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The relation between nZEB requirements, local climate, and building features. The nZEB model application to two sample buildings, in different climatic conditions

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ABSTRACT

In 2016, the European Commission (EC) published the Recommendation 2016/1318 on guidelines for the promotion of nearly zero-energy buildings (nZEBs) and best practices to ensure that, by 2020, all new buildings are nZEBs. In relation to the EC document, the study examines the applicability of the design of nZEBs in various climatic conditions, evaluating possible global scenarios for the renovation of the existing residential buildings. The analysis is applied to two building types, a single-family house and an apartment block located in different climatic zones, through the reference notional building (RNB). The requirement for the building under design is represented by the energy performance of the RNB. This one is outlined at national level, by local legislation, aiming at the nZEB target. Therefore, in the present investigation, the RNB is used to calculate the energy performance indexes, depending on different climatic conditions, chosen to be representative of various Heating Degree Days ranges. The results are intended to demonstrate that there is not a unique nZEB level, but the reference strongly depends on the local conditions and the building features. As the framework definition of nZEB in the EPBD and in the national legislation does not differentiate between new and existing buildings, the results of the study can be used as baseline energy performance for the quantification of energy and environmental savings, and to guide buildings refurbishment policies.

1. INTRODUCTION

In the 2010/31/UE Directive [1] (EPBD recast), specific indications to build, by 2020, all nearly zero-energy buildings, (nZEB) were presented.

The practical application of the nZEB definition is demanded to the Member States, depending on local conditions, and quantified by a numeric indicator corresponding to the primary energy parameter. In the national application of the Directive, several States have included also parameters such as thermal transmittance (U) values of building envelope components, net and final energy for heating and cooling, and CO_2 emissions.

The nZEB target was, afterwards, the subject of the Recommendation 2016/1318, regarding guidelines for the promotion of nearly zero-energy buildings [2].

It bases its considerations also on the Synthesis Report on National Plans for nZEB (2016) [3] that indicates the National dispositions and the numeric value of energy performance (primary energy, in kWh.m^{-2}.a^{-1}) that each country has indicated. The information is based on non-homogeneous calculation methods; therefore, the computational results for primary energy can widely varying.

In fact, the requirements range includes values from 0 to 160 kWh.m^{-2}.a^{-1} of primary energy, even if in most cases it varies from 20 to 50 kWh.m^{-2}.a^{-1}.

The nZEB target corresponds to the characteristics attributed to the reference notional buildings, outlined at national level, by local legislation. The reference or target building is represented by a notional building identical to the design one in terms of geometry (shape, volumes, walkable surface, surfaces of construction elements and components), orientation, territorial location, intended use, boundary situation, and having predetermined thermal characteristics and energy parameters.

In Italy, its main fixed features are indicated in the national Ministerial Decree on the definition of the minimum energy requirements for buildings [4], as resumed briefly in [5].

The main building envelope features are represented by:

(1) the thermal transmittance, U, calculated as indicated in EN ISO 6946 [6], reference values in Table 1;

Table 1. Climatic zones and HDD in Italy and corresponding reference thermal transmittances U [W.m^{-2}.K^{-1}] of the building components

Climatic zone	HDD	U wall	U window	U roof
A , B	≤ 900	0.43	3.0	0.35
C	≤ 1400	0.34	2.2	0.33
D	≤ 2100	0.29	1.8	0.26
E	≤ 3000	0.26	1.4	0.22
F	> 3000	0.24	1.1	0.20

(2) the mean overall heat transfer coefficient by thermal transmission, H'_T, calculated following EN ISO 13789 [7] (eq.1), reference values in Table 2;

(3) the effective solar collecting area of the glazed elements related to the building conditioned net floor area, A_{sol} / A_f, with A_{sol} calculated in accordance to EN ISO 13790 [8] (eq.2), only for the month of July. The maximum allowable value of $A_{sol,J}/A_f$ is 0.03 for the residential buildings and 0.04 for all the other destinations.

$$H'_T = \frac{H_{tr,adj}}{\sum_k A_k} \ [W.m^{-2}.K^{-1}] \quad (1)$$

where:

$H_{tr,adj}$ = the overall heat transfer coefficient by thermal transmission of the building envelope, calculated in accordance with EN ISO 13789;

A_k = the opaque or transparent envelope k-component area.

Table 2. Maximum allowable value of H'_T [$W.m^{-2}.K^{-1}$] referred to the building compactness ratio A_{env}/V_g [m^{-1}]

Climatic zone	HDD	A_{env}/V_g<0.4	0.4≤A_{env}/V_g <0.7	A_{env}/V_g≥ 0.7
A , B	≤ 900	0.80	0.63	0.58
C	≤ 1400	0.80	0.60	0.55
D	≤ 2100	0.80	0.58	0.53
E	≤ 3000	0.75	0.55	0.50
F	> 3000	0.70	0.53	0.48

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where, for each transparent envelope component k:

$$\frac{A_{sol,j}}{A_f} = \sum_k F_{sh,ob,k} \cdot g_{gl,sh,k} \cdot (1 - F_F)_k \cdot A_{w,p,k} \cdot F_{sol,sum,k} \quad (2)$$

$F_{sh,ob,k}$ = the shading reduction factor for external elements;

$g_{gl+sh,k}$ = the total solar energy transmittance of the transparent part of the element in presence of a shading device;

$F_{F,k}$ = the frame area fraction;

$A_{w,p,k}$ = the overall projected area of the glazed element [m^2];

$F_{sol,J,k}$ = a correction factor for the incident solar radiation, the ratio between the solar irradiation of July (for the site and orientation), and the mean annual solar irradiation in Rome on a horizontal plane.

In the European countries, different methodological approaches to reach the nZEB target have been developed.

Several analyses have tried to monitor the situation rapidly changing in the years. The EU project EPISCOPE [9], for example, integrated TABULA project, to refer about the current minimum requirements and the new building regulations of each European country. The methodological differences regard for example the requirements definition (limits for U-values, for the heat transfer coefficient by transmission, the energy need for heating, the primary energy demand), by using fixed values, a formula or a set of reference features, and the calculation periods (yearly/seasonal, monthly, hourly) for energy need for heating (building) and delivered energy (system).

Several researches present case studies about the energy performance of nZEB: in each case, the results depend on the national reference level. As example, the Polish Technical Conditions require for heating, ventilation and DHW, EP_{H+W} =70 $kWh.m^{-2}.a^{-1}$) [10], for single-family buildings from January 1, 2021. There aren't different U values like in Italy (Tab.1): they are the same for all the country, and for residential buildings are indicated in Table 3.

Table 3. Thermal transmittances U [$W.m^{-2}.K^{-1}$] of the building components for residential buildings in Poland

U wall	U window	U roof
0.20	0.90	0.150

In the updating of the Energy Performance Directive EPBD [11] aiming at achieving highly energy efficient and decarbonized building stock, Member States should implement national policies for increasing deep renovations with the access to financing.

To achieve this goal, several researches are underway, regarding the knowledge of the existing building stock, for example the EU project "Robust Internal Thermal Insulation of Historic Buildings" (RIBuild) [12] provides information on historical building stock in several countries (Denmark, Germany, Italy, Latvia, Sweden and Switzerland).

The main focus of the study is the description of the historical building stock and in particular of the thermal building envelope thermo-physical properties and of the any correlated deterioration issues in its transformation into nZEB.

In Italy over 70% of the entire existing building stock was built before the 1980s, a period in which specific measures on energy efficiency were not applied. In total there are 12 million residential buildings, for a total of 31 million of housing units. Other authors also performed similar research [13] to evaluate the most suitable integrated solutions for increasing energy performance of the building's envelope, avoiding moisture problems.

From the EU project RIBuild and the Italian national statistics (ISTAT 2011, ENEA 2009) emerges that quite the 29% of the whole national building stock was built before 1945 and it is therefore characterized by very poor energy performance.

Existing residential buildings are typically characterized by similar geometric characteristics. Some reference archetypes have reported in the PAnZEB (Italian National Action Plan to increase almost zero-energy buildings) [14], which provides an average index of total global energy performance for different typology of residential buildings. The document shows the energy needs of single-family houses and large apartment blocks referring only to two climate zones (zone B, HDD ≤ 900, and zone E, 2100 < HDD ≤ 3000).

According to the poor energy performance conditions of the residential existing building stock, there is a great potential of energy savings in accordance with EU level ambitions, to ensure a highly energy efficient and to facilitate the cost-effective transformation of existing buildings into nZEB.

Also the EU Project, RePublic_ZEB [15], on the refurbishment of the public building stock towards nearly the Zero Energy Building, deals with energy characteristics of buildings, their quantities, and the retrofit. It goes on through further studies and surveys for the subsequent identification of national reference buildings, for the determination of energy packages of measures for deep renovation and calculation and evaluation of cost-optimal levels for building energy performance requirements. The project has involved mainly countries from the South and East Europe.

From the examples found in literature, it emerges that the nZEB model application leads to values of the energy performance index that vary, depending on the climatic conditions [16-17], on the methodology applied, and on the limiting values locally imposed.

The real possibility to reach nZEB target depends on local climate conditions. Each country can define its own reference methods and data for calculating the energy performance of buildings to prove their compliance with the minimum requirements for energy performance of nZEB.

Political choices can also influence the overall performance of nZEBs, for example by means of the choice of primary energy factors (total primary energy factor, non-renewable primary energy factor, and renewable primary energy factor) [18]. The global energy performance of the building can be expressed by primary energy, based either on total or on non-renewable primary energy factors. The primary energy factor from delivered and exported energy could be different for EU member states, also per energy carrier.

As indicated in EN ISO 52016-1 [19], according to the method established at national level, for calculating the energy performance of buildings to prove their compliance with the minimum requirements, climate data set can be represented by monthly mean values (standard calculations) or by hourly data (dynamic simulation).

In the EN ISO 15927-4 Standard, the method to obtain the Test Reference Year (TRY) by significant series of data of several years is outlined [20].

The Italian standard UNI 10349 has been updated recently, in 2016 [21]: it contains test reference years (not present in the previous version) and monthly average data (updated from the 1994 edition), developed by the Thermotechnical Italian Committee, CTI, for 110 Italian locations.

They can be used respectively in the building energy simulation programs, and in calculation procedures indicated in EN ISO 52016-1 (steady-state method and hourly calculation). However, several authors [17] are studying an improved procedure for the construction of a typical meteorological year of nZEBs.

The EU Recommendation [2], after all, recognizes that numerical indicators are difficult to compare across Member States because of the different energy performance calculation methodologies adopted. It is recognized, the need of clearly stated calculation methodologies, and some energy performance benchmarks of nZEB are indicated for the different EU climatic zones. In particular, in the Mediterranean area, the indication is related to single-family houses, for which the net primary energy refers to 0-15 $kWh.m^{-2}.a^{-1}$ that could be represented by 50-65 $kWh.m^{-2}.a^{-1}$ of primary energy, covered by 50 $kWh.m^{-2}.a^{-1}$ of on-site renewable sources.

The use of the reference building determines different nZEB values, depending on the local climatic conditions. The results of the research presented in the paper intend to put in evidence that it is not possible to indicate a single reference value for the nZEB evaluation for the whole country, but it depends on local climate and thermal and geometrical building characteristics.

It is noteworthy that, in the revision of the EPBD, it is expected that the evaluation of building will consider, in addition to energy performance and renewable energy sources installed, the smart-readiness of buildings [11]: an indicator on measure buildings' capacity, to use Information and Communication Technology (ICT), and electronic systems, to adapt the operation of the building to the needs of the occupant and the grid, and to improve its energy efficiency and overall performance. This index will depend primarily on the energy performance of the building which will have to be very low.

2. METHODOLOGY

The energy performance indexes, depending on different climatic conditions, are calculated by means of a quasi-steady state method applied to the reference notional building.

The quasi-steady state method is based on the EN ISO 13790 standard, determines the energy need for space heating and cooling, through the steady-state balance of heat losses (transmission and ventilation) and heat gains (solar and internal) evaluated in average monthly conditions.

In the quasi-steady state methods, the dynamic effects are considered through the utilization factors that account for the mismatch between transmission/ventilation heat losses and solar/internal heat gains.

In most EU member states [22], the quasi-steady state method generally is used for the verification and design of nZEBs. A quasi-steady-state simulation is more time-effective than the dynamic method, but its results are in general less accurate.

According to research in progress [23], the quasi-steady-state method performs the calculation of the heating energy need with sufficient accuracy in case of highly insulated buildings in cold climate. In mild and hot climates, it overestimates the heat losses and this determines an increase of heating energy needs, compared to a dynamic model, with a consequent underestimation of the cooling energy need. For highly insulated buildings as nZEB, the quasi-steady-state model estimates well the cooling energy performance, because the weight of the heat transfer on the energy balance is low.

The results of the investigation aim at putting in evidence that there is not a unique nZEB level, but the reference strongly depends on the local conditions and the building features.

The following assumptions were considered: heating and cooling temperature set-points 20°C and 26°C respectively and a continuous operating schedule during the conditioning period, corresponding to the indications of the Italian regulations for residential buildings.

For the calculation of the energy performance, the climatic data defined by the UNI 10349-1 Italian national standard were considered.

In the calculation of the total solar irradiance on vertical surface, it is assumed that the solar radiation on vertical walls facing East and West are the same.

3. CASE STUDY

The case studies consist of two different building types with a fixed geometry, located in different Italian climatic zones: a single-family house and an apartment block (Table 4). The single-family house is a two-floor residential building. The conditioned space has a compactness ratio (envelope surface-to-heated volume) equal to 0,73 m^{-1}. The conditioned floor area is equal to 161 m^2.

The apartment block has four floors above ground. The conditioned spaces of the building include 12 dwellings, while the attic space and the staircases are unconditioned areas. The main data of the case studies are shown in Table 4.

The case studies are characterized by window-to-wall ratio (WWR) corresponding to the typical residential Italian building stock. This parameter represents the most sensitive design element of nZEB, as it heavily influences mainly cooling energy need. For each building component, the insulation layer thickness was determined to comply with the thermal transmittance value including the effect of thermal bridges.

Table 4. Main geometric characteristics of the case studies

Case study	Single-family house	Apartment block
Index		
V_g [m^3]	650	3401
V_n [m^3]	429	2643
A_f [m^2]	161	973
A_{env} [m^2]	479	1653
A_w [m^2]	28	143
A_{env}/V_g [m^{-1}]	0.73	0.49
WWR [-]	0.11	0.18

Both case studies are characterized by a non-habitable unconditioned space on the top floor (attic) with a temperature reduction factor b_{tr} equal to 0.70 (corresponding to insulated roof). The global sensible internal heat gain has a value of 4.86 W.m^{-2} for the apartment block and of 2.79 W.m^{-2} for the single-family house. The average ventilation flow rate is 0.30 changes per hour.

As regards the envelope system, it was used an externally insulated massive envelope technology different for each climate zone, to satisfy the minimum requirements, defined in

Table 1: The U-values of the building envelope components depend on the heating degree-days (HDD) of the location (Table 2). The solar factor is equal to 0.60.

Table 5 shows the main characteristics relating to the opaque envelope of the case study structures.

As far as the ground floor is concerned, the equivalent thermal transmittance calculated according to EN ISO 13370 [24] and, in brackets, the U-value calculated according to EN ISO 6946.

Table 5. Characteristics of the opaque building envelope components

	Climatic zone	U	Y_{IE}	Ms	κ_i
External wall	B	0.43	0.084	258	50.1
	C	0.34	0.062	259	49.8
	D	0,29	0.050	259	49.6
	E	0.26	0.044	260	49.5
	F	0.43	0.040	260	49.4
Floor vs. unconditioned space (attic) b_{tr}=0.70	B	0.50	0.153	257	63.3
	C	0.47	0.141	257	63.5
	D	0.37	0.106	258	63.1
	E	0.31	0.086	258	62.9
	F	0.29	0.080	259	62.8
Roof	B,C,D,E,F	0.80	0.130	381	69.5
Ground floor	B	0.44 (1.80)	0.942	416	62.9
	C	0.38 (1.00)	0.407	417	60.2
	D	0.29 (0.56)	0.198	422	59.8
	E	0.26 (0.48)	0.162	423	59.8
	F	0.24 (0.42)	0.137	425	59.7

All windows have double or triple glazing with a thickness variable as a function of climatic zone, and the thermal transmittance U_w of the entire opening (glasses and frame) is variable (Table 6). It is provided the use of curtain (outside white Venetian blinds), reaching g_{gl+sh} = 0.35 for all orientations except for the North side. Shading obstacles were not considered. Case studies are theoretical buildings with geometric and thermo-physical features corresponding to the average of Italian building stock, which they represent.

Table 6. Characteristics of the transparent building envelope components.

	Climatic zone	U_w	$g_{gl,n}$	g_{gl+sh}
Windows	B	3.00	0.75	0.35
	C	2.20	0.67	0.35
	D	1.80	0.67	0.35
	E	1.40	0.67	0.35
	F	1.10	0.67	0.35

4. RESULTS

Model calculations were conducted for the Italian reference notional building to analyze the difference between the energy performance levels of nZEB for all the 110 Italian locations considered in the UNI 10349.

Figure 1 and Figure 2 show the energy needs for heating (left) and cooling (right) respectively for the apartment block and the single-family house. The size of the dot indicates the energy performance for the energy service considered.

Table 7 shows the minimum, the average and the maximum values of the Energy Performance (EP) Index related to the energy needs for the examined case-studies, referring to the Italian climatic zones. The last column shows the number of locations on which these indices have been calculated.

Table 7. Energy performance of case studies

		Apartment block			Single-family house			
	EP_{nd}	Min	Average	Max	Min	Average	Max	Loc.
B	H	5.8	7.9	16.2	20.1	23.4	35.6	10
	C	21.5	29.9	34.6	11.9	21.8	26.1	
C	H	5.2	8.7	11.9	21.2	26.4	31.2	23
	C	20.0	27.1	35.3	10.7	18.4	27.8	
D	H	4.6	11.1	23.2	20.3	31.1	48.3	34
	C	17.0	24.6	33.9	7.4	15.0	23.7	
E	H	8.0	16.2	24.1	26.6	39.2	51.2	50
	C	17.1	23.5	28.0	7.1	13.5	18.0	
F	H	16.2	19.3	22.4	40.8	45.3	49.9	2
	C	14.7	16.8	19.0	4.9	7.2	9.4	

In the apartment block, the energy performance for cooling is always higher than the one for heating. Referring to the average values, this difference is more pronounced in the hot climatic zones: the summer energy needs are up to three times higher than in winter season. In the colder climatic zones, heating and cooling energy needs are more similar.

For the single-family house instead, the trend is contrary. In warmer climate zones, heating and cooling energy needs are similar, while in colder climate, despite the building envelope has much better thermal performance, the heating service generally shows a higher energy impact.

The difference of energy performance between the two case studies depends not only by the shape ratio (and therefore on the dispersion surface towards the external environment) but also from the internal heat gain contributions which are higher in the apartment block.

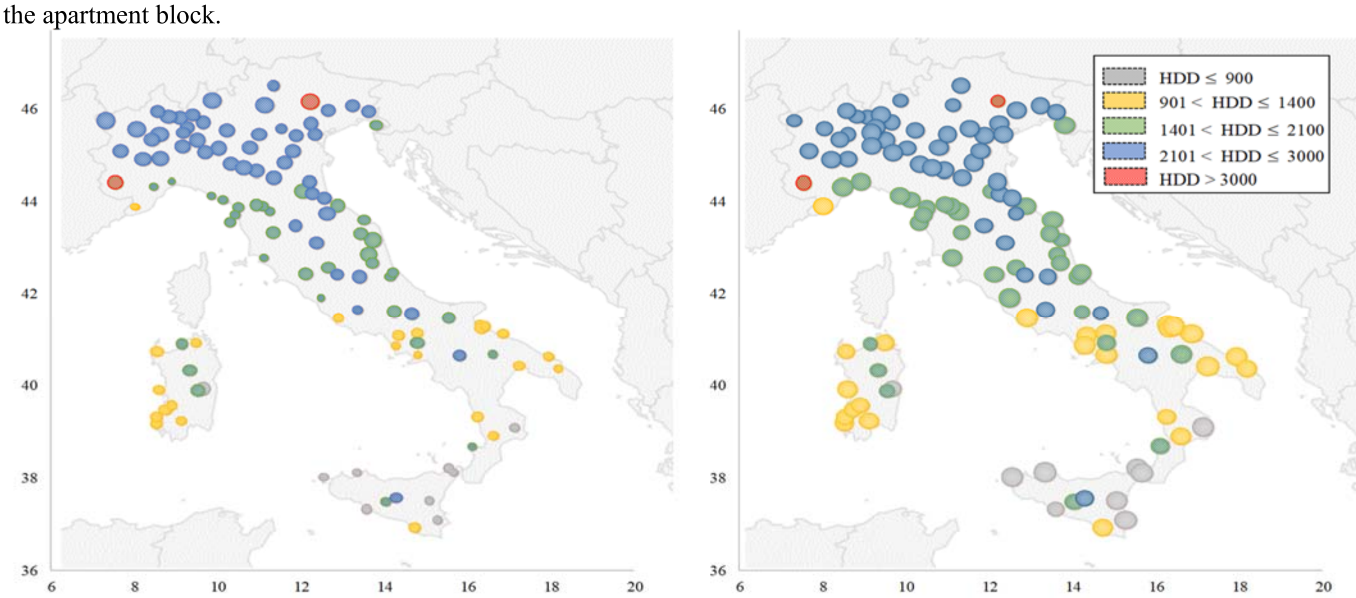

Figure 1. Energy needs for heating (left) and for cooling (right) – Reference apartment block

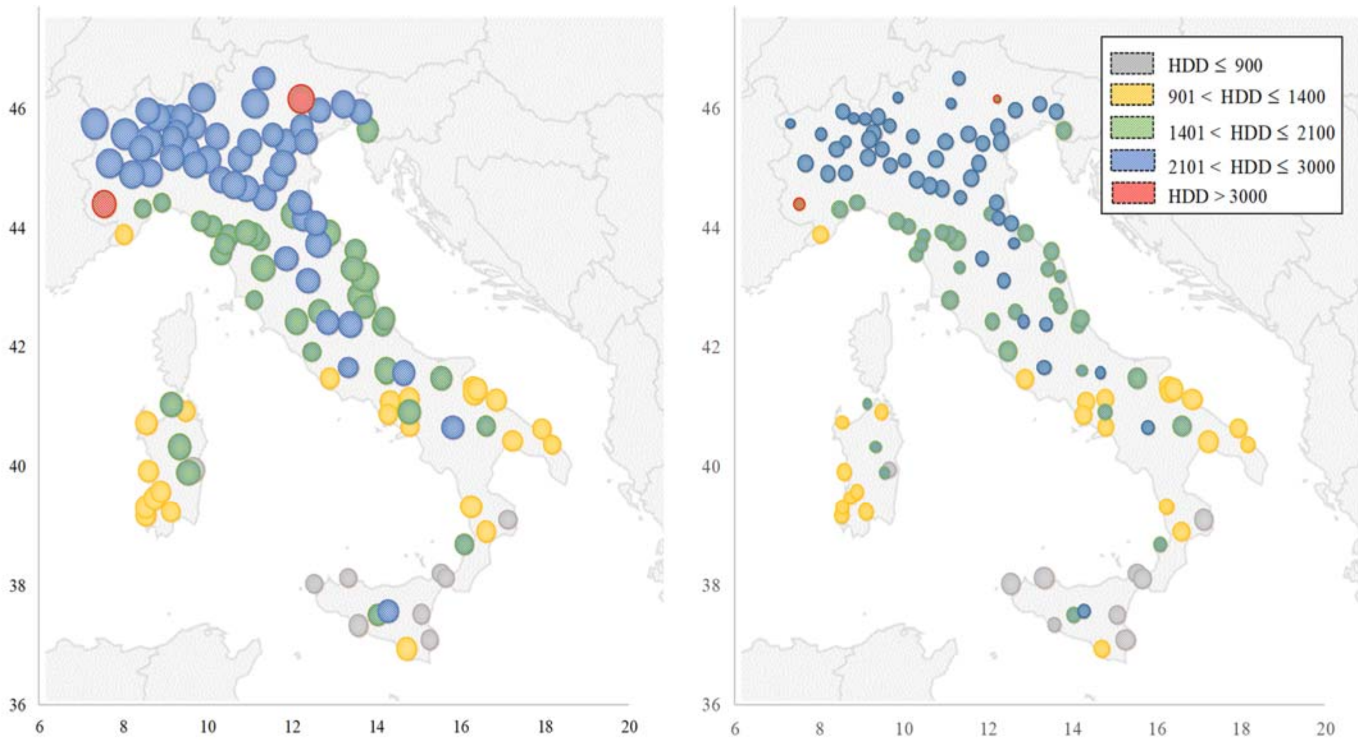

Figure 2. Energy needs for heating (left) and for cooling (right) – Reference single family house

Among the various sites, the buildings with the greatest differences in terms of heating energy performance were selected. In Figure 3 and 4, the energy performance of buildings with the same design features is compared, respectively for the apartment block and the single-family house. The locations that have higher and lower heating energy need within the climatic zones from B to F, are put in evidence and their energy performance data are indicated (energy needs for heating (H) and cooling (C)). It is evident that generally for single-family house the energy need is higher for almost all locations during the heating season.

It follows that, for the same climatic zones, the reference notional building could have very different energy performance characteristics. In fact, within the same climatic zone the boundary conditions can be very different, while the legislative requirements to be met can be identical.

Moreover, both Figure 1 and Figure 3 show that for apartment block the energy consumption is higher for almost all locations during the summer season. Some studies [25-27] have indicated that the reduction of the U-value can determine the decrease of the energy need for space heating.

By contrast, the super-insulation of the building might cause higher energy demand for space cooling and indoor overheating, above all in warm climates. This phenomenon is more pronounced in buildings with high internal heat gains, which are subject to a significant risk of overheating.

In nZEB buildings, in fact, the heat transfer through the envelope is very small, while the internal heat gains cannot always be controlled or reduced (heat gains due to occupants, appliance, and lighting). Instead the solar heat gains can be optimized through the installing more performant shading devices, taking care to maintain suitable lighting comfort conditions.

By examining Table 7, it is also clear that the energy behaviour of the two buildings analysed is completely different and therefore energy policies should consider different legislative requirements of the building envelope.

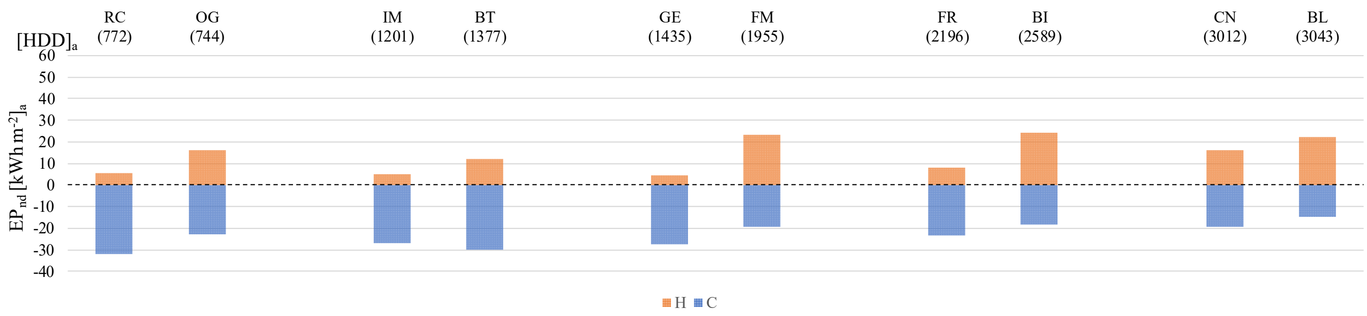

Figure 3. Detail of Energy needs for heating and for cooling – Reference apartment block for some locations

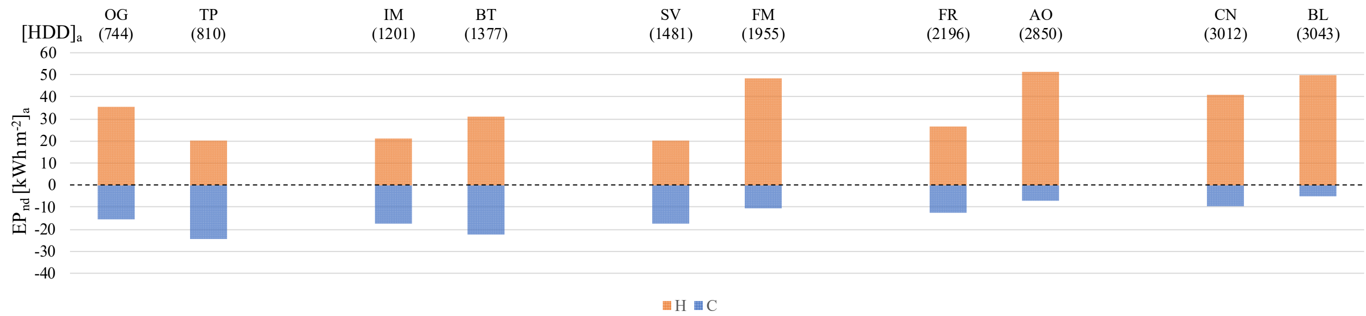

Figure 4. Detail of Energy needs for heating and for cooling – Reference single family house for some locations

5. CONCLUSIONS

The different energy policies implemented by the EU member states are based on the reduction of the energy demand of existing building and in particular on their refurbishment into "nearly zero-energy buildings", through measures aimed primarily at the envelope features improvement (insulation layer, windows and shading devices). Among the assumptions for the nZEB design there is that the energy needs should be successfully satisfied only by adding a moderate amount of renewable sources.

Nevertheless, the absence of reference data concerning the nZEB buildings for different climate zone is making it difficult for policy-makers and researchers to assess the challenges, prescribe the right solutions, and perspectives to guide the refurbishment market. In Italy, the residential building typologies have similar characteristics (divided by years of construction, size and geographical area). Therefore, by knowing the actual energy needs and the average performance of nZEBs in different weather conditions, it is possible to carry out a projection of the energy saving potentials. An attempt to establish benchmark performance was made by the EU Recommendation [2]. However, it has identified a few building types. Moreover, the documents elaborated at national level [14] do not take into account the different climatic configurations but only those relating to the warmer and colder geographical areas. Furthermore, they do not differentiate the energy performances for energy services.

In this study, the energy needs of most common residential typologies have been identified for the quantification of energy savings in heating and cooling periods. The reference benchmark data should provide information on the prevailing energy need given that energy efficiency measures could be significantly different depending on the local climatic conditions. For example, for locations marked by high cooling energy need, it could be more favourable air-conditioning installations, passive solar systems, solar protection, and thermal capacity increasing.

For other locations, characterised by a high heating energy need, thermal insulation, passive heating, reduction of thermal bridges, mechanical ventilation, air-tightness, could be more effective, in addition to the use of certain heating systems.

In energy planning, the policy-makers could therefore consider optimal combinations of improvements in energy performance, use of energy from renewable sources and use of district heating and cooling, assuming the potential future impact of such measures and scenario approaches.

In fact, while the thermal characteristics of the building to be refurbished (elements e.g. walls, roof, windows, etc.) can be more or less different, the nZEB target is always the same.

Financial and other support mechanisms can be linked to these benchmarks; the economic investments represent the main barrier for transforming the existing building stock into nZEBs.

The aim of the work is to guide building refurbishment policies and to make projections and estimates of the achievable savings. The lack of reference data, on energy needs of existing and refurbished buildings, represents the main obstacle for policy-makers to evaluate and support possible outcomes of their policies and measures of energy saving.

Reference energy need data can in-fact support a deep renovation of the public building stock, encouraging subsidies to energy efficiency. Outlining roadmaps for the transformation of existing buildings into nZEB, based on reference benchmark data, will encourage better solutions.

The analysis was carried out in reference to the energy need, since the resources available at the local level can be very different as well as the legislative limits. For example, in some areas there may restrictive measures for reasons related to air quality or other limit on emissions to environment of building heating systems (i.e. use of biomass boiler).

Further simplified procedures could be based on delivered or primary energy, starting from net energy need, by applying reference mean efficiency values of the thermal subsystems and primary energy conversion factors.

In Italy reference values could be assumed in compliance with M.D. 26/06/2015 [4].

Moreover, currently at national level, the member states require that the building energy performance is calculated by means of a quasi-steady-state calculation method.

Future research will enlarge the analysis by means of detailed dynamic numerical simulation and evaluating the energy performance of other energy-consuming buildings (offices, educational buildings, hospitals, etc.).

To improve the energy planning of the nZEBs, the findings of the present work pointed out that, where possible, the guidelines for defining minimum energy requirements should be more differentiated, given the different energy behavior of buildings analyzed (single family houses and apartments). A simplified methodology, like the one shown in the present study, could support the national authorities in their task of energy planning and in preparing the ground for meeting the target of nearly zero energy buildings.

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NOMENCLATURE

A	area, m^2
b	Correction factor for heat loss vs. un-conditioned space
EP	energy performance, $kWh.m^{-2}.a^{-1}$
F	Reduction/correction factor, -
g	total solar energy transmittance, -
H’	Mean heat transfer coefficient, $W.m^{-2}.K^{-1}$
HDD	heating degree days, °C
MS	areal thermal mass, $kg.m^{-2}$
U	thermal transmittance, $W.m^{-2}.K^{-1}$
V	volume, m^3
YIE	periodic thermal transmittance, $W.m^{-2}.K^{-1}$
WWR	window-to-wall ratio, %

Greek symbols

κ	areal heat capacity, $kJ.m^{-2}.K^{-1}$

Subscripts

a	annual
adj	adjusted
C	space cooling
env	envelope
f	floor
F	frame
g	gross
gl	glazing, global
J	July
H	space heating
i	internal
n	net, normal
nd	need (energy)
ob	obstruction
p	projected
tr	transmission
sh	shading
sol	effective solar referred to glazed element
T	overall
w	window
W	domestic hot water