Energies **2013**, *6*, 3506-3527; doi:10.3390/en6073506

OPEN ACCESS

energies

ISSN 1996-1073

www.mdpi.com/journal/energies

Article

Nearly Zero-Energy Buildings of the Lombardy Region (Italy), a Case Study of High-Energy Performance Buildings

Giuliano Dall'O' [1,*], Valentina Belli [2], Mauro Brolis [2], Ivan Mozzi [2] and Mauro Fasano [3]

[1] Department of Architecture, Building Environment and Construction Engineering, Polytechnic of Milan, Via E. Bonardi 9, Milan 10133, Italy;

[2] Finlombarda S.p.A., Energy Department, Via Taramelli 12, Milan 20124, Italy; E-Mails: valentina.belli@finlombarda.it (V.B.); mauro.brolis@finlombarda.it (M.B.); ivan.mozzi@finlombarda.it (I.M.)

[3] Regione Lombardia, Department for Environment, Energy and Sustainable Development, Energy Unit, Piazza Città di Lombardia 1, Milan 20124, Italy; E-Mail: mauro_fasano@regione.lombardia.it

* Author to whom correspondence should be addressed; E-Mail: giuldal@polimi.it; Tel.: +39-02-2399-4649; Fax: +39-02-2399-9491.

Received: 28 May 2013; in revised form: 10 July 2013 / Accepted: 11 July 2013 / Published: 16 July 2013

Abstract: The topic of nearly zero-energy buildings (n-ZEB), introduced by the Directive 2010/31/EU will direct the building market toward ever greater energy efficiency of new buildings. In some contexts, however, the building market for high-efficiency buildings has evolved, in recent years, on the basis of national and regional laws that have contributed to the acceleration of the process. This paper analyses the case study of the Lombardy Region (Italy), which transposed and assimilated the Directive 91/2002 (Energy Performance Building Directive), as of 2006, with regional legislation for energy efficiency of buildings. Within a few years the market for high energy-performance of buildings in the Lombardy Region had grown substantially: to date nearly 7500 energy performance certificates for buildings of Class A and Class A+ have been issued. The paper therefore analyses a success story in what is a field of great current interest, namely n-ZEB buildings. In the first part of the work, the evolution in terms of energy efficiency of the housing market in the Lombardy Region has been analyzed, with particular reference to the high energy-performance of buildings. The second part focuses on a sample of 20 n-ZEB buildings in order to highlight the design choices applied to them.

Keywords: energy efficiency; near zero energy buildings; green buildings; high-performance buildings; energy certification; energy policies; CENED; Lombardy

Abbreviations:

AHP	Air to air Heat Pump
AT	Air Terminals
BA	Building/home Automation
BB	Biomass boiler
BEST	Building Environment Science and Technology
CB	Condensing Boiler
CEN	European Committee for Standardization
CENED	Certificazione Energetica degli Edifici
CESTEC	Centre for Technological Development, Energy and Competitiveness
CHP	Combined Heat and Power
CS	Conscious in context and site
DH	District Heating
DHW	Domestic Hot Water
EC	Electric Chiller
EP	Primary Energy
EPBD	Energy Performance Building Directive
EPC	Energy Performance Certificate
FCU	Fan Coil Units
FCW	Free Cooling with hot Water
FRP	Floor Radiant Panels
GB	Green Building
GHP	Gas fired Heat Pump
GPD	Gross domestic product
GSHP	Ground Source Heat Pump
HP	Hat Pump
HTC	Heating Cooling Terminals
LI	Conscious Lighting design
NM	Use of Natural Materials
PV	Photovoltaic solar
RAB	Regional Accreditation Body
RET	Renewable Energy Technologies
RS	Renewable energy Sources
S	Storage
SC	Conscious in Summer comfort design
TC	Thermal fired Chiller
TS	Thermal Solar
VE	Conscious in Ventilation design

WP	Winter energy Performance
ZEB	Winter energy Performance

1. Introduction

The current development of our society is definitely oriented towards an improvement in environmental sustainability. This change, almost unanimously considered necessary, covers all areas responsible for consumption of energy and, amongst these, the construction industry (residential and tertiary buildings) plays a strategic role. In the European Union, the Green Paper "Towards a European strategy for the security of energy supply" [1] estimated that the residential and tertiary sector, the major part of which is represented by buildings, accounts for more than 40% of the final energy consumption in the Community and is indeed in expansion, a trend which is bound to increase its energy consumption and hence also its related carbon dioxide emissions.

The European Union is positioned as one of the economic areas most active in terms of measures for combating climate change. The European Directive 2002/91/EC [2], named EPBD (Energy Performance Building Directive) highlights the fact that buildings will have an impact on long-term energy consumption and new buildings should therefore meet minimum energy performance requirements, tailored to the local climate.

The transposition and assimilation of the above mentioned Directive in the Member States, generated new regulations and laws aimed at significantly increasing the energy performances of new constructions. The more recent Directive 2010/31/EC [3] goes further, in terms of energy performances for buildings: by 31 December 2020, all new buildings must be nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities must be nearly zero-energy buildings. Energy policies will cover both new buildings and existing buildings; however the high standards required by the high-performance buildings, nearly-ZEB (Zero Energy Building) buildings or ZEB buildings, become an important attractive element for the development of technological innovation in the construction industry. The topic of high energy-performance buildings, or more generally, sustainable buildings, is an issue of current public attention which arouses great interest among the key players in the building process such as designers, manufacturers, contractors and managers.

In Italy, the building sustainability trend started over thirty years ago, in 1976, when Law No. 373 [4] was passed containing the first constraints on the amount of power that could be used for wintertime heating, a game changer that required building designers to really start considering energy consumption in their projects. Another important legal milestone in Italy was reached in 1991 with the introduction of Law No. 10 [5], implementing the National Energy Plan. The rules changed again in the field of construction, becoming more restrictive as regards energy performance, and the concept of "energy planning" was introduced in the country for the first time.

The EPBD was transposed into Italian law through Legislative Decree No. 192 [6], supplemented by Legislative Decree No. 311 [7]. These instruments, however, were insufficient. Thus, in 2006, Lombardy Region, with a population of 9,759,209 inhabitants distributed over 12 provinces (counties) and 1547 municipalities, and the Italian region with the highest Gross Domestic Product (GPD), launched an independent legislative process, which coherently adds to the general principles of Legislative Decree No. 192 [6] and the EPBD.

The introduction of the new legislation on energy efficiency of buildings in Lombardy Region, and in particular the introduction of energy performance certificates, has contributed greatly to modifying the construction market: this has focused its interest on achieving high energy-performance buildings that are comparable, as regards their energy performance, with the nearly-ZEB standard. To date nearly 7500 energy performance certificates for Class A and Class A+ buildings have been issued.

The paper therefore analyses a success story in what is a field of great current interest, namely nearly-ZEB buildings. In the first part of the work, the evolution of the housing market in the Lombardy Region, in terms of energy efficiency is analyzed, with particular reference to the high energy- performance of buildings. The second part focuses on a sample of 20 n-ZEB buildings in order to highlight the design choices applied to them.

Before analyzing the case study of Lombardy it is helpful to provide references on the state of the art in nearly-ZEB and ZEB buildings. The International Energy Agency has created a taskforce called "Task 40 e Annex 52, Towards Net Zero Energy Solar Buildings" [8], with the objectives of developing international definitions of near ZEBs, studying current near ZEBs and supporting the transformation of the near ZEB concept from an idea into practical reality. Based upon existing studies with a comparison between methods currently used in various European countries, the criteria most widely shared among those countries have been identified by Marzal *et al.* [9,10].

In the European Union some countries are discussing the topic of nearly-ZEBs and ZEBs also in relation to the answers that should be given to Directive 31 [3]. The Danish Building Research Institute analyzed existing official and non-governmental European definitions of low-energy buildings. This study showed that seven countries have an official definition of very-low-energy buildings, seven countries have an official definition planned, four countries have an existing non-governmental definition, and four countries have both definitions [11].

A study by the Buildings Performance Institute Europe [12] analyses the differences between existing methodologies, including the floor area considered, internal heat load used in calculations, energy uses included in the calculations, conversion factors, external climatic conditions, indoor temperatures and the inclusion of renewable energy sources. The most common choice adopted in European countries is primary energy whose measurement is expressed in kWh/m^2 per year as a percentage of the minimum requirements given by national building codes. The energy uses included vary widely between the different methodologies. The criteria most widely shared among European countries' methods have been identified and compared in past studies [9,10]. The most common choices are: measured quantity of reference: primary energy; periodicity of reference: annual; supply options: on site.

So far as the Italian context is concerned, Dall'O' *et al.* [13] analyzed an Italian pilot project for ZEB buildings. That paper describes a pilot certification scheme promoted by the Province of Milan (Italy) and implemented in Italy in cooperation with the local builders association. This methodology, which uses a quality-driven approach, is described and discussed in the paper. The certification process proposed highlights the fundamental role of the contribution of renewable energy sources in achieving a high performance standard of ZEB buildings.

The theme of zero-energy buildings, or more generally the theme of green buildings, should also consider social and economic aspects and market conditions. For a constructive and a long-term policy it is important to understand how, beyond the law which often requires that certain choices are made, the real estate market reacts to the new standards that include, of course, a higher cost of construction. In the last few years many researchers have investigated in this field. Annunziata, Frey and Rizzi in their paper [14] conducted a survey questionnaire among the 27 European Union Member States with the aim of providing an overview of the current national regulatory framework, focusing on three aspects: (1) integration of energy efficiency and renewable energy requirements, (2) translation of investments in energy saving into economic value, and (3) commitment towards the "nearly zero-energy" target. The study shows that European countries have adopted different approaches in the design of their national regulatory framework. This heterogeneity consists of four main factors: different authorities involved in energy regulations, traditional building regulations and enforcement models, different contextual characteristics, and maturity of the country in the implementation of energy efficiency measures.

One of the most important barriers in implementation of energy policies is that the cost of potential energy savings, typically considered to be the only financial benefit, does not motivate investments sufficiently. Popescu *et al.* [15] investigated the impact of energy efficiency measures on the economic value of buildings. Their paper discusses whether a market-based instrument, capturing the increase of the economic value of energy efficient buildings, can be also used. Methods are developed which quantify the added value due to energy performance, including recommendations on how they can be incorporated in the financial analysis of investments in weatherization.

The market in developed Asian cities for green buildings (GBs) as perspectives for building designers is the subject treated and discussed by Chan *et al.* [16]. After the data analysis of the survey, the paper presents their findings on the business reasons for stakeholders to be involved in green buildings, the most favorable conditions required to promote GB business and the important obstacles that hinder their popularity.

Finally an interesting review on ZEB and sustainable development implication is conducted by Li *et al.* [17]. The authors highlight the growing interest in ZEB buildings in recent years, and agree that ZEBs involve two design strategies: minimization of the need for energy usage in buildings (especially for heating and cooling) through EEMs (energy efficient measures) and adoption of RETs (renewable energy and other technologies) to meet the remaining energy needs. Their paper reviews the works related to these two strategies.

The theme of nearly-ZEB buildings is a complex issue, with not only technical but also economic and social implications. Member States will soon have to provide Europe with the rules they intend to apply to transpose and assimilate Article 9 of Directive 31 [3] in their legislation. In this article a case study of a number of buildings constructed in the Lombardy region is analyzed. The concreteness of its results is the best demonstration of the effectiveness of a policy.

2. The Energy-Efficiency Building Policy in Lombardy Region

2.1. The Transposition of EPBD Directive

The Lombardy Region was the first regional government in Italy to independently transpose Directive 2002/91/EC [2] into its (regional) legislation, in accordance with Article 17 of Legislative Decree No. 192 [6] (compliance clause). Thus with regional law [18] Lombardy embraced the new rules about building energy certification, in compliance with the directive and the general principles contained in (Italian) Legislative Decree No. 192 [6].

Energy certification became operative with the Regional Council Decree No. VIII/5018 [19], later supplemented by the Regional Council Decree No. VIII/5773 [20]. Regional Council Decree No. VIII/8745 [21] amended the provisions relating to energy efficiency in buildings and, more particularly, confirmed the obligation to attach the certificate to the deed whenever a whole building or a single housing unit is sold. The sanctions against those who do not comply with the obligations stated by Regional Council Decree No. VIII/8745 [21] are set forth in Regional Law No. 10 [22]. Director General Decree No. 5796 [23] updated calculation procedures, whilst the Director General Decree No. 2554 [24] approved the procedure for verifying energy performance certificates.

2.2. The Regional Accreditation Body

The Lombardy Region has entrusted the Centre for Technological Development, Energy and Competitiveness (CESTEC), a company which it wholly owns, with the role of Regional Accreditation Body (RAB) for energy certifiers. As of 1 January 2013 CESTEC was taken over by Finlombarda which has now become the RAB. The tasks assigned to the RAB include the following:

- Providing accreditation for energy certifiers;
- Creating and managing an cadastral energy register of buildings;
- Developing a software that support calculation for energy certification of buildings;
- Updating the calculation procedure used to determine a building's energy performance, and the forms to be used as a part of the certification process;
- Monitoring the impact of the provision for energy certification on end-users, in term of bureaucracy, cost and benefits;
- Monitoring the impact of the provision for energy certification on the regional real estate market, as well as on builders, manufacturers of materials and components, and companies producing air conditioning systems or offering installation and maintenance services;
- Providing scientific and technical advice in assistance to local and regional bodies and to certifiers within the region, in order to ensure the effectiveness and uniformity of the implementation of energy efficiency standards;
- Adopting measures for the suspension and revocation of accreditation.

Through the energy cadastre of buildings managed by Finlombarda it is possible to monitor, in real time, the evolution of the housing market in Lombardy and in particular to assess the actual effects of energy policies on the buildings with a high energy class, similar to nearly zero energy building (nearly-ZEB).

2.3. Calculation Procedure and Energy Classification Criteria

Regional Committee Decree No. VIII/5018 [19] also details the procedure to calculate performance indicators that consider the use of energy for space heating, ventilation, domestic hot water, and air conditioning. To facilitate the calculations required for energy certification, Lombardy Region made available a free software called CENED, which could be downloaded directly from the official website of the Regional Accreditation Body.

On 26 October 2009 a new calculation procedure came into force according to Decree No. 5796 [23]; subsequently certifying technicians were given access to the updated software, CENED$^+$. The new calculation procedure is more complete and complex, and closer to that used nationally (UNI/TS 11300) and to the European standards issued by the European Committee for Standardization (CEN) on the basis of Mandate 343 of the European Commission to support the implementation of EPBD in the Member States: it integrates the latter so as to allow for the most varied buildings plants systems existing. For the tertiary sector, in comparison with the previous procedure, it also considers energy usage for lighting, in accordance with the requirements of the EPBD Directive.

Furthermore, the standard certification form has been extended to include a section with recommendations for improving the energy performance of the building, as indicated by the energy assessor on the basis of computation simulations. The energy performance of a building, assessed on a scale of classes ranging from A+ to G, is defined by the value of its primary energy demand for heating (EP_H), considering both the thermal energy (e.g., fuels) and the and the electricity required by the auxiliary equipment (e.g., pumps, fans, *etc.*), divided by the net floor area.

Table 1 shows the energy classification criteria adopted in Lombardy. Energy classification considers both the climatic zone (*i.e.*, Winter Degree-Days DD_H) and intended uses of the building: for residential buildings and similar the EP (primary energy) indicator is in kWh/m^2 per year whereas for other intended uses it is in kWh/m^3 per year.

When requested by the energy assessor, the energy label can be displayed outside buildings that rank in the A+, A or B classes, becoming a hallmark of the structure's high quality.

Table 1. Energy classification criteria in Lombardy Region for high energy performance buildings.

Energy Class	**Climatic Zone**		
	E	**F1**	**F2**
	$2101 \leq DD_H < 3000$	**$3001 \leq DD_H < 3900$**	**$DD_H > 3900$**
Residential buildings and similar (kWh/m^2 per year)			
A+	$EP_H < 14$	$EP_H < 20$	$EP_H < 25$
A	$14 \leq EP_H < 29$	$20 \leq EP_H < 39$	$25 \leq EP_H < 49$
B	$29 \leq EP_H < 58$	$39 \leq EP_H < 78$	$49 \leq EP_H < 98$
Other buildings (kWh/m^3 per year)			
A+	$EP_H < 3$	$EP_H < 4$	$EP_H < 5$
A	$3 \leq EP_H < 6$	$4 \leq EP_H < 7$	$5 \leq EP_H < 9$
B	$6 \leq EP_H < 11$	$7 \leq EP_H < 15$	$9 \leq EP_H < 19$

3. Sustainable Construction in Lombardy, the Results of Change

Building energy certification is instrumental for many purposes. Initially it was established to inform citizens and end-users about the energy quality of a building or housing unit: an invisible detail that can be relevant in the decision to buy or rent a certain flat or house. Energy certification in Lombardy has greatly stimulated the market for new buildings, directing choices towards high energy-performance buildings and creating competition among builders to attain ever better levels. The energy cadastre of buildings, managed by the RAB, has proved to be a strategic support for regional policies.

Once a sufficient number of energy certifications have been collected and the data acquired is handled in an organized data system, these documents can constantly add to and update a database that is able to show the energy quality level of the buildings in a certain area. This information is useful to gain a detailed knowledge about the status quo, as well as to monitor the evolution of building energy quality over time. The energy quality of Lombardy's buildings, both residential and non-residential, is illustrated in Table 2, which shows EPCs (Energy performance certificate) grouped by energy class.

Table 2. Energy performance certificates (EPCs) issued in Lombardy from 26 October 2009 to 15 May 2013, divided up according to energy class and the intended use of buildings (source: Finlombarda [25]).

Energy Class	Non residential		Residential		Total	
	Nr of EPCs	%	Nr of EPCs	%	Nr of EPCs	%
A+	106	0.01	931	0.10	1.037	0.11
A	523	0.06	5,914	0.65	6,437	0.71
B	2,436	0.27	42,901	4.71	45,337	4.98
C	11,269	1.24	57,060	6.27	68,329	7.51
D	19,673	2.16	74,509	8.19	94,182	10.35
E	18,002	1.98	91,022	10.00	109,024	11.98
F	19,422	2.13	102,281	11.24	121,703	13.37
G	64,070	7.04	400,020	43.95	464,090	50.99
Total	135,501	14.89	774,638	85.11	910,139	100.00

The table shows that 5.8% of EPCs in Lombardy concern buildings in Class B or better. Class G is the most populated group (50.99%), while the rest of the existing buildings are equally distributed between Classes D, E and F, which altogether represent 35.7% of the total. Looking at residential buildings, those constitute 85.11% of the total EPCs, the average EP_H value being 202.8 kWh/m^2 per year.

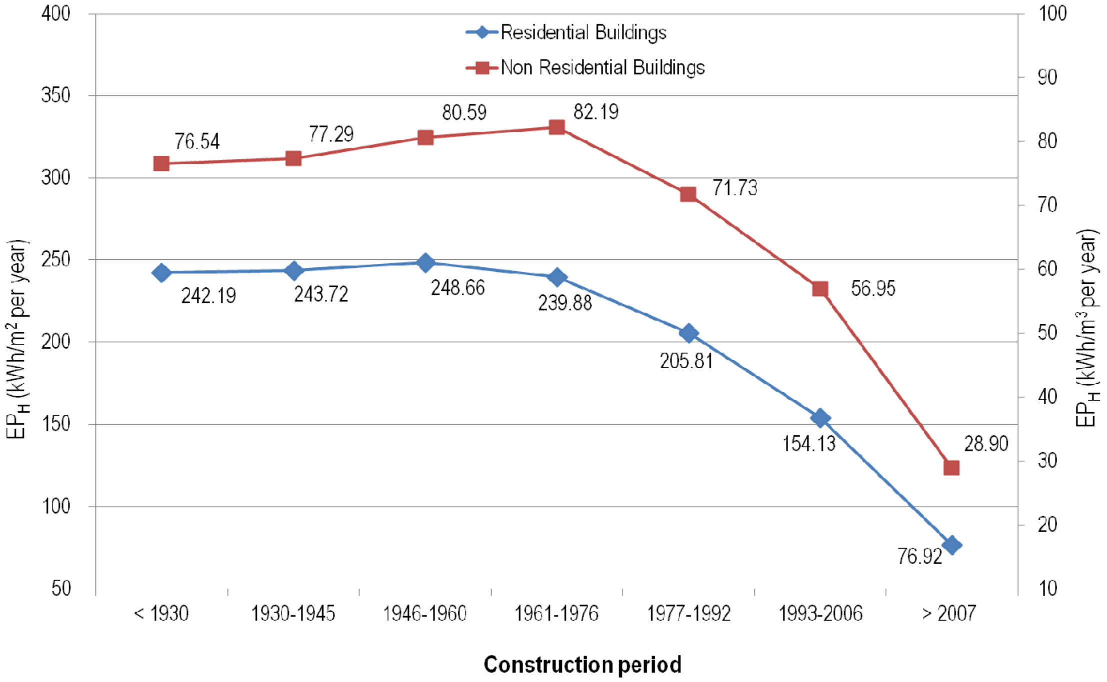
If the percentage of B, A and A+ buildings seems low, one must consider that these buildings are to be compared with the entire existing building stock which, as previously stated, is characterised by low energy-efficient buildings.

Energy policies promoted in the Lombardy Region had concrete effects on the energy quality of buildings. The diagram in Figure 1, elaborated on the basis of the regional energy cadastre [25], shows a significant reduction of the EP_H indicator, both for residential buildings (left-hand axis of the graph) and for non-residential buildings (right-hand axis of the graph) over the last few years.

From the data contained in the ACEs one can also extract information useful to understand the evolution of components in terms of performance, e.g., U-values of walls, roofs and floors in residential buildings, grouped by construction period. These values have generally decreased over time, but the most marked performance improvements were recorded in 1993–2007, following the implementation of Law No. 10 [5], and after 2007, when Regional Council Decree No. VIII/5018 [19] came into force.

The average U-value for walls decreased from 1.36 to 0.43 W m^{-2} K^{-1}: hence walls today insulate houses three times better than they did in the past. A similar improvement has been achieved in roofs (reduced from 1.09 to 0.37 W m^{-2} K^{-1}) and floors (down from 1.23 to 0.45 W m^{-2} K^{-1}).

Figure 1. Variation of the energy performance of residential buildings and non residential buildings in Lombardy region on the basis of the EP_H indicator (source: Finlombarda [26]).



Even windows in residential buildings have improved over time. Considering that before 1976 single-glazed doors and windows, which have a U-value of about 5 W m^{-2} K^{-1}, were still very popular, the results of the analysis on buildings up to 1992, with U-values ranging from 3.45 W m^{-2} K^{-1} (before 1930) to 3.88 W m^{-2} K^{-1} (between 1961 and 1976), implies that there have been several replacements, in part encouraged by a 55% tax credit incentive granted by the Italian government. However there was still room for improvement: after 2007, the average U-value for windows dropped to 2.01 W m^{-2} K^{-1}, indicating more widespread use of low emissivity windows.

The regional energy cadastre also provides an overview of systems, or rather the system choices that were made in different construction periods: indeed the data acquired from energy performance certificates represents the situation only at the time of certification, and one must consider that generation systems have usually been replaced more recently. What can therefore be observed with the available information, is how design choices have changed over time.

Conventional heat generators, which represented about 50% of systems in 1977–1992 and 1993–2006, dropped to only 15.1% after 2007. Condensing boilers, on the contrary, increased from 7.7% (in 1993–2006) to 58.6% after 2007. Heat pumps maintain a relatively low share: after being virtually nonexistent, they account for 8.6% after 2007.

4. Nearly Zero-Energy Buildings

4.1. The Concept of a Nearly Zero-Energy Building

The obligation to build (exclusively) nearly-ZEB buildings by 31 December 2020, introduced by Article 9 of Directive 31 [3] seems quite ambitious, but in any case it is worth providing here a few points for consideration.

One can start simply by quoting the fairly vague definition provided by the Directive 31 [3] in Article 2: "nearly zero-energy buildings means a building that has a very high energy performance—the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby."

Nearly-ZEBs are a new frontier which represents an ambitious goal and which raises a few causes for concern. However, the design choices that underlie the performance of these buildings, which strive to reach energy self-sufficiency, stem from a pre-existing trend that had already initiated the development of a new approach. The key elements of this new paradigm can be summarized as follows:

- The energy performance of building envelopes improves considerably thanks to the more widespread use of insulation materials, plants, and shielding systems, all of which reduce thermal loads during both the winter and the summer;
- Mainstream architecture has embraced the principles of bioclimatic architecture, which has gained increasing popularity (exploitation of the passive potential of buildings, direct gains, solar greenhouses, *etc.*);
- Renewable energy sources (solar thermal, solar photovoltaic, biomass, wind, *etc.*) become the primary sources, and are used to their full potential;
- Conventional energy sources are used merely to integrate building energy balances, and/or as a back-up;
- Instead of a single generation system, more systems are installed and employed depending upon their convenience (e.g., solar thermal, biomass, heat pump, condensing boiler, inertial accumulation systems, *etc.*);
- Exploiting the building's thermal inertia allows planners to install lower power-capacity systems: the thermal inertia of the whole system can be increased by, for example, installing inertial storage tanks;
- Buildings are no longer isolated in terms of systems, but instead become elements of a distributed, regional energy network: this approach allows the use of technologies (such as solar thermal or cogeneration systems) that can supply excess energy to the heating network (or excess electricity to the grid), contributing to the shift from centralized generation to distributed generation (which requires the implementation of smart energy infrastructures, such as smart grids);

– Home automation becomes the most important tool to manage energy services in the best possible way.

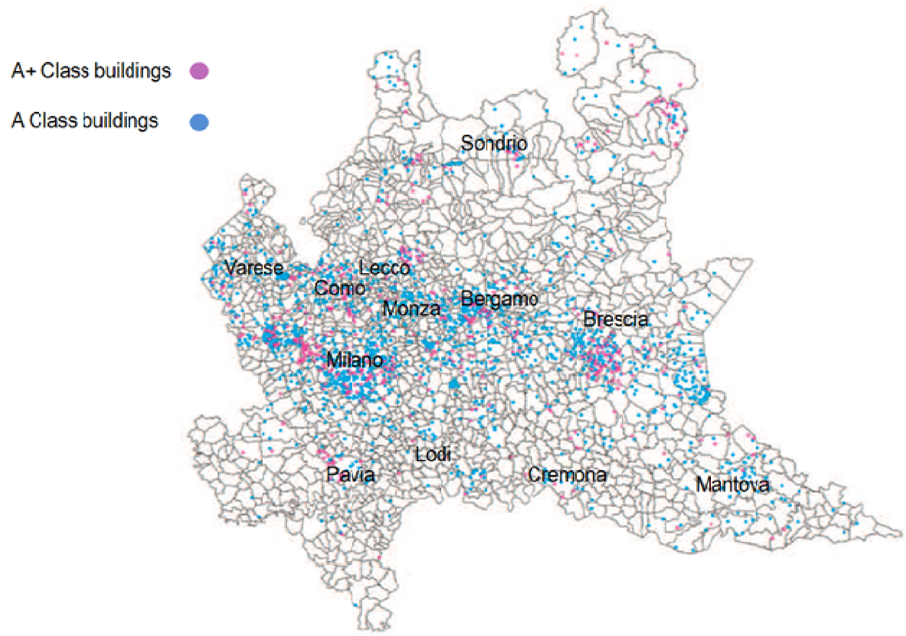
There are no technological barriers to nearly-ZEB buildings as they were conceived by Directive 31 [3]: the techniques for making efficient envelopes, installing high-performance systems, and exploiting renewable energy sources in a way that is both efficient and convenient are already available.

As often is the case, change is hindered not by technological, but by cultural barriers. However the examples presented in this paper, and the information provided, should reassure anyone working in the field of green building or in real estate: nearly-ZEB buildings not only exist, but thrive and the case study of Lombardy Region is evidence of this.

4.2. High-Performance Buildings: Regione Lombardia's Experience

Focusing now the analysis on the energy cadastre data that regard high-performance buildings in Lombardy, Figure 2 shows the map of Lombardy region with indicated the locations of Class A and Class A+ buildings.

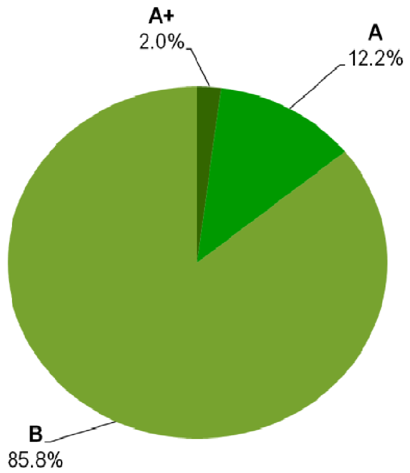
Figure 2. Location of A+ and A Buildings in Lombardy (source: Finlombarda [25]).



At the moment of our survey, there are about 52,811 EPCs deposited for buildings classified as energy Class B or better, of which 94.6% are residential. Figure 3 shows them grouped by energy class: there are 45,337 (85.8%) EPCs in Class B, 6437 (12.2%) in Class A, and 1037 (2.0%) in Class A+.

High performance buildings are almost all new buildings. The current number of EPCs concerning Class A has practically doubled when compared with last year. This is a good result when considering that the market for new buildings, not only in Italy in general, but also specifically in Lombardy is going through a period of deep recession. The new market standard for new building in Lombardy is currently Class A. In other words, builders believe that it is difficult to sell a new building with an energy class lower than A.

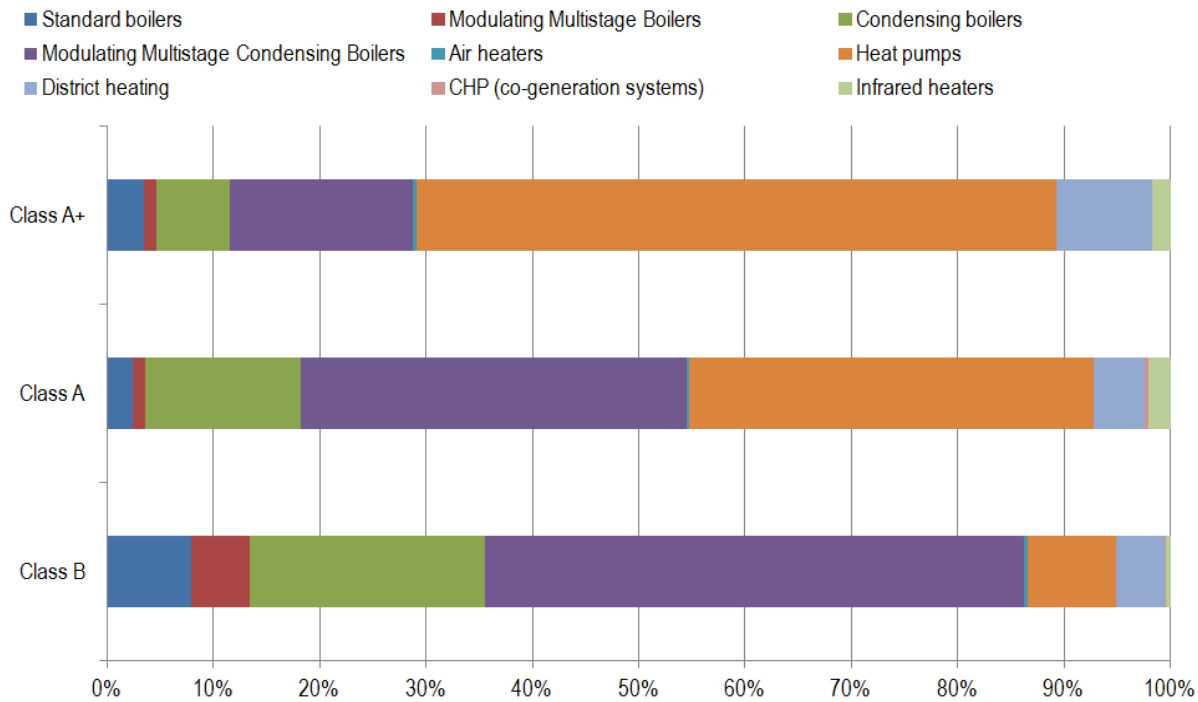
Figure 3. Class B or better residential and nonresidential buildings, divided by energy class.



The data contained in the regional energy cadastre [25] also allows us to analyse technical aspects and monitor the evolution of the technical choices.

In the search for more efficient solutions, next-generation buildings have changed the scenario in terms of climate control systems. It is interesting to examine heat generation systems installed in high-performance buildings, as illustrated in Figure 4.

Figure 4. Systems in energy-efficient buildings in Lombardy: heat generation as a function of energy class.



Conventional heat generators are installed in only 7.8% of Class B buildings, placing this technological choice numerically barely below heat pumps (8.3%). Condensing boilers and multistage modular-type condensing boilers (72.8%) are by far the most common type of heat generator in this class of buildings.

The statistics change when considering Class A buildings: condensing boilers and multistage modular-type condensing boilers, at 50.9%, have a smaller, although still considerable share, while traditional boilers drop to 2% and heat pumps rise to 37.9%. Finally, heat pumps appear to be the most common choice (60.13%) in the best-ranking buildings, classified as A+, whereas condensing boilers and multistage modular-type condensing boilers in this category decrease to a 24.04% share.

The combination of heat pump and solar photovoltaic system seems to have established itself as one of the most popular systems, thanks to the improved energy performance that can be achieved by better covering electricity consumption.

If a law's effectiveness can be judged by how the new rules which it sets are implemented, then change is a measure of success, and thus one should take a look at what really has changed in the field of sustainable building over time.

5. Analysis of the Case Study

5.1. Description of the Methodology

It has been seen how the market for high-performance buildings (Class B or better) is strong and substantial in Lombardy. The Figures which have been cited are impressive when compared to both the Italian situation as a whole and that of Europe, and they are on the increase. But going beyond mere numbers, it is necessary to show the quality of what was done in practice.

Lombardy region and CESTEC, now Finlombarda S.p.A., with the scientific support of the Building Environment Science and Technology (BEST) Department of Polytechnic of Milan, promoted a field survey on high energy-performance buildings, in order to investigate, in more detail, the technical choices of the designers involved [26]. The objective of this survey was not only to show what is visible (the aesthetics, the architectural shape) but also to unveil how these new structures have been able to increase their value by finally incorporating important elements such as energy-saving and sustainability. A selected number of these buildings are analyzed in this paper.

5.2. Description of the Methodology

Sample nearly-ZEB buildings were selected on the basis of the following reasons:

- as a representative sample considering size, intended use and building typology;
- Location within the territory of the Lombardy Region (considering different climatic conditions);
- Disposition of the owners and designers, and availability of their personnel, to permit the necessary inspections.

Before the start of the surveys, checklists had been developed which were needed to gather technical information related to:

- Context and site;
- Shape and function;
- Energy choices;
- Environmental choices.

In order to better visualise the information acquired, graphical representations were processed. Figure 5 illustrates the diagram which summarises the facilities, while Figure 6 shows the radar diagram that highlights the environmental and energy aspects.

Figure 5. Graphical schematic of the facilities [26].

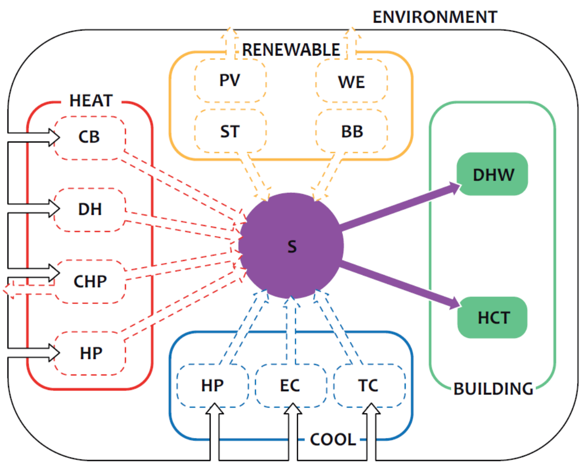
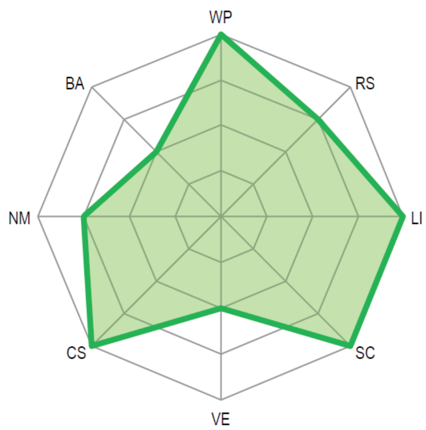


Figure 6. Graphical schematic of the facilities [26]. WP, Winter energy performance; RS, Renewable energy sources; LI, Conscious lighting design; SC, Conscious in summer comfort design; VE, Conscious in ventilation design; CS, Conscious in context and site; NM, Use of natural materials; BA, Building/Home Automation. Rating: (0) No consideration, (1) Minimum consideration, (2) Average consideration, (3) High consideration, and (4) Leading element of the project.



6. Results and Discussion

The sample buildings selected are representative of different intended uses. As shown in Table 3, this survey considered 11 residential buildings, five social housing buildings (*i.e.*, residential buildings designed for low-income people), one nursery school, one childcare centre and a school campus.

The construction period of all the buildings ranges from 2007 to 2012, *i.e.*, after the Lombardy region had issued new rules for energy efficiency in buildings, but especially after mandatory energy certification had been introduced. Without this policy it is most likely that not so many such buildings would have materialized (bearing in mind that those in the table are only a sample).

Table 3. General information of the selected nearly-ZEB buildings.

No.	Intended use	Location (Provence/County)	Energy Class	DD_H (°C)	Construction period (year)	
					Start	Completed
1	Childcare centre	Milano	A+	2404	2008	2010
2	Social housing	Brescia	A+	2420	2007	2009
3	Residential building	Bergamo	A+	2467	2009	2011
4	Residential building	Bergamo	A+	3000	2011	2012
5	Social housing	Bergamo	A+	2479	2007	2009
6	Social housing	Cremona	A+	2506	2010	2011
7	Residential building	Milano	A+	2404	2010	2011
8	Social housing	Brescia	A+	2399	2010	2012
9	Residential building	Bergamo	A+	2543	2009	2010
10	Nursery school	Milano	A	2563	2007	2009
11	Assisted living residence	Como	A	2383	2009	2010
12	School campus	Mantova	A	2442	2008	2010
13	Residential building	Brescia	A	2229	2008	2011
14	Residential building	Milano	A	2404	2007	2011
15	Residential building	Milano	A	2404	2007	2011
16	Residential building	Bergamo	A	3433	2008	2010
17	Residential building	Lecco	A	2382	2007	2009
18	Residential building	Lecco	A	2383	2007	2011
19	Residential building	Sondrio	A	2758	2007	2011
20	Social housing	Brescia	A	2410	2009	2010

Table 4 shows the building features of the selected nearly-ZEB buildings. As regard EP_H, as stated, one must distinguish between residential and similar buildings, in which the performance indicator is measured in kWh/m^2 per year, and the other buildings in which the performance indicator is measured in kWh/m^3 per year. In accordance with the calculation procedure adopted by Lombardy, the primary energy indicator for winter heating is calculated fixing a standard usage of the building (e.g., 20 °C of internal air temperature and 24 h per day) and fixing a monthly energy balance (the yearly energy balance is obtained from the sum of the monthly balances of the conventional heating period). In the real use of the buildings, especially the non-residential ones, the usage of a heating system is not extended over a period of 24 h per day.

Table 4. Building features of the selected nearly-ZEB buildings.

No.	Gross volume (m^3)	EP_H (kWh/m^2 per year)	S/V ratio (m^{-1})	Average U-values (W m^{-2}K^{-1})			
				Walls	Roofs	Floors	Windows
1	3,258	2.90*	0.50	0.19	0.17	0.20	1.12
2	6,817	12.70	0.56	0.21	0.18	0.21	2.05
3	2,567	10.42	0.64	0.12	0.11	0.17	1.10
4	2,537	6.43	0.55	0.15	0.10	0.20	0.93
5	2,310	8.70	0.62	0.13	0.10	0.18	1.24
6	28,183	7.32	0.46	0.22	0.19–0.22	0.12–0.21	1.40
7	3,228	8.9	0.57	0.16	0.19	0.14	1.40

Table 4. *Cont.*

No.	Gross volume (m^3)	EP_H (kWh/m^2 per year)	S/V ratio (m^{-1})	Average U-values (W $m^{-2}K^{-1}$)			
				Walls	Roofs	Floors	Windows
8	4,636	1.13	0.58	0.15–0.24	0.10–0.07	0.18	0.85
9	789	0	0.60	0.18	0.18	0.25	1.10
10	10,337	5.85*	0,57	0.16–0.20	0.30	0.23	1.30
11	21,489	4.70*	0,40	0.32	0.16	0.32	1.3
12	9,400	5.90*	0.63	0.11	0.20	0.15	1.40
13	15.390	21.72	0.60	0.26–0.39	0.29	0.43	1.47
14	3.948	26.68	0.36	0.23	0.32	0.34	1.50
15	10,172	25.84	0.51	0.25	0.28	0.33	1.65
16	207	34.60**	0.84	0.18	0.14	0.20	1.40
17	1,267	17.84	0.58	0.20	0.21	0.23	1.70
18	7,870	28.99	0.47	0.28	0.24	0.29	1.3
19	3,805	21.31	0.67	0.21	0.23–0.24	0.23	1.24–1.31
20	5,237	16.76	0.52	0.26	0.16	0.27	1.80

Notes: * for non residential buildings the EP_H indicator is given in kWh/m^3 per year; ** for this climatic zone the energy classification is different.

Furthermore for the buildings equipped with a grid-connected solar PV system, the calculation procedure takes into account only part of the amount of the energy exchanged with the public electricity grid. Considering an annual energy balance, *i.e.*, fully considering the electrical energy exchanges with the energy grid, the operative energy performance could be even better.

Table 5 also shows the energy performances of the building envelope: the average U-values of the building structures (walls, roofs, floors or basements and windows). Table 5 shows the average U-vales of the building structures referred to the buildings investigated, considering those of energy Classes A and A+. The values are compared with the mandatory minimum values of thermal transmittance under the laws of Lombardy.

Table 5. Average U-values for the selected nearly-ZEB buildings, compared with the mandatory minimum values for new buildings.

Building type	U-values of the building structures (W $m^{-2}K^{-1}$)			
	Walls	Roofs	Floors	Windows
Mandatory minimum	0.34	0.30	0.33	2.20
Class A	0.23	0.23	0.27	1.46
Class A+	0.17	0.15	0.19	1.24

Comparing the values it is possible to appreciate this difference: the building envelopes of nearly-ZEB buildings must be much better insulated than the minimum requirements. Then if one compares the U-value with those of the existing building stock, the difference is even greater: the ranges of the U-value of the thermal building stock are: 0.75 ÷ 1.35 W/$m^{-2}K^{-1}$ for walls, 0.73 ÷ 1.18 W/$m^{-2}K^{-1}$ for roofs and 2.58 ÷ 3.58 W/$m^{-2}K^{-1}$ for windows, respectively [26].

The technical choices for heating and cooling systems, domestic hot water systems and lighting are particularly important in nearly-ZEB buildings. Some of these items of information for the nearly-ZEB buildings investigated are shown in Table 6. Analyzing this information it is possible to make some deductions about the technical choices of the designers.

Table 6. Energy performance of HVAC systems and renewable energy sources of the selected nearly-ZEB buildings.

No.	Heating system			Cooling system			Ventilation System	Solar thermal surface (m^2)	Solar PV Peak power (kWp)
	Type	HC (kW)	Terminals	Type	CC (kW)	Terminals			
1	GSHP	59.1	FRP	FCW	-	FRP	CMV	-	14.8
2	GSHP	113.4	FRP	GSHP	113.4	FRP	CMVE	76.0	15.0
3	AHP	24.4	FRP	AHP	25.3	FRP	CMV	22.0	2.82
4	GSHP	52.3	FRP	-	-	-	CMV	2.34	1.15
5	CB	28.5	FRP	AHP	50	AT	CMV	13.9	-
6	GSHP	109.6	FRP	-	-	-	CMV	-	-
7	AHP	33.6	FRP	AHP	35.1	FRP	CMV	-	5.76
8	AHP	33.6	AT	AHP	27.6	AT	CMV	-	36.6
9	GSHP	20.0	FRP	GSHP	20.0	FRP	-	-	19.74
10	GSHP	105.9	FRP	GSHP	50.7	FRP	CMV	-	19.8
11	GSHP	114.6	FRP	GSHP	220	FRP	CMVE	-	19.6
12	AHP	156.1	FRP	AHP	141.5	FRP	CMVE	13.5	-
13	GSHP	8.2	FRP	GSHP	8.2	FRP	CMV	2.34	1.15
14	GHP	25.7	FRP	-	-	-	-	13.2	7.0
15	GHP	114.9	FRP	-	-	-	-	70.4	3.0
16	AHP	3	FRP	-	-	-	CMV	-	2.4
17	CB	90	FRP	-	-	-	CMV	-	-
18	GSHP	55.6	FRP	GSHP	42.7	FRP-FCU	-	18.0	13.8
19	CB	79.8	FRP	-	-	-	-	18.8	-
20	DH	93.5	RAD	-	-	-	CMV	30.8	5.8

Notes: HC—heating capacity; CC—cooling capacity; kWp—Peak power.

So far as the heat generators are concerned, the electrical heat pumps, ground source heat pump (GSHP) or air-to-air heat pump (AHP), together represent the technology which is most consolidated with the designers. Many reasons for this choice suggest themselves: the possibility to associate heat pumps with solar PV (photovoltaic) systems and to use locally the electricity thus generated; the higher thermal performance when compared with condensing boilers (CB) and the possibility to use the same equipment, in the reversible version, both for heating and cooling. In only one case a gas-fired heat pump (GHP) had been installed.

The other technologies, respectively combined heat and power (CHP) and district heating (DH) are used only in two cases. The terminals of the most widely used of the HVAC (heating ventilation air conditioning) systems are floor radiant panels (FRP) that are becoming e new standard for nearly-ZEB and ZEB buildings. The reasons for this could be twofold: their ability to work with heat transfer fluids at low temperature in winter, which allows operation using heat pumps or solar thermal systems with high energy-performance and their ability to perform the cooling of the spaces in summer using cold transfer fluids that could be generated either by a reversible heat pump or by free-cooling with ground water (FCW). The other terminals used, but only in a few cases, are fan-coil units (FCU) and air terminals (AT).

In the nearly-ZEB building controlled mechanical ventilation is a "must". The technology used for this is essentially of two types: controlled mechanical ventilation system with heat recovery units (CMV) and controlled mechanical ventilation system with enthalpy heat recovery units (CMVR). The main purpose of the controlled mechanical ventilation is to guarantee internal air quality, indeed the high quality of the building envelope excludes any type of unwanted infiltration. Furthermore in these buildings the losses owing to heat transmission are drastically reduced whilst the ventilation losses, also caused by the periodic opening of windows in order to guarantee air change, are relatively insignificant. A mechanical ventilation system, equipped with a heat recovery unit, can reduce losses, hence increasing the overall energy performance of the building.

Table 7 shows the environmental and energy aspects of the buildings (for the meaning of the symbols and the meaning of the rating numbers see Figure 6).

Table 7. Environmental and energy aspects of the selected near-ZEB buildings.

No.	Environmental and energy aspects							
	WP	**RS**	**LI**	**SC**	**VE**	**CS**	**NM**	**BA**
1	4	3	3	4	4	4	2	1
2	4	4	1	3	4	3	3	4
3	4	4	4	4	3	4	3	2
4	4	4	3	3	3	3	4	2
5	4	3	2	4	4	3	3	1
6	4	3	1	1	4	4	1	2
7	3	1	1	3	4	4	2	1
8	4	2	2	3	4	4	3	2
9	4	3	2	4	4	3	3	1
10	4	3	4	4	2	4	3	2
11	4	4	4	3	4	4	4	3
12	4	4	4	2	4	3	3	1
13	4	4	4	4	3	4	3	2
14	4	4	2	2	2	3	2	2
15	4	4	2	2	2	3	2	2
16	4	3	2	4	4	3	3	1
17	3	1	1	2	4	4	2	1
18	4	4	2	2	0	2	2	1
19	4	3	3	3	2	4	3	3
20	4	4	2	2	4	4	3	2

The winter energy performance (WP) represent the main goal of most designers. The reasons for this are twofold: the energy classification adopted in Lombardy (but also in Italy) currently considers only the winter energy performance (heating and ventilation), additionally in the residential sector, especially in the northern regions of Italy, the culture of summer air conditioning is not yet widespread. However many of the buildings investigated are equipped with mechanical ventilation (VE) and this technical choice can make a contribution to the control of indoor climate in summer, avoiding overheating due to the considerable thermal insulation of the walls (*i.e.*, when the external walls of the building envelope are very significantly insulated, during summer it is more difficult to dissipate the heat entering). Building designers, however, should better consider the problem of the summer control of room conditions which, for high performance buildings could be critical. Analyzing the information in Table 7 one can observe that the energy issues have taken precedence over the environmental ones. The reason for this is that the energy certification, compulsory, is more diffuse than the environmental certification. In other words the construction market is currently more "energy efficiency" oriented than "green" oriented. It is conceivable that, in the coming years, the environmental aspects will become more important, thanks to the spread of national or international protocols, such as LEED (Leadership in Energy & Environmental Design), and that the construction market will consider highly the "green" value of buildings.

7. Conclusions

"Green building", "energy-efficient", "Class A", ZEB or nearly-ZEB buildings: these expressions have come into common usage to describe how we conceive our homes, as increasingly independent of conventional energy sources and environmentally-friendly. Above all, they are evidence of a cultural change under way. This shift has been taking place in the whole of Europe and in Italy for some time, but what has happened in Lombardy is different: the cultural change has turned into a tangible transformation, with eco-friendly, sustainable, energy-efficient homes becoming the new, real standard in construction.

In this evolution in action there are some things to consider. The first is the need to spread, among new users, the culture and information on how to use these buildings in an intelligent way, enhancing their performance. Dall'O' *et al.* [27,28] performed a study on the comparison between predicted and actual energy performance for winter heating and summer cooling in high-performance residential buildings in Lombardy. The monitoring campaign demonstrated that users did not use the facilities in the correct way, also owing to lack of sufficient skills.

The diffusion of solar photovoltaic systems connected to the public electricity grid in Italy is generating concern because the grid itself is overloaded in some periods. The opportunity to exchange electricity with the power grid and use the grid as an energy storage system is certainly convenient at this stage, however it is useful to think now in terms of buildings which have the ability to hold some local storage. The design, construction and operation of these buildings require skills that are not always available: an acceleration of the entire process is therefore necessary through wider dissemination of the lessons learned.

This case study demonstrates, however, that the construction market of nearly-ZEB building in as great a Region as Lombardy is a reality despite the recession in the sector in recent years. The number of these buildings which are likely to have many of the energy-performance characteristics required by the Directive 31 [3] is by no means small and the standard is moving in this direction.

The energy performance assessments considered in this paper refer to the technical documentation and the energy performance certificates of the buildings. However it could be useful to check whether the actual performances correspond to the theoretical ones: an assessment based only on energy consumption is not reliable. The theoretical evaluation, in fact, refers to standard conditions for both the climate and the mode of usage. A proper assessment of the actual performance, therefore, requires monitoring of indoor climatic conditions and monitoring of the outdoor weather conditions. The authors' hope is to be able to make this check, at least on some of the buildings considered here, although the implementation of this research is not simple as it involves end-users, who are not always willing to cooperate. Based on this positive experience, the Lombardy Region has recently enacted a law that anticipates from 2020 to 2016 the requirements for nearly-ZEB buildings, provided by Directive 31 [3].

Among the latest innovations for the promotion of efficient buildings, there is also a new instrument, the "CENED Photogallery" [29] this is a repertoire of high performance buildings, freely available on the portal dedicated to energy certification of buildings. Here it is possible to access, in addition to proposals of new applications of buildings which are virtuous from the standpoint of energy efficiency, detailed pages with photos and descriptions of system solutions and architecture of the various buildings, selectable by province, municipality and energy Class (A+, A and B).

Conflict of Interest

The authors declare no conflict of interest.

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