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ON THE LIMITS OF THE QUASI-STEADY-STATE METHOD TO PREDICT THE ENERGY PERFORMANCE OF LOW-ENERGY BUILDINGS

by

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The recent European energy policies progressively introduced more restrictive energy performance requirements aimed at achieving the nearly zero-energy building target for all new buildings and major renovations. To check compliance with these requirements, the building energy performance can be evaluated through different calculation methods, as widely presented in literature. The present article is aimed at identifying in which boundary conditions (e. g. climate, use category, building size, thermal insulation level) a simplified steady-state calculation method can predict with sufficient accuracy the energy performance of low-energy buildings if compared with a dynamic simulation model. The analysis was performed on two building types, representative of the Italian residential typology, located in three different climatic zones and characterised by two insulation levels. The insulation levels fit the U-values of the notional reference building, established by the Italian legislation for checking compliance with energy performance requirements in two different steps; the first level is in force until 2020, while the second level is that of a reference nearly zero-energy building in force from 2021 onwards. The building energy performance, in terms of net energy needs for space heating and space cooling, was assessed by means of both the monthly calculation method of CEN standards and the detailed simulation model of EnergyPlus. Consistency options were applied to the models to guarantee that their outputs could be comparable. The quasi-steady-state method demonstrated to predict the cooling energy need quite well, but to lose in accuracy when the weight of the thermal transfer in the energy balance increases.

Key words: *building energy performance, quasi-steady-state calculation method, dynamic simulation, Italian building stock, building typology, nearly zero-energy building, energy performance requirements*

Introduction

Context and aim of the work

The building energy performance (EP) modelling is a topic still deeply investigated by the scientific community. According to a review of Borgstein *et al.* [1], the available methods for assessing the building EP can be classified in: engineering calculations (*e. g.* methods established by international standards), simulation (*e. g.* detailed dynamic simulation tools), statistical methods (*e. g.* regression models), machine learning (*e. g.* neural networks,

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clustering analysis) and other methods (*e. g.* energy audits). Calculation methods of the building EP are widely used in the regulatory framework either to check compliance with the EP requirements or to carry out an EP certification of buildings. In this context and for these scopes, the types of calculation methods fall under the classes of engineering calculations and simulations. EN ISO 13790 [2] categorises these methods in monthly quasi-steady-state, simple hourly and detailed dynamic.

With the aim to verify the EP requirements for new buildings or major renovations, a simplified model is generally preferred to a dynamic simulation tool, for its capability to be easily understood and manageable, the rapidity in collecting and processing input data and the consequent reduced costs for customers. Anyway, specific characteristics are required to steady-state models; according to van Dijk *et al.* [3], they should guarantee transparency, robustness and reproducibility.

In literature, the comparison between calculation methods of the building EP usually concerns the simplified monthly method *vs.* the dynamic simulation, with the aim to validate the former as to boost its use in the context of energy regulations. Research works revealed that generally significant deviations in the results of the methods occur, despite the boundary conditions and input data are made consistent between models, as pointed out by several studies, see next section.

The issues around this research field are still open. In addition, new requirements, specifically targeted for nearly zero-energy buildings (nZEB), have been established by the national legislations complying with the EPBD recast [4]. Limits and strengths of simplified methods still need to be investigated for this type of buildings, above all for those countries, like Italy, in which the regulations introduced the quasi-steady-state model as official method to verify compliance with the requirements.

In the present article, a parametric analysis was carried out to investigate in which boundary conditions the quasi-steady-state calculation method can predict with sufficient accuracy the EP of low-energy buildings, like nZEB, if compared with a dynamic simulation model. The analysis was not aimed at discussing about deviations between models and the related causes, which have been widely analysed in literature; rather the research was meant to identify the building categories for which the monthly method might be applied for compliance verification of the current EP requirements without incurring in significant estimation errors.

The analysis was performed on two building types, representative of the Italian residential building typology, located in three different climatic zones and characterised by two insulation levels. The insulation levels match with the *U*-values of the *notional reference* building, established by the Italian legislation for verifying the building EP in two different steps of time, one of which relates to nZEB. Consistency options were applied to the models to guarantee the comparison of their outcomes. The building EP calculation was carried out by means of EN ISO 13790 and EnergyPlus.

This work is aimed at contributing to the normative activity. At this purpose, the mandate M/480 to CEN, CENELEC and ETSI [5] has addressed the elaboration and adoption of new standards to assess the integrated EP of buildings, in accordance with the objective of the EPBD recast. The aim of the mandate has been to develop an integrated approach for calculating minimum EP requirements for the technical building systems and the building envelope, by including alternative systems and setting up procedures for the nZEB assessment.

State-of-the-art

In literature, several research works dealt with the comparison between simplified and detailed models for the assessment of the building EP. In the work of Horvat and Dović [6], a model for dynamic analysis of heat-flows in the building envelope and in the technical building systems was developed. The results were compared with those derived from the application of CEN standards and the quasi-steady-state method, applied to a residential building in Zagreb, overestimated the heating energy need of about 15%. Jokisalo and Kurnitski [7] pointed out that the causes of deviation of the EN ISO 13790 quasi-steady-state method compared with a validated dynamic simulation tool (IDA-ICE) are mainly due to the parameters used to calculate the utilisation factor of the heat gains. The authors identified new values of the reference parameters and concluded that the calibrated model is suitable for residential massive buildings but not applicable in case of lightweight constructions and office buildings, for which simply hourly or detailed simulation methods should be used. A study with similar goals was performed by Wauman *et al.* [8] who determined optimal parameters values for the utilisation factor in school buildings. The researchers stated that the simplified method remains unreliable for highly insulated and air tight buildings and in case of intermittent use. A more deepened analysis was conducted by Kim *et al.* [9] by comparing EN ISO 13790 and EnergyPlus for an office building. They carried out a stochastic comparison of the models and calibrated the parameters of the utilisation factor through Bayesian method.

Another cause of deviation between quasi-steady-state and dynamic methods (DYN) is due to the different modelling of the heat transfer by thermal transmission. The former considers together the convective and the long-wave radiation heat exchanges, while the latter models the heat transfer by thermal radiation among the internal surfaces of the thermal zone and then solves a convective heat balance equation on the air temperature node of the thermal zone. At this regard, Corrado and Fabrizio [10] highlighted the necessity to consider nonlinearity effects on the surface heat transfer coefficients and the operative temperature instead of the air temperature in the quasi-steady-state model. The surface heat transfer coefficients need to be carefully assessed as they can have high influence on the building energy consumption, as demonstrated in the work of Evangelisti *et al.* [11]. A research developed by Gasparella and Pernigotto [12] demonstrated and quantified the deviations in the building thermal losses by applying either air temperature or operative temperature as set-point temperatures both in the monthly method and in TRNSYS. The authors found out that the use of the air set-point temperature in the quasi-steady-state method always overestimates the thermal losses by transmission, above all in case of uninsulated buildings both in heating and in cooling season. Related to the thermal losses of the building envelope, it is also necessary to correctly consider and evaluate the weight of thermal bridges; to this purpose, Asdrubali *et al.* [13] provided a methodology to assess the effect of thermal bridges by means of quantitative incidence factors that could be easily implemented in calculation methods of the building EP.

In order to identify other causes of deviations between EP assessment models, Ballarini *et al.* [14] proposed a new methodology of thermal analysis by splitting the different contributions to the internal air heat balance in function of different driving forces (*e. g.* outdoor air temperature, solar radiation, internal heat sources, *etc.*). The methodology was applied in both calculation models (EN ISO 13790 and EnergyPlus) for analysing a residential building located in two different Italian climatic zones. While the deviation in the heating needs was quite limited (5-10%), the cooling need demonstrated to be overestimated in the quasi-steady-state method (about two times of that resulted from dynamic simulation). A similar outcome was found by other research works; in general, higher deviations between methods are revealed in the cooling energy need than in the heating energy need. Anyway in case of highly insulated buildings, an opposite situation occurs (*i. e.* the deviations for cooling are lower than those for heating), as found in a work of Corrado *et al.* [15]. Beccali *et al.* [16] pointed out that the cooling need should be calculated by means of a different approach of that used for the heating need. The authors concluded that a detailed dynamic simulation model should be preferable even in form of certified software to verify the building EP requirements.

In the work of Kokogiannakis *et al.* [17], the monthly steady-state, the simple hourly and the detailed DYN were applied to an office building and a parametric analysis was carried out. Their scope was not to verify the numerical deviations between results of the methods but to verify different compliance with the EP class in the classification scheme. They found out that in most of the analysed cases, the same EP class is obtained provided that the input data and the boundary conditions are made consistent.

Method and theory

Italian legislative requirements for nZEB

According to ISO 52000-1 [18] different requirements should be combined towards a coherent assessment of nZEB. These requirements should include indoor environmental conditions, thermal characteristics of the building envelope, HVAC system, domestic hot water supply, lighting installation, active solar systems and other systems, such as district heating and district cooling.

The Italian regulations [19] adopted such a methodological approach by considering an overall EP requirement, EP_{gl}, and requirements for the net energy needs – space heating, $EP_{\mathrm{H,nd}}$, and space cooling, $EP_{\mathrm{C,nd}}$, – minimum allowable seasonal efficiencies of the heating, cooling, and domestic hot water systems (η_{H}, η_{C}, η_{W}), specific requirements related to the whole building envelope and provisions for the use of renewable energy sources.

The requirements on the building EP and the technical building systems efficiencies have to be verified through a *notional reference* (or *target*) building. According to the *notional 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 real building, but with parameters such as insulation level, technical systems efficiency, *etc.* replaced by reference values. As regards the building envelope, the Italian regulations established the *U*-values of the *notional reference* building in function of the heating degree days (HDD) of the location. The *U*-values come into force in two different steps with the aim of gradually increasing the building EP level: (step 1) up to 2018 for the public buildings and up to 2020 for all the other buildings, and (step 2) since 2019 for the public buildings and since 2021 for all the other buildings. The second step specifically refers to the requirements of nZEB. Another reference parameter for the *notional reference* building is the total solar energy transmittance of the window, when the solar shading is in use, $g_{\mathrm{gl+sh}}$, that is assumed equal for all the windows oriented to East, South and West.

Quasi-steady-state calculation method

The quasi-steady-state calculation method of the EP is specified in EN ISO 13790 [2] and is based on the balance of heat losses (transmission and ventilation) and heat gains (solar and internal), assessed in monthly average conditions. The dynamic effects on the net energy needs for space heating and space cooling are taken into account by introducing a utilisation factor for the overlapping between transmission plus ventilation heat losses profiles and solar plus internal heat gains profiles, leading to heating/cooling loads. The utilisation factor depends on the time constant of the building, on the ratio of heat gains to heat losses and on the occupancy/system management schedules.

The energy need for space heating and cooling for each month is calculated:

$$Q_{\mathrm{H,nd}} = Q_{\mathrm{H,ht}} - \eta_{\mathrm{H,gn}}\, Q_{\mathrm{gn}} \tag{1}$$

$$Q_{\mathrm{C,nd}} = Q_{\mathrm{gn}} - \eta_{\mathrm{C,ls}}\, Q_{\mathrm{C,ht}} \tag{2}$$

where $Q_{\mathrm{H/C,nd}}$ is the energy need for space heating/cooling, $Q_{\mathrm{H/C,ht}}$ – the total heat transfers (transmission plus ventilation), Q_{gn} – the total heat gains (internal plus solar), $\eta_{\mathrm{H,gn}}$ – the utilization factor of heat gains, and $\eta_{\mathrm{C,ls}}$ – the utilization factor of heat losses.

The actual lengths of the heating and the cooling seasons are determined on the basis of the limit value of the dimensionless heat-balance ratio for the heating mode and the cooling mode, respectively. The limit value is expressed as a function of a dimensionless numerical parameter depending on the time constant of the building.

Detailed dynamic simulation

The detailed dynamic model carried out in the analysis refers to the EnergyPlus software tool (version 8.5.0) [20]. It is a modular energy analysis program, developed by the research laboratories of the US Department of Energy since 2001. The building thermal zone calculation method of EnergyPlus is the air heat balance model. It is based on the assumptions that the air in the thermal zone, by default, has a uniform temperature, the temperature of each surface is uniform, the long-wave and short-wave radiation is uniform, the surface irradiation is diffusive and the heat conduction through the surfaces is 1-D. The air heat balance, neglecting the heat transfer due to infiltration and to inter-zone air mixing, can be written:

$$C_{\mathrm{z}} \frac{\mathrm{d}\theta_{\mathrm{z}}}{\mathrm{d}\tau} = \sum_{i=1}^{N} \dot{Q}_{\mathrm{c},i} + \sum_{i=1}^{N_{\mathrm{s}}} h_i A_i (\theta_{\mathrm{s}i} - \theta_{\mathrm{z}}) + \dot{m}_{\mathrm{v}} c_p (\theta_{\mathrm{e}} - \theta_{\mathrm{z}}) + \dot{Q}_{\mathrm{sys}} \tag{3}$$

where N is the number of convective internal loads $\dot{Q}_{\mathrm{c},i}$, $h_iA_i(\theta_{\mathrm{s}i} - \theta_{\mathrm{z}})$ – the convective heat transfer from the zone i-surface at temperature $\theta_{\mathrm{s}i}$ to the zone air at temperature θ_{z}, $\dot{m}_{\mathrm{v}}c_p(\theta_{\mathrm{e}} - \theta_{\mathrm{z}})$ – the heat transfer due to ventilation with the outside air, and $\dot{Q}_{\mathrm{sys}}$ – the system output. The capacitance C_{z} takes into account the contribution of the zone air as well as that of the thermal masses assumed to be in equilibrium with the zone air (*e. g.* furniture and internal partitions that are not explicitly modelled as walls). In order to determine the building net energy need under ideal conditions and to make the result independent from the system features, the so-called *ideal loads air system*, which can be operated with infinite heating and cooling capacity, was applied. A time step of fifteen minutes was adopted in the simulation.

Data

Description of the case studies

In order to obtain results as general as possible, the comparison between the two calculation models was performed on some Italian reference buildings. Twelve case studies, which consist in two residential building types with a fixed geometry, located in three Italian climatic zones and characterised by two insulation levels, were analysed.

The considered building types are a single-family house (SFH) and an apartment block (AB) derived from the IEE-TABULA project [21]. The geometry of each building type is representative of the Italian building stock for the respective building size class and for the specific building age class, as established in the TABULA project. The selected SFH is a two-storey building with unconditioned attic space and cellar. The AB consists in a seven-storey multi-family building with 31 apartments and four unconditioned areas, *i. e.* the cellar, two stairwells and the attic.

Each building type was placed in the following Italian cities, corresponding to three different climatic zones: Catania (CT, 833 HDD) in southern Italy, Rome (RM, 1415 HDD) in central Italy and Milan (MI, 2404 HDD) in northern Italy.

The main geometric data of the case studies are reported in tab. 1. The thermal transmittance of the building envelope components is that of the Italian *notional reference* building and are listed in tab. 2; the two thermal insulation levels (TIL) refer to the steps of application provided for by the Italian regulations, as introduced in the section *Italian Legislative Rquirements for nZEB*. The external walls are heavyweight clay blocks ($M_\mathrm{S} \approx 200$ kg/m^2) with mineral wool insulation on the external side.

As the work focuses on the determination of the net energy needs for space heating and space cooling, the technical building systems were not modelled. Since the other building energy services (*e. g.* ventilation, domestic hot water, lighting) are not significant for the aim of comparing the calculation methods, they were not included in the analysis.

The geometrical model of the buildings was developed in DesignBuilder 5.0.

Table 1. Main geometrical data of the case studies and pictures of the models

Parameter	SFH	AB
V_g [m^3]	605	8199
V_net [m^3]	470	5738
$A_\mathrm{f,net}$ [m^2]	174	2125
$A_\mathrm{env}/V_\mathrm{g}$ [m^{-1}]	0.73	0.40
$A_\mathrm{w}/A_\mathrm{env}$ [–]	0.05	0.08
Number of floors	2	7
Number of units	1	31

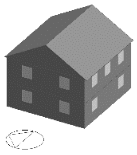
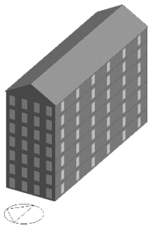
Picture of the building models	
SFH	AB
	

Table 2. Thermophysical parameters of the case studies by location and TIL

Parameter	Catania (833 HDD)		Rome (1415 HDD)		Milan (2404 HDD)	
	TIL#1	TIL#2	TIL#1	TIL#2	TIL#1	TIL#2
U_wl [Wm^{-2}K^{-1}]	0.45	0.43	0.34	0.29	0.30	0.26
$U_\mathrm{fl,up}$ [Wm^{-2}K^{-1}]	0.38	0.35	0.30	0.26	0.25	0.22
$U_\mathrm{fl,lw}$ [Wm^{-2}K^{-1}]	0.46	0.44	0.32	0.29	0.30	0.26
U_w [Wm^{-2}K^{-1}]	3.20	3.00	2.00	1.80	1.80	1.40
$g_\mathrm{gl+sh}$ [–]*	0.35		0.33		0.33	0.31

* The value of $g_\mathrm{gl+sh}$ was set as to comply with the Italian legislative requirement on the control of the solar heat gains in the cooling season.

Calculation assumptions and consistency options between models

In order to compare the results obtained by the application of the quasi-steady-state method and the dynamic simulation, the modelling procedures were made consistent, as described below.

Hourly climatic data of the selected locations were derived from the database of the Italian Thermotechnical Committee [22]. The mean monthly values of the outdoor air temperature, the solar radiation for each orientation, the water vapour pressure, the wind speed and the equivalent sky temperature were used in the quasi-steady-state calculation method.

A constant daily set-point temperature profile was assumed, set at 20 °C in the heating season and at 26 °C in the cooling season, in both models. This is in accordance with the national legislation that requires to consider a continuous operation of the thermal systems to verify the EP requirements.

The air-flow rate by natural ventilation and the thermal flow rate from internal heat sources were determined in accordance with UNI/TS 11300-1 [23], which specifies the Italian application of EN ISO 13790. The mean monthly values of the hourly profiles modelled in the dynamic simulation for the air-flow rate and the heat gains were considered in the quasi-steady-state method.

The heat transfer by thermal transmission through unconditioned spaces was modelled in the simplified method by means of the adjustment factor $b_{\mathrm{tr,U}}$, in accordance with EN ISO 13789 [24]. The value of $b_{\mathrm{tr,U}}$ was determined from the mean monthly values of the unconditioned space air temperature and the outdoor air temperature, both derived from the dynamic simulation. The value of $b_{\mathrm{tr,U}}$ was calculated:

$$b_{\mathrm{tr,U}} = \frac{\theta_{\mathrm{i}} - \theta_{\mathrm{U}}}{\theta_{\mathrm{i}} - \theta_{\mathrm{e}}} \tag{4}$$

In EnergyPlus the thermophysical features of glass, frame and shading devices were set as to obtain the same window *U*-value and total solar energy transmittance used in the quasi-steady-state model. The operation of shading devices in the simplified model follows a factor of operating time. For each location and exposure, this factor is defined as the ratio of the sum of hourly solar irradiance values greater than 300 W/m^2 and the sum of all the solar irradiance values for the analysed month. Even though in the simplified method the value of the factor is provided regardless of the location and climate, in the dynamic simulation these variables were taken into account.

The effect of thermal bridges was neglected in both models. The heat capacity of the building thermal zone was assessed in the simplified method by means of the admittance method (EN ISO 13786 [25]). This method allows to assess the heat storage in the wall during a 24 hours-sinusoidal cycle of internal temperature. No external obstacles are applied in the models.

Results and discussion

The results of the analysis are shown in fig. 1 for space cooling and in fig. 2 for space heating.

A comparison between the net energy need for cooling, $EP_{\mathrm{C,nd}}$, resulting from the quasi-steady-state method and the DYN is shown in fig. 1(a). As far as the analysed cases are concerned, the quasi-steady-state method generally underestimates the energy need in the cooling season. The thermal insulation level does not affect the deviation, which is rather affected by the shape factor, A_{env}/V_g, – higher in the SFH than in the AB. A better match between the calculation methods is obtained by restricting the cooling season to its central months (*i. e.* June, July, and August). In this case, as shown in fig. 1(b), the deviation is always lower than 7%.

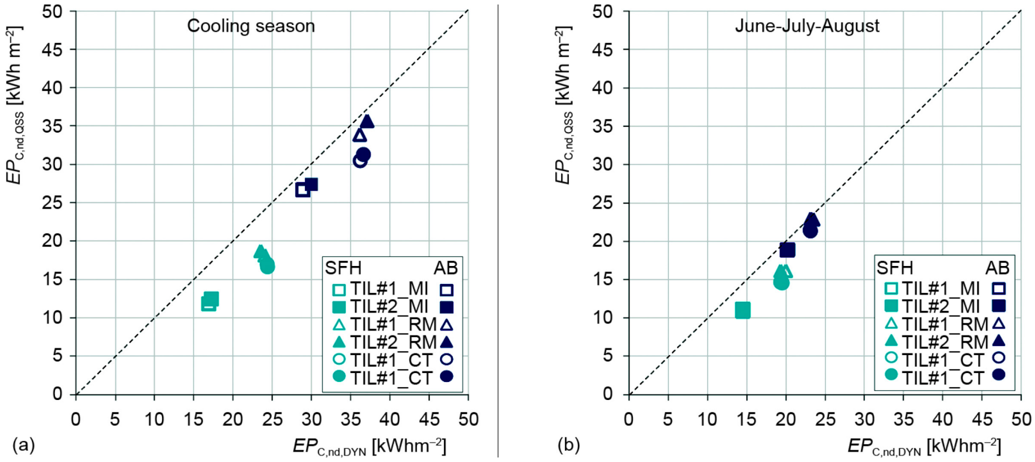


Figure 1. Net energy need for space cooling: comparison between quasi-steady-state and DYN methods for the entire cooling season (a), and June, July, and August (b)

Compared to space cooling, the net energy need for space heating, fig. 2(a) presents higher gap between the calculation methods. The simplified model overestimates the energy need in all case studies. Specifically, the overestimation is more evident in the climatic zones with a lower number of HDD (*e. g.* Catania). The increase of the thermal insulation level determines a reduction of the overestimation of the heating need only for buildings with higher shape factor (SFH); this reduction is greater in the climates dominated by the heating season. For instance for the SFH, the gap of the $EP_{H,nd}$ between models is 13% in Milan and 57% in Catania with TIL#1, while it becomes 10% in Milan and 56% in Catania in case of TIL#2.

Among the analysed buildings, the highest deviation between models occurs in the

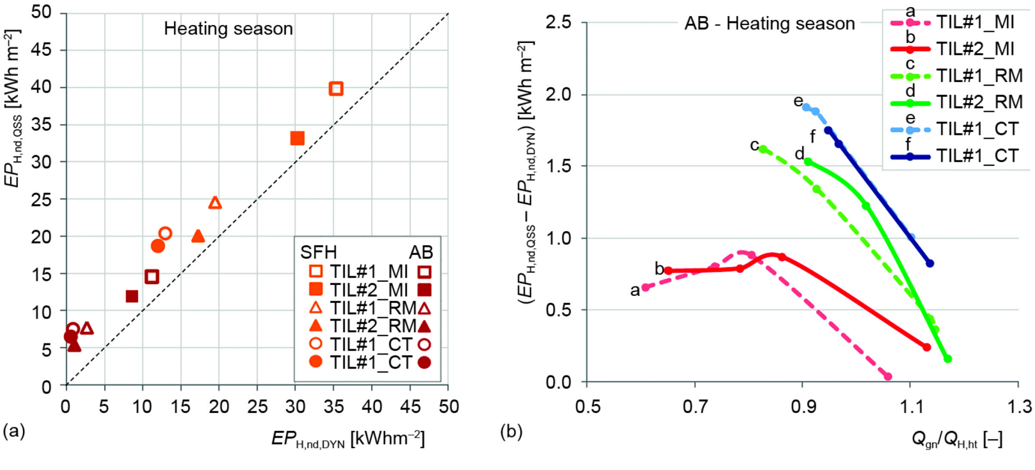


Figure 2. Net energy need for space heating: comparison between quasi-steady-state and DYN (a), absolute deviation in function of the gains to losses ratio (AB) (b)

AB, for the heating season and above all in Rome and Catania. Despite the heating energy need is very low (1-3 kWh/m^2 according to dynamic simulation), its value is overestimated about three times by the quasi-steady-state method. In order to investigate the reasons, the absolute deviation of $EP_{\mathrm{H,nd}}$ between quasi-steady-state method and DYN is plotted in function of the ratio of heat gains to heat losses derived from quasi-steady-state method, on monthly basis, fig. 2(b). It can be noted that the gap between the calculation methods increases when the HDD of the location are lower (*e. g.* Rome and Catania). This is more noticeable when the heat gains are smaller than heat losses ($Q_{\mathrm{gn}}/Q_{\mathrm{H,ht}} < 1$). Indeed, for each location the trend of the absolute monthly deviation of net energy need for space heating in function of the gains to losses ratio is quite similar for the two considered insulation levels.

With reference to the analysed buildings, it can be pointed out that the quasi-steady-state of EN ISO 13790 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, like Rome and Catania, the monthly model overestimates the heat losses and this determines an increase of the heating energy need compared to a dynamic model. Conversely, the overestimation of the heat transfer causes an underestimation of the energy need in summer. Anyway in the present analysis, the quasi-steady-state model performs well the cooling EP for the central summer months whereas the weight of the heat transfer on the energy balance is low. This occurs for highly insulated buildings with reduced shape factor, $A_{\mathrm{env}}/V_{\mathrm{g}}$. In fact, buildings with a higher envelope area by unit of conditioned building volume are more affected by the external boundary conditions, which are determinant factors for the heat transfer through the building enclosures.

Conclusions

A parametric analysis was carried out on two residential building types in different Italian climatic zones. It allowed to find out the limitations of the quasi-steady-state calculation method (EN ISO 13790) to predict the building EP compared with a DYN (EnergyPlus) for highly insulated buildings. The TIL were established in accordance with the *U*-values of the *notional reference* building, which is used to verify the EP of new buildings and renovated buildings (including nZEB), according to the Italian regulations.

The literature findings, that attribute the limitation of the quasi-steady-state method to the overestimation of thermal losses, were confirmed in the present work. In fact, it has been demonstrated that the simplified model predicts well the building EP in those cases where the weight of the heat transfer on the energy balance is low. For the analysed building categories (with fixed use and geometry), it can be concluded that the simplified model presents sufficient accuracy in the prediction of the cooling energy need for the central summer months (< 7% deviation between models, regardless of the climatic zone); the method still has limitations for intermediate months. Less consistency is shown for the heating energy need, of which the lowest gap between the models is 10% and occurs for a SFH in Milan with an insulation level comparable with that of a *notional reference* nZEB.

A future research activity on this topic will concern the application of the building EP calculation methodologies introduced by the new standards of mandate M/480 and their comparison with dynamic models. Specifically, the calculation methods of the new technical standard, namely the ISO 52016-1 Standard, that will replace EN ISO 13790, are going to be compared. In addition, the parametric analysis will be enlarged by including more building types and use categories.

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Nomenclature

A – area, [m^2]
b – adjustment factor for heat transfer, [–]
C – heat capacity, [JK^{-1}]
c_p – specific heat capacity, [Jkg^{-1}K^{-1}]
EP – energy performance, [kWhm^{-2}]
g – total solar energy transmittance, [–]
h – heat transfer coefficient, [Wm^{-2}K^{-1}]
$\dot{m}$ – mass-flow rate, [kgs^{-1}]
M_s – areal thermal mass, [kgm^{-2}]
Q – thermal energy, [Wh]
$\dot{Q}$ – heat flow rate, [W]
U – thermal transmittance, [Wm^{-2}K^{-1}]
V – volume, [m^3]

Greek symbols

η – efficiency, utilisation factor, [–]
θ – temperature, [°C]
τ – time, [s]

Subscripts

C – space cooling
c – convective
e – external, outdoor
env – envelope
f, fl – floor
g – gross
gl – glass, overall
gn – heat gains
H – space heating
ht – heat transfer
i – internal
ls – heat losses
lw – lower
nd – need (energy)
QSS – quasi-steady-state calculation method
s – surface
sh – shading
sys – system
tr – transmission
U – unconditioned
up – upper
v – ventilation
W – domestic hot water
w – windows
wl – wall
z – zone

Acronyms

AB – apartment block
CEN – European Committee for Standardisation
CENELEC – European Committee for Electrotechnical Standardisation
DYN – dynamic calculation method
EP – energy performance
ETSI – European Telecommunications Standards Institute
HDD – heating degree days
HVAC – heating, ventilation, air conditioning
IEE – Intelligent Energy Europe
nZEB – nearly zero-energy building
SFH – single-family house
TIL – thermal insulation level

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