.9%	0.4%
	#1.0	2.2%	5.3%	5.1%	0.6%
	#1.1	4.4%	19.5%	20.0%	1.3%
	#1.2	5.0%	24.3%	24.9%	1.5%
	#2.0	6.2%	10.5%	10.2%	2.3%
	#2.1	11.2%	28.6%	28.8%	4.2%
	#2.2	12.9%	34.6%	35.0%	4.8%
Naples	#0.1	0.7%	7.2%	8.4%	0.4%
	#0.2	0.9%	9.6%	11.1%	0.4%
	#1.0	2.3%	5.3%	5.2%	0.6%
	#1.1	4.4%	16.4%	17.4%	1.4%
	#1.2	5.1%	20.1%	21.5%	1.6%
	#2.0	6.4%	10.8%	10.5%	2.5%
	#2.1	11.5%	25.8%	26.7%	4.6%
	#2.2	13.1%	30.8%	32.0%	5.2%

From data it emerges how July and August are the most critical months for the electrical grid. The outdoor temperature shift-up along with the installation of new air conditioners can lead to an increase in electricity consumption of over 20%. Furthermore, it is well-known how the month of July is the time period characterised by the greatest electricity off-takes [54]. Therefore, a further increase could affect negatively the grid stability or the capacity availability, especially in large cities.

A viable option to overcome those criticalities is to adopt largely self-production, as well as self-consumption of electrical energy, for instance, hailing from photovoltaic systems installed on building roofs. Once well-oriented PV arrays (in terms of slope and azimuth, focused on the maximum yearly production) are assumed, and they are made of crystalline silicon, by the annual capability it is possible to deduce the required receiving surfaces (using the average surface equal to 19.8 m^2/kW). Those surfaces have to match the additional electricity needs which have been calculated before.

Table 5 shows the results of such estimates indicating the relative surface increase when the flat surface of each apartment is considered as reference.

Table 5. Surfaces of photovoltaic systems in percentage compared to the flat surface of single apartment.

City	Scenario	June	July	August	September
Milan	#0.1	0.2%	1.3%	0.9%	0.1%
	#0.2	0.3%	1.8%	1.2%	0.1%
	#1.0	0.7%	1.4%	1.1%	0.0%
	#1.1	1.3%	3.7%	2.9%	0.1%
	#1.2	1.5%	4.5%	3.4%	0.1%
	#2.0	1.8%	2.9%	2.4%	0.0%
	#2.1	3.3%	6.3%	5.1%	0.1%
	#2.2	3.7%	7.4%	6.0%	0.1%
Florence	#0.1	0.8%	2.9%	2.4%	0.1%
	#0.2	1.1%	3.9%	3.2%	0.1%
	#1.0	1.2%	1.4%	1.4%	0.0%
	#1.1	2.9%	5.3%	4.8%	0.1%
	#1.2	3.4%	6.6%	6.0%	0.1%
	#2.0	2.6%	2.8%	2.8%	0.1%
	#2.1	5.3%	7.7%	7.3%	0.2%
	#2.2	6.2%	9.3%	8.8%	0.3%
Rome	#0.1	0.2%	2.6%	2.9%	0.1%
	#0.2	0.2%	3.5%	3.9%	0.1%
	#1.0	0.5%	1.3%	1.3%	0.2%
	#1.1	1.0%	4.9%	5.3%	0.4%
	#1.2	1.2%	6.2%	6.6%	0.4%
	#2.0	1.4%	2.7%	2.7%	0.6%
	#2.1	2.6%	7.2%	7.6%	1.1%
	#2.2	3.0%	8.8%	9.3%	1.3%
Naples	#0.1	0.2%	1.7%	2.1%	0.1%
	#0.2	0.2%	2.3%	2.8%	0.1%
	#1.0	0.5%	1.3%	1.3%	0.2%
	#1.1	1.0%	3.9%	4.3%	0.4%
	#1.2	1.1%	4.8%	5.3%	0.4%
	#2.0	1.4%	2.6%	2.6%	0.6%
	#2.1	2.6%	6.2%	6.6%	1.2%
	#2.2	2.9%	7.4%	7.9%	1.3%

Referring to the most critical month for the electricity system (July), the estimates indicate that the surface of new photovoltaic systems (to meet the additional demand for electricity) can exceed 4.5% of the flat surface related to the single apartment.

Those data represent average values which are usable only for preliminary evaluations; yet, in the urban context, they are very often approximated since:

i. There are typically multi-storey buildings in cities; consequently, the usable roof surface must be divided by the various floors;
ii. Not all roofs can be used for PV installation (surfaces already used, architectural constraints, poor irradiation conditions);

iii. The modern construction strategies lead to build new apartments characterised by a not wide floor surface (i.e., small < 50 m^2; small-medium 50–85 m^2), as well as by high specific consumptions for air conditioning, it being even double compared to the larger ones (see Figures 14–17).

Whether some of the adverse circumstances listed above occurred at the same time, the buildings' roof surface will be likely insufficient to figure out the criticalities pointed out in this article.

For those reasons, the potential solution to the outdoor temperature shift-up must be identified on a broad territorial scale, involving a dwellings number as large as possible. Thereafter, an inclusion process, taking into account what has just been presented and discussed, it should be developed.

In the end, depending on the territorial context where dwellings are located (e.g., city centre, outskirts, countryside), taking into account the presence of cultural heritage and listed buildings, as well as the prevalent construction typology (e.g., multi-storey building, terraced buildings, single dwellings, etc.), the best territorial scale will be defined (small group of buildings, neighbourhood, urban cell, whole city). To do so, the most appropriate subject able to coordinate the interventions, such as cooperatives, energy communities and municipalities, has to be involved.

4. Conclusions

In this work, the effects of an outdoor temperature shift up due to climate change, on the energy consumption of the Italian residential sector have been assessed. Using a statistical sample of 419 dwellings, the demand for heating and cooling has been calculated for different scenarios by a simplified dynamic simulation model. Those scenarios consider an increase in the outdoor temperature together with the simpler measure of climate adaptation, represented by the introduction of new air conditioners. Thus, four different climatic conditions have been assumed in order to calculate the sample buildings energy balance. The environmental data refer to Milan, Florence, Rome, and Naples.

The simulation results indicate a general reduction in energy consumption for all scenarios; the reduction in heating demand is much higher than the increase in cooling demand. On the basis of a one-year period the achievable primary energy savings can be even higher than 20%.

That result is undoubtedly positive since it is caused by the particular climatic conditions and equipment of Italian residences (heating systems are installed everywhere, and they serve the whole house; cooling systems are present only in part of the sample buildings and only in a few rooms). In terms of pollutants emissions, a general reduction can be accomplished since the local emissions are strictly related to natural gas-based heating systems.

Nevertheless, it emerges how the increase in cooling demand (due to the introduction of new air conditioners) could generate technical issues in summer months, when the greatest electricity demand occurs. As a matter of fact, the simulations indicate an increase in electricity demand more than 20% during July and August, for many scenarios.

For that reason, the PV systems introduction has been analysed as a compensatory measure, calculating the required receiving surface, as well as the gross surface for the installation. Referring to July, the estimates indicate that in many cases that area can exceed 4.5% of the flat surface related to the single house. Additionally, the single building roof might be not enough, in all those cases which are particularly unfavourable, such as multi-storey buildings, not usable roof surfaces and small houses.

This latter occurrence suggests that the broad territorial scale approach has to be adopted for figuring out all issues related to the outdoor temperature shift up. Thereafter, the most suitable dwellings for the interventions have to be identified along with all of those subjects able to coordinate effectively the activities. That choice has to be made among cooperatives of users, energy communities, or municipalities.

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Appendix A

Table A1. Questionnaire structure.

Building Location

- Province; municipality

Number of occupants in the dwelling over the day

- From 8 a.m. to 1 p.m.; from 1 p.m. to 7 p.m.; from 7 p.m. to 12 p.m.; from 12 p.m. to 8 a.m.

Architectural Characteristics

- Building construction year
- Apartment dimensions and boundary surfaces vertical walls and roof external colour
- Shading
- Refurbishment actions on building (walls; roof; ground; windows)

Heating System

- Centralised; autonomous
- Heat source type

  traditional boiler, condensing boiler, heat pump
- Control

  on/of, climatic thermoregulation, chrono-thermostat
- Emission system

  radiators, fan-coils, radiant floor

Cooling System

- Electric air conditioner

  Energy class; number of served rooms
- Fans; dehumidifiers

  number of hours switched-on

Domestic Hot Water (DHW) plant

- Traditional boiler; condensing boiler; heat pump water heater; electric water heater; storage device (yes/no)

Solar Collectors

- Flat solar collectors/vacuum solar collectors

  Number of modules; slope; orientation

PV Array

- Plant peak power

  Slope; orientation; self-consumption

Energy Bills

- Natural gas; electricity

  Monthly consumption; annual costs

Kitchen

- Cooking plane; oven; microwaves oven

  type, minutes per day switched-on
- Grill; steak grill pan/electric stove; toaster electric coffee maker for espresso; electric coffee maker mocha; blender; food processor (minutes per day switched-on)

Refrigeration

- Refrigerator

  type, capacity, energy class

Washing

- Washing machine; tumble dryer; dishwasher capacity, weekly cycles, energy class

Cleaning and Ironing

- Vacuum cleaner; electric broom

  minutes per day switched-on
- Iron without water boiler; iron with built-in water boiler

  minutes per day switched-on

Lighting

- Filament lamps; halogen lamps; fluorescent lamps; LED lamps

  number

Audio/Video

- TV, monitor

  size, quantity, energy class, hours per day switched-on)
- Decoder; videorecorder; DVD reader; radio, stereo; hi-fi/home theatre

  quantity, daily use in hours

Computer/Internet

- Desktop PC; notebook; modem

  quantity, daily use in hours
- Inkjet printer; laser printer

  quantity, copies per day

Personal Care

- Hairdryer; hair straightener

  daily use in hours

Other Equipment

- Other equipment

  quantity, electric power, daily use in minutes

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