The significant imbalance of nZEB energy need for heating and cooling in Italian climatic zones

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 126 (201709) 258–265

Energy Procedia

www.elsevier.com/locate/procedia

72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017, 6-8 September 2017, Lecce, Italy

The significant imbalance of nZEB energy need for heating and cooling in Italian climatic zones

Giovanni Murano[a,*], Ilaria Ballarini[a], Domenico Dirutigliano[a], Elisa Primo[a], Vincenzo Corrado[a]

[a]*Department of Energy, Politecnico di Torino, C.so Duca degli Abruzzi 24, Torino 10129, Italy*

Abstract

Building energy performance requirements aiming at the nZEB target have been recently established by the national legislation. In Italy, the requirements are verified through the notional reference building, whose *U*-values are reduced in two steps: up to 2018 and since 2019 for public buildings, and up to 2020 and since 2021 for all other buildings. This might cause a reduction of the heating need but an increase of the cooling need. The objective of the study is to investigate in which conditions and extent a significant imbalance of the energy needs occurs. Different building types and climatic zones are considered.

Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association

Keywords: energy performance assessment; building energy performance; building envelope; nZEB; building typology; thermal insulation; energy performance requirements; dynamic simulation.

1. Introduction

In last decades, governments worldwide have implemented several energy policies, aimed at reducing energy consumption and CO_2 emissions of buildings. In order to comply with the European Directive 2010/31/EU, the Member States have established stricter energy performance requirements for new buildings and major renovations towards the nearly zero-energy building (nZEB) target.

* Corresponding author. Tel.: +39-011-090-4543; fax: +39-011-090-4499.
E-mail address: giovanni.murano@polito.it

1876-6102
Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association
10.1016/j.egypro.2017.08.150

At national level, the Italian Ministerial Decree (MD) 26/06/2015 [1] establishes prescriptions for nearly zero-energy buildings, whose energy performance requirements have to be verified through the notional reference building approach [2]. The features of the notional reference building are partly the same as the real or design building, partly described through reference parameters with predetermined values. In Italy, the main reference parameter is the thermal transmittance of the envelope components.

According to the MD 26/06/2015, the *U*-values of the notional reference building come into force in two different steps with the aim of gradually increasing the building energy performance level: (1) up to 2018 for the public buildings and up to 2020 for all the other buildings, and (2) since 2019 for the public buildings and since 2021 for all the other buildings. The second step specifically refers to the design of nZEBs. The energy performance (*EP*) of the reference building represents the energy performance requirement of the building under design.

The reduction of the *U*-value determines the decrease of the energy demand for space heating; by contrast, the super-insulation of the building might cause higher energy demand for space cooling and indoor overheating, above all in warm climates. This has been demonstrated in several studies, as for instance [3-6]. Some of these investigations were supported by dwellings monitoring during summer periods; for instance, Pathan et al. [5] applied the adaptive thermal comfort method and demonstrated that, under the current climate, dwellings in London face a significant risk of overheating. Chvatal et al. [3] investigated the influence of the increase of thermal insulation upon the building energy performance, in terms of the consequences of overheating in summer. They observed that for the housing buildings, in summer, the solar gains need to be carefully avoided, especially when ventilation is low, coupled to enough thermal inertia indoors. If solar gains are high, the increase of thermal insulation thickness will result in increasing discomfort and energy consumption for air conditioning. In case of office buildings, this phenomenon is more accentuated because internal gains are high and cannot be reduced. All cases examined by Chvatal et al. [3] have a building envelope with high level of thermal inertia. In addition, also the variability of climatic data can have high influence on the building energy needs for heating and cooling, as demonstrated in the study of Murano et al. [7] for Italian nearly zero-energy buildings.

In literature, several authors have compared various construction solutions by evaluating the influence of the walls thermal properties on the building energy performance ([8-10]). According to Aste et al. [11], the thermal inertia always becomes more important in the presence of effective solutions that provide energy savings. As reported by Bojic et al. [12] the difference on the heating energy demand between a low inertia wall and a high inertia wall may reach about 10%; while, the difference on the cooling energy demand between a low inertia wall and a high inertia wall may reach about 20%. The technological configuration of the exterior wall can significantly affect the thermal building performance. The thermal mass has positive effects on the indoor conditions both during cooling and heating seasons.

Starting from such evidences, the present research aims to investigate in which conditions and extent a significant imbalance of energy needs for heating and cooling occurs by gradually reducing the *U*-values of the notional reference building up to 2020 limits as required by the Italian legislation. Despite the reduction of the heating energy need due to the limitation of the heat transfer through the envelope, there might be the risk that the cooling energy need increases and necessary measures for avoiding overheating should be adopted. The present article discusses the feasibility of technical solutions that comply with the legislative requirements set up for nZEBs. In addition, solutions aimed at reducing the summer energy needs and the cooling peak loads are investigated. The analysis is performed for three different building types, i.e. single-family house, apartment block and office building, in two different Italian climatic locations (Milan and Palermo).

Although the MD 26/06/2015 requires that the building energy performance is calculated by means of a quasi-steady-state calculation method, in the present work a detailed dynamic numerical simulation is applied. Compared to the quasi-steady-state method, the dynamic method better mirrors the real thermal behaviour of the building for the following main reasons: (a) it takes into account the high time variability of the thermal driving forces and the consequent thermal storage effects, (b) it correctly considers energy systems described by non-linear models. The dynamic method therefore allows to achieve a higher representativeness and quality of output data, especially in complex buildings; in addition, it can be an effective instrument to carry out sensitivity analyses through different procedures and methodologies, as done for instance by Ballarini et al. [13].

Nomenclature

A	area [m^2]	M_s	areal thermal mass [$kg \cdot m^{-2}$]
Alt	altitude [m]	P	peak load per unit floor area [$W \cdot m^{-2}$]
EP	energy performance [$kWh \cdot m^{-2}$]	U	thermal transmittance [$W \cdot m^{-2}K^{-1}$]
g	total solar energy transmittance [-]	V	volume [m^3]
HDD	heating degree days [°C]	Y_{ie}	periodic thermal transmittance [$W \cdot m^{-2}K^{-1}$]
I	solar irradiance [$W \cdot m^{-2}$]	κ	areal heat capacity [$kJ \cdot m^{-2}K^{-1}$]

Subscripts

C	space cooling	gl	glazing, global	nd	need (energy)
env	envelope	H	space heating	sh	shading
f	floor	i	internal	w	window
g	gross	n	net		

Acronyms and abbreviations

AB	apartment block	MI	Milan	PA	Palermo
e, EXT	external	nZEB	nearly zero-energy building	SFH	single-family house
i, INT	internal	OB	office building	WWR	window-to-wall ratio
MD	Ministerial Decree				

2. Energy performance requirements for buildings

The MD 26/06/2015 [1] requires, through the notional reference building approach, to verify the annual net energy need of the building for space heating and space cooling, respectively, divided by the building conditioned net floor area ($EP_{H,nd}$ and $EP_{C,nd}$). In addition, it is required to verify other energy performance indices such as the overall annual primary energy normalized on the conditioned net floor area (EP_{gl}) and the global mean seasonal efficiencies of the thermal systems. The *notional reference building* is a theoretical building characterised by reference values of the following parameters: U-value of the envelope components, total solar energy transmittance of windows combined with shading devices (g_{gl+sh}), efficiency of the heat utilization and heat generation subsystems of the space heating, space cooling and DHW systems, and features of lighting and ventilation systems. All the other features are assumed equal to the real or design building. The energy performance of the reference buildings is the baseline performance (maximum limit) for the design of any type of building, new or subjected to major renovation. The reference features defined by the MD 26/06/2015 are the same for all buildings, regardless of use category.

Other building parameters to be verified concern the thermal quality of the building envelope and the performance of the technical building systems. They are not dealt with in this paper; they have been deeply analysed in another work of the authors [14].

As regards the summer energy performance of the building, in order to limit the cooling peak loads and to maintain the thermal comfort conditions, the MD 26/06/2015 requires: (1) to evaluate the effectiveness of solar shading systems, (2) for locations with horizontal solar irradiance equal to or higher than 290 $W \cdot m^{-2}$ in the month with maximum solar irradiation, to carry out one of the following checks regarding the opaque envelope:

- for vertical walls, except those at North, North-West and North-East, areal mass M_s > 230 $kg \cdot m^{-2}$ or periodic thermal transmittance $|Y_{ie}|$ < 0.10 $W \cdot m^{-2}K^{-1}$ [15],
- horizontal and tilted roofs, periodic thermal transmittance $|Y_{ie}|$ < 0.18 $W \cdot m^{-2}K^{-1}$ [15].

According to standard guidelines [16], some Italian locations do not reach the threshold value of 290 $W \cdot m^{-2}$ for solar irradiance and therefore, despite having a predominant warm climate, are not subject to the second prescription listed above. Some of these locations are in South-Centre of Italy, as listed in Table 1. In such cases, the reference U-values can be achieved using various technical solutions, even with lightweight walls or placing the thermal insulation in different positions inside the wall, thus determining the risk of overheating in summer conditions. Some authors deeply investigated this issue. As reported by Corrado et al. [17] in case of lightweight components, an equivalent periodic thermal transmittance should be evaluated to take into account both the external surface solar absorbance and the exposure of the building components. To classify the envelope thermal quality, Di Perna et al. [18] also proposed to assign a threshold value to the internal areal heat capacity of the building envelope [15].

Table 1. Monthly horizontal global solar irradiance of some Italian locations. Source UNI 10349-1 [16].

Town	Agrigento (AG)	Jerzu (OG)	Palermo (PA)	Reggio Calabria (RC)	Siracusa (SR)	Iglesias (CI)	Decimomannu (CA)	Nocera Inferiore (NA)	Taranto (TA)	Mesagne (BR)	Luras (OT)	Otranto (LE)	Sassari (SS)	Samassi (VS)	Vibo Valentia (VV)	Nuoro (NU)	Teramo (TE)	Forlì del Sannio (IS)	Villa Fastiggi (PU)
Alt [m]	230	13	14	31	17	111	6	17	15	13	15	49	225	135	476	549	432	423	11
Italian climatic zone	B	B	B	B	B	C	C	C	C	C	C	C	C	C	D	D	D	D	D
I_{max} [$W \cdot m^{-2}$]	286	271	285	289	289	268	263	283	268	267	280	287	276	269	249	265	282	284	289
Month	Jul	Jun	Jul	Jun	Jun	Jun	Jun	Jun	Jun	Jun	Jul	Jul	Jun	Jul	Jul	Jul	Jul	Jul	Jun

3. Case studies

3.1. Description of the case studies

The analysis was performed on three different building types: single-family house, apartment block and office building, supposed located in Milan (2404 HDD – Italian climatic zone E) and Palermo (751 HDD – Italian climatic zone B). The residential buildings have been selected among the representative building types of the IEE-TABULA research project [19]. The office is a reference office building analysed in [20]. The buildings have been chosen as to cover different compactness factors and use categories. The main geometric data of the case studies are shown in Table 2. The *U*-values of the building envelope components are those of the notional reference building, as reported in the MD 26/06/2015 [1]. They differ in function of two application steps – from 2015 to 2020 and from 2021 onwards – and of the climatic zones. For each building component, the thickness of the insulation layer was determined so as to comply with the thermal transmittance value including the effect of thermal bridges.

Despite the legislative requirement related to the building thermal inertia is not mandatory for the considered locations, two opaque envelope solutions with different levels of areal thermal mass and periodic thermal transmittance were tested for each insulation level. The insulating material is placed either on the internal side or on the external side of each component.

For each envelope configuration, two types of solar shading system have been considered, each one characterised by different position and performance level: (1) on the internal side of the window and g_{gl+sh}=0.35, and (2) on the external side of the window and g_{gl+sh}=0.15. Table 3 summarises the properties of the building envelope components of the analysed configurations.

Table 2. Main geometric characteristics of the case studies.

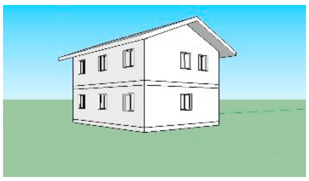
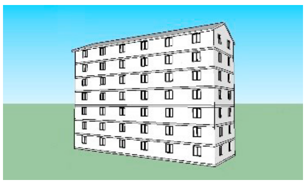
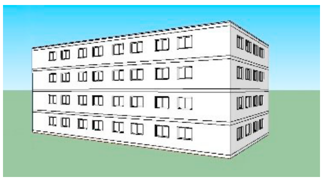
Case study	Single-family house (SFH)	Apartment block (AB)	Office building (OB)
			
V_g [m^3]	584	8 199	6 100
V_n [m^3]	486	5 738	4 101
A_f [m^2]	162	2 125	1 519
A_{env} [m^2]	424	3 261	2 129
A_w [m^2]	20.3	275	434
A_{env}/V_g [m^{-1}]	0.73	0.40	0.35
WWR [-]	0.097	0.123	0.591

Table 3. Characteristics of the building envelope components.

Parameter [Unit]		Case study	Palermo Zone B (751 HDD)				Milan Zone E (2404 HDD)			
Application step			from 2015 to 2020		from 2021 onwards		from 2015 to 2020		from 2021 onwards	
Thermal insulation position			INT	EXT	INT	EXT	INT	EXT	INT	EXT
Walls	U [$W \cdot m^{-2}K^{-1}$]	SFH, AB,OB	0.45	0.45	0.43	0.43	0.30	0.30	0.26	0.26
	κ_i [$kJ \cdot m^{-2} K^{-1}$]		17.1	50.2	16.6	50.1	14.4	49.6	14.0	49.5
	$\|Y_{ie}\|$ [$W \cdot m^{-2}K^{-1}$]		0.19	0.09	0.18	0.09	0.11	0.05	0.09	0.04
	M_s [$kg \cdot m^{-2}$]		152	258	152	258	153	259	153	260
Roof	U [$W \cdot m^{-2}K^{-1}$]	SFH, AB	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	κ_i [$kJ \cdot m^{-2} K^{-1}$]		32.1	69.5	32.1	69.5	32.1	69.5	32.1	69.5
	$\|Y_{ie}\|$ [$W \cdot m^{-2}K^{-1}$]		0.12	0.13	0.12	0.13	0.12	0.13	0.12	0.13
	M_s [$kg \cdot m^{-2}$]		381	381	381	381	381	381	381	381
Roof	U [$W \cdot m^{-2}K^{-1}$]	OB	0.38	0.38	0.35	0.35	0.25	0.25	0.22	0.22
	κ_i [$kJ \cdot m^{-2} K^{-1}$]		14.1	68.7	13.9	68.6	13.7	68.4	13.8	68.4
	$\|Y_{ie}\|$ [$W \cdot m^{-2}K^{-1}$]		0.04	0.04	0.03	0.04	0.02	0.03	0.02	0.02
	M_s [$kg \cdot m^{-2}$]		632	632	632	632	634	634	634	634
Ground floor	U [$W \cdot m^{-2}K^{-1}$]*	SFH	0.46	0.46	0.44	0.44	0.30	0.30	0.26	0.26
	κ_i [$kJ \cdot m^{-2} K^{-1}$]		62.8	62.8	59.7	59.7	59.8	59.8	59.8	59.8
	$\|Y_{ie}\|$ [$W \cdot m^{-2}K^{-1}$]		1.04	1.04	0.46	0.46	0.22	0.22	0.16	0.16
	M_s [$kg \cdot m^{-2}$]		392	392	586	586	421	421	424	424
Floor vs. unconditioned space (attic)	U [$W \cdot m^{-2}K^{-1}$]	SFH, AB	0.54	0.54	0.50	0.50	0.36	0.36	0.31	0.31
	κ_i [$kJ \cdot m^{-2} K^{-1}$]		27.3	63.7	27.0	63.6	24.1	62.1	24.1	62.0
	$\|Y_{ie}\|$ [$W \cdot m^{-2}K^{-1}$]		0.22	0.17	0.20	0.15	0.03	0.05	0.03	0.04
	M_s [$kg \cdot m^{-2}$]		257	257	257	257	377	377	378	378
Floor vs. unconditioned space (cellar)	U [$W \cdot m^{-2}K^{-1}$]	AB, OB	0.73	0.73	0.67	0.67	0.48	0.48	0.43	0.43
	κ_i [$kJ \cdot m^{-2} K^{-1}$]		39.9	54.9	35.3	54.7	34.2	54.0	37.1	53.8
	$\|Y_{ie}\|$ [$W \cdot m^{-2}K^{-1}$]		0.31	0.20	0.25	0.18	0.17	0.11	0.16	0.10
	M_s [$kg \cdot m^{-2}$]		256	256	256	256	257	257	257	257
Windows	U [$W \cdot m^{-2}K^{-1}$]	SFH, AB,OB	3.20	3.20	3.00	3.00	1.80	1.80	1.40	1.40
	$g_{gl,n}$ [-]		0.75	0.75	0.75	0.75	0.67	0.67	0.67	0.67
	g_{gl+sh} [-] **		0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)	0.15 (e) 0.35 (i)

(*) Equivalent thermal transmittance (EN ISO 13370).
(**) Solar shading devices are not installed on the windows at North. The solar shading is on the external side (e) or on the internal side (i).

3.2. Calculation assumptions and simplifications

The energy performance was assessed by means of *EnergyPlus*. The geometric model of the buildings was developed through the *DesignBuilder* software. The hourly climatic data were derived from the database of the Italian Thermotechnical Committee (CTI) [21]. Hourly profiles of the internal heat sources and the ventilation flow rate were modelled according to Part 1 of UNI/TS 11300 [22]. As specified by the Italian regulations, a continuous thermal system operation is considered during the heating and the cooling seasons. The set-point temperature was fixed at 20 °C and 26 °C for heating and for cooling respectively. For the solar heat gains evaluation, the solar shading devices are considered in function when the hourly value of solar irradiance exceeds 300 $W \cdot m^{-2}$.

4. Results and discussion

The results concern the net energy need (EP_{nd}) and the peak power (P) for heating and cooling, as shown in Fig. 1. This initial study does not investigate the primary energy, since it focuses on the effects of the improvement of the building envelope features.

For all case studies, and for the different envelope configurations examined, the results indicate that the increase of the insulation layer thickness, corresponding to the reduction of U-values from 2015 to 2021 requirements, has a twofold and opposite effect. On the one hand, there is a reduction of the heating demand of the building and on the other an increase of the cooling energy need. The effect of higher insulation level on heating and cooling demands discloses an imbalance that emerges above all in relation to the energy needs rather than to the peak powers.

By increasing the envelope insulation, the space cooling demand grows about 5-6% without significant difference among the cases. By contrast, the heating energy savings are more relevant and are estimated between −13% (SFH in Palermo with high thermal mass and g_{gl+sh}=0.15) and −44% (OB in Palermo with high thermal mass and g_{gl+sh}=0.35). Instead, installing more performant shading devices on the external side of the windows the energy need for cooling decreases about 10% in general, while the heating demand increases between 3% (SFH in Milan) and 25% (AB in Palermo). By improving the solar shading efficiency, the thermal mass level demonstrates to have no effect on the building energy need. Combining the insulation of the building envelope and the improvement of the solar shading performance simultaneously, the results reveal energy savings both for heating and for cooling in almost all cases, even if the variation of the heating energy need (between +1% and −28%) is less significant than considering the insulation option only. Similarly, the effects on the cooling demand is favourable (between −2% and −9%), although less convenient than the single improvement due to the shading devices.

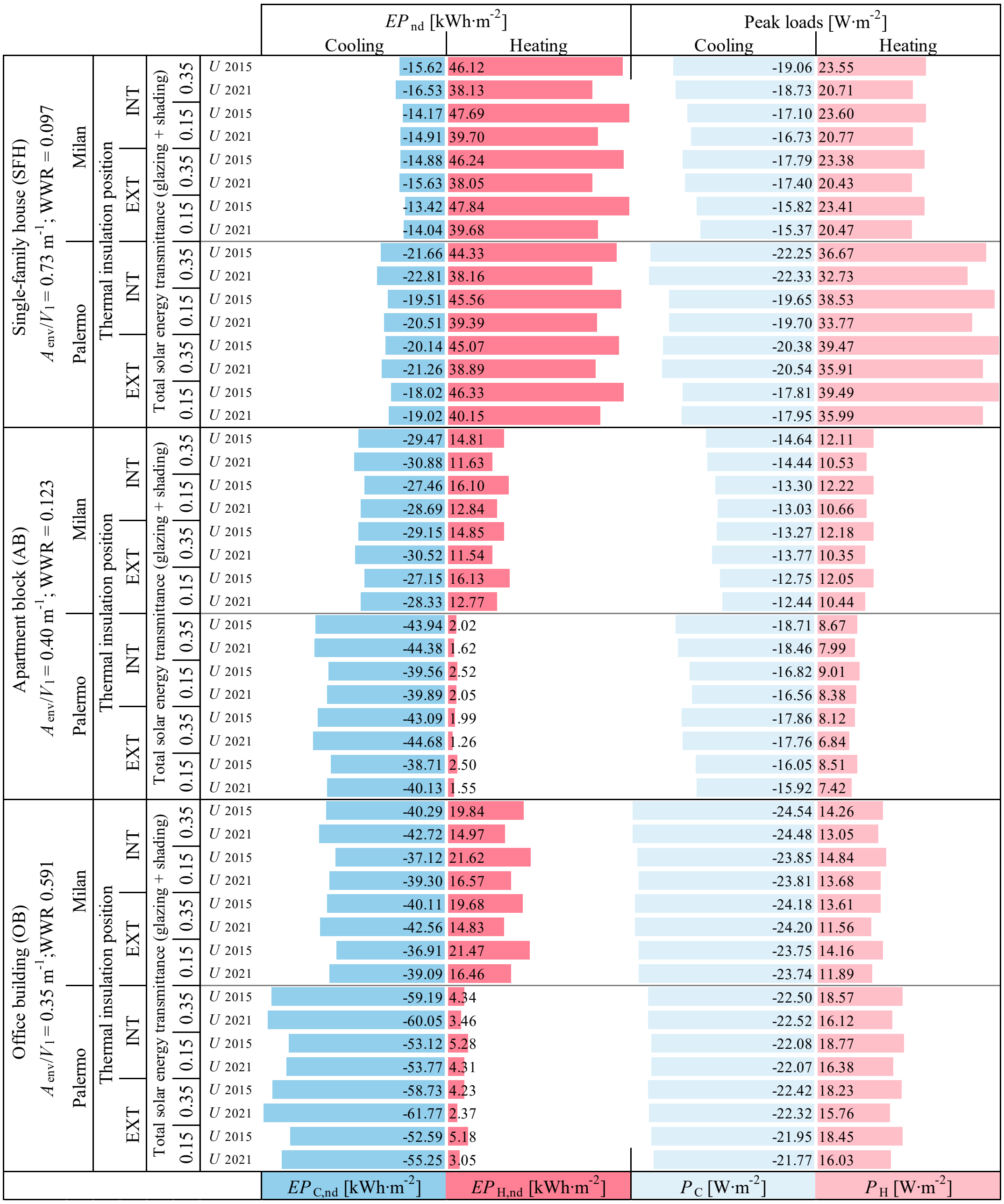


Fig. 1. Results of the analysed configurations: net energy need (EP_{nd}) for cooling and heating and peak power (P) of cooling and heating.

Fig. 2 presents two significant examples of imbalance between cooling and heating energy needs for two building types, i.e. office building in Milan and single-family house in Palermo, both insulated on the external side. For each case study, the axes origin represents the starting condition, i.e. thermal insulation level referred to the first application step (U_{2015}), g_{gl+sh}=0.35 and internal shading device. The arrows identify three different efficiency measures applied to the starting condition (SC) and the consequent variation of the net energy needs for heating and for cooling is shown for each applied measure. The measures are: (M1) increasing of thermal insulation up to U_{2021} level, (M2) improving of the solar shading efficiency, and (M3) combination of M1 and M2. Four quadrants are highlighted: the red quadrant, encompassing measures with higher cooling and heating needs; the green quadrant with lower cooling and heating needs (as occurs by applying M3); the two white quadrants with an imbalance between the energy needs (higher cooling and lower heating needs, as the case of M1, or higher heating and lower cooling needs, as the case of M2).

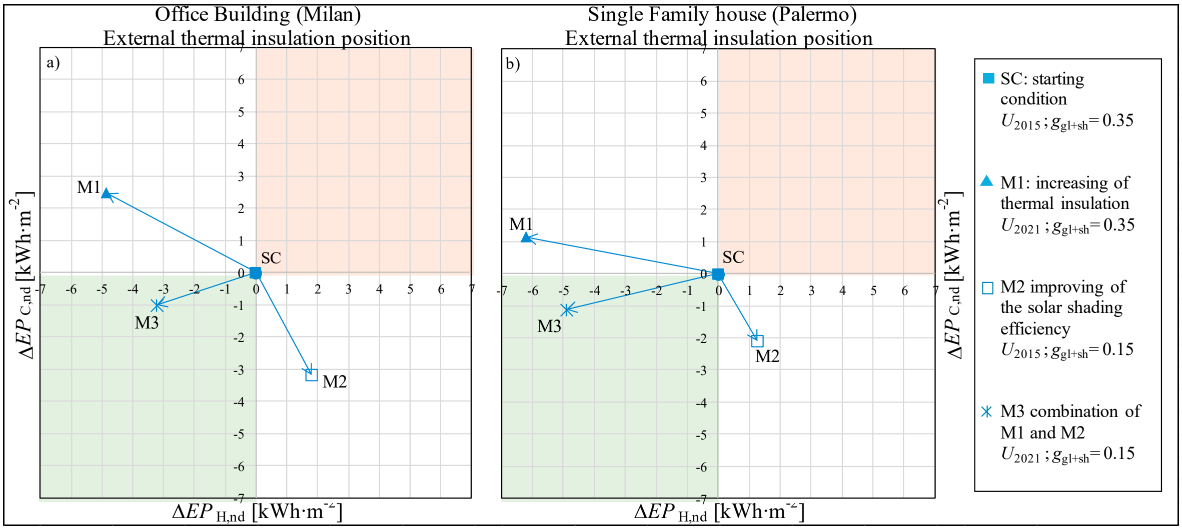


Fig. 2. Variations of EP_{nd} for two case studies, office building in Milan (a) and single-family house in Palermo (b).

For buildings located in climatic zones dominated by the heating season (HDD>2100), it is preferable to increase the insulation of the building envelope than to improve the solar shading efficiency. In fact, by installing high performing solar shading devices, the heating energy demand would increase much more than the cooling would decrease, as emerges in the cases of apartment block and office building in Milan (see Fig. 1).

As regards the peak power (see Fig. 1), the reduction of the U-values of the building envelope causes a decrease of the heating load but negligible variations of the cooling load. The cooling peak power only lowers in combination with the installation of more performant solar shadings. For instance, it is reduced of about 12% in the single-family house both in Milan and in Palermo. The thermal inertia of the building influences the cooling peak power variation only for the case studies in Palermo and it is irrelevant for those in Milan. Considering both the solar shading solutions, the case studies with the insulation layer on the internal side of the opaque components present a cooling peak power of 9-10% higher than those with insulation on the external side. All the office buildings configurations highlight negligible variations on the cooling peak power because of the high influence of the internal gains on the building energy need.

5. Conclusions

The Italian national legislation establishes different levels of building envelope insulation for the notional reference building, which is used to verify the EP requirements. Different U-values are provided for the Italian climatic zones and the types of envelope component, on the basis of two temporal steps of application. Even if these requirements aim to improve the energy performance of buildings by reducing the heating energy need, a consequent increase of the cooling energy need occurs. This phenomenon determines an imbalance of opposite energy demands. In the present work, different building types have been considered.

By reducing the *U*-value of the envelope components, the imbalance between the cooling and the heating energy needs always occurs; the cooling need increases up to 5-6% in all the analysed cases. The cooling need can be effectively reduced by applying high performing shading devices. Anyway for apartment blocks and office buildings located in cold climatic zones, the reduction of the thermal transmittance is more effective on the annual energy performance of the building than the improvement of the solar shading. In fact, the super-insulation of the building envelope yields to higher reduction of the heating need compared to the cooling energy savings that would result from the installation of more efficient solar shadings. The imbalance is less evident in the cases, like the office buildings, where the solar and internal gains have high influence on the building energy need. As concerns the peak load, the *U*-value reduction has negligible influence on the cooling power.

Future research will enlarge the analysis of imbalance by investigating the effect of the technical building systems. In addition, the following activities are expected: identification of an indicator of imbalance, deepening of the parametric analysis, analysis of single energy efficiency measures applied to building units.

References

[1] 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". *O.J. of the Italian Republic*, 15 July 2015.

[2] International Organisation for Standardisation (ISO). ISO 52003-1, Energy performance of buildings – Indicators, requirements, ratings and certificates. Part 1: General aspects and application to the overall energy performance, 2017.

[3] Chvatal S K M, Corvacho H. The impact of increasing the building envelope insulation upon the risk of overheating in summer and an increased energy consumption. *Journal of Building Performance Simulation* 2009; 4:267-282.

[4] Gaterell S M, Montazami M, Ahmed A. Overheating investigation in UK social housing flats built to the Passivhaus standard. *Building and Environment* 2015; 92:222-235.

[5] Pathan A, Mavrogianni A, Summerfield A, Oreszczyn T, Davies M. Monitoring summer indoor overheating in the London housing stock. *Energy and Buildings* 2017; 141:361-378.

[6] Ballarini I, Corrado V, Analysis of the building energy balance to investigate the effect of thermal insulation in summer conditions. *Energy and Buildings* 2012; 52:168-180.

[7] Murano G, Corrado V, Dirutigliano D. The new Italian climatic data and their effect in the calculation of the energy performance of buildings. *Energy Procedia* 2016; 101:14-16.

[8] Kossecka E, Kosny J. Influence of insulation configuration on heating and cooling loads in a continuously used building. *Energy and Buildings* 2002; 34:321-331.

[9] Gregory K, Moghtaderi B, Sugo H, Page A. Effect of thermal mass on the thermal performance of various Australian residential construction systems. *Energy and Buildings* 2008; 40:459-465.

[10] Balaras C A. The role of thermal mass on the cooling load of buildings: an overview of computational methods. *Energy and Buildings* 1996; 24:1-10.

[11] Aste N, Angelotti A, Buzzetti M. The influence of the external walls thermal inertia on the energy performance of well insulated buildings. *Energy and Buildings* 2009; 41:1181-1187.

[12] Bojic M, Loveday D L. The influence on building thermal behavior of the insulation / masonry distribution in a three-layered construction. *Energy and Buildings* 1997; 26:153-157.

[13] Ballarini I, Corrado V. A new thermal analysis by numerical simulation to investigate the energy performance of buildings. *Proceedings of Building Simulation 2011*: 12th Conference of International Building Performance Simulation Association, Sydney, 14-16 November 2011.

[14] Corrado C, Ballarini I, Dirutigliano D, Murano G. Verification of the New Ministerial Decree about Minimum Requirements for the Energy Performance of Buildings. *Energy Procedia* 2016; 101:200-207.

[15] European Committee for Standardization (CEN). EN ISO 13786, Thermal performance of building components - Dynamic thermal characteristics - Calculation methods, 2007.

[16] Italian Organisation for Standardisation (UNI). UNI 10349-1, Heating and cooling of buildings - Climatic data - Part 1: Monthly means for evaluation of energy need for space heating and cooling and methods for splitting global solar irradiance into the direct and diffuse parts and for calculate the solar irradiance on tilted planes, 2016 (*In Italian*).

[17] Corrado V, Paduos S. New equivalent parameters for thermal characterization of opaque building envelope components under dynamic conditions. *Applied Energy* 2016; 163:313–322.

[18] Di Perna C, Stazi F, Ursini Casalena A, D'Orazio M. Influence of the internal inertia of the building envelope on summertime comfort in buildings with high internal heat loads. *Energy and Buildings* 2011; 43:200–206.

[19] Ballarini I, Corrado V, Madonna F, Paduos S, Ravasio F. Energy refurbishment of the Italian residential building stock: energy and cost analysis through the application of the building typology. *Energy Policy* 2017; 105:148-160.

[20] Margiotta F. Metodologia per la determinazione delle caratteristiche strutturali ed impiantistiche di "Edifici Tipo" del Parco Edilizio Nazionale ad uso ufficio e Valutazione del Potenziale di Risparmio energetico sulla base della fattibilità degli interventi di riqualificazione energetica. *ENEA RdS/2010/197*, Roma: ENEA; 2010 (*in Italian*).

[21] Italian Thermotechnical Committee (CTI), Test reference years for thermotechnical applications (http://try.cti2000.it/, accessed: May 2017).

[22] Italian Organisation for Standardisation (UNI). UNI/TS 11300-1, Energy performance of buildings, Part 1: Evaluation of energy need for space heating and cooling, 2014 (*In Italian*).