The Energy Performance Assessment of nZEBs: Limitations of the Quasi-Steady State Approach

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The Energy Performance Assessment of nZEBs: Limitations of the Quasi-Steady State Approach

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Abstract

The European Directive 2010/31/EU on the energy performance of buildings (EPBD recast) establishes the target of nearly Zero Energy Buildings (nZEB) for all new buildings and major renovations of existing buildings by the end of 2020. This paper investigates the accuracy of the quasi-steady state method, according to the Italian technical specification UNI/TS 11300, in predicting high performance buildings' energy consumptions. Both the terms of the building energy balance and the simplified dynamic parameters are assessed by comparing the simplified model with dynamic numerical analysis. The two calculation models are applied to some real low energy buildings, which are representative of the Italian building stock. The envelope U-values are assumed as complying with Italian official nZEB requirements. Weather data from some Italian locations, two inertial mass configurations and different system operating schedules are considered. The comparison between the dynamic and static calculations for low energy buildings' energy performance assessment reveals some discrepancies: the quasi-steady state model generally overestimates the energy need for space heating and underestimates the energy need for space cooling; the gaps are bigger among various Italian locations and inertial mass configurations than among different system operating schedules. The reasons of this gap are discussed in the paper. It is highlighted that in some particular cases the national regulations should introduce the dynamic numerical analysis as reference calculation model.

Keywords - building energy assessment; quasi-steady state calculation method; dynamic parameters; Italian building stock

1. Introduction

The European Directive 2010/31/EU (EPBD recast) on the energy performance of buildings establishes the target of nearly zero-energy for all new buildings and major renovations of existing buildings by the end of 2020. According to the EPBD recast, *'nearly zero-energy building'* (nZEB) *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* [1].

This EPBD recast requires the development of new energy efficient and renewable energy technology to satisfy the nearly zero-energy target. Anderson and Roberts [2] state that the available building systems need to be replaced by new technologies and systems in order to reach an increase of 40% on the energy savings. In the article, the authors subdivide the possible technologies for nZEB according to their high or low risk and associated energy benefit. Kamel et al. [3] suggest an integrated building photovoltaic and thermal collector coupled with a cold climate variable capacity air source heat pump and a thermal energy storage, in order to increase the heating system energy performance in harsh winter conditions. In [4] Castaing-Lasvignottes et al. present a photovoltaic system connected to a compressed air energy storage to be used to produce electricity thanks to a turbine, when the solar energy is not available.

In order to accelerate the implementation of the nZEB target, many experiences also suggest optimizing the technical solution already established on the market. In this direction, the IEE project RePublic_ZEB [5] is focused on the reliability of refurbishing the public building stock towards nZEB by improving the confidence of the actors involved in the process on the current available building technology. Micono and Zanzottera [6] present a case study in which they achieved both the net and the nearly zero-energy targets through a detailed management process at the early design stages. Here the very high building energy performance results from the use of solid technical solutions, which help in reducing the energy needs: envelope thermal insulation, solar shadings, energy recovery wheels, district heating and cooling, full-LED lighting system controlled by a building management system, photovoltaic plan, solar collectors and thermal storage.

Anyway, the common goal in all the above examples is to reach a "*very high energy performance*", but what this means in practice is not clear yet.

Despite the implementation of the concept in the national building codes and standards, a common agreement on the nZEB expression is still missing [7, 8]. Many difficulties exist in defining the building assessment boundary, the energy carriers weighting factors, the metric and the time step of the heat balance calculation [9, 10].

Annex I of the Directive states that the methodology for calculating the energy performance of buildings should take into account European standards. Moreover, mandate M/480 [11] for the elaboration and adoption of standards strengthens the importance of an increased accessibility, transparency and objectivity of the energy performance assessment in the Member States facilitating the comparison of best practices and supporting the internal market for construction products.

Two questions arise. Are the simplified models still able to estimate the energy performance of very low energy building correctly? Do the standards support the performance calculation for new technologies and building technical systems ever closer characterized by dynamic features and integrated components?

The mandate M/480 provides for "*improved and (if needed) new standards*", and it also plans to "*updating the standards to the needs of the recast EPBD*". Is aim is giving more consideration inter alia, to alternative systems, to an integrated approach for calculating minimum performance requirements for technical building systems and building envelope taking into account all energy uses, and finally to the expansion of the procedures to nearly zero-energy buildings by way of renewable sources of energy, and procedures for energy producing buildings.

Nevertheless, a review of the scientific literature reveals that most of the studies on the nZEB topic are based the dynamic simulation models, such as TRNSYS [12], EnergyPlus [13]. More detailed models are also used for the assessment of specific issues like TNO WIS 3.0 and INFOMIND FLIXO 7.0 for the façade performances, RADIANCE for the evaluation on natural lighting contribution, IES <VE> for the whole building analysis and a tailored sheet for the simulation of the charge-discharge cycle of the thermal storage [6].

In this context, the present paper investigates the accuracy of the quasi-steady state method, implemented according to the Italian technical specification UNI/TS 11300 [14], in predicting high performance buildings' energy consumptions. Both the terms of the building energy balance and the simplified dynamic parameters are assessed by comparing the simplified model with dynamic numerical analysis.

The work takes into account the current requirements of ZEB according to the EU and Italian regulations. A national reference residential building is used as a case study, with different thermal mass properties and user's activity schedules. The energy performance is calculated for different Italian climatic zones. As the focus of the work is on the calculation of the energy need for space heating and cooling, the building technical systems and the renewable energy sources are neglected; they will be analysed in a next study. The results of the simplified and of the dynamic models are finally compared and commented.

2. Normative framework for nZEB definition in Italy

According to ISO/DIS 52000-1 [15] different requirements should be combined to a coherent assessment of a nZEB. These requirements should include indoor environmental conditions, thermal characteristics of the building, HVAC installation, DHW supply, built-in lighting installation, active solar systems and other systems based on energy, from renewable sources, district or block heating and cooling.

The Italian regulations [16] adopt such a methodological approach and combine an overall energy performance requirement (EP_g) with specific requirements based on thermal characteristics of the envelope, on energy needs for heating ($EP_{H,nd}$) and cooling ($EP_{C,nd}$), on the seasonal efficiencies of heating, cooling and domestic hot water systems (η_H, η_C, η_W) and on renewable energy production.

Two main requirements regard the building envelope: the maximum mean thermal transmittance of the envelope (H'_T), which is set as a function of the heating degree days (HDD) and of the compactness factor of the building (A_e/V_g), as shown in Fig. 1; the maximum summer effective solar area per unit floor area ($A_{sol,summer}/A_f$), fixed to 0.03 for residential buildings and to 0.04 for commercial buildings. $A_{sol,summer}$ is the sum of the effective solar collecting area of glazed elements, calculated for the month of July according to EN ISO 13790 [17], multiplied by the monthly solar irradiance on each orientation and divided by the average yearly solar irradiance on the horizontal plane in a reference location (Roma).

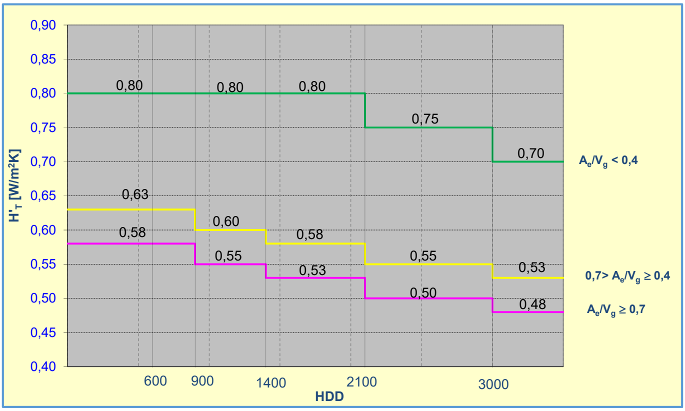


Fig. 1 Required maximum value of the transmission heat transfer global coefficient (H'_T).

The requirements based on the energy needs for heating and cooling, on the technical systems efficiencies and on the global energy performance are calculated through a *reference building*. According to the reference building approach, the requirement is the value of the performance parameter calculated for a building having the same location, building function, geometry and boundary conditions as the design building, but with parameters such as insulation level, technical systems efficiency, etc. replaced by reference values. As regards the building envelope, the U-values of the reference building envelope components depend on the heating degree days (HDD) of the location as shown in Table 1. Moreover, a total solar energy transmittance (g_{gl+sh}) of 0.35 is assumed for all the windows oriented to East, South and West.

Table 1. U-values of the reference building envelope components

	External walls	Roofs	Floors	Windows
HDD≤ 900	0.43	0.35	0.44	3.00
900<HDD≤ 1400	0.34	0.33	0.38	2.20
1400<HDD≤ 2100	0.29	0.26	0.29	1.80
2100<HDD≤ 3000	0.26	0.22	0.26	1.40
HDD>3000	0.24	0.20	0.24	1.10

As regards the renewable energy production, a minimum value of the Renewable Energy Ratio (RER) for DHW and for heating, cooling and DHW are specified (RER_W ≥50%, RER_{H+C+W} ≥50%). Besides, the minimum electrical power from renewable sources produced on-site per unit footprint of the building area is set to 20 W/m^2.

3. Case studies description

Six case studies are concerned in the analysis. They consist in the same residential building with a fixed geometry, located in three different Italian climatic zones and characterized by two thermal mass levels.

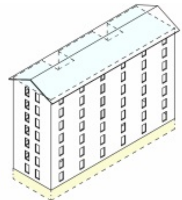
The building is an apartment block derived from the Italian "National Building Typology", as developed in the Intelligent Energy Europe TABULA project [18, 19]. According to TABULA, the geometry of this building type is considered representative of the Italian residential building stock for the same building size class (i.e. apartment block) and for the construction period after 2005 (new buildings). The conditioned spaces of the building include 31 dwellings, while the attic space, the cellar and the staircases are unconditioned areas.

The buildings are located in the following Italian cities: Catania (CT, 833 HDD), Roma (RM, 1415 HDD) and Milano (MI, 2404 HDD).

The main data of the case studies are shown in Table 2. The thermal transmittance of the building envelope components differs for the considered locations. The reference U-values for a nearly zero-energy building according to the Italian regulations [16] are reported in Table 1.

For each opaque envelope component, two thermal mass configurations, which correspond to a heavy building structure (M1) and to a light building construction (M2), are taken into account.

Table 2. Main data of the case studies

Picture of the building


Geometric data	
V_g [m^3]	8199
$A_{f,n}$ [m^2]	2125
A_e/V_g [m^{-1}]	0.40
A_w [m^2]	275
no. of floors	7
no. of dwellings	31

Building construction data				
Climatic zone		CT	RM	MI
External walls	U [W m^{-2}K^{-1}]	0.43	0.29	0.26
	$M1$ [kg m^{-2}]	464	465	465
	$M2$ [kg m^{-2}]	92	94	95
Upper floor	U [W m^{-2}K^{-1}]	0.35	0.26	0.22
	$M1$ [kg m^{-2}]	632	632	634
	$M2$ [kg m^{-2}]	181	182	183
Lower floor	U [W m^{-2}K^{-1}]	0.44	0.29	0.26
	$M1$ [kg m^{-2}]	562	563	563
	$M2$ [kg m^{-2}]	164	165	173
Windows	U [W m^{-2}K^{-1}]	3.00	1.80	1.40

4. Calculation method and results

The energy performance of the case studies is calculated by two different approaches: a quasi-steady state method and a dynamic simulation.

The quasi-steady state method, as specified in UNI/TS 11300 [14], is based on the EN ISO 13790 standard [17], determines the net 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. The dynamic effects on the net heating and cooling energy needs are considered through dynamic parameters, such as the utilization factors, that account for the mismatch between transmission /ventilation heat losses and solar/internal heat gains; and an adjustment of the set point temperature for intermittent heating/cooling or set-back.

The dynamic simulation is performed by means of *EnergyPlus* (version 8.1). *EnergyPlus* is a modular energy analysis program, developed by the research laboratories of the *U.S. Department of Energy* since 2001. The building thermal zone calculation of *EnergyPlus* is based on an air heat balance solution method and on the assumptions that the temperature of the air in the thermal zone and of each surface are uniform, the long and short-wave irradiation is uniform, the surface irradiation is diffusive and the heat conduction through the surface is one-dimensional. The geometrical model of the building is developed in *DesignBuilder* (version 4.2) which presents a simplified interface for *EnergyPlus* simulation.

Some consistency options are adopted to compare the energy needs obtained by the quasi-steady state and the dynamic models.

The simulations are run in three Italian locations, with different weather conditions: Catania, Roma and Milano. The full consistency between the hourly weather data of the locations, got from CTI (Italian Thermo-technical Committee), and the monthly values of the outdoor air temperature and solar radiation applied to the quasi-steady state calculation method is verified.

Internal heat gains are calculated in the simplified model with a constant value of 5.6 W/m^2, obtained as the mean value of the weekly profile used in the dynamic model. The same approach is followed for the ventilation flow rate, equal to an average value of 0.50 m^3/s.

In the simplified model the adjustment factors, $b_{tr,U}$, which allow to consider the transmission heat transfer between the conditioned space of dwellings and the external environments via unconditioned spaces, in accordance with EN ISO 13789 [20], are calculated by means of *EnergyPlus*.

The thermal transmittance of the opaque components includes the effect of thermal bridges. The areal internal heat capacity κ_i [kJ $m^{-2}K^{-1}$] is calculated by means of the admittance method, as specified in EN ISO 13786 [21]. The elements considered for the calculation of the building time constant τ [h] are the internal slabs and the building constructions in direct thermal contact with the thermal zone air, as specified in [17].

In the solar heat gains evaluation, the factor of time using shadings, weighted on the incident solar irradiation, is evaluated by *EnergyPlus* hourly simulation, for each exposure and for each locality, as the ratio of the sum of hourly irradiance values greater than 300 W/m^2 and the sum of all irradiance values for the whole month. No shading reduction factor for external obstacles is considered.

Two different heating operating schedules are considered: a continuous operation during the conditioning period, as specified by the Italian regulations, and an intermittent schedule related to user's presence and to the city considered. In both case, a heating set point of 20 °C is considered, while in the intermittent heating mode the set-back temperature is fixed at 16 °C. The cooling set point is 26 °C.

Figs. from 2 to 4 show the energy need for space heating and cooling for a continuous heating mode and for buildings characterized by the heavy building structure (M1), in Milano, Roma and Catania respectively. Table 3 presents the deviation of the annual energy use for space heating and cooling, between the quasi-steady state and the dynamic models.

The results show that the quasi-steady state method overestimates the energy need for heating and underestimates the energy need for cooling, regardless of the climatic conditions, occupants' schedule and building thermal inertia. The heating need overestimation increases when higher outdoor air temperature and solar radiation occur, that is typical for the Southern Italian towns: in Catania the quasi-steady state method over-estimates the yearly energy need for heating for more than 1100%. For the intermittent operation mode, the gap between the two models decreases.

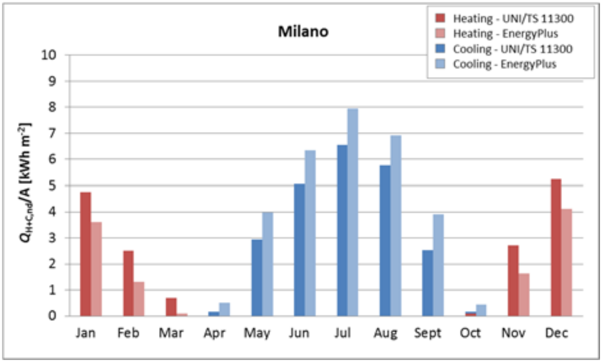


Fig. 2 Comparison between the quasi-steady state (UNI/TS 11300) and the dynamic (EnergyPlus) models for the energy use for space heating and cooling needs. City of Milano.

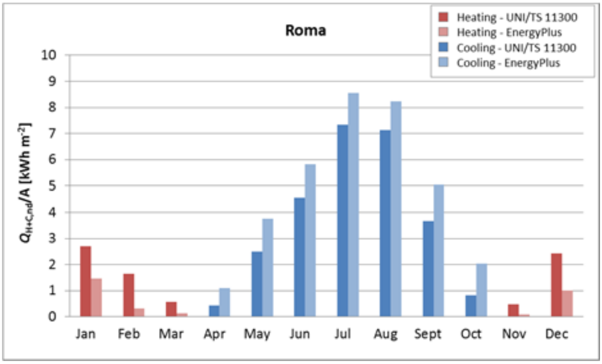


Fig. 3 Comparison between the quasi-steady state (UNI/TS 11300) and the dynamic (EnergyPlus) models for the energy use for space heating and cooling needs. City of Roma.

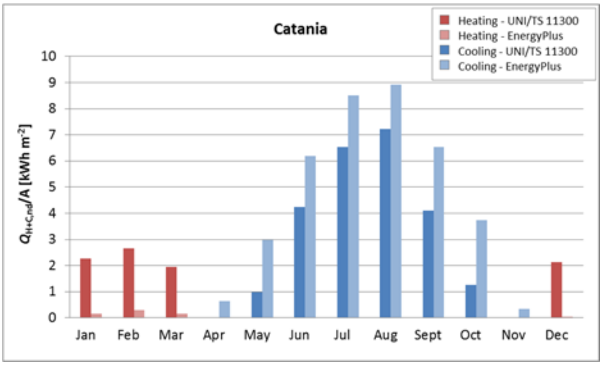


Fig. 4 Comparison between the quasi-steady state (UNI/TS 11300) and the dynamic (EnergyPlus) models for the energy use for space heating and cooling needs. City of Catania.

The lower building thermal mass associated to the heating intermittent operational schedule is the case that shows for all the three considered cities, the lowest deviations between the models. Again, the cooling need underestimation is higher for the Southern Italian cities, but the yearly deviation is lower than the heating service, in between -23% and -36%.

Table 3. Percentage deviation Δ of the annual energy use for space heating and cooling, between the quasi-steady state and the dynamic models.

Energy service	Operational schedule	Milano		Roma		Catania	
		τ [h]	Δ [%]	τ [h]	Δ [%]	τ [h]	Δ [%]
Heating	Continuous	59.5	49	55.5	160	41.3	1259
	Intermittent	59.5	37	55.5	115	41.3	724
	Continuous	42.7	57	39.7	165	29.6	753
	Intermittent	42.7	29	39.7	71	29.6	112
Cooling	Continuous	59.5	-23	55.4	-24	41.3	-36
	Continuous	42.7	-24	39.7	-24	29.6	-36

5. Conclusions

The main conclusion of this work regards the limits of the simplified methods based on quasi-steady state models to predict the energy needs of low-energy buildings accurately.

Regardless the application of consistency options, huge deviations appear in warm climates, especially in the heating demands. The quasi-steady state model considers purely convective contribution of the solar radiation and of the internal sources, neglecting the infrared radiation exchange. Another major cause of deviation is the heat exchange through the unconditioned spaces. It is necessary to introduce technical standards on building dynamic simulation, while the transition to nearly zero-energy buildings is in progress.

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References

[1] Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), OJEU, 18 June 2010.
[2] R. Anderson and D. Roberts. Maximizing Residential Energy Savings: Net Zero Energy Home Technology Pathways. National Renewable Energy Laboratory Technical Report NREL/TP-550-44547, November 2008.

[3] R. Kamel, N. Ekrami, P. Dash, A. Fung and G. Hailu. BIPV/T+ASHP: Technologies for NZEBs. Energy Procedia 78 (2015) 424–429.
[4] J. Castaing-Lasvignottes, M. David, F. Garde, F. Maillard, E. Ottenwelter, R. Garnier and P. Tranier. Modeling of a Compressed Air Energy Storage Connected to a PV Field for NZEB in Tropics. Energy Procedia 61 (2014) 1175–1178.
[5] RePublic_ZEB, IEE Project. Website: www.republiczeb.org.
[6] C. Micono and G. Zanzottera. Energy Modeling for NZEBs: a case-study. Energy Procedia 78 (2015) 2034– 2039.
[7] D. D'Agostino. Assessment of the progress towards the establishment of definitions of Nearly Zero Energy Buildings (nZEBs) in European Member States. Journal of Building Engineering 1 (2015) 20–32.
[8] S. Deng, R.Z. Wang and Y.J. Dai. How to evaluate performance of net zero energy building – A literature research. Energy 71 (2014) 1–16.
[9] A.J. Marszal, P. Heiselberg, J.S. Bourrelle, E. Musall, K. Voss, I. Sartori and A. Napolitano. Zero Energy Building–A review of definitions and calculation methodologies. Energy and Buildings 43 (4) (2011), 971–979.
[10] P. Torcellini, S. Pless, M. Deru and D. Crawley. Zero Energy Buildings: A Critical Look at the Definition. National Renewable Energy Laboratory Conference Paper NREL/CP-550-39833, US, June 2006.
[11] EU Commision. Directorate-general for energy. Mandate to CEN, CENELEC and ETSI for the elaboration and adoption of Standards fora methodology calculating the integrated energy Performance of buildings and promoting the energy efficiency of Buildings, in accordance with the terms set in the recast of the directive On the energy performance of buildings (2010/31/eu). M/480 EN, Brussels, 14th December 2010.
[12] M. Cellura, F. Guarino, S. Longo and M. Mistretta. Different energy balances for the redesign of nearly net zero energy buildings: an Italian case study. Renewable and Sustainable Energy Reviews 45 (2015) 100–112.
[13] V.M. Barthelmes, C. Becchio, S.P. Corgnati and C. Guala. Design and construction of an nZEB in Piedmont Region, North Italy. Energy Procedia 78 (2015) 1925–1930.
[14] UNI. UNI/TS 11300 (series), Energy performance of buildings, 2010-2014.
[15] International Organization for Standardization, "Energy performance of buildings - Overarching EPB assessment – Part 1: General framework and procedures", ISO/DIS 52000-1, 2016.
[16] Italian Republic. Decree of the Italian Ministry of Economic Development 26 June 2015 "Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici". Official Journal of the Italian Republic, 15 July 2015 (*in Italian*).
[17] CEN. EN ISO 13790:2008. Energy performance of buildings - Calculation of energy use for space heating and cooling, March 2008.
[18] T. Loga, N. Diefenbach, B. Stein (Eds.) et al. Typology Approach for Building Stock Energy Assessment. Main results of the TABULA project. Final Project Report. Institut Wohnen und Umwelt GmbH, Darmstadt, 2012.
[19] V. Corrado, I. Ballarini, S.P. Corgnati and N. Talà. Building Typology Brochure – Italy. Fascicolo sulla Tipologia Edilizia Italiana, Politecnico di Torino, Torino, 2011 (*in Italian*).
[20] CEN. EN ISO 13789:2008. Thermal performance of buildings - Trasmission and ventilation heat trasnfer coefficients – Calculation method, December 2007.
[21] CEN. EN ISO 13786:2007. Thermal performance of building components - Dynamic thermal characteristics - Calculation methods, December 2007.