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Energy Savings after Comprehensive Renovations of the Building: A Case Study in the United Kingdom and Italy

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Abstract: The housing sector is one of the largest energy consumers in the world. There is an urgent need to renovate the housing stock of existing buildings. Therefore, it is necessary to correctly calculate the energy savings that can be obtained in a renovation project. The correct collection of energy data, the main variables that affect consumption, and people's usage habits are fundamental elements to quantify the success or consequences that occur in an energy efficiency project. This research study quantifies the results of the energy savings of the European project DREEAM (District Scale Renovation for Energy Efficiency and Market Uptake). This article aims to facilitate the calculation of energy savings with mathematical linear regression models in two different climatic zones in Europe. Furthermore, it aims to improve the calculation of energy savings with mathematical models based on energy data and variables that affect consumption before and after renovations. The variables used for the calculation are hours of use, degree days, and reading days. Tenant behavior has been found to play an important role in actual measured savings. Additionally, the energy consumption patterns of the tenants are different after the renovations.

Keywords: energy efficiency; energy use; energy retrofitting of buildings; energy savings evaluation; measurement; verification; monitoring of energy data

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1. Introduction

The generation of a sustainable energy system is the main challenge of international environmental agendas since the implementation of the emblematic Kyoto Protocol, which reinforced the importance of reducing greenhouse gas emissions. Furthermore, in 2015, the Member States of the United Nations approved the 2030 Agenda for Sustainable Development [1], which is an opportunity for countries and their inhabitants to embark on a new path to improve their lives. One of the objectives is to combat climate change and defend the environment.

The European Union aims to be the world's first carbon neutral area by 2050 through the European Green Deal [2], which is a roadmap to create a sustainable economy. It has focused much of its research activities on the Horizon 2020 [3] and Horizon Europe [4] programs aimed primarily at researchers across the continent joining forces to find a solution to reduce global warming and ensure efficient energy management.

To ensure compliance, commitments and directives have been created to advance the mitigation of climate change by improving energy efficiency at both the productive and residential levels. According to the European Commission Recommendation [5], it is a commitment to create an energy system that has the necessary elements for sustainability. It also aims to reduce greenhouse gas emissions by 40% by 2030 compared to 1990. Furthermore, the objective is to increase the consumption of renewable energy by at least 32%, achieving important changes in the elements inherent to energy efficiency. It is important to mention that Directive 2012/27/EU [6] mended by Directive (EU) 2018/2002 [7] "sets a headline target of at least 32.5% energy savings at the EU level by 2030". A change in the actions taken today is necessary. Despite all the existing regulations in the European Union, further measures are still needed to comply with the EU program.

In the current literature, Borowski [8] stated that to achieve further reductions in consumption, a new energy system must be complemented by energy saving measures and greater attention afforded to people's energy use. He also emphasized that the economy needs cheap and reliable energy supplies, which are sourced in a green and environmentally friendly way [9].

Energy efficiency projects are becoming a more complex process that requires mathematical modelling and data analysis to evaluate and calculate savings [10]. There is research that uses mathematical modelling based on performance measurement and verification protocols to calculate energy savings following the implementation of energy improvements [11,12]. These benchmarks can be used to determine the savings from retrofitting and to understand the consumption patterns of tenants. In the literature, research can be found which uses measurement and verification protocols that range from simple linear regression models to advanced techniques, such as neural networks [11,12]. There are studies in the residential domain that evaluate energy consumption by focusing on variables such as time of the week and outdoor temperature [13].

In the residential sector, energy consumption is assessed by focusing on variables such as time of the week and outdoor temperature. Others rely on variables such as working days and cooling degree days to quantify their savings [14,15]. However, the research collected so far, which is supported by measurement models and verification of savings by regression, is based on estimates. Energy data collection is through surveys, databases, and monthly and annual energy consumption details provided by electricity companies or commercial bills [11,12]. Studies have not physically measured actual consumption before and after reforms, thus it has not been possible to evaluate energy savings in depth [14–19]. Furthermore, in the absence of actual measurements, it is not possible to deduce in detail the changes in the energy consumption of consumers and how this has affected the estimated savings.

Tenants play a very important role in the energy use of buildings and have a strong correlation with the activities they perform, thus human behavior is an important factor to consider for energy savings calculations [20–22]. The lack of knowledge about energy use and a certain conscious attitude towards energy savings create discrepancies in energy consumption. Research [23,24] shows that there is an energy efficiency gap, which is defined as the difference between the vision of the consumer and the calculation of the expected energy savings of a project.

Consumers have responsibilities in the choices they make in terms of energy use and this has a direct impact on the rebound effect. This effect is introduced by Jevons [25] and other authors have provided a classification of the rebound effect [25–30]. Additionally, they present studies of the rebound effect and divide it into three parts. The first is the "direct rebound effect". This refers to the direct consequence of the reduction in the real price of energy due to the implementation of improvements in energy efficiency. The second, according to the authors, is the "Indirect Rebound Effect", which, together with the previous one, refers to the fall in the real price of energy, creating an increase in economic income that can lead to an increase in demand for other goods and services that require higher energy consumption rates. Finally, there is the "Effect on the economy", which refers to the reduction in energy needs caused by technological improvements in equipment, which stimulates a change in the relative prices of goods and services throughout the economy, especially those goods and services that require energy. This will reduce their prices and lead to a shift in the consumer demand for energy. A recent study in the residential sector in Europe [31] indicates that more than 20 countries obtained values of more than 50% in the direct and indirect rebound effect. Therefore, it is important to evaluate the energy savings achieved and the consumption pattern of consumers to determine the causes of energy savings or overconsumption.

The European project DREEAM (District Scale Renovation for Energy Efficiency and Market Uptake) aims to demonstrate that up to 75% of the total net energy demand (NED) can be reduced by renovating residential buildings with net zero energy (NZE) [32]. The project has been carried out in two different climate zones in Europe. Treviso (Italy) and Padiham (UK). In this work, the data measured in the DREEAM project is analyzed to quantify the savings obtained after the renovations. The novelty of the savings calculation relies on the use of electrical energy signals to obtain an average base load of the household. With this information, the data is processed and a new variable is introduced into the mathematical regression model, specifically the hours of use. Furthermore, with the average base load of the household, comparisons can be made regarding the load connected to the household grid before and after the improvements. The purpose of this article is to verify the energy savings proposed in the DREEAM project, as well as to discuss and analyze the possible causes of energy savings or excess energy consumption in the different households studied.

2. Description of the Project

This section describes in detail the buildings under study and the specific measures that have been carried out. The buildings belong to two different areas: the United Kingdom and Italy. In the UK, individual houses were evaluated, and in Italy, a six-floor building with 18 apartments was evaluated. The measures adopted have two objectives: the first is to reduce energy demand through the renovation or replacement of equipment; the second is to encourage self-consumption, reduce electricity consumption from the grid by installing renewable energy, and raise awareness of electricity consumption among residents.

For this research study, renewable energies will supplement a percentage of household energy consumption. There are off-grid and on-grid connected renewable energy options. The first term refers to the fact that renewable energies can satisfy all energy demands. The production of renewable energy is dependent on weather conditions. This implies dependence on some form of storage to meet periods of low or no energy generation. A recent study showed that there are still many barriers and limitations to achieving a 100% renewable energy supply [33].

The second term refers to a small contribution of renewable energy, while still being dependent on the grid at times of low or no generation. The advantages are the reduction of energy consumption. In addition, it allows tenants to be "prosumer", a term that refers to the consumer of a product or service who in turn participates in its creation. In the future, consumers can simultaneously become prosumers and generate electricity to both meet their energy needs and sell surplus to the grid [8,9].

In this work, the renewable energies will be on grid.

2.1. United Kindom

Seven properties have been monitored and studied in the UK. They are individual houses whose year of construction is 1973 and all have an individual connection to the electricity grid. In addition, for heating, energy is supplied to two properties by natural gas, while five properties use electric storage heating.

The energy improvement actions are detailed in Table 1. As can be seen, on the one hand, we have the renovation and equipment measures that affect the energy demand, namely wall insulation and window replacement. On the other hand, to reduce the external demand for natural gas and electricity supply, photovoltaic panels and a set of thermal solar panels are installed. These values are negative and must be quantified as energy savings. With all these improvements, the aim is to save a total of 88%.

Table 1. Summary of the objective of improving energy performance in the United Kingdom.

Energy Demands	Specific Measure	Before Renovations (kWh/m^2/Year)	Post-Renovations (kWh/m^2/Year)
Heating and ventilation	Insulation, glazing, and high efficiency radiant panels	87.1	20.6
Domestic hot water (DWH)	Solar thermal system	24.2	8.1
Energy Supply			
Electricity	Photovoltaic array	0.0	−9.2
Heat and domestic hot water	Solar thermal array	0.0	−7.2
	Percentage of savings	88%	

2.2. Italy

The building under study is located in Italy and is a tower built in 1975. The tower has six floors and on each floor there are three apartments. The energy improvement actions are described in Table 2 and are divided into items parts. The first details specific measures to reduce energy demand, as follows: implementation of a new building envelope; fiber-cement ventilated facade system; reduction of heat losses through insulation of all facades (outer layer); partial redefinition of some openings in the north-east to reduce heat losses (during winter); replacement of windows with high thermal transmittance windows; and replacement of heat machines (boilers) with aquifer thermal energy storage (ATES). The second item in Table 2 includes measures to reduce electricity demand by raising awareness of the electricity consumption among residents. All these improvements aim to reduce energy demand by 67%.

Table 2. Summary of the objective of improving energy performance in Italy.

Energy Demands	Specific Measure	Before Renovations (kWh/m^2/Year)	Post-Renovations (kWh/m^2/Year)
Heating and ventilation	Insulation, glazing, ventilated façade, and heat pump	244.0	61.5
Electrical appliances	Resident electrical consumption awareness	31.0	28.0
	Percentage of savings	67%	

3. Materials and Methods

This section explains the theory and calculations applied for the analysis of the data. The International Performance Measurement and Verification Protocol is used and its application for the calculation of savings after renovations is detailed in the following subsections

3.1. Data Collection

Data were collected for one year before improvements were made (2016–2017). Conditions after the energy improvements, such as the number of tenants and the temperature conditions, did not change. All this information was compared with the data obtained after the improvements (2018–2020). This allowed us to verify the energy savings and to explain the changes in energy consumption. The electrical energy and temperature measurements were carried out with a 15 min sampling time with a remote monitoring system. A scheme of this system is shown Figure 1. The meters were connected to a router and the router transferred the data via 3G to the data platform, where the information was analyzed and managed. Additionally, information on natural gas consumption was obtained from energy companies.

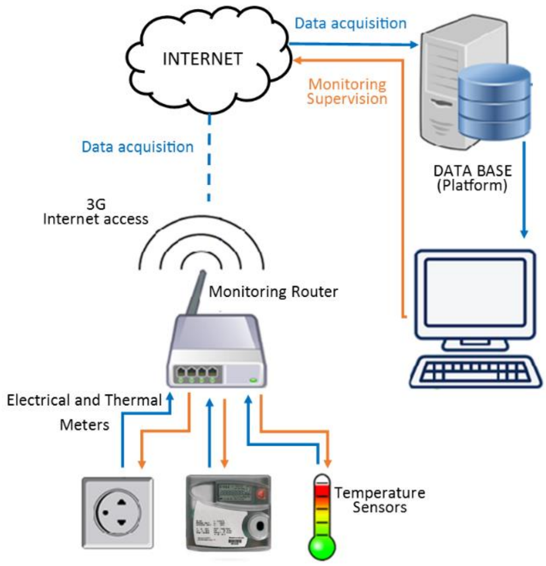


Figure 1. Data collection diagram.

3.2. Average Base Load

This is described as the load for which it is considered that there is no activity in the dwelling because its occupants are sleeping or away from home. Let us say that it is the minimum load for a household. It is calculated in kilowatts (kW) for each household with the data collected in consideration of the fact that sleeping and night hours are not the same for each dwelling due to different routines.

It is important to mention that for this study, the average base load was calculated by taking into account data of six months during the night hours when tenants claimed that there was no activity in their homes, as they were sleeping.

3.3. Time of Use

This is the period measured in hours when the dwelling is active and the tenants are consuming energy; therefore, the load is above the average base load. To calculate the time of use of households, see Table 3. First, the electricity consumption measured every 15 min was collected in kWh and then converted to load (kW). Subsequently, it is compared with the average base load, as in the example of Table 3, the average base load is 0.115 (kW). For all values higher than this, the time of the use column will quantify 15 min or, conversely, when the load is lower than this load, the time of use will register as zero because it is assumed that there is no activity or occupation in the household during that time.

Table 3. Quantification of time of use.

Main Switch Measurements			
Average base load (kW): 0.115			
Hour	kWh	Load (kW)	Time of use (min)
15:30:00	0.091	0.364	15
15:45:00	0.028	0.112	0
16:00:00	0.034	0.136	15

Finally, the data are summed and the daily, weekly, monthly, or annual hours of use are quantified according to the measured data.

3.4. Degree Days

The degree days are the difference between the average temperature inside the houses and the outside temperature. For the calculation, the quarter hourly measurements of the devices located indoors and outdoors were used. In Figure 2, there is an example of the inner and outer temperature for a house in Italy. It is important to note that the energy consumed for cooling or heating is different in the summer and winter months because the temperature difference depends on the outside temperature, as it is the main variable. For this reason, it is especially important to collect the temperature of both temperatures.

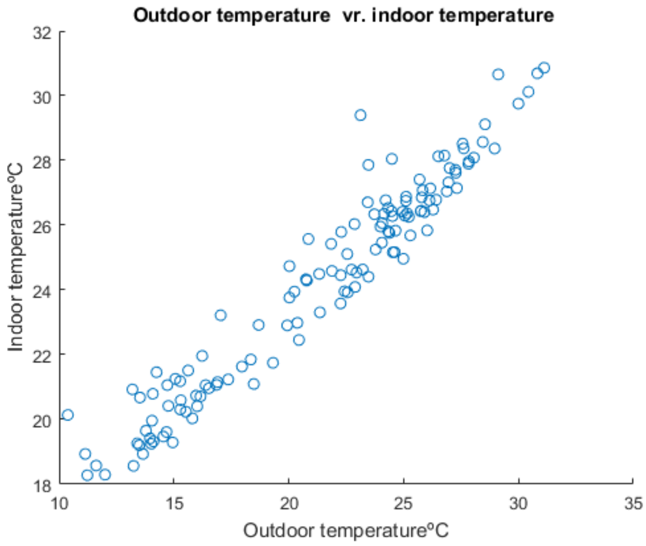


Figure 2. Indoor and outdoor temperatures in flat 5 (Italy).

3.5. Reading Days

These are the complete days of measurement in which the devices sent information to the platform. For the calculation, days were excluded if, for any reason, the devices did not measure or had communication problems with the data management platform.

3.6. Energy Baseline

This is a quantitative reference to evaluate the energy savings of the improvements. To obtain it, a mathematical model must be created that establishes a relationship between energy consumption and the variables that affect it [34]. The model used for the calculation of the energy baseline for electricity and natural gas is shown in Equation (1).

$$\text{Energy baseline} = \text{B1} \times \text{Hour of use} + \text{B2} \times \text{Degree days} + \text{B3} \times \text{Reading days} + \text{D} \quad (1)$$

B1, B2, B3, and D are the regression model coefficients that need to be calculated.

To verify the energy savings obtained, the International Performance Measurement and Verification Protocol (IPMVP) [35] is used. Within the protocol, there are several options to determine savings. For the calculation of electricity savings, option B was used, which states that continuous measurements of energy consumption and the key parameters that affect it must be carried out. For the calculation of natural gas savings, option C was used, which allows for the use of consumption data from the energy companies' meters. The mathematical model used for the calculation of electricity and natural gas savings is described in Equation (2).

$$\text{Energy savings} = \text{Energy consumption measured} - \text{Energy baseline} \quad (2)$$

The calculation method described above results in energy savings, which represents the difference between the measured energy consumption and the energy baseline (see Figure 3). It is important to emphasize that if the measured energy consumption is lower than the energy baseline, it is considered an energy saving; if otherwise, it is considered an overconsumption.

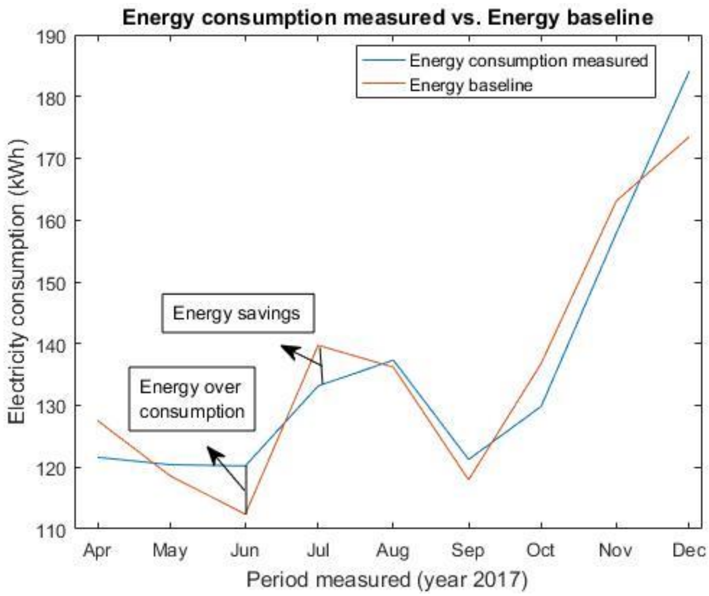


Figure 3. Energy savings or overconsumption vs. energy baseline.

4. Results

This section presents the results of the project divided by the countries in which the study was carried out (United Kingdom and Italy). In addition, it refers to the mathematical model used for the calculation of the electricity and natural gas energy baseline.

4.1. United Kindom

4.1.1. Model

The mathematical model used for the calculation of the electricity baseline is described in Equation (3). Furthermore, for the calculation of the natural gas energy baseline, Equation (4) was used and finally the calculation of the energy savings is described in Equation (2).

$$\text{Energy baseline} = \text{B1} \times \text{Hour of use} + \text{B2} \times \text{Cooling degree days} + \text{B3} \times \text{Reading days} + \text{D} \quad (3)$$

$$\text{Energy baseline} = \text{B1} \times \text{Hour of use} + \text{B2} \times \text{Heating degree days} + \text{B3} \times \text{Reading days} + \text{D} \quad (4)$$

Table 4 presents the coefficients of determination R^2 obtained in the calculation of the baselines of electricity and natural gas for each of the homes studied.

Table 4. Summary of coefficient of determination (R^2) in the United Kingdom.

Number of Dwelling	Electric	Gas
D1	0.99	0.99
D2	0.96	
D3	0.96	
D4	0.97	
D5	0.99	0.99
D6	0.99	
D7	0.98	

As can be seen from the value of the R^2 obtained for each dwelling, the equation models successfully fits the data measured.

4.1.2. Electricity Savings

Table 5 presents the electricity savings for each dwelling studied in the period of measurements from 18 November to 19 July. The average savings for all the dwellings was 25%. Furthermore, it is important to distinguish that dwellings D1 and D5 used two types of energy, namely electricity and natural gas, and the remaining dwellings only used electricity. Of the total number of dwellings studied, only D5 did not achieve any savings. The dwelling that saved the most was D4 with more than 50% of energy savings.

Table 5. Summary of energy savings in the United Kingdom.

Number of Dwelling	Electric Energy Savings (%)	Gas Energy Savings (%)
D1	14%	−54%
D2	41%	
D3	26%	
D4	51%	
D5	−14%	33%
D6	41%	
D7	14%	

4.1.3. Natural Gas Savings

Table 5 presents the savings regarding natural gas in homes with heating gas for the period of 18 November to 19 July. The average energy savings was −10%. D5 achieved a 33% energy saving, while house D1 had an overconsumption of natural gas at 54%.

4.2. Italy

The following section presents the results of the energy savings obtained in Italy. The flats are in a tower with six floors, with there flats on each floor. Each flat is identified with a number from 1 to 18.

4.2.1. Model

The mathematical model used for the calculation of the electricity baseline is described in Equation (3). For the calculation of the natural gas baseline, see Equation (4) and the calculation of the savings is shown in Equation (2).

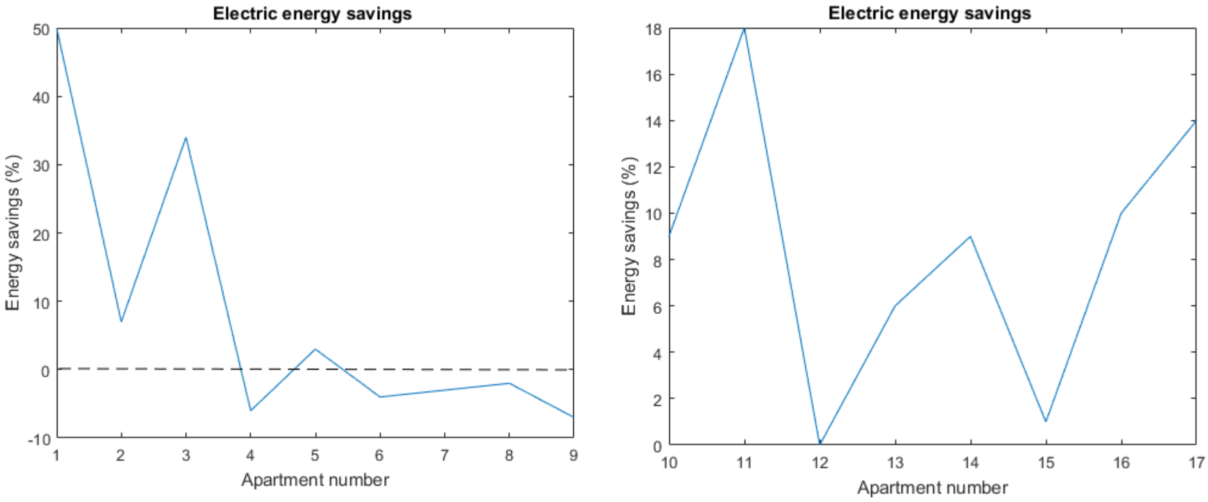
Table 6 presents the coefficients of determination R^2 for the calculation of the baselines for the electricity and natural gas of each of the flats. In the calculation of electricity and natural gas, the average coefficient of determination R^2 was 0.95 for electricity and 0.96 for natural gas.

Table 6. Summary of coefficients of determination (R^2) in Italy.

Number of Flat	Electric	Gas
1	0.87	0.99
2	0.95	0.85
3	0.86	0.99
4	0.91	0.97
5	0.95	0.97
6	0.99	0.91
7	0.95	0.97
8	0.99	0.96
9	0.95	0.99
10	0.98	0.98
11	0.95	0.92
12	0.99	0.98
13	0.97	0.97
14	0.98	0.98
15	0.93	0.95
16	0.97	0.99
17	0.99	0.99
18	0.90	0.98

4.2.2. Electricity Savings

The measurement period used for the calculation of the savings ran from May 2019 to April 2020. The summary of savings for each floor is shown Figure 4. In total, they achieved an average saving of 6% (see Figure 4a), especially flat 1 which stands out by having the best energy savings of up to 50%, followed by flat 3 with savings greater than 30%. In addition, there were flats that did not achieve savings, such as flat 4 with −6% and flat 9 with −7%. Finally, flats 7 and 18 are excluded from the investigation due to tenant changes.

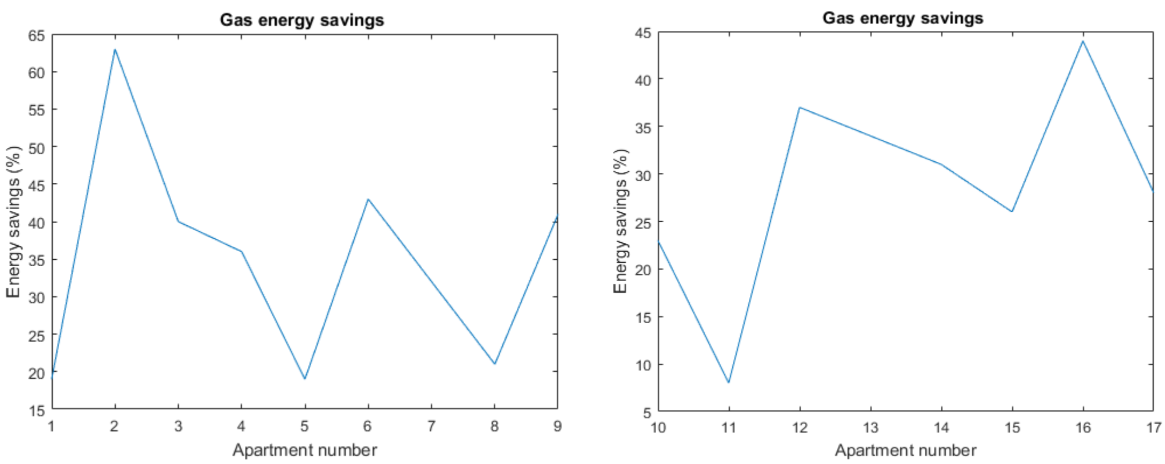


(**a**) (**b**)

Figure 4. Summary of the electrical energy savings in Italy; (**a**) apartments from 1 to 9 and (**b**) apartments from 10 to 17.

4.2.3. Natural Gas Savings

The period of natural gas savings ran from 19 May to 20 April. Furthermore, flats 7 and 13 have been excluded from the study due to a change in tenants and the calculation of the natural gas savings for flat 13 has been omitted due to failures in the metering devices. The savings percentages for each flat are shown Figure 5a,b. The average savings achieved by all flats is 32%, with flat 2 saving the most at over 60%, followed by flats 6 and 16 which saved over 40%. The lowest savings were on floor 1 with a savings rate of 19% and on flat 11 with a savings rate of less than 10%.



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

Figure 5. Summary of the gas energy savings in Italy; (**a**) apartments from 1 to 9 and (**b**) apartments from 10 to 17.

5. Discussion

This section analyzes the effect of energy savings and discusses other aspects that influence electricity consumption which are not easily visible and can be explained by analyzing the measurements in depth. This allows us to explain why some tenants save and others consume more energy than necessary while the energy efficiency measures are the same for all dwellings.

The literature on energy savings focused on measurement and verification protocols [14–19], and they used estimated data or billing from energy suppliers. This limits the analysis of energy savings as well as the possible causes that influence energy consumption. This research study provides a link between energy savings and user consumption patterns. In addition, it provides a comparison between the situations before and after the energy improvements through the analysis of measured data. This generates a small breakthrough in the calculation of energy savings.

Additionally, we agree with the authors in [36,37] who stated that the time of use or occupancy is difficult to quantify and model in building research. Some studies have calculated occupancy by measuring Co^2 levels [38], while others have done so by connecting to the Wi-fi and Bluetooth Low Energy (BLE) network [39,40], alongside studies based on electricity consumption [41,42]. It must be kept in mind that these solutions require special programming with high computational power and many measuring devices must be installed. Most common Wi-fi devices do not allow access to the data, which is a limitation. In this study, the quantification of hours of use or occupancy was achieved in a conventional spreadsheet and a meter or access to the quarter-hourly data of household consumption was needed. This makes the calculation simpler and more accessible to people.

In the following subsections, each case, namely in the UK and Italy, will be discussed separately.

5.1. United Kindom

5.1.1. Electricity

Figure 6 shows the comparison of hours of use, average base load, and energy consumption between 2017 and 2019. The results obtained indicate that the average base load decreased by 14.94%, the time of use of the dwelling decreased by 19.40%, and the energy consumption decreased by 8.76%. These overall results are positive and we will focus on the analysis of both the house with the highest energy savings (D4) and the house with overconsumption (D5) to assess why there are differences in the energy savings. In dwelling D4, there was an improvement in the average base load (see upper subfigure of Figure 6), time of use (middle subfigure), and electricity consumption (lower subfigure), but in dwelling 5, the average base load increased, although the hours of use and energy consumption remained constant.

To explain the effects on energy, it is necessary to analyze the data in more depth. Figure 7 illustrates that dwelling 4 had a consumption pattern with high and prolonged peaks, but in the 2019 period, the peaks were lower and shorter in duration. These observations have an impact on the hours of use and on the total consumption in both periods. Furthermore, the average base load was lower after the energy improvements, resulting in less equipment being connected to the grid.

In the case of dwelling 5, as depicted in Figure 8, the energy consumption peaks in 2017 were lower and shorter compared to 2019. On the contrary, for the period 2019, the peaks were higher and its average base load increased, which is because more equipment was connected to the electricity grid, leading to an increase in the average base load. These observations made on the electrical consumption profile seem to be a consequence of the behavior of the inhabitants and their different profiles as well as activity patterns [20–22]. Other works, such as [43,44], also emphasize the influence of the tenants on the measured consumption. In this research study, the results also indicate that the savings or overconsumption can be due to the tenants and their actions.

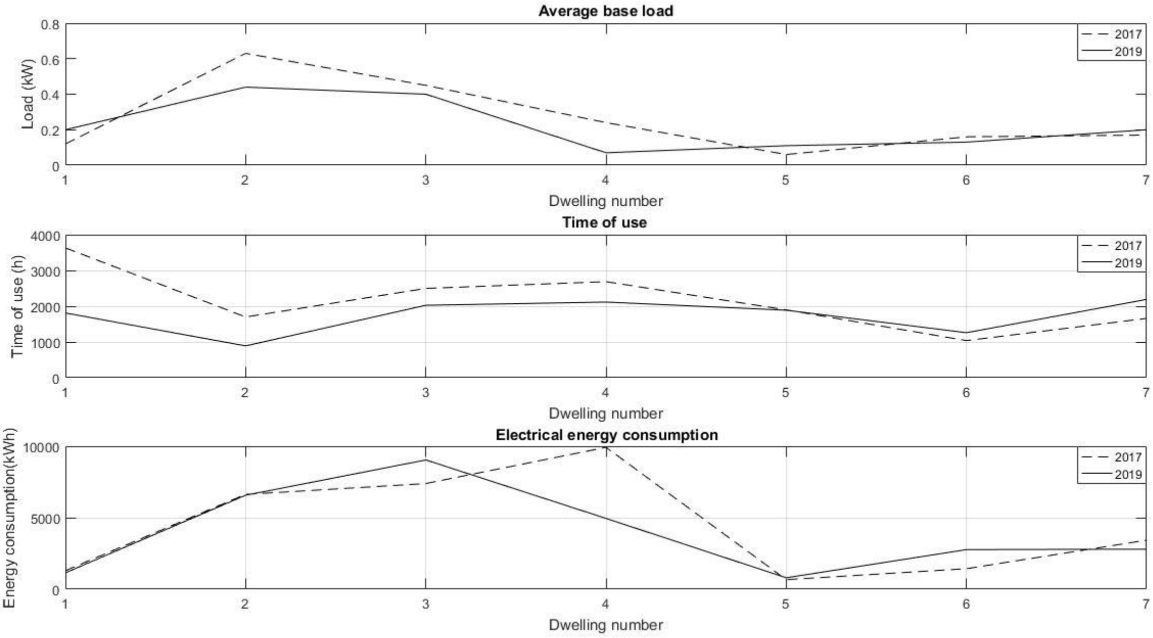


Figure 6. Comparison of average base load, hours of use, and electricity consumption in the United Kingdom.

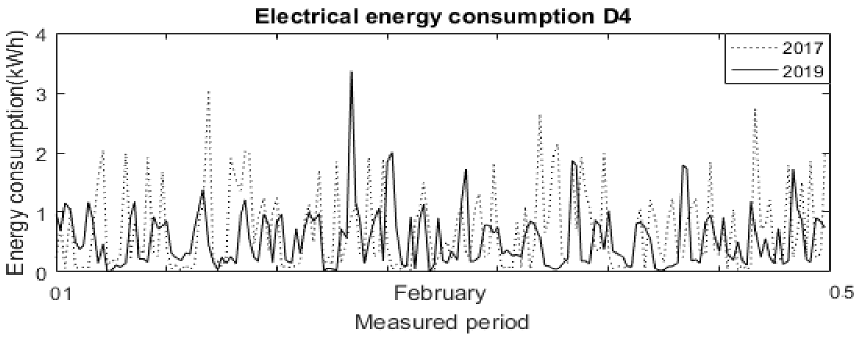


Figure 7. Comparison of electrical energy consumption measurements in D4.

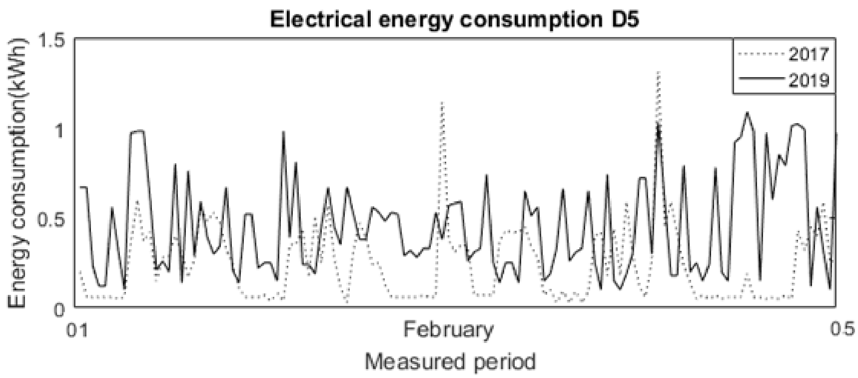


Figure 8. Comparison of electrical energy consumption measurements in D5.

5.1.2. Natural Gas

Natural gas consumption can be seen Figure 9, which describes the evolution of energy consumption in the winter after energy efficiency improvements. Dwelling 1 (a) had a higher energy consumption and the opposite was the case for dwelling 5 (b), with a lower gas consumption.

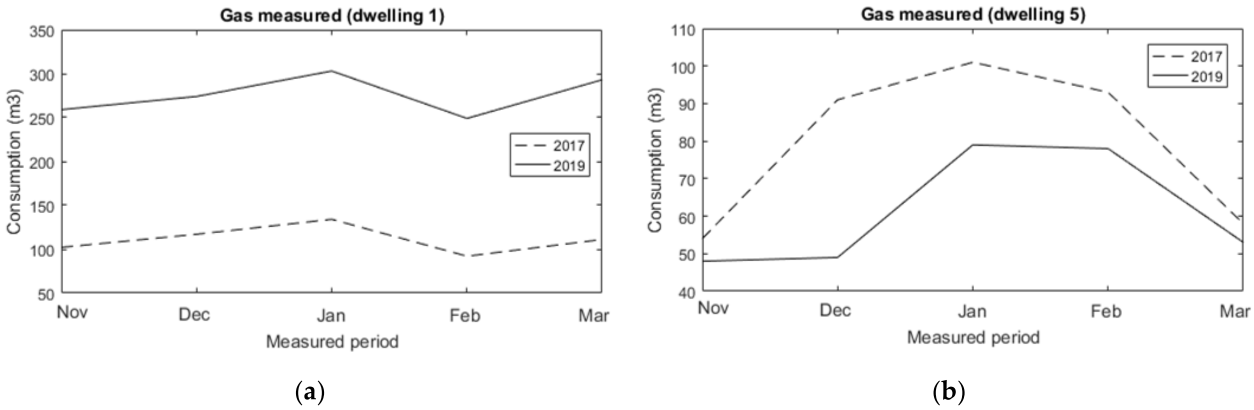


Figure 9. Gas consumption evolution in the United Kingdom; (**a**) gas consumption evolution for dwelling 1 and (**b**) gas consumption evolution for dwelling 5.

In Figure 10, the indoor temperatures of each dwelling are compared. In D1 (a), the indoor temperature increased considerably, resulting in a higher consumption of natural gas. These effects were due to the actions of the occupants who manipulated the set point of the thermostat, causing the indoor temperature to be modified. In D5 (b), the temperature remained constant with small temperature variations in both periods.

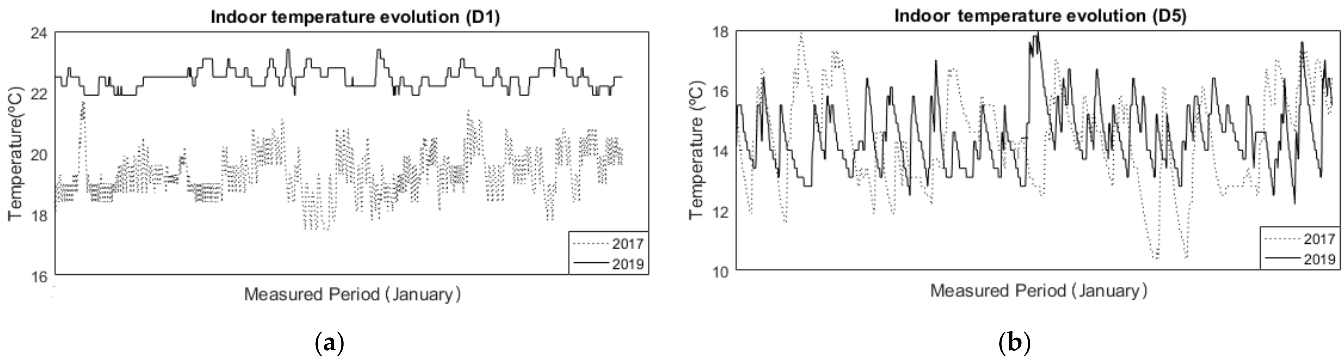


Figure 10. Comparison of indoor temperatures in the United Kingdom: (**a**) indoor temperatures in dwelling 1 and (**b**) indoor temperatures in dwelling 5.

In addition, savings were analyzed considering the size of the dwellings and the number of tenants (see Table 7). In all cases, savings and overconsumption did not appear to be related to the number of tenants or the size of the dwellings, and it is important to note that in this study, most of the dwellings were single-tenant dwellings. Regarding energy savings, dwelling D4, with only one tenant, presented the highest value. On the contrary, dwelling 7, with the largest floor area and number of tenants, also achieved energy savings but they are very low compared to dwelling 4. From this observation, it seems that the lower the number of tenants, the higher the savings, but this is not true if we observe dwelling 1. In this single-tenant dwelling, electricity savings are very low and there is an overconsumption of 103.2 kWh/m^2/year in natural gas compared to the situation before the reform. In [45], the authors state that consumption per person can vary depending on the variety of households. Their results indicate that larger households with more members consume more energy overall, although individual energy consumption rates per member decreases [45]. In this research study, it was not possible to arrive at that conclusion. The households have different consumption patterns and there was no correlation between the size of the dwelling and the number of tenants. The Pearson correlation is described as a measure of the structure of a scatter plot between two variables, namely x and y [46]. The x variable is the number of tenants and the y variable is the energy savings or overconsumption. For example, the Pearson correlation was applied in an investigation of markets of power [47].

Table 7. Summary of the annual average consumption and energy saving rates in kWh/m^2/year in the United Kingdom.

Size of Dwelling	Dwelling Number	Number of Tenants	Energy Savings (kWh/m^2/Year)	
			Electric	Gas
55 m^2	1	1	0.04	−103.20
	4	1	108.96	-
	6	1	100.24	-
80 m^2	2	2	31.48	-
	3	2	23.55	-
88 m^2	5	1	−1.90	18.35
	7	3	5.63	-

5.2. Italy

5.2.1. Electricity

Figure 11 shows a comparison of the periods of 2017 and 2020, wherein the average base load decreased by 8.34% but the time of use increased by 2.80% and energy consumption by 3.86%. We note that most of the flats improved in these factors, but there were others that did not. The comparison focuses on those with the highest energy savings, namely flats 1 and 3, and those with excessive consumption, namely flats 6 and 9.

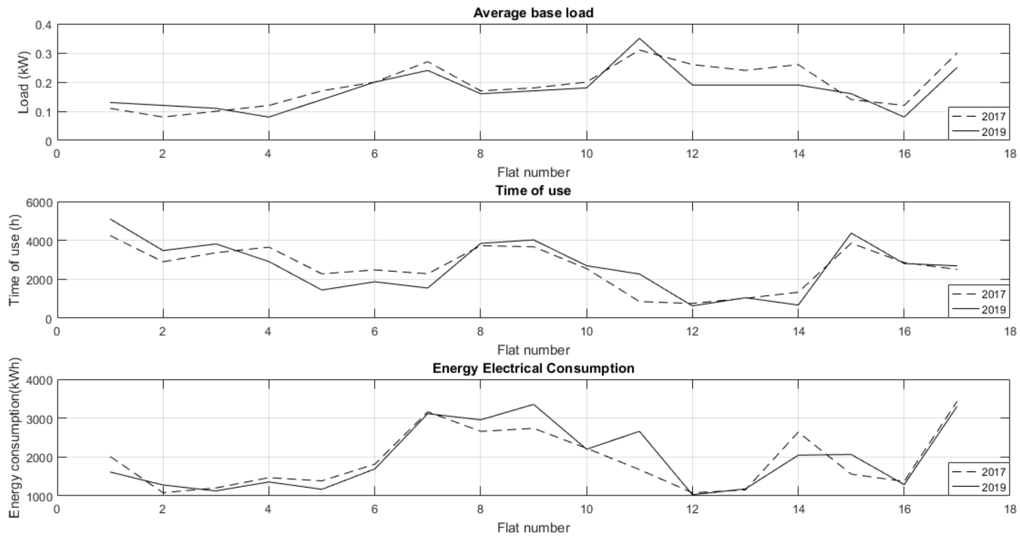
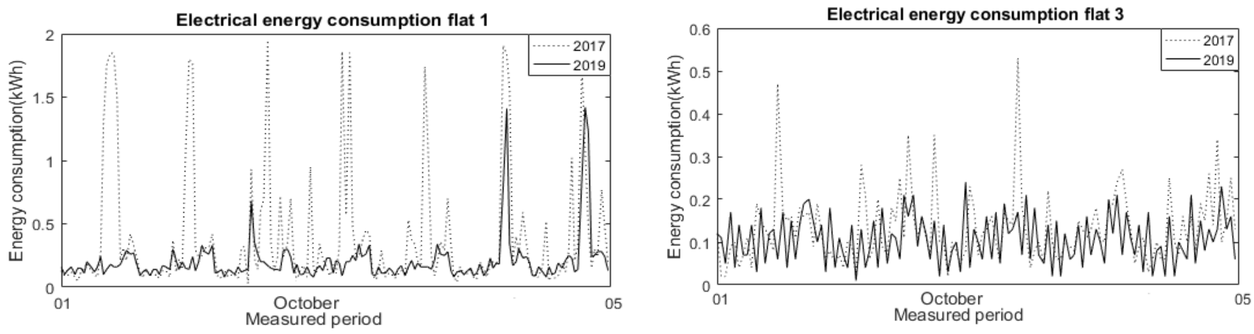


Figure 11. Comparison of the average base load, hours of use, and electricity consumption in flats in Italy.

Flat 1 obtained the highest energy savings, improving in all three factors during 2019, while flat 3 maintained a constant average base load and energy consumption rate, although increasing its hours of use. Additionally, the flat with the highest consumption, flat 6, increased in all three factors. The flat with the worst energy savings is flat 9 because it decreased its power and increased both its hours of use and energy consumption.

Figure 12 describes the consumption behavior of those who saved energy. Flat 1 in the 2017 period had higher and more frequent consumption peaks compared to the 2019 period. In addition, its minimum energy consumption was reduced; therefore, there was a decrease in the average base load between the compared periods. Flat 3, which also saved, reduced its peak energy consumption, maintained the average base load, and reduced usage times.



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

Figure 12. Comparison of electrical energy consumption measurements: (**a**) energy consumption in flat 1 and (**b**) energy consumption in flat 3.

Among the flats that did not save energy (see Figure 13), flat 6 had higher consumption peaks in 2019. Moreover, the total quantification of consumption and average base load remained constant; this may be because it used appliances simultaneously in frequent periods and with shorter durations. Flat 9 had higher energy consumption peaks and they were longer than in the 2017 period. This causes an increase in consumption and hours of use. The minimum and average base load consumption increased. Furthermore, these effects are similar to those described in the UK and again coincide with the fact that these effects are influenced by the behavior of the inhabitants [43], in addition to their profiles, activity patterns, and the operational control of the tenants in their homes [44].

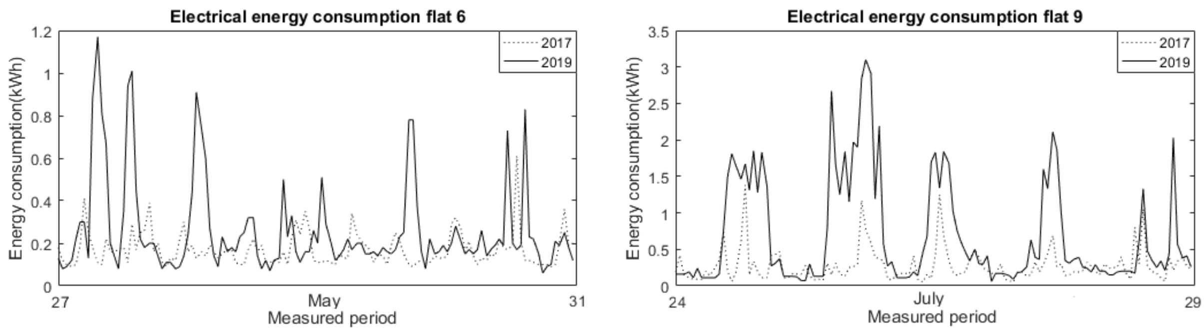


Figure 13. Comparison of electrical energy consumption measurements: (**a**) energy consumption in flat 6 and (**b**) energy consumption in flat 9.

5.2.2. Natural Gas

In the overall quantification of the natural gas savings, all flats saved energy. However, it was observed that in certain periods, no savings were achieved at all. In order to show the possible cause of this increase in energy consumption, indoor temperatures from flats 5, 7, and 9 are plotted in Figure 14. The dotted lines show the indoor temperature in January 2017 and the black lines represent that in January 2020. As can be seen, the tenants increased the temperature of their thermostats in the three flats. Flat 5 showed the largest difference compared to the previous period. In addition, in flat 7, the temperature registered showed certain peaks throughout the whole plotted period. These three examples agree that the differences in usage before and after the energy improvements are due to the actions of the occupants who, as in the UK, manipulate the devices that allow them to change the indoor temperature; therefore, this is reflected as an increase in energy consumption.

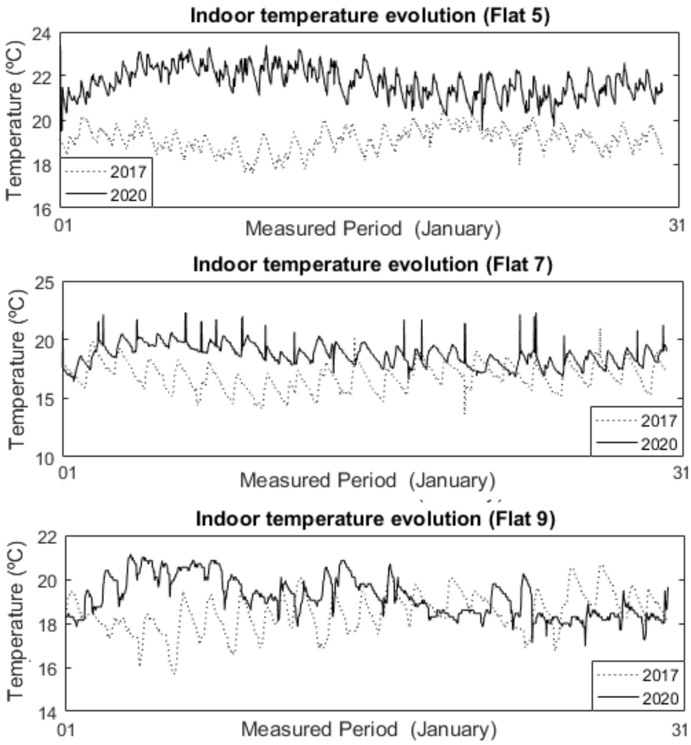


Figure 14. Comparison of indoor temperatures in flat 5, 7, and 9 in Italy.

However, savings were analyzed according to the size of the homes and the number of tenants (see Table 8). In all households, energy savings and overconsumption rates were different, thus there is no direct relationship between these characteristics and energy savings. This was also observed in the UK. In both cases, no correlation was found between the number of tenants and size of the flat and the energy consumption. This is a function of energy management habits.

Table 8. Summary of annual average consumption and energy saving rates in kWh/m^2/year in Italy.

Size of Dwelling	Dwelling Number	Number of Tenants	Energy Savings (kWh/m^2/Year)	
			Electric	Gas
79 m^2	1	2	25.37	42.76
	2	1	1.30	72.26
	3	1	7.36	153.97
	12	3	0.05	76.75
	13	1	1.00	-
	14	1	2.51	88.76
82 m^2	8	1	−0.53	7.66
	9	4	−2.80	6.82
	10	2	2.56	40.59
	11	6	6.96	48.39
94 m^2	4	3	−0.84	89.46
	5	4	0.32	121.71
	6	3	−0.71	75.69
	15	2	0.22	71.85
	16	2	1.44	46.27
	17	2	5.58	91.80

Finally, in both countries, electricity and natural gas were affected in terms of excessive energy consumption due to changes in consumption habits and in the way energy was managed in households. This may be due to the so-called rebound effect, which is described as higher energy consumption due to improved efficiency [48,49]. To calculate the rebound effect, empirical methods were used to quantify its magnitude [26–28]. Furthermore, another study focusing on heating and cooling systems in Austria quantifies the rebound effect to be between 20% and 30% of energy overconsumption [50]. In more recent studies [31], they quantified it in economic terms at more than 50%.

In this work, the results coincide with the rebound effect indicated by these authors, i.e., there is a mismatch between the measured consumption and the expected savings due to the behavior of the occupants. Moreover, it has been proved that the average base load increased in most of the dwellings. This indicates that the tenants connect more appliances to the grid after the reforms.

6. Conclusions

This research study presents a procedure for measuring energy savings in buildings using the International Performance Measurement and Verification Protocol (IPMVP) and demonstrates the method using real-time measurements with real cases before and after energy improvements made within the framework of the European DREEAM project. This technique considers weather changes, hours of use, and measurement days. It also provides information to quantify the effectiveness of savings measures in households.

The use of the hours-of-use variable to measure energy savings can lead to the improved accuracy of the building energy baseline regression model. This information helps to identify changes in energy use by tenants.

Data on average baseload, hours of use, and energy consumption before and after energy improvements have been compared to understand consumption patterns and possible causes affecting energy consumption.

It was found that there is a discrepancy between the estimated savings in the project and the results obtained. In UK homes, the total energy savings obtained for all homes was 14%, in contrast to the predicted savings calculation of 88%. Additionally, the quantification of energy savings in Italy was 38%, in contrast to the estimated savings of 67%.

The energy savings obtained are very different from the savings calculated before the energy improvements. They depend to a large extent on the habits and behavior of the tenants. In addition, it was observed that households that did not save energy may be due to the so-called rebound effect because the energy use and comfort conditions inside some of the buildings have changed before and after the energy improvements. Another aspect that supports the rebound effect is the increase observed in the average base load in most of the dwellings compared to the situation before the reforms.

To avoid the rebound effect, governments need to develop policies to mitigate these effects and must go beyond just assessing the effect of energy efficiency: they must also identify which types of consumers are likely to consume more energy and be able to follow-up on good energy practices after the improvements are done.

The analysis of energy data should extend to the estimation and inclusion of rebound effects, together with the evaluation of energy efficiency improvements, as well as should include the evaluation of strategies to compensate for these effects by minimizing the impact on the well-being of tenants.

The results obtained indicate that the size of the dwelling and the number of tenants do not have a direct impact on energy consumption and savings rates due to the different profiles and energy management practices of the occupants.

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