Nearly zero energy buildings: Analysis on monitoring energy consumptions for residential buildings in piedmont region (it)

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***Abstract* –The energetic behaviour of ten nZEB built in Piemonte (region located in NW Italy) is analysed from experimental data. The energy consumptions are normalized for the weather conditions and size of the building, then the consumptions are compared with the design data. The data analysis shows that nZEB can be built in northern part of Italy and even if the real consumptions are slightly higher than the values expected from design. Low energy demand can be achieved and good percentage of renewable energy sources can be utilized, but some improvements may be done to exploit more renewable energy sources with storage systems and with restrictive legislation.**

I. Introduction

Air quality is a critical problem for the Regione Piemonte in the North-West part of Italy. The major threat to the public health is the pollution from particles and nitric oxide. Air pollution largely comes from the burners and stoves employed for space heating and domestic hot water.

The orography of the territory of Regione Piemonte - and Pianura Padana too - with mountain on the borders does not allow a normal ventilation of the region and this create accumulation of pollutants. Taking accounts of the largely inefficient buildings stock, the main concern of the policy makers, since 2001, was to set up a strategy aiming to reduce the emission and to improve the average performances of the old houses.

The Government of Regione Piemonte adopted on 2002, October 7th the Regional Law n.23. This first Law set the rules to deploy the Regional Energy Plan (in Italian: "Disposizioni in campo energetico. Procedure di formazione del piano energetico-ambientale") and provided funding for the adoption of new technologies and buildings techniques. This action aimed to sustain feasibility of new efficient houses with low energy demand and lower emissions.

After this first experiences the regional laws were harmonized with the EU Directive 2002/91/CE about Energy Performance of Buildings and with the recast of the main directive, the 2010/31/UE which defined the nZEB. Then, the Regione Piemonte executive board allocated specific funds to promote the next generation building. A call to sustain low energy single-family houses owned by private citizen was launched in 2011. This call named "Grant for nearly zero energy buildings" (in Italian: Contributi per edifici a energia quasi zero [1]) had the purpose to explore the new technologies available on the market unemployed by the average builders.

The call could support the 25% of the additional costs like for innovative technical solutions and more serious and accurate design; the modeling and evaluation of the energy performances was also an eligible cost. The call started with an initial allocation of 2.2 Millions of euros. On expiry 97 instances about new nZEB buildings were submitted, 63 of which were judged positively.

The total cost of the new houses was about 43.8 M€ and the additional eligible cost was 7.6 M€. The mean eligible cost of every square meter built was 1.6 k€/m^2, the public contribution weighted for some 400 €/m^2.

The call financed the best 36 submitted project and in the next 24 months, 15 buildings were constructed and then monitored.

The key points of the new houses was:

- High level of wall thermal insulation (thermal transmittance U=0.15 W/m^2/K) which compares with a standard value of 0.30 W/m^2/K.
- New type of walls (porous blocks, framed wood or XLAM wood wall, concrete wall with expendable insulated formwork) instead of a typical Italian wall made by bricks layered with intermediate or external thermal insulation.
- Windows with LE coating and triple glazing (U=1.0 W/m^2/K) better than the standard value of 1.6 W/m^2/K; every windows exposed to sun should have an active shading system.
- Heat recovery ventilation system with, in same case, geothermal pre-heating and active thermodynamic recovery.
- Heat produced only by solar system (for domestic hot water) or by a heat pump (for both heating and cooling); the most frequently adopted configuration is hydronic aero-thermal heat pump integrated with solar collectors and radiant floors with installed power of 8/10 W/m^2.
- Photovoltaic grid connected plants for electricity used in the systems.
- Advanced monitoring system.

A second call was launched in 2013 for buildings enterprise only. It aim to sustain the additional cost of the nZEB in residential multi-storey buildings, with a glance to the upcoming new social-housing buildings. In this case the only significant difference is a more interesting level of general energy performance due to a better average surface to volume ratio (0.58 instead of 0.9 m^{-1}) and bigger - and more efficient - centralized heating system.

II. State of art

This section presents the state-of-the-art with respect to the characteristics and energy consumption of nZEB buildings.

The term "nZEB" originated in the '70s and it was subjected to many changes in the years. In 1977, Esbensen & Korsgaard designed the first buildings called "zero-heating buildings" to oppose the oil price rise problem (during the first energy crisis) [2]. Esbensen & Korsgaard described a nZEB located in Denmark as follows: "With energy conservation arrangements, such as high-insulated constructions, heat-recovery equipment and a solar heating system; the Zero Energy House is dimensioned to be self-sufficient in space heating and hot-water production during normal climatic conditions in Denmark".

In 1984, Saitoh et al. [3] presented the "Natural Energy Autonomous House": "(…) a multi-purpose energy-autonomous Japanese house ... For this purpose, solar energy, the natural coldness of the ground and sky-radiation cooling are utilized".

In 2001, Parker et al. [4] re-propose a new definition of nZEB: "the Zero Energy Home generates its own power, allowing the homeowner essential energy security. In a Florida study, a prototype Zero Energy Home outperforms a conventional model by providing almost all of its own power needs throughout the year". In 2006, Torcellini et al. [5] defined ZEB: "A net zero-energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies".

In 2008, in the report of the International Energy Agency (IEA) 'Towards Net Zero Energy Solar Building', Laustsen [6] gave a general definition of ZEB confirming the non-use of fossil fuels: "Zero Energy Buildings do not use fossil fuels but only get all their required energy from solar energy and other renewable energy sources". In 2010, the definition of nZEB is contained in EPBD Recast (European Directive 2010/31/EU): nearly Zero-Energy Building (nZEB) means a building that has a very high-energy performance producing energy from renewable sources on-site or nearby. The energy performance of a building shall be determined considering all energy needs to maintain the thermal comfort conditions. "Member States shall ensure that by 31/12/2020, all new buildings will be nZEB and after 31/12/2018, new buildings occupied and owned by public authorities will be nZEB".

A study by Erhorn and Erhorn-Kluttig in 2012 [7] identifies four characteristics that have a strong impact on the energy needs of residential buildings: low thermal transmittance values of the roof covering ($U \approx 0.14$ W/m^2/K) and the use of: triple low-emissivity glasses, heat pumps and mechanical ventilation systems with heat recovery. In 2014, a new residential Italian nZEB with eleven apartments was analysed with the Itaca Protocol to evaluate the environmental impact of electric emission heating systems. The analysis evaluated the interventions (also with roof-integrated solar thermal collectors and photovoltaic modules) that can compensate the increase in primary energy demand and GHG emissions with an electric emission heating system, in order to maintain the rating of Itaca Protocol to a minimum score of 2.5 [8].

Finally, the civil sector can contribute to improve the quality of life of human beings as it can create high negative environmental impacts related to energy, environment, climate change, energy poverty and vulnerability issues. In particular, the civil sector [9]:

- is the major consumer of energy, accounting for around 30-40% of the worldwide consumption
- affects the environment by consuming resources and producing waste and pollution (it is responsible for the use of many resources of raw materials).
- is responsible for the global and local climate change with 38% of the greenhouse gases emissions.

At the moment, the best solutions are those combining high thermal insulation with high-efficient systems using low carbon technologies and exploiting the available on-site renewable energy sources. Also the energy produced, or taken from the grid, should be renewable. For the future, the scientific community is studying how to accumulate thermal and electric energy with few heat dispersions and for long periods of time to optimize the use of renewable sources.

III. Case study

With the call of Piedmont Region for "Economic grants for the construction of nearly zero energy buildings" [1], the construction of twenty-five buildings has been financed, of which some information has been reported in Table I. As it is possible to observe, all buildings are residential detached houses in little municipalities at about an altitude of 378 m a.s.l. with a temperate climate with an average of 2823 HDD at 20°C. The detached houses have an average value of the heated gross volume of 905 m^3, a net heated surface of 218 m^2 and a surface to volume ratio of 0.77 m^{-1}.

The "Economic grants for the construction of almost zero energy buildings" recommended to the nZEB the following requirements:

1. Low heating net energy demand: $Q_{H,nd}/S_n \leq 15$ kWh/m^2/y
2. Low cooling net energy demand: $Q_{C,nd}/S_n \leq 10$ kWh/m^2/y
3. High use of renewable energy sources: $EP_{tot,RINN}/EP_{tot} \geq$ 50%.

It was not possible to verify the second requirement, as the monitoring data for the case studies analyzed were not compiled in the parts needed to evaluate the requirement, because probably they did not use the summer cooling service.

Of these twenty-five interventions, the top 10 of the list were selected because they have send the monitoring data on energy consumptions for at least one or two heating seasons with all information on the technological systems used. To evaluate energy consumptions, climatic data were obtained from the closest weather data station with similar altitude. In Figure 1 the analyzed municipalities with the relative HDD at 20°C (UNI 10349-3:2016) and the considered weather station are represented. In this first analysis of energy consumption of 10 nZEBs, the following years were analysed: 2013 with a cold heating season (about +9 % of HDD), 2014 with a warm heating season (about -5 % of HDD) and 2015 with an average heating season.

For each building, calculations were carried out to verify the two requirements about energy consumption demanded by the call. In Table II the principal characteristics of the energy production systems. As it is possible to observe, the monitored buildings are detached houses with an average volume of about 850 m^3 and an average S/V of 0.77 m^{-1}. The envelope is well insulated with low thermal transmittances (U) for both opaque envelope and windows of about 0.15 and 0.87 $W/m^2/K$. These values are lower than the limits of Italian Law of 0.26 $W/m^2/K$ for walls, 0.22 $W/m^2/K$ for roofs, 0.26 $W/m^2/K$ for floors or slabs and 1.4 $W/m^2/K$ for windows (i.e. D.M. 26/6/15 for climatic zone E), but similar to the values indicated in [7, 8].

As it is possible to observe in Table II, the heating system is principally characterized by heat pump using electrical energy (EE) with the assistance of photovoltaic modules and solar thermal collectors integrated on the roof of the buildings. The heat pump air-air or air-water are the most used in nZEB because they are the cheapest and they do not require invasive installations. Moreover, there is a mechanical ventilation with heat recovery with a heat exchanger between the inbound and outbound air flow for energy saving. For all the selected buildings, from 1 to 2 m^2 of solar collector at person were installed and then it was supposed their use for domestic hot water (only nZEB n.8 had a bigger surface of solar collectors).

As already mentioned, for these 10 buildings a complete monthly monitoring has been provided for one or two years. In particular, the following data were monitored with a weekly or monthly time schedule:

- Indoor air temperature
- Global energy consumption for space heating, cooling, hot water production and electric appliances: Q_{in}
- Energy consumption of the heat pump (HP): $Q_{G,in}$
- Energy consumption of electric appliances and artificial lighting (App): Q_{App}
- Energy provided by the heat pump (HP): Q_{HP}
- Energy produced by photovoltaic modules (PV): Q_{PV}
- Energy produced by solar thermal collectors (ST): Q_{ST}.

In Table III is reported the yearly energy consumptions of the monitored nZEB and the energy provided to the buildings by the heat pump. The energy consumed by the electric appliances and artificial lighting (Q_{App}) varied from the different years with higher values in 2013 (the colder year) and lower values in 2014 (the warmer year); Q_{App} varied form 37% to 60% of the global consumptions with an average value of 51%.

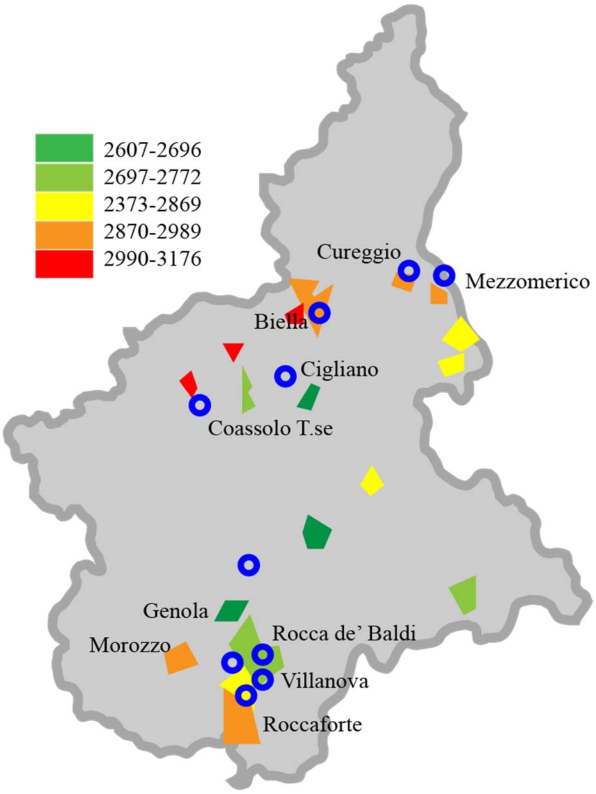


Figure 1 - Analyzed municipalities with the relative HDD at 20°C (UNI 10349-3:2016) and considered weather stations.

The energy demand for domestic hot water was calculated as a function of the net heated surface of buildings with Italian Standard on Energy Performance of Buildings UNI/TS 11300-2:2014.

The aim of the experimental monitoring was to verify the real energy consumptions of nZEB taking into account the use of low carbon technologies exploiting the available renewable energy sources on monthly interval.

IV. Methodology and Results

Through the elaboration of the energy consumption monitoring data sent by the beneficiaries, a comparison was made with estimated consumption at the design stage with the aim of verifying the low energy consumption of the nZEB buildings. Firstly, the efficiency of the space heating system was verified with the first requirement of low heating energy demand: $Q_{H,nd}/S_n \leq 15\ kWh/m^2/y$. Then, the second requirement for energy coverage of 50% from renewable energy sources was also verified with monitored data.

All energy balances of energy demand and supply systems are made with monthly interval considering that renewable energy sources can be exploited to cover the monthly energy demand.

TABLE I – LIST OF CONSIDERED MUNICIPALITY AND RELATIVE DATA

NZEB	Municipality	Altitude [m a.s.l.]	$HDD_{UNI\ 10349}$ (HDD_{2015}) at 20°C [°C]	Climatic zone	V [m³]	Sn [m²]	S/V [m⁻¹]
1	Cigliano (VC)	237	2607 (2940)	E	665.25	128.78	0.74
2	Morozzo (CN)	431	2772 (2981)	E	1002.56	215.73	0.73
3	Mezzomerico (NO)	266	2965 (3066)	E	607.54	139.45	0.74
4	Cureggio (NO)	289	2989 (2981)	E	1028.70	288.40	0.81
5	Villanova (CN)	520	2869 (3176)	E	686.60	178.00	0.85
6	Rocca De' Baldi (CN)	414	2754 (3089)	E	986.90	218.90	0.74
7	Biella (BI)	420	2893 (2428)	E	735.59	149.91	0.79
8	Coassolo T.se (TO)	742	3176 (3019)	F	620.31	128.13	0.89
9	Genola (CN)	345	2684 (2807)	E	1027.83	198.27	0.73
10	Roccaforte (CN)	574	2918 (3176)	E	1104.84	259.40	0.72
11	San Damiano (AT)	179	2689	E	1212.00	216.00	0.74
12	Samone (TO)	247	2670	E	658.64	226.91	0.70
13	Samone (TO)	247	2670	E	1423.60	372.83	0.75
14	Galliate (NO)	153	2850	E	1103.74	198.03	0.65
15	Mondovì (CN)	395	2735	E	944.40	248.50	1.00
16	Sinio (CN)	357	2696	E	1336.93	291.77	0.70
17	Sant'Albano Stura (CN)	378	2718	E	1162.50	316.00	0.84
18	Lerma (AL)	293	2740	E	1033.76	332.38	0.67
19	Rivarolo C.se (TO)	304	2728	E	698.92	251.09	0.80
20	Grana (AT)	289	2801	E	713.47	129.15	0.86
21	Trinità (CN)	383	2723	E	909.00	327.96	0.80
22	Caraglio (CN)	575	2919	E	676.20	145.23	0.70
23	Chiesanuova (TO)	664	3096	F	1135.51	225.56	0.79
24	Garbagna N.se (NO)	132	2828	E	635.00	140.00	0.76
25	Netro (BI)	606	3083	F	515.33	119.33	0.75

TABLE II - MONITORED BUILDINGS DATA

NZEB	V [m³]	S/V [m⁻¹]	Uoe [W/m²/K]	Uw [W/m²/K]	Emission system	Energy generation systems						Monitored year
						Service	HP Power [kW]	Fuel	Type of HP	PV Power [kW]	ST area [m²]	
1	665.25	0.74	0.170	0.883	Radiant floor	H + DHW	6.84	EE	air-water	4.40	4.20	2013-14
2	1002.56	0.73	0.131	0.693	Radiant floor	H + DHW	12.30	EE	air-water	3.20	5.80	2014-15
3	607.54	0.74	0.149	0.880	Split	H	10.00	EE	air-air	4.00	4.66	2014-15
4	1028.70	0.81	0.175	0.952	Radiant floor	H + DHW	6.00	EE	air-water	6.00	7.50	2014
5	686.60	0.85	0.151	1.238	Radiant floor	H + DHW	6.00	EE	air-water	4.50	7.80	2015
6	986.90	0.74	0.152	0.938	Split	H	7.28	EE	air-air	6.50	9.30	2015
7	735.59	0.79	0.119	0.710	Radiant floor	H + DHW	6.31	EE	air-water	5.00	7.50	2014-15
8	620.31	0.89	0.157	0.939	Radiant floor	H + DHW	6.00	EE	air-water	3.50	15.00	2015
9	1027.83	0.73	0.156	0.832	Split	H	6.10	EE	air-air	6.00	6.96	2014
10	1104.84	0.72	0.150	0.633	Radiant floor	H + DHW	11.20	EE	air-water	8.00	12.00	2014-15

Data about the monitored buildings with the: gross heated volume, surface to volume ratio, thermal transmittance of opaque envelope and windows, type of emission system, the type and power of the heat pump (H = space heating, DHW= domestic hot water), fuel (EE= electric energy), the photovoltaic modules and solar thermal collectors power and the monitored years.

A. *Verification of low heating energy demand*

The calculation was performed monthly for all the heating seasons in order to obtain the heating energy performances considering different temperature conditions. Considering the global electric consumption measured with a monthly period, the energy signatures of the average daily consumption were represented as a function of outside temperatures for each building. In Figure 2 the total energy consumption of buildings was normalized by the heated surface S_n to avoid the dependence on the size of the building. The slope of energy signature depends on many variables affecting energy consumption but the low slope of the energy signatures means adequate thermal insulation and good system efficiency.

TABLE III - YEARLY ENERGY CONSUMPTIONS OF THE MONITORED NZEB AND THE ENERGY PROVIDED TO THE BUILDINGS BY THE HEAT PUMP.

nZEB	year	Q_{in}	$Q_{G,in}$	Q_{App}	Q_{HP}
		kWh/y	kWh/y	kWh/y	kWh/y
1	2013	1978	803	1175	2078
1	2014	1725	772	953	1954
2	2014	1933	1120	813	3034
2	2015	1986	1240	746	3418
3	2014	1851	788	1064	2102
3	2015	1941	837	1104	2214
4	2014	3074	1923	1151	5001
5	2015	2570	1177	1392	3030
6	2015	2779	1223	1556	3128
7	2014	2150	873	1277	2202
7	2015	2226	896	1330	2285
8	2015	1626	813	813	2115
9	2014	2176	1001	1175	2641
10	2014	2183	1237	946	3041
10	2015	2460	1191	1269	3270

Regarding system efficiencies, the storage, distribution, emission and control systems, information were obtained from the design technical reports. Generation efficiency of the heat pump (i.e. COP), instead, was derived from monitoring data.

In Table IV the comparison between design "d" and monitored "m" data on space heating energy demand is represented.

From Table IV it is shown also that only two of the ten buildings did not respect the first requirement on annual energy demand of $Q_{H,nd}$ / Sn $\leq$ 15 kWh/m^2/y (i.e. buildings 7 and 8).

In addition, also buildings 4 and 5 had high annual energy demand; these buildings have high thermal transmittance of opaque and transparent surfaces and also high S/V ratio, meaning higher heat dispersions. On the contrary, buildings 2, 9 and 10 had lower energy demand compared with other buildings, with lower S/V ratio and lower thermal of transmittance of opaque and transparent surfaces (see also Table II). The Coefficient of Performance (COP) of the heat pump was collected from monitoring data knowing the energy consumption of the heat pump and the energy delivered from the heat pump. From Table IV is it possible to observe that, during the monitored heating seasons, the average value of COP was 2.81-2.99 with maximum values of 2.97-3.12 registered mainly in April 2014 and October 2015. These values are always lower than 3.2 the performance limits for air-air or air-water heat pumps of the Piedmont Region (D.G.R. 46-11968/2009).

In Figure 3 the global energy consumption for space heating, cooling, hot water production and electric appliances is represented as a function of the relative specific global energy consumption. This graph is subdivided in four quadrants considering the median values of energy consumption and the specific energy consumption. In graph (a) the global energy consumption is highly influenced by:

- climate conditions then consumptions have been normalized on the average year 2015 in (b);
- energy consumption of electric appliances then in the graph (b) only the energy consumption of the heat pump $Q_{G,in}$ is represented.

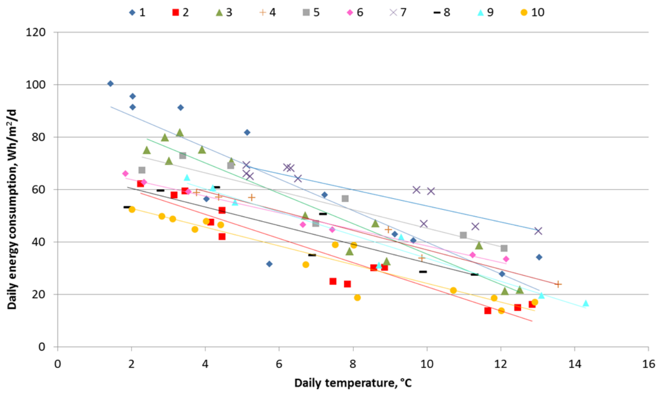


Figure 2 - Total energy consumption of buildings normalized by the heated surface.

TABLE IV - COMPARISON BETWEEN DESIGN "D" AND MONITORED "M" DATA ON SPACE HEATING ENERGY DEMAND

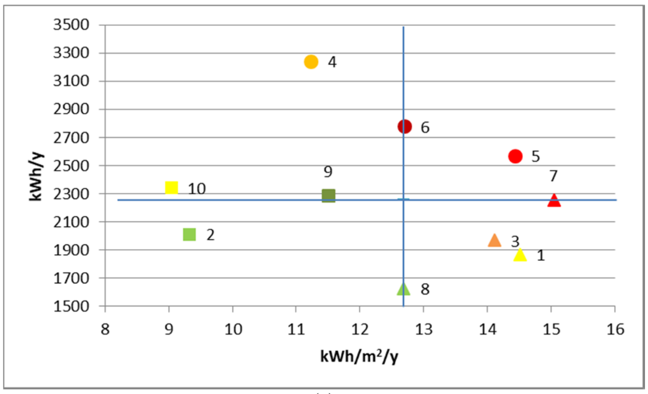
nZEB	$(COP_{avg})_m$	$(COP_{max})_m$	$(Q_{H,nd}/S_u)_m$ [kWh/m^2/y]	$(Q_{H,nd}/S_u)_d$ [kWh/m^2/y]	Relative deviation [%]
1	2.86	3.00	13.02	13.34	-2%
2	2.94	3.12	11.29	12.74	-13%
3	2.94	3.10	12.84	11.61	10%
4	2.81	2.97	14.90	9.84	34%
5	2.90	2.98	14.72	14.04	5%
6	2.90	2.97	12.58	12.02	4%
7	2.92	3.03	15.12	13.18	13%
8	2.89	3.09	16.97	13.37	21%
9	2.95	3.09	12.76	10.51	18%
10	2.99	3.08	10.72	10.80	-1%

Both the graphs in Figure 3 gives an idea of the real energy consumptions and energy efficiency levels of buildings with the specific energy consumptions. Particularly, the low and high values of the COP heat pump, respectively for buildings 4 and 10 can be observed also in Figure 3 (b).

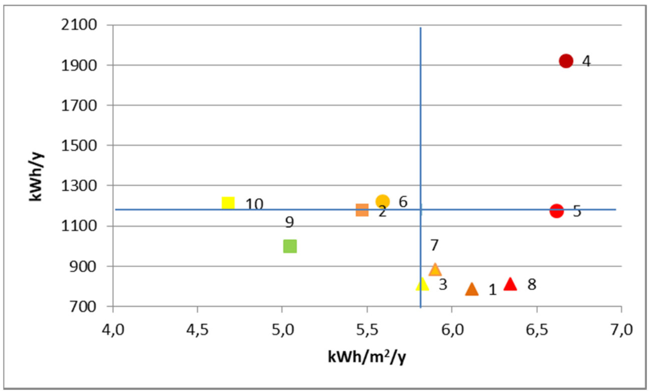
B. Verification on the use of the available renewable energy sources

Renewable energy sources in the analyzed nZEB buildings are photovoltaic modules, solar thermal collectors as well as the heat recovered from the outdoor environment by the heat pump.

About the heat pump, in Table V is reported the percentage of renewable energy recovered during the heating season (hs) and the maximum value that usually is referred to the warm months when the COP is maximum. Building n.4 had a lower value of renewable energy used by the heat pump because of the higher supply energy due to the low compactness of the building, high value of U_e and low efficiency of the heat pump (low COP); on the contrary, building n.10 is compact with low values of U_e and U_w and high COP (as also building n.2).



(a)



(b)

Figure 3 - Annual global energy consumption Q_{in} (a) and annual energy consumption for space heating and hot water production $Q_{G,in}$ (b) of the 10 monitored buildings and the relative specific value of energy consumption normalized on the average climatic data of the year 2015 (kWh/m^2/y).

For all the monitored buildings, solar technologies are completely roof integrated and only building n.5 has a flat roof. For photovoltaic modules (PV) and solar thermal collectors (ST) the average values of energy used during the year and during the heating season are reported (the maximum values were of 97 and 100%). With the PV modules, the percentage of renewable energy used was about 42% because with electric heat pumps the maximum request of energy is during the heating season, when the solar irradiation is lower. During the heating season, the percentage of PV renewable energy used was 76%. The higher percentage was registered for buildings n. 9 and 4 with similar power installed for PV modules and heat pump. With ST collectors, as they provide mainly domestic hot water service, the percentage of ST renewable energy used was of 81% with 99% considering only the heating season. The total primary energy PE_{tot} of the building is given by renewable and not renewable energy sources:

$PE_{tot} = PE_{ren} + PE_{nren}$.

To obtain the primary energy, energy consumptions were multiplied by the coefficients of conversion into primary energy. For electricity was used a coefficient of conversion of 2.42, while for photovoltaic, solar collectors and the heat recovered by the heat pump, the coefficient of conversion was 1 (as specified in the Italian Decree DM 26/6/2015).

The $PE_{tot,nren}$ has to be calculated using energy related to heating, hot water production and artificial lighting. Electricity used for heating and domestic hot water services was collected in the monitoring database. As regards to the electricity used for artificial lighting, it has been calculated as 10% of the difference between the total energy consumption and the energy used for space heating and hot water services [10, 11].

For the calculation of $PE_{tot,nren}$ different hypotheses has been made:

1. The total input energy at the electricity meter was used:

$$PE_{tot,nren} = Q_{in} \cdot f_{p,el} \tag{1}$$

$$PE_{tot,ren} = Q_{ren,HP} \cdot f_{p,HP} + Q_{ren,PV} \cdot f_{p,ST} + Q_{ren,ST} \cdot f_{p,PV} \tag{2}$$

2. The energy for space heating, domestic hot water and lighting was used:

$$PE_{tot,nren} = (Q_{G,in} + Q_{ill}) \cdot f_{p,el} \tag{3}$$

3. Only the energy consumption of the HP for space heating and domestic hot water was used without the photovoltaic contribution:

$$PE_{tot,nren} = Q_{G,in} \cdot f_{p,el} \tag{4}$$

$$PE_{tot,ren} = Q_{ren,ST} \cdot f_{p,ST} + Q_{ren,HP} \cdot f_{p,HP}. \tag{5}$$

Table VI shows how the 10 monitored nZEB met the second requirement for energy coverage of 50% from renewable energy sources. Only in two cases for the year 2014, the energy coverage from renewable energy sources was lower than 50% (buildings n.2 and 3). On average, it was reached the 51% of renewable energy sources on the global energy consumption. Not considering the energy consumption for electric appliances, the average percentage reaches the 72% and, with only thermal renewable energy sources, the 67%.

V. Conclusions

Italy is a country with a mild climate and many renewable resources and good practices in energy efficiency and low carbon technologies are finally starting to align Italy with international commitments to reduce greenhouse gas emissions and to create a country-wide system to accommodate future challenges.

As shown in this work, nZEB can be designed and built in the Northern part of Italy with low energy demand and efficient energy supply systems because, in Europe, all low carbon technologies are widely used from years and in these regions there is a good know-how.

TABLE V - PERCENTAGE OF RENEWABLE ENERGY RECOVERED DURING THE HEATING SEASON (HS) AND THE MAXIMUM VALUE

nZEB	$Q_{ren,HP}\|_{avg,hs}$	$Q_{ren,HP}\|_{max}$	$Q_{ren,PV}\|_{avg,y}$	$Q_{ren,PV}\|_{avg,hs}$	$Q_{ren,ST}\|_{avg,y}$	$Q_{ren,ST}\|_{avg,hs}$
1	185%	200%	30%	57%	84%	100%
2	189%	212%	36%	70%	99%	100%
3	189%	210%	41%	75%	91%	100%
4	177%	197%	52%	95%	81%	100%
5	187%	198%	49%	92%	73%	99%
6	188%	197%	39%	71%	69%	97%
7	189%	203%	36%	65%	68%	98%
8	185%	209%	43%	75%	69%	97%
9	192%	209%	60%	85%	79%	100%
10	196%	208%	37%	72%	95%	100%

TABLE VI - NZEB MET THE SECOND REQUIREMENT FOR ENERGY COVERAGE OF 50% FROM RENEWABLE ENERGY SOURCES MET BY 10 MONITORED NZEB.

nZEB	year	$PE_{tot.ren}/EP_{tot}\|_m$ Eqq. (1, 2) [-]	$PE_{tot.ren}/PE_{tot}$ Eq. (3, 2) [-]	$PE_{tot.ren}/PE_{tot}$ Eqq. (4. 5) [-]
1	2013	51.94%	75.08%	70.14%
1	2014	51.27%	73.34%	67.33%
2	2014	48.49%	68.85%	60.84%
2	2015	50.57%	70.62%	64.18%
3	2014	49.26%	72.25%	65.83%
3	2015	52.14%	73.59%	68.97%
4	2014	52.36%	69.82%	65.78%
5	2015	50.50%	71.24%	66.89%
6	2015	51.70%	72.37%	67.17%
7	2014	51.15%	72.81%	67.48%
7	2015	50.53%	72.48%	67.05%
8	2015	52.54%	71.98%	66.77%
9	2014	52.50%	74.81%	73.43%
10	2014	50.96%	66.25%	59.74%
10	2015	51.60%	72.89%	67.34%

Even if the monitored data shown lower efficiencies than the design reports, the final results have demonstrated low energy demands and energy-uses with a good percentage of utilized renewable energies. Only two buildings have exceeded the limit of low heating energy demand (buildings n.7 with +1% and n.8 with +13%) and, only for the year 2014, two buildings did not meet the limit on the share of renewable sources (buildings n.2 with -3% and n.3 with -1%) but always with percentages very near to the request. Moreover, in mild climates as the ones in the southern part of Italy, heat pump can also obtain better results in terms of renewable thermal energy.

This analysis also found that Italian legislation provides thermal transmittances for building envelope far higher than the state of the art of the nZEB. The average U-value for a vertical opaque wall fixed by the rules of Italian regulation today is about 0.3 W/m^{2}K. This level will be enhanced in 2020 to 0,26 W/m^{2}K, only 13% less and far away from the best practices. A greater effort should be made in this field.

Also, for a good optimization on the use of renewable energy sources, storage systems should be integrated in the nZEB, especially for the electric energy, as during the year, only the 30-60%.of the energy produced by PV systems is exploited.

One of the problem of this work was that all of the nZEB were detached houses, representing only 35% of Italian residential buildings. No interventions on condominiums where registered but more than half of the Italian population live in condominiums. The real challenge for the future is the design and construction of nearly zero energy condominiums, or nearly zero energy neighborhoods and cities.

A further problem of this work is that the analysed nZEB are localized in suburbs or in the country side without constraints or where it is not difficult to find spaces for the positioning of renewable energy technologies. In urban spaces, in high density areas, much more difficulties can be founded. One solution might be to think about the energy demand and supply systems of the entire neighborhood, not at building scale, so to optimize also the use of outdoor spaces to produce renewable energy.

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