Reference Building Approach Combined with Dynamic Simulation in Designing nZEBs

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Abstract

The building energy performance requirements in the regulations are usually expressed by means of a fixed value or a variable value defined through a formula or the *notional reference building* approach. The aim of the article is to enhance the application of the notional reference building approach in the energy performance legislation. To this purpose, a detailed dynamic simulation is performed on an Italian residential nZEB located in two different climatic zones. The paper highlights the need of more detailed specifications of the reference parameters in the notional reference building, especially when dynamic simulation is performed.

Introduction

Ways to verify the energy performance requirements of buildings

The Directive 2010/31/EU establishes that Member States define minimum energy performance requirements for building elements that have a significant impact on the energy performance with a view to achieving cost-optimal levels (European Union, 2010).

According to ISO 52003-1 (International Organisation for Standardisation, 2017), the requirements may be written as to modify (i.e. reduce, neutralize, correct or normalise) the impact of some parameters. For instance a requirement for an energy performance (*EP*) index may be expressed either (1) by a fixed value, or (2) by a variable value defined through a formula (or a table) as a function of some neutralising parameters (e.g. climate, building shape), or (3) by a variable value according to the *notional reference building* approach. In the last case, a reference *EP* is calculated for a building having the same location, building function, size etc. of the real building, but with parameters, such as thermal insulation level, heating system efficiency, activity schedules etc., replaced by reference values.

As highlighted by Pérez-Lombard et al. (2009) in a review of benchmarking and rating concepts, the threshold value obtained through the formula approach should be dependent upon the parameters whose impact is to be reduced or neutralized. The authors suggest that the limit value should be discriminated at least by building category, climate, building shape, energy source and ventilation rate. In fact, the energy performance of different building categories cannot be comparable since they provide different energy services. In addition, especially in areas characterized by considerable geographic variations, the requirements should also take into account the climatic spatial variability. About that, some authors propose an increasing of the *EP* limit with the increasing of climate severity (Sánchez de la Flor et al., 2006). Pérez-Lombard et al. (2009) suggest that a customised limit may be obtained by the self-reference (also called *notional reference building*) approach.

The EU countries gradually abandoned the fixed limit approach in their regulations in favour of a more flexible approach (Concerted Action EPBD, 2015).

For instance, the current building regulations of England require that the energy performance of new buildings, based on annual carbon dioxide emissions, must not exceed the *Target CO_2 Emission Rate* (TER), which is determined by means of the notional reference building. This building has the same size and shape as the actual building, but with specified properties, such as thermal transmittance and thermal capacity of the envelope components, air permeability of enclosures, parameters for lighting, technical building system efficiencies, etc. (HM Government, 2014a,b).

According to EnEV 2013 (German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, 2013), the notional building is characterised by pre-determined values of some building parameters. They include envelope air tightness, thermal transmittance of envelope components, total solar energy transmittance of glazing, characteristics of the shading devices, thermal bridges effect, solar absorption coefficient of the external opaque surfaces, building automation, features of reference technical building systems.

The Greek regulations (Greek Ministry of Environment, Energy and Climate Change, 2010) provide the parameters of the notional reference building in function of the climatic zone. They include the maximum *U*-value for walls, windows, roofs etc., the average *U*-value of the whole building, at least 50% heat recovery in the central air-conditioning units, minimum levels of insulation of heating and cooling distribution networks, at least 60% of DHW production from solar panels, minimum requirements for lighting and minimum efficiency for heating generators.

In Italy, according to the Ministerial Decree (MD) 26/06/2015 (Italian Ministry of Economic Development, 2015), the notional reference building, also named *reference building* or *target building*, is characterised by reference values of the following parameters: thermal transmittance of the envelope components, total solar energy transmittance of windows in presence of shading device, efficiency of the heat utilization and of the generation subsystems of space heating, space cooling and DHW systems, and features of lighting and ventilation systems.

The choice of the reference parameters varies from one country to another; for instance, a reference thermal

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transmittance is common to all countries, while just some States use the envelope air tightness as reference parameter (e.g. Germany and England) and only some impose specific technologies for the technical building systems (e.g. Greece). The threshold values of the parameters can be different and can vary in function of the climatic zone, the building category, etc. For example, the reference *U*-values of the Italian and Greek notional reference buildings are provided in function of the climatic zone, while in Germany and in England the *U*-values differ in function of the envelope component types (e.g. cavity wall *vs* solid wall, vertical window *vs* skylight). In the European Union, the reference parameter values have been identified by each Member State through the cost-optimality comparative methodology framework (European Union, 2010).

As regards technical standards, ANSI/ASHRAE/IES Standard 90.1 (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2010) provides minimum energy efficient requirements for design and construction, and a plan for operation and maintenance of new buildings or portions of buildings and their systems, new systems and equipment in existing buildings. The standard also provides criteria for determining compliance with these requirements by using a notional reference building, the so-called *baseline building*. The baseline building approach is used for calculating the baseline building performance for rating above-standard design. The design building performance and the baseline building performance shall be calculated using the same simulation program, weather data, energy price, building model, space use and schedules. The baseline building differs from the design building for the *U*-value of the envelope components, the amount of glazing and its thermal properties, the type of lighting control, the HVAC system requirements.

Objective of the work

Although the notional reference building approach is more flexible than the fixed value or the formula approach, some issues arise. They mainly concern: (1) the choice of the reference parameters of the notional reference building, and (2) the detail level used for its description. This last issue is strictly related to the adopted *EP* calculation model. Both issues are fully addressed in the Section "Theory and method".

The present article investigates the above aspects, aiming at enhancing the application of the notional reference building approach in the regulations and suggesting an effective procedure for its specification. The study is performed on a reference residential nearly zero-energy building (nZEB) located in Milan and Palermo, representative of different climatic zones.

In a previous work of the authors (Corrado et al., 2016), a preliminary analysis was conducted through the application of the standard quasi-steady-state calculation method, highlighting the limits of the notional reference building approach in the national legislation. In the present work, the analysis of the reference building is combined with a detailed dynamic simulation carried out using *EnergyPlus*.

Firstly, a sensitivity analysis of some thermal parameters, concerning both the thermal envelope and the technical building systems, is carried out. The aim is to verify to which extent these parameters, which are specified as reference features of the notional reference building by the MD 26/06/2015, influence the building energy performance and can be really considered as reference.

Secondly, the features of the building are described with different levels of detail; the final aim is to check whether the simplified reference parameters adopted in the legislation provide sufficient information to correctly determine the *EP* of the notional reference building even when a detailed dynamic simulation tool is used. The deviations in the results are pointed out and guidelines to give accuracy to the notional reference building approach are provided, as to improve its capability to handle different solutions with different degrees of complexity.

Theory and method

Notional reference building definition

The use of the notional reference building approach is finalised to verify the *EP* requirements of a given building, either under design or subject to renovation. According to this approach, the estimated energy use for the building is compared with the estimated energy use of a virtual building, usually named *notional reference* or *baseline building*. The notional reference building has some features as the actual building and other features characterised by predetermined parameters (reference values). If the estimated energy consumption of the given building is not higher than the estimated energy consumption of the notional reference building, the building requirements are met.

The use of the notional reference building approach is intended to reduce or neutralise the impact of some parameters on the compliance with the building energy performance requirements. In fact, the building parameters whose values are not replaced by reference values are excluded from the requirements: the effects of these parameters are neutralised. These parameters are usually known as *neutralising parameters*.

The neutralisation is aimed at, either:

- cancelling the effect of the boundary conditions, as the driving forces of the building thermal behaviour (i.e. boundary factors), or
- promoting or penalising specific design choices (i.e. technical features).

The boundary factors include climatic data and building use data (e.g. indoor air temperature, ventilation rate, occupancy profile). The technical features of the building include, for instance, the building type (e.g. shape, dimensions) and the energy carrier.

The modification of the impact of certain parameters is necessary to avoid excessive imbalances between the technologies used and consequent market disturbances. The technological level is adapted to climate, type of use, etc. as to achieve the technical and economic optimisation of the building.

According to van Dijk and Spiekman (2004), the parameters are neutralised either intentionally or unconsciously. In the former case, the reasons of neutralisation are political or practical. An example of political reason is the neutralisation of the building size: if the size is not neutralised, the construction of smaller buildings might be discouraged. Other reasons for intentional neutralisation are either the small influence of certain parameters on the building energy performance or too complex effects to be taken into account (e.g. the effects of various control systems). The unconscious neutralisation includes cases in which the energy implications are not known.

Procedure for specifying the notional reference building

A structured methodology for specifying the notional reference building is suggested, as shown in Figure 1. The procedure follows four main steps:

1. *Choice of the calculation method.* First, the calculation method of the building energy performance is chosen. The choice is influenced by the building typology and by the boundary conditions (including building use and climate), in function of data availability, complexity level of the building, patterns of use, etc. In some cases, the type of calculation method is decided by the regulatory framework.
2. *Distinction between reference and actual features.* The calculation method requires as inputs the building characteristics (geometry, thermo-physical properties, technical building systems features) and the boundary data (use, climate). According to the notional reference building approach, these inputs can be either reference features (i.e. described by predetermined parameters) or actual features (i.e. the same as the real building).

   The appropriateness of setting a feature either as reference or actual firstly depends upon its effect on the building *EP*. In fact, if the influence of a certain building or boundary feature on the *EP* is negligible, setting it as a reference is meaningless. A sensitivity analysis is carried out to detect the most important features.

   The distinction between reference and actual features is also driven by political choices. The actual features are directly described by means of neutralising parameters.
3. *Specification of the level of detail and simplifying assumptions*. The number of parameters describing the features generally depends on the complexity of the technological systems and is higher for advanced envelopes and technical building systems. It is necessary to define the level of detail to describe the reference features of the building. For instance, the wall properties can be simply described through a lumped parameter (e.g. the *U*-value) or in a detailed way, specifying the properties of the layers of the wall. The level of detail should be consistent with the calculation method and with the complexity of the building technology. A higher number of parameters is usually required by detailed calculation models, while lumped parameters are used in simplified methods.
4. *Setting of the reference parameters values.* Finally, a value should be established for each reference parameter, taking into account specific aspects, as for instance technical feasibility and economic viability.

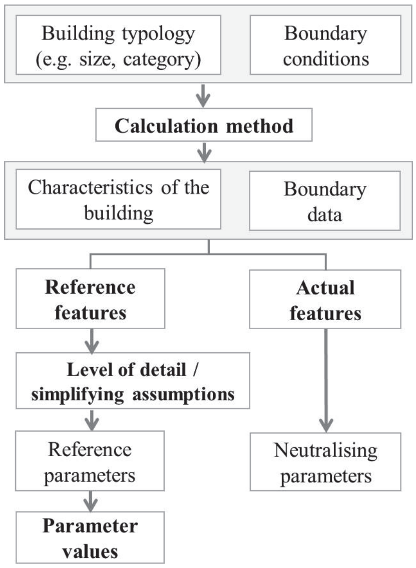

Figure 1: Flowchart of the proposed procedure for specifying the notional reference building

Improving the notional reference building approach

The article provides an application of the above described methodology aimed at improving the notional reference building approach as used in the legislation on the energy performance of buildings, with specific focus on the Italian regulations.

The four steps of the methodology are applied as follows:

1. *Choice of the calculation method.* The dynamic numerical simulation is a way to enhance the modelling of the notional reference building. Compared with the quasi-steady-state method specified by the national regulations, a dynamic model better mirrors the real thermal behaviour of the building for the following main reasons:
   - it takes into account the high time variability of the thermal driving forces that can determine relevant thermal storage effects and overlap between opposite effects (e.g. heat gains vs. heat transfer, power demand vs. power on-site production),

- it considers systems described by non-linear models (e.g. thermal plants, passive solar systems, advanced thermal control systems).

The dynamic numerical simulation is also an effective instrument to carry out sensitivity analyses by means of different procedures and methodologies, as performed for instance by Ballarini and Corrado (2011).

Anyway, the dynamic simulation can hardly be fit to a standard calculation, unless it includes many simplifications; this represents a disadvantage for its application in the notional reference building approach.

2. *Distinction between reference and actual features*. As a starting point, a sensitivity analysis should be carried out on the reference parameters already defined in the current legislation (i.e. *U*-value of the envelope components, g_{gl+sh} value of the windows, efficiency of the generators).
3. *Specification of the level of detail and simplifying assumptions*. The default description of the reference building features should be based on a high level of detail as required by the dynamic simulation tool. If the national legislation provides lumped reference parameters, different technical solutions complying with the simplified reference parameter value set by the national regulation should be analysed and compared.
4. *Setting of the reference parameters values.* The parameters values should be derived from cost-effective analyses. The parameters values used in this paper are those fixed by the Italian regulations.

Notional reference building case study

Description of the base case

The case study is a two-storey single-family house, located in two different cities, Milan (2404 HDD) and Palermo (751 HDD). The two locations belong to the climatic zones with the highest number of inhabitants, respectively dominated by the heating and by the cooling season. The view of the building is shown in Figure 2. The main geometric data are reported in Table 1.

Figure 2: View of the building.

Table 1: Geometric data of the case study

Symbol	Unit	Value
$A_{f,net}$	m^2	158
V_g	m^3	646
V_{net}	m^3	458
A_{env}/V_g	m^{-1}	0.74
A_w	m^2	25.3
$A_w/A_{f,net}$	-	0.16
A_w/A_{env}	-	0.054

The reference parameters values for the building envelope of the notional reference building are provided by the MD 26/06/2015 and listed in Table 2. They correspond to the requirements of a nZEB. The *U*-values are defined in function of the climatic zone (heating degree-days).

Table 2: Parameters of the building envelope of the notional reference nZEB (MD 26/06/2015). Base case

Parameter	Unit	Climatic zone from 2101 to 3000 HDD (Milan)	Climatic zone up to 900 HDD (Palermo)
U_{wl}	W·m^{-2}K^{-1}	0.26	0.43
U_r	W·m^{-2}K^{-1}	0.22	0.35
$U_{fl,up,un}$	W·m^{-2}K^{-1}	0.31*	0.50*
$U_{wl,un}$	W·m^{-2}K^{-1}	0.43*	0.72*
$U_{fl,gr}$	W·m^{-2}K^{-1}	0.26**	0.44**
U_w	W·m^{-2}K^{-1}	1.40	3.00
g_{gl+sh}	-	0.35***	

* attached to an unconditioned space
** equivalent thermal transmittance (ISO 13370)
*** shading devices not installed on the north windows

The heating and cooling systems are composed of a generator, a circulation pump, the heating/cooling emitters and a temperature control system in each thermal zone. Two configurations of generator are investigated: (1) a biomass boiler for space heating and a split air conditioner system for space cooling, (2) a reversible air-to-water heat pump for space heating and space cooling. The emitters are radiators in case of biomass boiler and fan coils in case of heat pump. The components of the considered technical building systems are representative of the most widespread technologies available on the market.

The design parameters of the technical building systems (i.e. heating and cooling capacity, water temperature, etc.) are determined by calculating the heating and the cooling loads in design conditions. The inlet water design temperature is 70 °C for radiators and 55 °C for fan coils. The thermal flow supplied by the fan coil unit is controlled by varying the water flow rate in the coils. The circulation pump has a variable speed control and operates intermittently; so when there is no load on the loop the pump is stuck. The set-point air temperature is 20 °C for space heating and 26 °C for space cooling.

The MD 26/06/2015 requires that both the typology and the features of the technical building systems components are the same as those of the real building; however, reference mean seasonal efficiencies are given for the emission *plus* distribution subsystems and for the generation subsystem, which are listed in Table 3.

Table 3: Reference parameters of the generation subsystems (MD 26/06/2015). Base case

Parameter	Unit	Energy service	
		Heating	Cooling
η_{gn} (biomass boiler)	-	0.72	-
COP (heat pump)	-	3.00	-
EER (split system/heat pump)	-	-	2.50

The technical building systems are modelled according to DOE2 specifications based on manufactures extended ratings data for each component.

As concerns the modelling of the non-generation components of the systems, the MD 26/06/2015 reference seasonal efficiency is disregarded, due to the impossibility of the simulation model to properly fit this numerical value. The distribution pipes are assumed adiabatic. The radiator model takes into account the convective and radiant heat transfer from the device to the zone.

For each generator, the nominal efficiency value is set as to verify the mean seasonal efficiency of the MD 26/06/2015 (Table 3).

For the biomass boiler, the following main parameters are required: nominal power, nominal efficiency and flow temperatures. The performance curve, which is a bi-cubic function, uses, as input data, the load factor and the temperature in the water inlet into the boiler.

The main input parameters for the split system are the *EER* and the nominal power. The hourly power can be determined by means of two performance curves. The first one requests, as input, the wet-bulb temperature of the air entering in the cooling coil and the dry-bulb temperature of the air entering in the air-cooled condenser coil. The other curve requires the ratio of the actual air flow rate across the cooling coil to the rated air flow rate.

The air-to-water heat pump for the heating season is described with heating nominal power, nominal *COP* at reference inlet temperatures of air and water of the evaporator and the condenser respectively. The *COP* at each time step is determined taking into account the partial load ratio (PLR) and the inlet temperatures of evaporator and condenser. Concerning the heat pump cooling operation, the nominal power, the nominal *EER* at the outlet chilled water temperature and at the inlet condenser fluid temperature are needed.

Sensitivity analysis of the reference parameters

The whole analysis is performed through *EnergyPlus v8.3*.

The same neutralising parameters as established by the current Italian legislation (i.e. building geometry, use, location, types of technical building systems) are assumed in this study, because they derive from a political choice.

The sensitivity analysis of the reference parameters is based on the variation of the thermo-physical properties of the building envelope and of the technical building systems. The sampling method considers the technically achievable solutions available on the market, ranging from basic solutions widespread in existing buildings to the most advanced technologies.

The sensitivity analysis is carried out on the *U*-value of the envelope components, the g_{gl+sh} value of the windows and the efficiency of the generators.

A total number of 30 simulations is carried out.

The sensitivity analysis of the thermal transmittance consists in assuming, for each envelope component, a higher and a lower *U*-value compared to the actual reference value reported in Table 2. More specifically, for each component and location, the thermal transmittance reference values established by the MD 26/06/2015 for the two closest climatic zones are tested. In Palermo, as a closer climatic zone with a higher *U*-value does not exist, it is applied the same percentage increase as it occurs between the closest climatic zone with lower *U*-value and the *U*-value of the actual climatic zone. The analysed cases are listed in Table 4. The case ID no. *00* concerns the base case (Table 2).

A second sensitivity analysis concerns the total solar energy transmittance of glazing with a shading device. It consists in testing different g_{gl+sh} values got by considering various features of glazing and shading device as reported in Table 5. For each location, all variants allow the requirement on thermal transmittance value of windows to be met (see Table 2).

As regards the generation subsystem, the sensitivity analysis takes into account three levels of the nominal efficiency value of biomass boiler, split system and heat pump, as reported in Table 6. The upper and the lower nominal values are set with respect to the nominal value of the base case, as follows:

- ±2% variation of the efficiency of the biomass boiler,
- ±0.5 variation of the coefficient of performance (*COP*) of the heat pump in heating mode,
- ±0.5 variation of the energy efficiency ratio (*EER*) of the split system and the heat pump in cooling mode.

Table 4: Sensitivity analysis of the envelope components thermal transmittance. Case studies

ID case study	**Description**	***U* [W·m^{-2}K^{-1}]**				
		U_{wl}	U_r	$U_{fl,up,un}$	$U_{wl,un}$	U_w
MI-00	Milan – base case (Table 2)	0.26	0.22	0.31	0.43	1.40
MI-SA-TT-01	Milan – higher *U*-value	0.29	0.26	0.37	0.48	1.80
MI-SA-TT-02	Milan – lower *U*-value	0.24	0.20	0.29	0.40	1.10
PA-00	Palermo – base case (Table 2)	0.43	0.35	0.50	0.72	3.00
PA-SA-TT-01	Palermo – higher *U*-value	0.52	0.37	0.53	0.87	3.80
PA-SA-TT-02	Palermo – lower *U*-value	0.34	0.33	0.47	0.57	2.20

Table 5: Sensitivity analysis of the total solar energy transmittance of glazing with shading device. Case studies

ID case study	**Description**	g_{gl+sh} **[-]**	$g_{gl,n}$ **[-]**	$\tau_{sol,sh}$ **[-]**	$\rho_{sol,sh}$ **[-]**	**Shading device position**
MI-00	Milan – base case (Table 2)	0.35	0.67	0.15	0.70	internal
MI-SA-TST-01	Milan – lower g_{gl+sh} value	0.09	0.67	0.10	0.70	external
MI-SA-TST-02	Milan – higher g_{gl+sh} value	0.67	0.67	no shading device		
PA-00	Palermo – base case (Table 2)	0.35	0.75	0.15	0.70	internal
PA-SA-TST-01	Palermo – lower g_{gl+sh} value	0.05	0.75	0.00	0.70	external
PA-SA-TST-02	Palermo – higher g_{gl+sh} value	0.75	0.75	no shading device		

Table 6: Sensitivity analysis of the generator efficiency. Case studies

ID case study	**Description**	***Biomass boiler***	***Split system***
		η	***EER***
MI-00-BS	Milan – base case	0.73	2.59
MI-SA-BS-01	Milan – higher efficiency	0.75	3.09
MI-SA-BS-02	Milan – lower efficiency	0.71	2.09
PA-00-BS	Palermo – base case	0.80	2.81
PA-SA-BS-01	Palermo – higher efficiency	0.822	3.31
PA-SA-BS-02	Palermo – lower efficiency	0.78	2.31

ID case study	**Description**	***Heat pump***	
		COP	***EER***
MI-00-HP	Milan – base case	3.63	3.25
MI-SA-HP-01	Milan – higher efficiency	4.13	3.83
MI-SA-HP-02	Milan – lower efficiency	3.13	2.185
PA-00-HP	Palermo – base case	2.93	3.43
PA-SA-HP-01	Palermo – higher efficiency	3.43	3.93
PA-SA-HP-02	Palermo – lower efficiency	2.43	2.93

Table 7: Envelope components configurations with fixed thermal transmittance. Case studies

ID case study	**Description**	**Envelope component**	***U* [W·m^{-2}K^{-1}]**	Y_{ie} **[W·m^{-2}K^{-1}]**	m_s **[kg·m^{-2}]**	κ_i **[kJ·m^{-2}K^{-1}]**
MI-00	Milan - base case External insulation Heavy thermal mass	wall (EXT)	*0.26*	0.044	260	49.5
		roof (EXT)	*0.22*	0.049	249	63.5
		upper floor (UNC)	*0.31*	0.040	335	62.1
		wall (UNC)	*0.43*	0.084	258	50.1
MI-DE-TT-01	Milan Internal insulation Heavy thermal mass	wall (EXT)	*0.26*	0.057	260	24.5
		roof (EXT)	*0.22*	0.071	249	25.8
		upper floor (UNC)	*0.31*	0.031	335	24.2
		wall (UNC)	*0.43*	0.108	258	25.1
MI-DE-TT-02	Milan Internal insulation Light thermal mass	wall (EXT)	*0.26*	0.094	153	14.0
		roof (EXT)	*0.22*	0.071	249	25.8
		upper floor (UNC)	*0.31*	0.031	335	24.2
		wall (UNC)	*0.43*	0.178	152	16.6
PA-00	Palermo - base case External insulation Heavy thermal mass	wall (EXT)	*0.43*	0.085	257	50.1
		roof (EXT)	*0.35*	0.085	247	64.0
		upper floor (UNC)	*0.50*	0.076	333	62.4
		wall (UNC)	*0.72*	0.248	217	52.9
PA-DE-TT-01	Palermo Internal insulation Heavy thermal mas	wall (EXT)	*0.43*	0.109	257	24.8
		roof (EXT)	*0.35*	0.123	247	25.7
		upper floor (UNC)	*0.50*	0.058	333	25.1
		wall (UNC)	*0.72*	0.305	217	29.8
PA-DE-TT-02	Palermo Internal insulation Light thermal mas	wall (EXT)	*0.43*	0.177	152	16.6
		roof (EXT)	*0.35*	0.123	247	25.7
		upper floor (UNC)	*0.50*	0.058	333	25.1
		wall (UNC)	*0.72*	0.462	127	23.2

Table 8: Configurations of glazing and shading device with fixed total solar energy transmittance. Case studies

ID case study	Description	g_{gl+sh} [-]	$g_{gl,n}$ [-]	$\tau_{sol,sh}$ [-]	$\rho_{sol,sh}$ [-]	Shading device position
MI-00	Milan - base case Low-e double glazing, white and medium translucent shading device	0.35	0.67	0.15	0.70	internal
MI-DE-TST-01	Milan Low-e double glazing, dark and high translucent shading device	0.35	0.67	0.45	0.25	external
MI-DE-TST-02	Milan Low-e triple glazing, pastel and semi-opaque shading device	0.35	0.46	0.10	0.50	internal
PA-00	Palermo - base case Uncoated double glazing, white and medium translucent shading device	0.35	0.75	0.15	0.70	internal
PA-DE-TST-01	Palermo Uncoated double glazing, black and translucent shading device	0.35	0.75	0.30	0.05	external
PA-DE-TST-02	Palermo Low-e double glazing, white and medium translucent shading device	0.35	0.67	0.15	0.70	internal

Level of detail of the reference features

The detailed dynamic numerical simulation method requires a high level of detail in the description of the notional reference building features. For example, the building envelope components are described by the thermal properties of single layers. In such a way, various technical solutions for each envelope component can lead to the same thermal transmittance value as established by the national decree (see Table 2).

As shown in Table 7, three different envelope configurations are tested for each location, taking into account a different position of the thermal insulation layer and a different thermal mass. It can be noted that a specific envelope component may have different dynamic thermal characteristics while achieving the same thermal transmittance value.

The MD 26/06/2015 provides all climatic zones with a unique reference value of the total solar energy transmittance of glazing with shading device (see Table 2). As for the thermal transmittance, different technical solutions using different types of glazing and shading devices would allow to achieve the same reference value of g_{gl+sh}. The configurations listed in Table 8 are tested for the notional reference building.

As regards the modelling of the generation subsystem, a very detailed description of the system based on the aforementioned parameters (see Section "Description of the base case") would be required. Anyway, this aspect is not considered in the present study. In a future research, different real performance curves will be compared and simulated.

Results and discussion

Energy performance of the notional reference building

The Italian MD 26/06/2015 requires to calculate the *EP* of the notional reference building by means of the UNI/TS 11300 series, which specifies a quasi-steady-state calculation method based on EN ISO 13790 and EN 15316 series. In Figure 3, a comparison between the results of the quasi-steady-state method and the detailed dynamic simulation (*EnergyPlus*) are shown for Milan and Palermo. The *EP* is expressed in terms of net energy need for space heating and space cooling normalised on the conditioned net floor area of the notional reference building object of study.

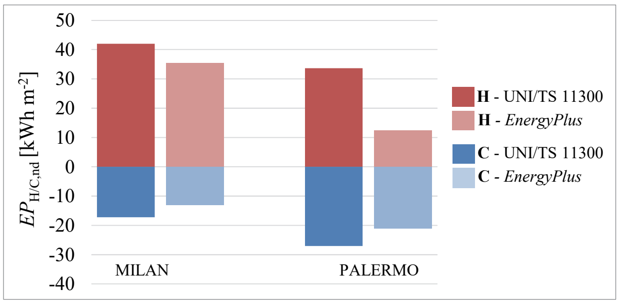

Figure 3: Comparison between UNI/TS 11300 and EnergyPlus.

As pointed out by Corrado et al. (2016), the quasi-steady state method overestimates the energy need both for heating and for cooling. The overestimation of space heating energy need significantly increases in Palermo, where higher outdoor air temperature and higher solar radiation occur. In addition, some critical points were identified, specifically concerning the effect of thermal bridges and of the technical building system auxiliaries in the reference building approach. The results reveal the limits of the simplified method in predicting the energy needs of low-energy buildings, as introduced in the Section "Theory and method".

Therefore in the present work, a detailed dynamic simulation is chosen as reference calculation method to investigate the notional reference building approach.

Results of the sensitivity analysis

The results of the sensitivity analysis are reported in Figures 4-6. In Figure 4, the percentage variation of the *EP* in terms of annual net energy need for space heating and space cooling normalised on the building net floor area is plotted versus the percentage variation of the average *U*-value of the building envelope (U_{avg}), which is expressed through Equation (1):

$$U_{avg} = \sum_{k=1}^{n} b_k \cdot U_k \cdot A_k \Big/ \sum_{k=1}^{n} A_k \qquad (1)$$

where, the sum includes all the building envelope components, b_k is the adjustment factor for heat transfer coefficient, A_k is the area of building envelope component *k* and U_k is its thermal transmittance.

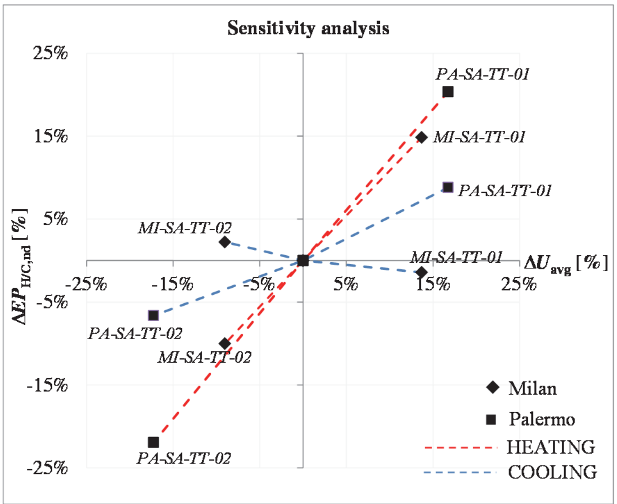

Figure 4: Sensitivity analysis of the thermal transmittance. Results for Milan and Palermo.

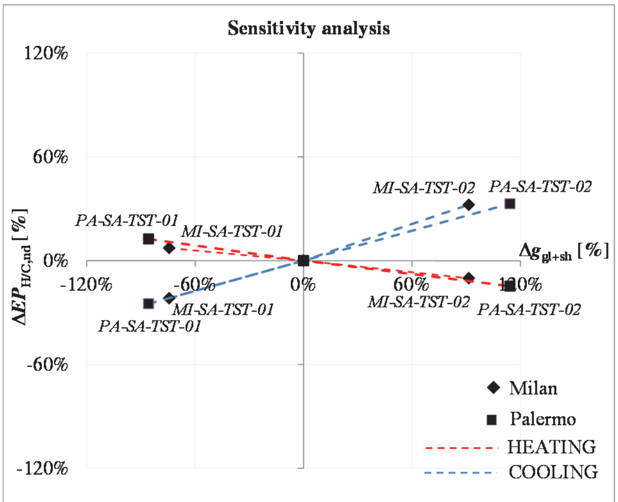

Figure 5: Sensitivity analysis of the total solar energy transmittance. Results for Milan and Palermo.

Considering a variation of –9÷+14% of U_{avg} (see Figure 4), the net energy need for space heating is more sensitive (−10÷+15%) than the net energy need for space cooling (below ±2%) for the building located in Milan. In Palermo, a variation of about ±17% of U_{avg} determines a deviation of about −22÷+20% of the net energy need for space heating and of about −7÷+9% of the net energy need for space cooling.

On the contrary, the total solar energy transmittance (Figure 5) affects more the energy need for space cooling (−22÷+32% in Milan and −25÷+33% in Palermo) than for space heating (−10÷7% in Milan and −15÷+13% in Palermo). The influence of the g_{gl+sh} value on the building *EP* is however lower than the influence of the *U*-value.

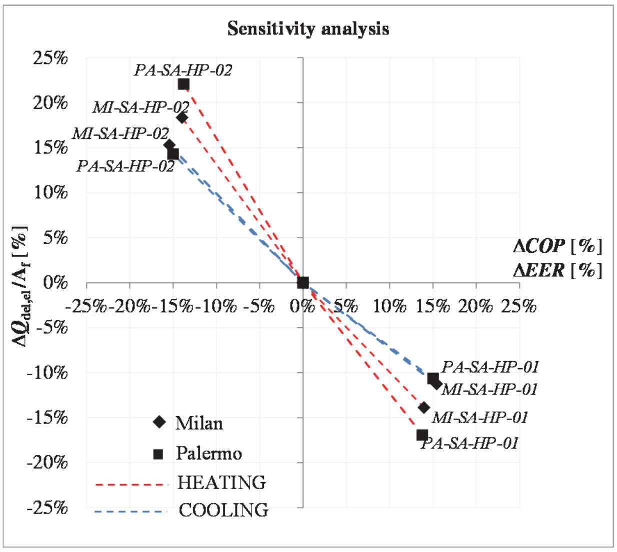

Figure 6: Sensitivity analysis of the generator efficiency. Heat pump.

Table 9: Sensitivity analysis of the generator efficiency. Biomass boiler and split system.

ID case study	$\Delta\eta$ [%]	$\Delta Q_{del,bio}$ [%]	Δ*EER* [%]	$\Delta Q_{del,el}$ [%]
MI-00-BS	-	-	-	-
MI-SA-BS-01	3%	-3%	19%	-15%
MI-SA-BS-02	-3%	2%	-19%	22%
PA-00-BS	-	-	-	-
PA-SA-BS-01	2%	-1%	18%	-15%
PA-SA-BS-02	-2%	3%	-18%	22%

The sensitivity analysis of the generator efficiency (Figure 6 and Table 9) highlights the high influence of the *COP* on the delivered energy both in Milan and in Palermo. As regards the *EER* effect, there is not an appreciable difference between Milan and Palermo.

The analysed parameters of both building envelope and thermal systems prove to affect the building *EP* with considerable extent. Thus the related building features can be really considered as reference for characterising the notional reference building.

Results of the building features description

The analysed envelope configurations, which are characterised by the same thermal transmittance value and different thermal dynamic parameters, determine a variation of the *EP* as shown in Table 10.

In Milan, while the deviation in the annual net energy need for space heating is negligible, the space cooling presents an increment of about 12% in both configurations with the thermal insulation layer on the internal side. In Palermo, the variation of the energy need for space cooling is very high (about 45%) in both configurations.

The results of the analysed configurations of glazing and shading device, which determine the same g_{gl+sh} value, are shown in Table 11. For the building in Milan, the *EP* is strongly affected by the type of glazing and by the shading device features. Specifically in this case, the variation of the total solar energy transmittance of glazing affects the *EP* more than the position of the shading device.

Table 10: Results of the envelope components configurations

ID case study	$EP_{H,nd}$ [kWh·m^{-2}]	$\Delta EP_{H,nd}/EP_{H,nd,base\ case}$	$EP_{C,nd}$ [kWh·m^{-2}]	$\Delta EP_{C,nd}/EP_{C,nd,base\ case}$
MI-00	31.74	-	12.77	-
MI-DE-TT-01	31.54	–0.63%	14.39	12.7%
MI-DE-TT-02	31.92	0.57%	14.34	12.3%
PA-00	13.86	-	14.65	-
PA-DE-TT-01	12.15	–12.3%	21.29	45.3%
PA-DE-TT-02	12.32	–11.1%	21.02	43.4%

Table 11: Results of the configurations of glazing and shading device

ID case study	$EP_{H,nd}$ [kWh·m^{-2}]	$\Delta EP_{H,nd}/EP_{H,nd,base\ case}$	$EP_{C,nd}$ [kWh·m^{-2}]	$\Delta EP_{C,nd}/EP_{C,nd,base\ case}$
MI-00	31.74	-	12.77	-
MI-DE-TST-01	31.28	–1.46%	13.55	6.17%
MI-DE-TST-02	33.87	6.71%	9.46	–25.9%
PA-00	13.86	-	14.65	-
PA-DE-TST-01	14.02	1.17%	13.87	–5.37%
PA-DE-TST-02	13.51	–2.49%	14.65	0.01%

The results of the building features description highlight that significant deviations in the building *EP* may occur if an insufficient number of parameters is assumed for the reference building when using a dynamic simulation method. This aspect implies that the legislation should provide more detailed information to characterise the notional reference building.

With reference to the analysed case studies and building features, suggestions for improving the notional reference building approach are provided as follows.

- Besides a lumped thermal transmittance value, one or more thermal dynamic features of the envelope components should be provided, either adopting neutralising parameters (e.g. the areal heat capacity of the notional building is the same of the building under design), or fixing reference values.
- The total solar energy transmittance of glazing with shading device should be complemented with other parameters, as for instance the position of the shading device and the g_{gl} value. The former might be fixed as external, the latter might be considered a neutralising parameter.

Conclusion

The present article is aimed at enhancing the application of the notional reference building approach in the legislation on the energy performance of buildings.

The analysis, performed on an Italian single-family nZEB in two different climatic zones, demonstrates that the reference parameters established by the national regulations are correctly chosen, as they significantly influence the building *EP*. Anyway, the level of detail used to describe the notional reference building by the Italian legislation, even if suitable for a quasi-steady-state numerical method, is not sufficient to fully characterise the building by means of a dynamic simulation tool. A more detailed information about the thermal envelope and the technical building systems would be necessary.

An improved procedure for specifying a notional reference building is addressed in the article and consists of four main steps: (1) choice of the calculation method of the building *EP*, (2) distinction between reference and actual features, (3) specification of the level of detail and simplifying assumptions of the reference parameters, (4) setting of the reference parameters values.

The realm of validity of the results is affected by the choice of the case study, as regards its geometry and its use category. A future research is going to enlarge the analysis by investigating more building features and their level of detail. Open issues will be addressed, such as how to take into account the thermal bridges effect in the notional reference building and more specific features related to the technical building systems (e.g. system auxiliaries).

Moreover, future analysis will concern the comparison between dynamic simulation and quasi-steady state calculation methods in the notional reference building approach. Final aim is to investigate to which extent the choice of the calculation method can influence the compliance of the design building with the *EP* requirements.

Nomenclature

Symbol	Quantity	Unit
A	area	m^2
b	adjustment factor for heat transfer coefficient	-
COP	coefficient of performance	-
EER	energy efficiency ratio	-
EP	energy performance	kWh·m^{-2}

g	total solar energy transmittance	-
HDD	heating degree-days	°Cd
m_s	areal mass	kg·m^{-2}
Q	thermal energy	Wh
U	thermal transmittance	W·m^{-2}K^{-1}
U_{avg}	average *U*-value	W·m^{-2}K^{-1}
V	volume	m^3
Y_{ie}	periodic thermal transmittance	W·m^{-2}K^{-1}
Greek symbols		
η	efficiency (system)	-
κ	areal heat capacity	J·m^{-2}K^{-1}
ρ	reflection coefficient	-
τ	transmission coefficient	-
Subscripts		
bio	biomass boiler	
C	space cooling	
del	delivered (energy)	
el	electricity	
env	building envelope	
f, fl	floor	
g	gross	
gl	glazing	
gn	generation (system)	
gr	ground	
H	space heating	
i	internal	
n	normal	
nd	need (energy)	
net	net	
r	roof	
sh	shading	
sol	solar	
T	thermal transmission	
un	unconditioned (space)	
up	upper	
w	window	
wl	wall	
Acronyms and abbreviations		
BS	biomass boiler+split system	
DE	description	
DHW	domestic hot water	
EXT	outdoor (facing)	
HP	heat pump	
HVAC	heating, ventilation, air conditioning	
MD	Ministerial Decree	
MI	Milan	
nZEB	nearly zero-energy building	
PA	Palermo	
SA	sensitivity analysis	
TST	total solar transmittance	
TT	thermal transmittance	
UNC	unconditioned space (facing)	

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