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Article

Energy Performance Database of Building Heritage in the Region of Umbria, Central Italy

Cinzia Buratti [1], Francesco Asdrubali [2,*], Domenico Palladino [1] and Antonella Rotili [2]

[1] Department of Engineering, University of Perugia, Via G. Duranti 67, Perugia 06125, Italy; E-Mails: cinzia.buratti@unipg.it (C.B.); palladino.unipg@ciriaf.it (D.P.)

[2] CIRIAF (Inter-University Research Center on Pollution and Environment "Mauro Felli"), University of Perugia, Via G. Duranti 63, Perugia 06125, Italy; E-Mail: rotili.unipg@ciriaf.it

* Author to whom correspondence should be addressed; E-Mail: francesco.asdrubali@unipg.it; Tel.: +39-075-585-3716.

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Abstract: Household energy consumption has been increasing in the last decades; the residential sector is responsible for about 40% of the total final energy use in Europe. Energy efficiency measures can both reduce energy needs of buildings and energy-related CO_2 emissions. For this reason, in recent years, the European Union has been making efforts to enhance energy saving in buildings by introducing various policies and strategies; in this context, a common methodology was developed to assess and to certify energy performance of buildings. The positive effects obtained by energy efficiency measures need to be verified, but measuring and monitoring building energy performance is time consuming and financially demanding. Alternatively, energy efficiency can also be evaluated by specific indicators based on energy consumption. In this work, a methodology to investigate the level of energy efficiency reached in the Umbria Region (Central Italy) is described, based on data collected by energy certificates. In fact, energy certificates, which are the outcomes of simulation models, represent a useful and available tool to collect data related to the energy use of dwellings. A database of building energy performance was developed, in which about 6500 energy certificates of residential buildings supplied by Umbria region were inserted. On the basis of this data collection, average energy and CO_2 indicators related to the building heritage in Umbria were estimated and compared to national and international indicators derived from official sources. Results showed that the adopted methodology in this work can be an alternative method for the evaluation of energy indicators; in fact, the ones calculated considering simulation data were similar to the ones reported in national and international sources. This allowed to validate the adopted methodology and the efficiency of European policies.

Keywords: energy saving; greenhouse gas emission; simulation code; buildings; energy performance; energy database; energy indicators

1. Introduction

The Kyoto Protocol was signed in 1997 by many countries, including European ones, in order to limit global warming and to reduce greenhouse gas emissions. Specifically, it was issued with the aim of reducing carbon dioxide emissions by 8% within 2012 compared to the 1990 values (base year).

As international sources showed, 3600 million tons (Mt) of CO_2 emissions were released in Europe in 2010 [1–5], with a decrease of about 10% with respect to the base year. In order to reduce the CO_2 emissions and to obtain important energy saving, the European Union (EU) provided a common strategy; in agreement with directive 2009/29/EC [6], the European countries were committed to obtain energy saving, renewable energy increase, and CO_2 reduction of 20% by 2020.

In accordance with the common European strategy, Italy had to reduce CO_2 emissions by about 6.5% by the end of 2012 compared to 1990, but it reached only 5.8% CO_2 reduction [2–5]. This result is mainly due to the building sector, which accounted for 40% of total emissions; in particular, many studies in Italy have shown that buildings are responsible for about 40% of the total energy consumptions, because the main part of Italian buildings were built before the 70s and have high heating energy needs [6].

Hence, it is necessary to achieve a sustainable development in the next decades; this process should be pursued by means of energy efficiency strategies in order to further reduce CO_2 emissions and energy consumption. The Energy Performance of Buildings Directive 2010/31/CE [7] played a key role in supporting energy saving measures to move towards new nearly zero-energy buildings by 2020. Government policies encourage the improvement of energy efficiency of buildings, in order to reduce energy demand and the energy-related CO_2 emissions in compliance with the European common strategy [7].

Moreover, in agreement with European strategies, Italy splits its reduction objective using a different "Burden Sharing" for each region; specifically, the Region of Umbria has to increase its renewable energy share up to 14% within 2020, consequently reducing both energy consumption of fossil fuels and CO_2 emissions.

In this paper, the buildings of the Region of Umbria were chosen as a sample because they are representative constructions of central Italy; besides, in recent years different measures were promoted in Umbria to achieve energy saving in the building sector, for example, green buildings were funded within the Annual Operational Program [8,9]. Therefore, the aim of this work is also to evaluate the efficiency of the adopted Regional policies.

In order to evaluate the actual energy efficiency of the Umbria Region heritage, many time demanding checks and experimental investigations are required. However, the effects of energy efficiency strategies on the building sector can also be evaluated by means of energy efficiency indicators [10–13] based on energy consumption of the building heritage.

Energy efficiency indicators were estimated on the basis of data collected by energy certificates related to residential buildings in Umbria. Energy certificates are a useful tool to provide information on both building features and energy performance. An energy database was developed in which all the energy certificates received by the Regional Authorities from 2009 to 2012 were inserted [14]; the energy database contains about 6,500 energy certificates of residential and non-residential buildings.

Furthermore, energy and CO_2 indicators were evaluated from the energy database data and compared to the average values at a different level (regional, national, international), estimated from data derived by statistical sources and official reports [2–5].

2. State of Art

The effect of the Energy Performance of Buildings Directive (EPBD) [15] on the European building stock has been a central theme since it was issued, in particular how it can contribute to CO_2 emissions reduction from the building sector by 2020. In this context, a study was carried out by EURIMA, the European Insulation Manufacturers Association, and EuroACE, the European Alliance of Companies for Energy Efficiency in Buildings, which examined five standard buildings, in order to represent the different features of European buildings, varying insulation systems and climatic conditions (consisting of 210 building types under study) [16]. The study highlighted that the EPBD can actually lead to important energy saving, even if it is very difficult to represent all the characteristics of a building stock because energy performance depends on many factors [17].

Many studies were carried out in order to evaluate the energy performance of buildings; some of them were based on statistical data provided by European reports or by municipalities [18–21], others evaluated the efficiency of the European methodology by using a survey questionnaire carried out in all European countries [22,23]. Other interesting works evaluated the energy performance of buildings based on a database in which different parameters were included [22–26]. One of them created a database in which 255 different parameters related to building characteristics were included [26]. Based on this database, a statistical analysis was carried out and the energy performance of dwellings as a function of several parameters was examined. In some studies [20,23], an original method was adopted in order to evaluate the energy performance of the investigated area. Specifically, they developed a database in which data from energy certificates were reported and were based on a cartographic representation of the examined area using GIS. All the examined papers were focused only on the statistical analysis and did not use the simulation data as input to define and to evaluate the energy and emissions indicators.

However, simulation data are easily found and collected, so they are also a great sample to calculate energy indicators: in this work this approach was attempted. In order to verify the reliability of the results, the calculated indicators were compared to the ones reported in national and international reports. Energy certificates were chosen as sample data because they are the results of the methodology provided by the European Union for evaluating and for certifying the energy performance and emissions of buildings. In fact, in compliance with the European Directive, each Country has to provide a common method for the calculation of energy performance of buildings by using simulation codes; in Italy this methodology has been specifically provided since 2009.

The sample data was collected using an energy database as in previous works [14–26]: all the energy certificates received until 2012 by the Regional Authorities were inserted in this database, already described in a previous work in which an original and useful energy index for checking the energy certificates was developed [14]. All the data included in the energy database were analyzed and used for the energy indicator calculation.

The novelty of this paper is due to the establishment of benchmarks of energy consumption and CO_2 emissions in Umbria that can be compared to other energy and environmental performance indicators at different levels (national or international). In this way it is possible to evaluate the improvements obtained with the application of the regulations [15,25,27].

3. Methodology

All the energy certificates received by the Regional Authorities were inserted into an energy database [14,16–23,26], in order to collect the sample data required for this study. The energy certificates were chosen because they represent the common method provided by European countries and used to check the energy performance of the buildings; in 2009 the D.M. 26/06/2009 [27] was issued in Italy, based on EPDB [13], in which the methodology for the calculation of the energy performance and the issuing of the energy certificates were supplied. In agreement with European and Italian regulations [15,27,28], the energy performance of buildings was estimated using validated simulation codes [29]; these simulations represent a great data set on which the study of energy performance of the building heritage in Umbria can be based on, as the other works have shown; besides, unlike other works, they could also represent a great data set on which energy indicators can be calculated.

More than 6500 energy certificates were collected; some of them, about 2700, are self-declarations, in which only limited information about the geometry and energy performance class of the buildings is reported. This sample data represent about 2% of Umbria building heritage, however the collected data represent a wide sample data, which was much larger than the one used in previous works [14,16–24].

The energy database was implemented in Access software; in order to simplify the insertion of energy certificates, five main tables were created, containing the following information:

1 building characteristics;
2 energy performance;
3 advice to improve the energy performance of the buildings;
4 plant characteristics;
5 data and calculation methodology.

Each energy certificate was saved in a digital format, with an identification sequential numerical code, in which all the data included in the tables are reported. In order to check energy certificate data, a secondary numerical code was also associated to each table.

The energy database was elaborated and the mean energy performance in $kWh/(m^2year)$ and CO_2 emission in $kgCO_2/(m^2year)$ of the buildings were calculated.

The obtained mean values were compared to the ones reported in national and international sources, such as national inventory, international agencies and statistical databases [30–32]. In this paper, all the data taken from national and international reports are called “official” values, while the ones calculated using the simulation results are called “simulation code” values. The methodology layout adopted in this work is summarized and shown in Figure 1.

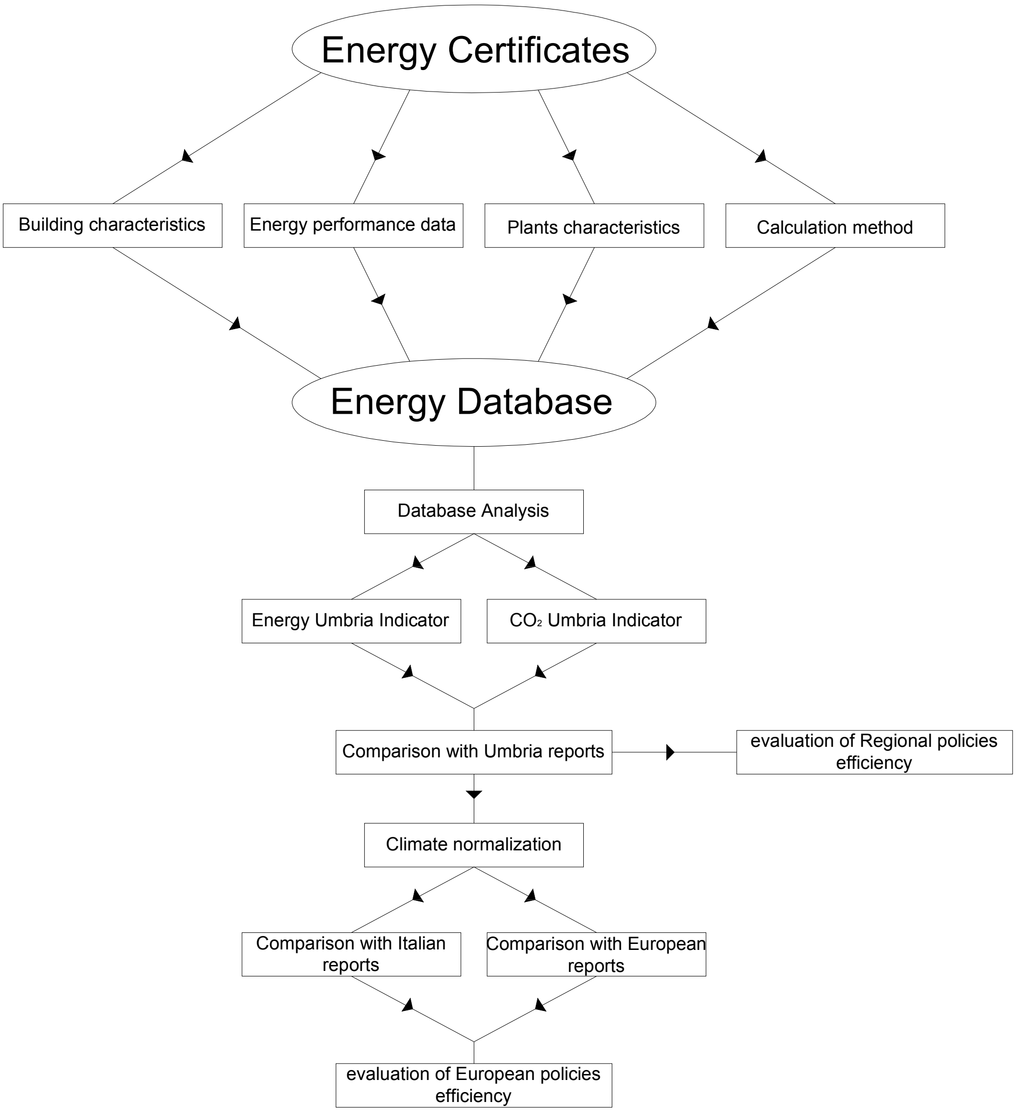

Figure 1. Methodology layout used to define Energy and CO_2 indicators by means of simulation codes.

The first comparison of energy indicators was carried out between the "simulation code" and the "official" data referred to the building heritage in Umbria.

For the comparison, regional energy consumption for heating was evaluated considering national reports, issued by the Italian National Institute of Statistics (ISTAT) [30]. Natural gas consumption (Nm^3) per capita per year, reported by ISTAT was expressed in kWh/(m^2year) with the appropriate conversion unit.

In this model, the Italian and European energy consumption in kWh/(m^2year) was taken from national [30] and international [32] statistical databases respectively.

It is important to clarify that, according to [28], the Italian energy certificates provide the energy consumption only for heating and for hot water; so, for the energy performance evaluation of buildings the energy consumption for cooking and lighting was neglected and they were not considered for the energy indicator comparisons.

Besides, in order to compare the mean "simulation code" value of Umbria to the "official" Italian and European ones, a climate normalization was also required considering the mean heating degree-day (HDD).

In Italy, six different climate zones were created as a function of HDD which are calculated considering a design indoor air temperature equal to 20 °C; then, in order to compare the Umbria values to the Italian ones, a climate normalization considering the mean Italian HDD is necessary. Besides, the same normalization is required for the European comparison, but in most European countries the heating degree-day is calculated considering a design indoor air temperature equal to 18 °C; this value is provided by many European sources for all the European countries (25 countries). Therefore, before these two comparisons between Umbria data and Italian and European ones, a new calculation of HDD for the Umbria Region setting the indoor air temperature to 18 °C was carried out. In Table 1, the mean heating degree-day for Umbria, Italy and Europe are shown.

Table 1. Mean Heating Degree-Day for Umbria, Italy and Europe.

Zone	Design Indoor Air Temperature (°C)	Mean Heating Degree-Day (HDD)
Umbria	20	2282
Umbria	18	1920
Italy	18	1968
Europe	18	3420

The CO_2 indicator available on energy certificates is supplied in kilograms of CO_2 per square meter per year ($kgCO_2/(m^2year)$). All the national and international sources provided the mean value of CO_2 measured in kg per dwelling, so the CO_2 indicator of energy certificates was multiplied by the floor area of the dwelling, in order to compare it to the statistical data.

Generally, the amount of the total CO_2 emissions from households can be calculated by direct use from fuel combustion and indirect use from electricity consumption. Energy demands for heating and electricity were multiplied by the specific CO_2 production coefficient of the energy carrier; the emission factors were provided by international or national inventory of greenhouse gases and environmental reports issued by official sources, such as the Intergovernmental Panel on Climate Change and the International Energy Agency.

In this study, CO_2 emission estimates were calculated by using CO_2 indicators available on energy certificates for each dwelling, which correspond to the amount of CO_2 emissions due to energy use for heating and for hot water, expressed in $kgCO_2/(m^2year)$. On the basis of these values, the average value of CO_2 emissions was calculated as the mean of the CO_2 indicators related to about 3200 energy certificates for residential dwellings in Umbria (corresponding to 2% of the total regional housing stock [30,31]).

Therefore, the mean value of CO_2 indicators was scaled to the EU climate conditions in agreement with the previous methodology used for the energy performance of the buildings.

Moreover, in order to evaluate the efficiency of the Umbria Region policies, the same energy indicators were also calculated considering the year of construction of the building. For the comparison, the average annual value for Italy was calculated as the ratio between the CO_2 emissions per dwelling—adapted according to climate conditions—and the average floor area of dwellings (96 m^2) [30]. The average CO_2 emissions per square meter of European dwellings was finally derived from EEA estimates [3].

Finally, considering the "simulation code" values, five typical dwellings, built in five different years (1990, 1995, 2000, 2005, 2010), were also investigated. Each dwelling was characterized by an average floor area and an average CO_2 emission per square meter.

4. Results

4.1. Energy Performance

The main characteristic of buildings certified and inserted into the energy database are reported in Tables 2 and 3. As shown in Table 2, the main part of energy certificates are related to the years 2005–2010 (about 50%), *i.e.*, after the Legislative Decree [28], and the main part of dwellings belongs to apartment buildings (49%).

Table 2. Main features of residential buildings in Umbria region included in the energy database.

Year of Construction	Energy Certificates (%)	Heated Volume (m^3) *	Floor Area (m^2) *	Heat Transmission Surface (m^2) *	Heat Transmission Surface/Heated Volume Ratio—S/V (m^{-1}) *
<1950	6.0%	457.41	115.32	281.67	0.86
1950–1960	2.5%	387.06	104.52	222.78	0.77
1960–1970	4.9%	503.52	130.71	267.31	0.67
1970–1980	4.2%	434.50	120.05	251.97	1.18
1980–1990	3.7%	387.32	105.31	225.14	0.75
1990–2000	6.3%	351.18	94.07	201.22	0.67
2000–2005	5.2%	320.29	375.81	228.72	0.92
2005–2010	49.7%	312.81	92.77	182.12	1.15
>2010	12.2%	314.73	127.46	199.66	0.61
Other **	5.3%	372.20	97.63	239.69	0.91

Notes: * Mean value from energy database; ** Year of construction not available.

Table 3. Typology of buildings in Umbria included in the energy database.

Type	Share	Type	Share
Apartment building	49.10%	Terraced house	4.70%
Multi-family house	13.30%	Multi-story building	3.10%
Tower house	7.90%	Historic building	1.40%
Detached house	6.20%	Undeclared *	14.30%

Note: * Building typology not available.

The mean "simulation code" energy value of Umbria buildings was calculated. Firstly, the energy consumption of buildings for the two main areas of Umbria (Perugia, Terni) was evaluated and compared to the national report [30]. Table 4 shows that the mean energy consumption calculated using the energy database data is higher than the one reported in the official reports, with a mean percentage error of about 17% for Perugia and 8% for Terni. However, this trend is mainly due to the methodology adopted and provided by the European Union; in fact this method allows to evaluate the energy performance of buildings by using a semi-stationary calculation code that implies a slight overestimation of the energy consumption.

Table 4. Comparison between official and energy database values for Umbria buildings.

Province	Regional Consumptions [30]		Umbria Energy Database		Difference (%)
	Natural Gas for Heating (Nm^3)	Energy (kWh/(m^2Year))	Natural Gas (Nm^3)	Energy (kWh/(m^2Year))	
Perugia	9.87	103.59	11.94	125.33	+17.3%
Terni	7.83	82.21	8.54	89.64	+8.3%

A more detailed analysis shows that it is possible to evaluate the mean energy consumption of buildings (on the right y-axis of Figure 2) and the percentage of the number of certificates (on the left y-axis of Figure 2) as a function of the energy class. The main part of the buildings are in the C and D energy class, with a mean energy consumption of about 85 kWh/(m^2year) for Perugia and 72 kWh/(m^2year) for Terni. The remaining part of the buildings presents a very high energy consumption, especially the ones in class F (with a mean energy consumption of about 173 kWh/(m^2year) for Perugia and 137 kWh/(m^2year) for Terni) and in class G (about 300 kWh/(m^2year) for both cities).

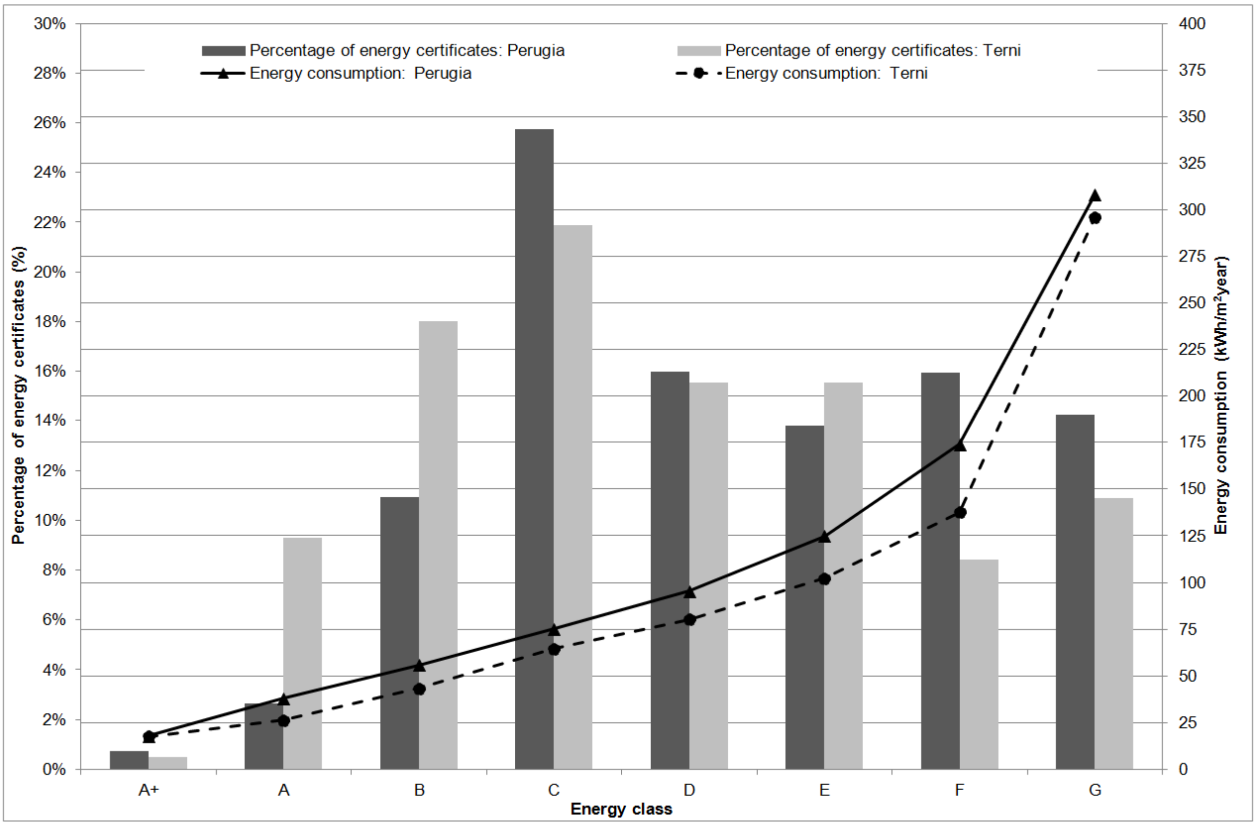

Figure 2. Percentage of energy certificates received and mean energy consumption as a function of the energy performance class of Umbria buildings.

On the basis of this preliminary comparison, the mean energy performance of the buildings, equal to 104.85 kWh/(m^2year), was evaluated considering its mean HDD; this value is slightly higher than the one reported in official sources (97.96 kWh/(m^2year) [30], +6.5%). However, this difference is in agreement with the previous analysis and it can be considered acceptable.

In order to compare the mean energy performance of the buildings in Umbria with the Italian and European ones, a climate normalization was carried out.

In this way, the energy performance of a building located in Umbria in the Center of Italy can be comparable with the energy performance of a European building. In fact, the actual winter season is different in European countries and heating energy consumption is obviously influenced by climatic factors and temperature differences. The mean energy consumption of Umbria buildings considering the climate normalization are shown in Table 5.

Table 5. Mean energy consumption of Umbria buildings corrected with climate normalization.

Zone	Mean Heating Degree-Day (DD)	Mean Energy Consumption (kWh/(m^{2}Year))
Umbria mean value	2282	104.85
Umbria mean value climate corrected	1920	88.22
Umbria mean value climate scaled to Italy	1968	90.43
Umbria mean value climate scaled to Europe	3420	157.1

The calculated value was compared to the Italian one reported in official sources; specifically, Figure 3 shows the comparison of "official" energy consumption in Italy, in the various Italian Regions and in Umbria (according to the mean "simulation code", equal to 104.85 kWh/(m^{2}year)).

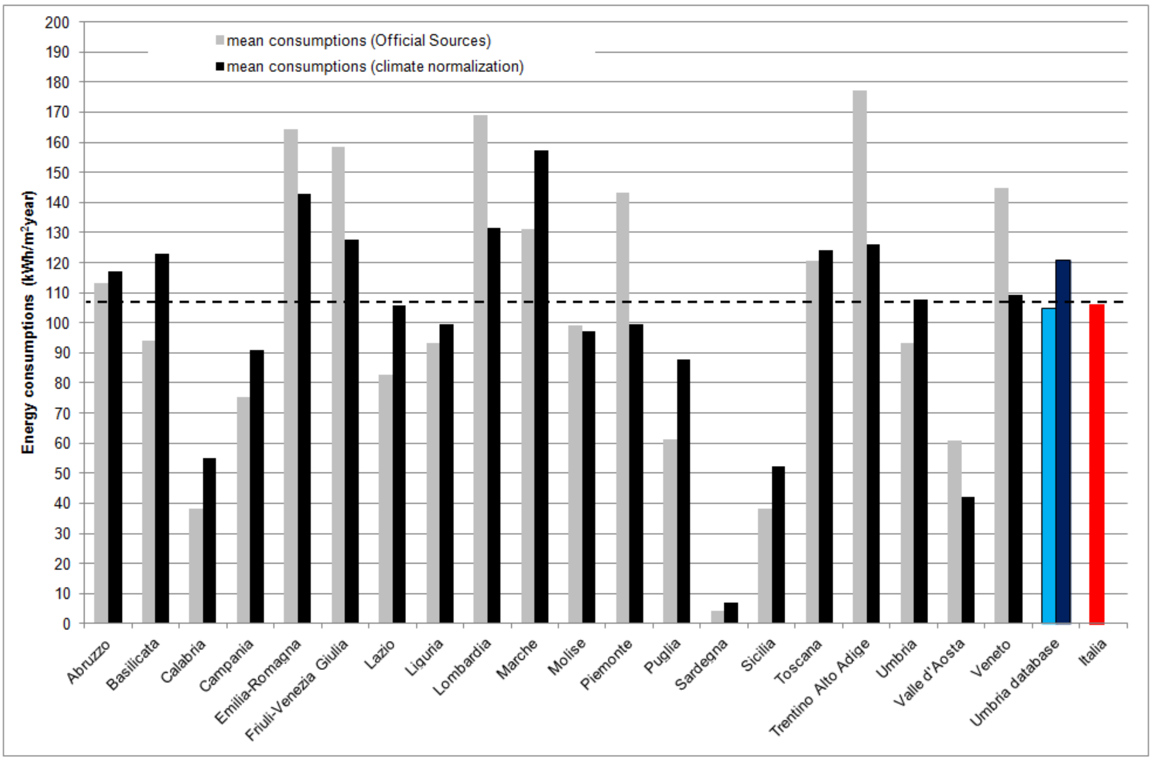

Figure 3. Comparison of the energy consumption of Umbrian buildings with the mean values of Italy and of the various Italian Regions.

The energy consumption rises with the increase of HDD and the mean "simulation code" values confirm this trend; specifically the calculated mean Umbria value (104.85 kWh/(m^{2}year)) is slightly higher than the "official" one, but it is lower than the mean Italian value (106.33 kWh/(m^{2}year)), with a difference of about 1,5%. All the official data were normalized according to mean Italian HDD, in order to avoid the influence of climate on energy consumption (the black bar on the right).

Therefore, considering the data of the energy certificates, a higher value, which was much closer to the mean Italian consumption, was calculated; therefore, the energy indicator calculation considering the energy certificates data can be considered as a more precautionary approach.

The comparison with European energy indicators provided by official sources is shown in Figure 4; the histograms in grey represent the energy consumption of European countries provided by international reports [32], the ones in black are respectively the mean value of Umbrian buildings, calculated by using the energy database and scaled to Europe (157.1 kWh/(m^{2}year), the mean Italian and the mean European consumption.

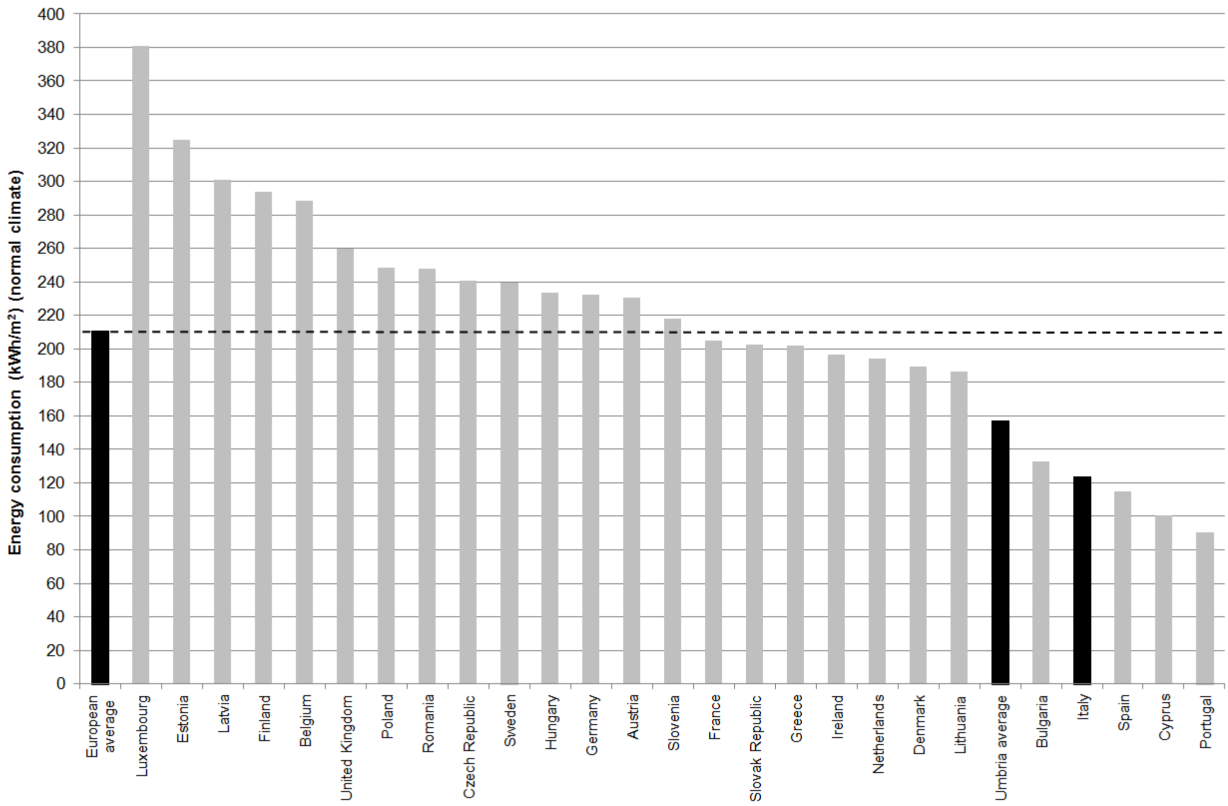

Figure 4. Comparison of the energy performance of Umbrian buildings with the one of European countries and with the mean value for European buildings.

Figure 4 shows that the energy consumption of the buildings in Umbria is lower than almost all the European countries but, as Figure 3 shows, it is higher than the one estimated for Italy in the international sources, with a difference of about +33 kWh/(m^{2}year). Considering the mean European value (European average), an important difference in energy consumption was also highlighted; in fact, the mean "simulation code" consumption of Umbrian buildings (indicated in Figure 4 with Umbria average) is lower than the mean "official" of Europe, with an important energy saving of about −55 kWh/(m^{2}year).

Considering the climate normalization, this last comparison allows to highlight that the energy performance of the mean Umbrian building is better than the ones of other European countries; besides, the mean energy consumption of Umbrian buildings will decrease thanks to the more restrictive limits of the Italian regulations D. Lgs. 192/05 [28].

Finally, in order to highlight the efficiency of the new Umbria and Italian regulations, the mean energy consumption of Umbrian buildings depending on the year of construction was also calculated.

In Figure 5 the comparison of these energy indicators was reported: considering only the recent buildings (after 2010), the mean energy performance value is lower than the other ones, with a mean energy saving of 60% considering the buildings built before 2005 and about 17% of the ones built between 2005 and 2010.

This trend shows how the new political actions of the Regional Authorities, such as the Protocol for the environmental certification of buildings [28], has had a good impact on energy consumptions.

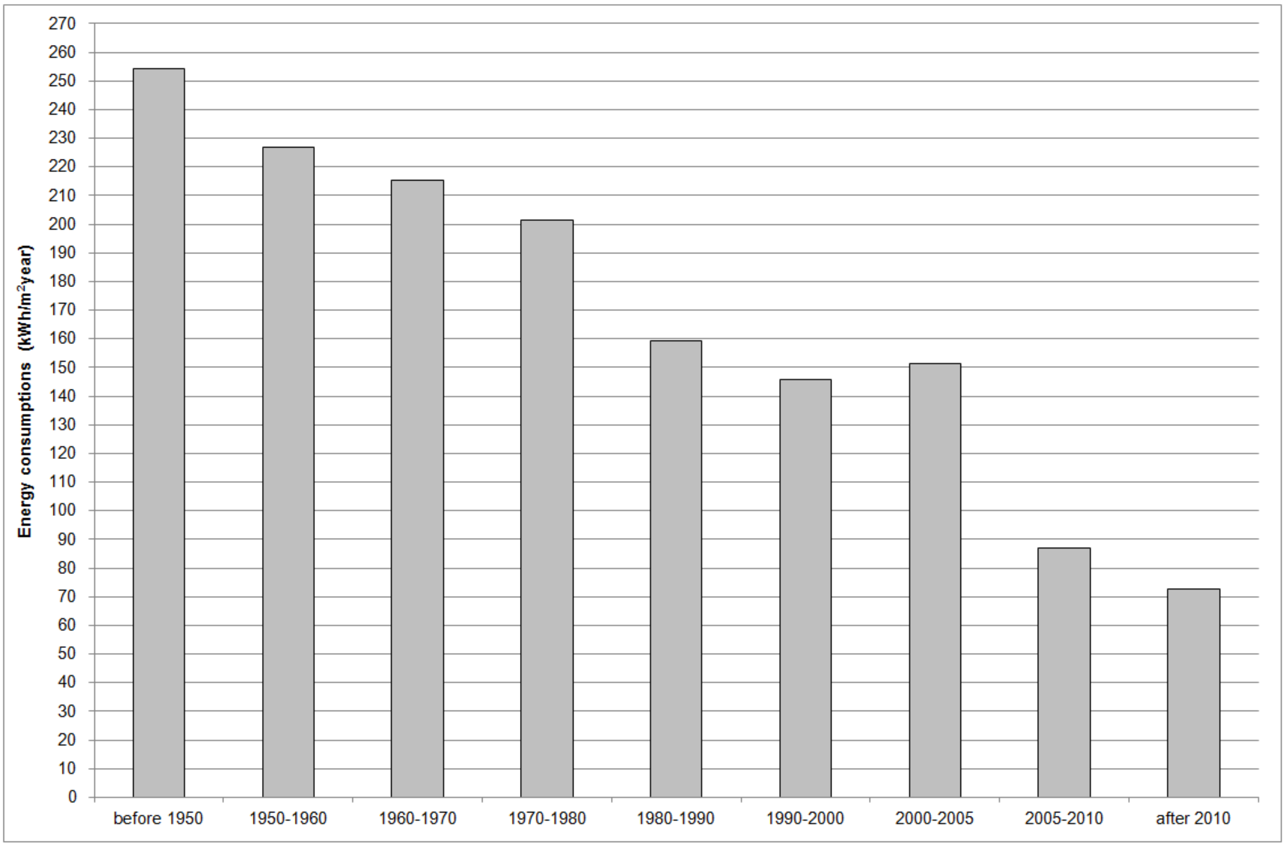

Figure 5. Energy consumption of Umbrian buildings as a function the of year of construction.

4.2. CO_2 Emissions

According to the data from the energy database, the dwellings in Umbria released an average of 24.5 kilograms of CO_2 per unit of useful floor area per year (kg/m^{2}year) into the atmosphere. Because of the influence of recent international regulations on building consumption, Figure 6 shows the comparison between new and existing buildings in Umbria; the mean value of Umbrian buildings performance, scaled to European climate, is also shown (the average value of CO_2 emissions was scaled to the European climate as described in the methodology section, in order to compare the results with the values estimated for other residential buildings in Europe).

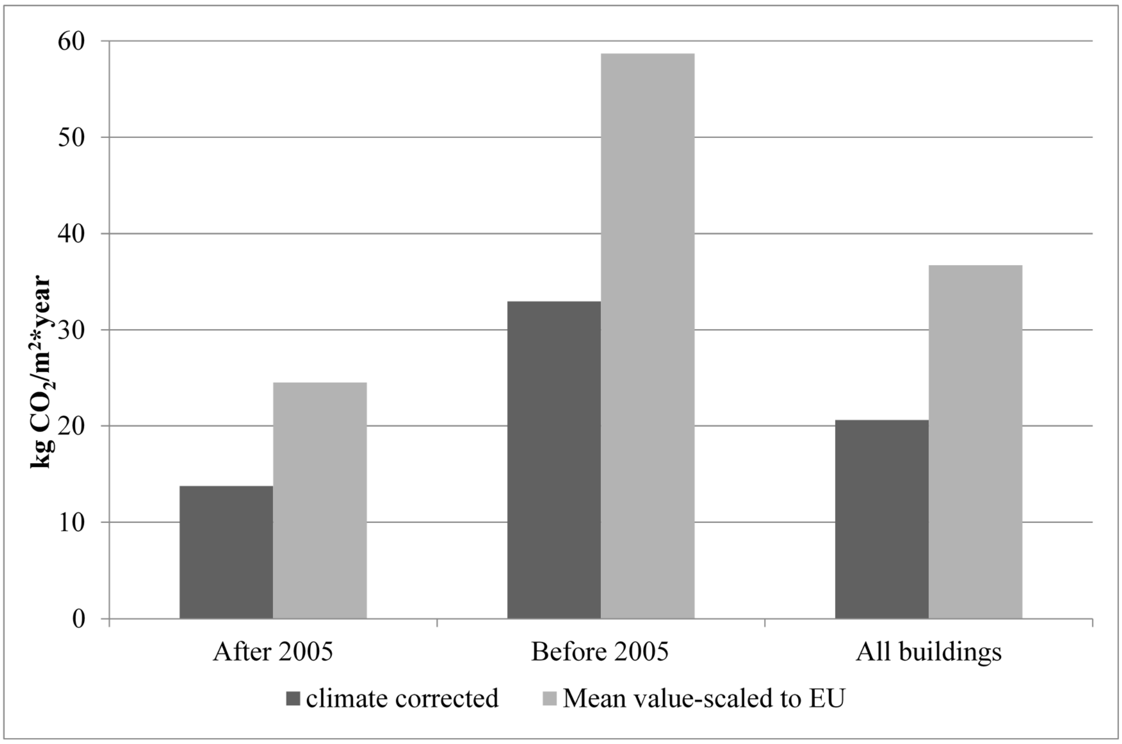

Figure 6. Annual average CO_2 emissions per useful floor area for new buildings (built after 2005), existing buildings (built before 2005) and overall Umbrian buildings and corresponding values scaled to EU climate.

The emissions of existing buildings are 60% higher than the ones of new dwellings in Umbria. This trend is due to bad energy performance, above all in the dwellings built before 1990 [33]. In fact, old buildings have a higher value of the thermal transmittance (U-value), due to the absence of insulation or refurbishment, and therefore the envelope has a higher consumption for heating. Based on the energy certificates received by the Regional Authorities, buildings built before 1990 have an average energy consumption for heating of 185 kWh/(m^2year)) (average value not climate corrected). Energy mix also affected CO_2 emissions values; based on collected data, natural gas is the main fuel used for heating in Umbrian dwellings (82%), followed by LPG (12%).

When Umbrian dwellings are classified by age of construction, the average value per square meter varies between 15 and 50 kgCO_2/m^2year as shown in Figure 7. The comparison highlights a decreasing trend of the emission rate; in particular the emissions from new buildings (built after 2005) are lower than the ones estimated for the old buildings, with a maximum rate of decrease of about 70%.

This trend also confirmed the results obtained for the energy consumption of Umbrian buildings (Figure 3); the two indicators are closely correlated because of the fossil fuels used for heating.

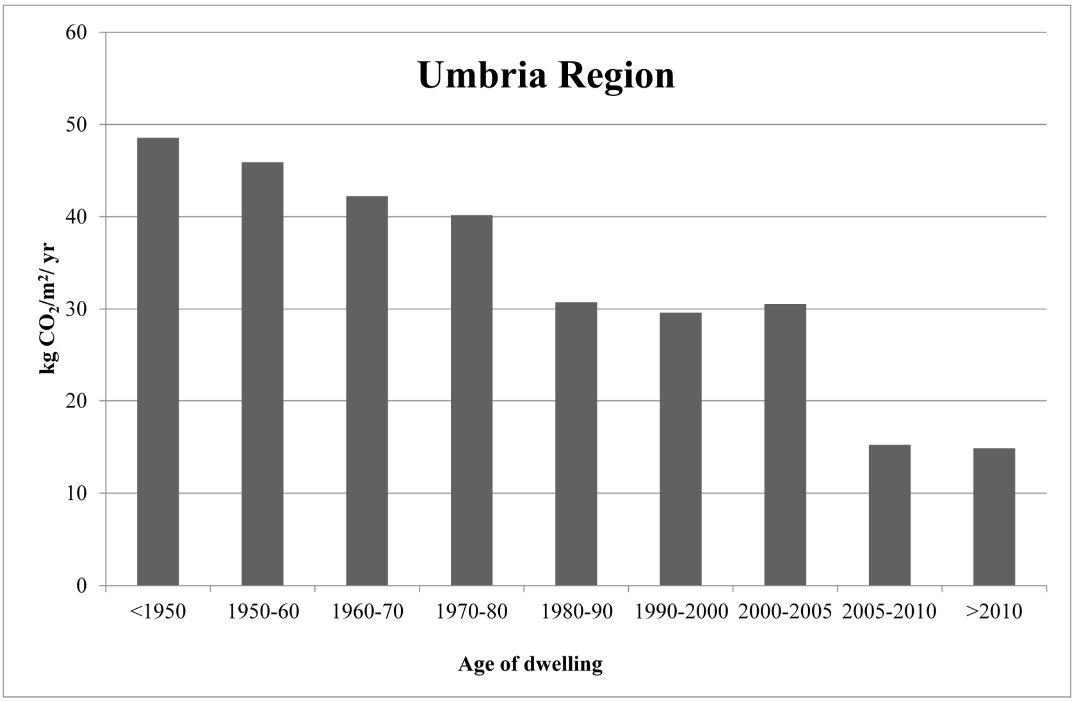

Figure 7. Annual average CO_2 emissions per unit of floor area (m^2) as a function of the age of dwelling (not climate corrected) in Umbria.

Based on Eurostat database, CO_2 emissions from the residential sector in Italy were about 2 tons per dwelling, corresponding to 23.76 kilograms of CO_2 per square meter per year. The comparison of mean CO_2 emissions between Umbria and Italy considering the climate correction is shown in Figure 8. These values are in agreement with the ones provided by other studies [3,34]. The building heritage in Umbria can be representative of the buildings in Central Italy and CO_2 emissions are slightly lower than the national average value.

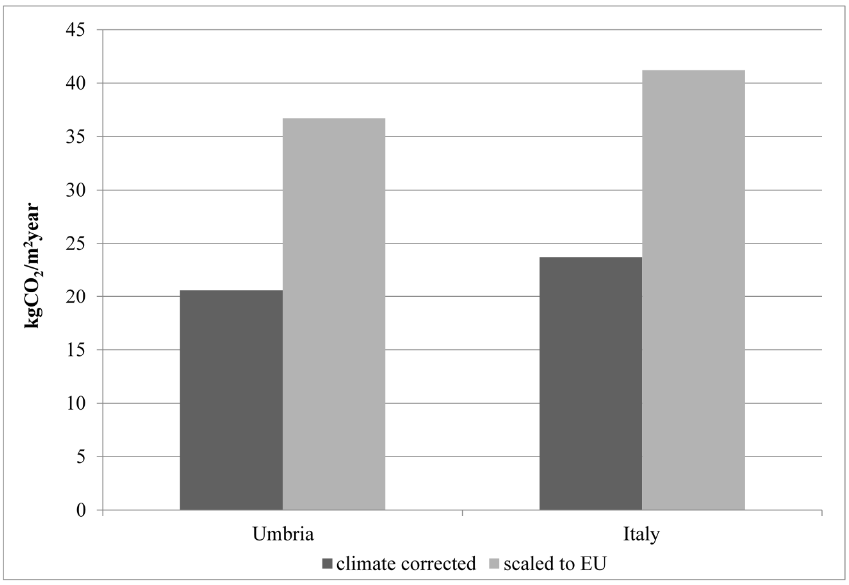

Figure 8. Average CO_2 emissions per useful floor area for Umbria and Italy: comparison between climate corrected and EU scaled data.

Finally, the calculated CO_2 emissions per dwelling were compared to the mean values of European countries; this comparison is shown in Figure 9. The mean value of Umbria is lower than the mean value of European countries, with a difference of about 2 tons of CO_2 per dwelling, and it is very close to the Italian mean value.

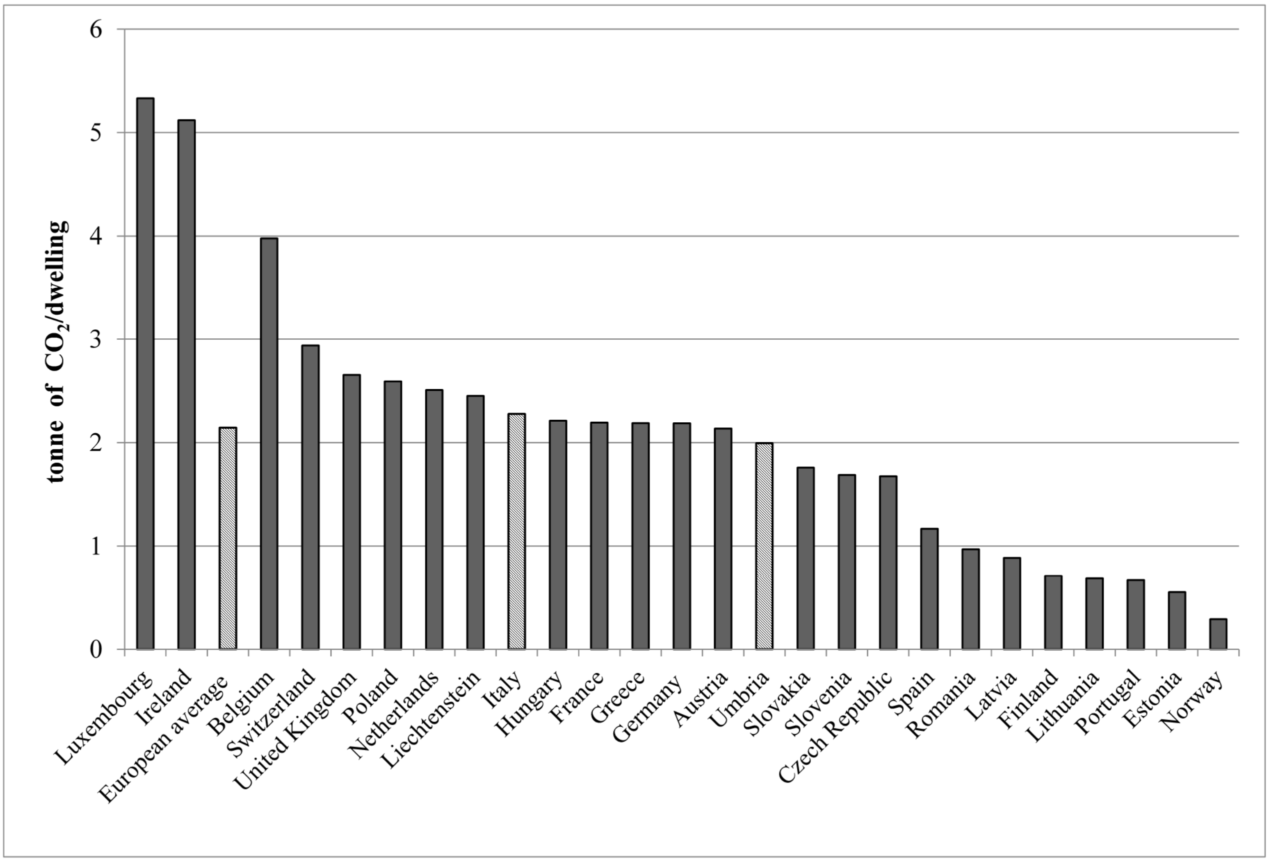

Figure 9. Annual average CO_2 emissions per dwelling by country in Europe.

The comparison of the CO_2 indicators calculated using energy certificates with the ones reported in official sources allowed to highlight the effectiveness of the methodology adopted in this study; in fact using the data of the energy certificates allowed to obtain energy indicators very close to the reference values, but with a significant saving of time.

Five "mean dwellings" for five different years of construction (1990, 1995, 2000, 2005, 2010) were examined, in order to evaluate CO_2 emission savings as result of the application of energy and environmental policies and measures [8,15,28]. Moreover, certification of environmental sustainability was also introduced for residential buildings in Umbria in recent years [35].

The reference case is the "mean dwelling" built in Umbria in 1990, as shown in Figure 10, CO_2 emissions of the "mean dwelling" built in Umbria in 2010 decrease by 50% compared to the reference dwelling.

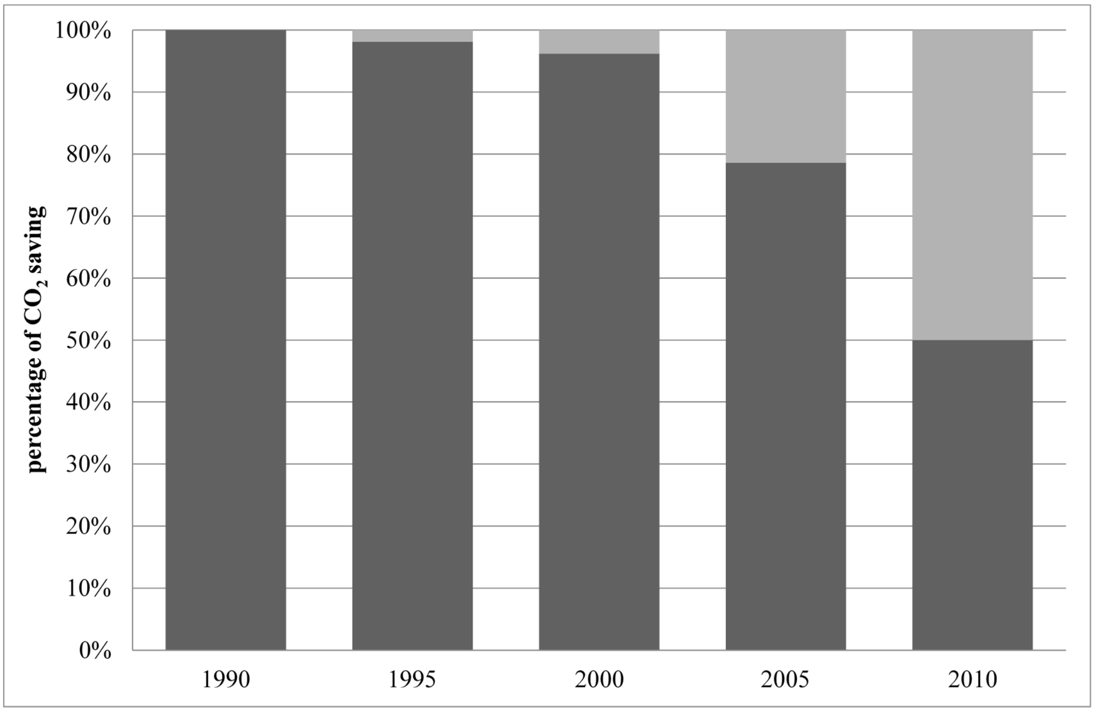

Figure 10. CO_2 saving for households in the Umbria: trend in the years 1990–2010.

5. Conclusions

Many international agencies declared that total primary energy demand will increase in the next decades with a large use of fossil fuels. In order to obtain an important energy saving, a common European strategy was promoted in the building sector and it has played a key role in energy saving measures to achieve the objective of Nearly Zero-Energy Buildings (NZEB) by 2020.

All the data used by international agencies are based on real or experimental values, not always available; however the methodology provided by Europe allows to evaluate and to certify the energy performance and the emissions of buildings by using simulation codes. They are an interesting tool to provide and represent data on which a statistical analysis can be based on.

In this work the energy performance of buildings in Umbria was collected from energy certificates, and inserted in a database, in order to provide the necessary input data on which further statistical analysis was based. In particular, the mean energy consumption and the CO_2 emissions were calculated and then compared to the ones reported in the Italian and European official sources. In order to compare these indicators, a climate normalization was necessary, to take the different climate conditions into account.

Both the energy and CO_2 indicators estimated using simulated data are very close to the ones reported in European official reports and they allow to highlight an effective energy saving and CO_2 emissions reduction in the residential sector, which is one of the major energy consumers.

The energy consumption of buildings and the CO_2 emissions in Umbria are decreasing with respect to the base year (1990) thanks to the European policies; considering only the new buildings (built after 2005) in Umbria, a CO_2 reduction and an energy saving of about 50% and 70% respectively were obtained.

Results shown in this study highlight that the energy consumption and CO_2 emissions of Umbrian building heritage are very close to the Italian ones, while they present a worse energy performance and higher CO_2 emissions when normalized and compared to Italian and European ones; this trend is mainly due to the climate correction that is necessary in order to compare the performance of buildings in different climates. In fact, differently to Italian Regions and European countries, Umbria has a heating degree-day value lower than the mean European one.

However, the statistical analysis based on about 3200 simulations highlights that the average building in Umbria presents an energy consumption and CO_2 emissions lower than the ones of most European countries, and this result is in agreement with official sources.

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Author Contributions

Authors equally contributed to the collection and analysis of data and to the writing of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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