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The effect of glazing on nZEB performance

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Abstract

In the last decades, European countries have provided for stringent energy requirements for new buildings. In improving the energy performance of buildings, windows play a significant role as they largely influence the energy need. The windows design should base on the balanced trade-off between the solar heat gains and the heat transfer by transmission.
In the paper, for some Italian climatic zones, the relation between the optimal window-to-wall ratio (WWR) and the energy need in residential nearly zero-energy buildings (nZEBs) is investigated. In the case studies, the envelope thermo-physical properties are consistent with the nZEB requirements established at national level. The energy performance assessment is carried out by means of a detailed dynamic simulation tool (*EnergyPlus*). The influence of different orientations and sizes of windows on the energy performance and the peak power are studied. The paper analyses the effect of WWR in the design of nZEBs.

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

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1. Introduction

In 2010, with the recast of the Energy Performance of Buildings Directive (EPBD) [1], the concept of nearly zero-energy buildings has been introduced in the European Union (EU) legislative framework. The implementation of nZEBs target represents one of the biggest opportunities to increase energy savings and minimize greenhouse gas emissions. The revised EPBD [2] reinforces this requirement defining new long-term goals for the reduction of greenhouse gas emissions in the UE by 80-95% in 2050 compared to 1990, as to ensure a highly energy efficient and decarbonized national building stock and to facilitate the cost-effective transformation of existing buildings into nearly zero-energy buildings. While the EPBD has set the framework definition of nZEBs, its application in practice is the responsibility of the Member States. In 2016, the European Commission has published the Recommendation 1318 [3] on guidelines for the promotion of nearly zero-energy buildings and best practices to ensure that, by 2020, all new buildings are nearly zero-energy buildings. Some energy performance benchmarks of nZEB are indicated for different EU climatic zones. For the Mediterranean area, the reference is related to residential single-family houses, for which the yearly net energy need refers to 0-15 kWh/m^2 that could be represented by 50-65 $kWh{\cdot}m^{-2}$ of primary energy, covered by 50 $kWh{\cdot}m^{-2}$ of on-site renewable sources. In Italy, the detailed definition of nZEB has been specified by the Ministerial Decree (MD) 26/06/2015 [4]: a set of provisions concerning the building envelope, the technical building systems and the use of renewable energy must be complied with to achieve the nZEB target.

For new buildings and in the refurbishing of the existing buildings stock, the MD doesn't provide maximum values of window-to-wall ratio (WWR). Besides the verification of the energy performance through the notional reference building, additional parameters related to the quality of the building envelope, as the mean overall heat transfer coefficient by thermal transmission and the summer solar effective collecting area of the building, are specified. The last parameter has the function of avoiding the overheating through the efficient use of shading devices (fixed or moveable).

Feng et al. [5] have shown that the greater impact on the energy performance of buildings is represented by windows orientation and in the following order East (West) > South > North. Poirazis et al. [6] have simulated the energy performance of some office buildings with a window-to-wall ratio between 30% and 100%, for different windows property, shadings and orientations in cold area of Göteborg. The results have shown that the office building with smaller WWR shows a great energy-saving. In the nearly-zero energy buildings, the increase of transparent surface to the East, West and South will increase energy need for cooling more significantly than the energy need for heating.

Pernigotto et al. [7] have evaluated the impact on the energy performance of a well-insulated residential building of different kinds of glazing systems, window size, orientation and internal gains. In the simulation, they have considered Paris, Milan, Nice and Rome. For all localities, the energy need for heating always decreases with increasing window area for orientations different from the North. To the South, the increase of windows allows to reduce the energy need for heating. In the cooling season, shadings on the South oriented configurations help to reduce the energy need to the levels of the West-East orientations. In the heating season, the energy need is only marginally affected by overhangs. For the considered localities, the heating peak loads variation in relation to WWR is very little. In all localities loads slightly increase with windows area for the North, East and West orientations. In the cooling season, except for North orientation, with the increasing of WWR the peak loads amplify. From the study, it results that the *U*-value is a relevant parameter in heating and cooling conditions both for energy needs and peak loads. The *g*-value, instead, appears to be more important for heating and cooling energy needs and for summer peak loads.

Tsikaloudaki et al. [8] have compared the window energy performance of office and residential buildings, to identify its impact on the overall energy performance of Mediterranean buildings. The study concerned several window typologies with varying properties (combinations of *U* and *g*-value) configurations (frame and window fractions, orientations) and intended use (office and residential). They have observed that windows with low *U*-value are not always as efficient in cooling dominating climates.

Ochoa et al. [9] have determined the suitability of combined optimization criteria on window sizing procedures for standardized office located in a temperate climate with low energy need and high visual comfort. They have definite that the complexity of the design lies in considering jointly several comfort measures and criteria as acoustics, energy performance, thermal and lighting comfort. It has shown that optimizing window size for one objective can hinder attaining additional ones; for example, windows optimized exclusively for visual comfort produce large energy consumption patterns.

Ma et al.[10] have determined relationship in thermally autonomous buildings between maximum WWR and the ambient temperature amplitudes with different envelope thermal resistances. In the study it has been demonstrated the utility of process assumption-based design alongside heat balance design as the tool for achieving real building energy saving.

Goia [11] has searched for the optimal WWR in different European climates in relation to an office building characterized by best-available technologies for building envelope components and installations. The optimal WWR was obtained considering the minimum sum of the energy use for heating, cooling, and lighting. According to Goia, an optimal WWR can be found in a relatively narrow range (0.30 ≤ WWR ≤ 0.45). Only South-oriented facades in very cold or very warm climates require WWR values outside this range.

Harmatia and Magyar [12] have investigated for an office building the preferable WWR and window geometry in the function of indoor daylight quality and annual energy need. According to the authors, WWR and wind geometry can be analyzed from the aspect of daylight dispersion and daylight factor to offer performable results for improvement of indoor environmental quality in offices. In the research, the WWR per single office was decreased from 50% to 30% and 25% per single office exterior wall area depending on the orientation, and by application of adequate glazing type. Whit these implementations, for the case study analyzed the heating energy demand could be reduced by 83%.

This paper investigates the role of the building envelope in achieving nearly-zero energy target and in particular the impact of different orientations' WWR on the energy performance of buildings in three Italian climatic zones. To this purpose the energy performance of a case study with different envelope features (i.e. level of thermal insulation, windows properties, shading devices, WWR) was assessed in three Italian locations by means of a dynamic simulation model. The energy performance was calculated taking into account the thermophysical characteristics of the notional reference building as defined by the Italian MD 26/06/2015 entered into force in October 2015. Thermal energy sensible needs for heating and cooling are investigated in the study, while the energy needs for lighting are neglected as envisaged for the residential buildings by the MD. The overall energy performance in terms of non-renewable primary is also assessed with a simplified method.

Nomenclature

A	area [m^2]	P	peak load per unit floor area [W·m^{-2}]
EP	energy performance [kWh·m^{-2}]	U	thermal transmittance [W·m^{-2}K^{-1}]
g	total solar energy transmittance [-]	V	volume [m^3]
H'	mean overall heat transfer coefficient [W m^{-2}K^{-1}]	Y_{ie}	periodic thermal transmittance (module) [W·m^{-2}K^{-1}]
HDD	heating degree days [°C·d]	η	efficiency [-]
I	solar irradiance [W·m^{-2}]	τ	solar transmittance [-]
M_s	areal thermal mass [kg·m^{-2}]	ρ	solar reflectance [-]
F, f	factor [-]	κ	areal effective heat capacity [kJ·m^{-2}K^{-1}]

Subscripts

C	space cooling	sol	solar	p	projected
el	electricity	F	frame	ob	obstacles
env	envelope	H	space heating	sh	shading
f	floor	i	internal	sum	summer
g	generation, gross	n	net	t,T	thermal transmission
gas	gas	nd	need (energy)	u	utilization
gl	glazing, overall	nren	non-renewable	w	window

Acronyms and abbreviations

AG	Agrigento	EU	European Union	RM	Roma
EPBD	Energy Performance of Building Directive	MD	Ministerial Decree	TO	Turin
		nZEB	nearly zero-energy building	WWR	window-to-wall ratio

2. The Energy performance requirements of the building envelope

Heat loads directly depend on the following factors: climate, form and orientation of the building, shading devices, properties of the building envelope (*U*-values, windows properties, WWR and air tightness) and indoor environment (set-point temperature during the heating and cooling seasons). The Italian Ministerial Decree 26/06/2015 specifies the energy performance requirements concerning the building envelope in the design of nZEBs:

(a) the mean overall heat transfer coefficient by thermal transmission (H'_T), calculated as the overall heat transfer coefficient by thermal transmission of the building envelope ($H_{tr,adj}$) normalized to the area of the *k*-th dispersant envelope component (A_k). The maximum allowable value of H'_T is fixed by the MD 26/06/2015 in function of the climatic zone and of the compactness ratio of the building (A_{env}/V_g).

(b) the summer solar effective collecting area of the building ($A_{sol,sum}$), calculated according to equation (1), normalized to the useful floor area ($A_{sol,sum}/A_f$). According to the MD, the maximum limit is 0.03 for the residential use and 0.04 for all the other uses.

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

where, for each transparent envelope component *k*: $F_{sh,ob,k}$ is the shading reduction factor for external obstacles, $g_{gl+sh,k}$ is the total solar energy transmittance of the *k*-th transparent part of the element in presence of a shading device, $F_{F,k}$ is the frame area fraction, $A_{w,p,k}$ is the overall projected area of the glazed element, and $F_{sol,sum,k}$ is the correction factor for the incident solar radiation, which is determined as the ratio between the solar irradiation in July, in the same site and orientation, to the mean annual solar irradiation in Rome on a horizontal plane.

3. Case studies

3.1. Description of the case studies

The case study is a single room of a residential apartment. The reference room is of rectangular plan, 4.5 m wide and 4.5 m long, with a story height of 3.0 m. The aim of the WWR optimization is to minimize the overall building energy need. The sensitivity analysis took into account ten levels of WWR, from the lowest (level no. 1) equal to 10% to the highest (level no. 10) equal to 100%. All opaque building components of the reference room have been regarded as adiabatic, with the exception of the front wall, which was regarded as thermally insulated according to the thermal characteristics of the notional reference building as described by the MD 26/06/2015. The insulation layer is placed on the exterior side of the wall. 1 summarises the properties of the building envelope.

The impact of shading devices on the energy performance has been examined through two fixed types of solar shadings (a) g_{gl+sh} = 0.15 (τ=0.20, ρ=0.70, external side of the window) and (b) g_{gl+sh} = 0.35 (τ=0.15, ρ=0.70, internal side of the window). The characteristics of solar protection devices combined with glazing have been determined according to standard EN ISO 52022-1 [13].

The analysis was carried out in reference to a room with a single orientation (only one wall facing outwards) because the comfort conditions can change considerably for each environment in relation to the incident solar irradiation. The case study is located in three Italian localities: Turin (TO, climatic zone E), Rome (RM, climatic zone D) and Agrigento (AG, climatic zone B). The weather data were derived from the new national Typical Meteorological Year of the Italian Thermotechnical Committee (CTI) [14]. Summary climatic data are given in 1.

Table 1. Climatic data of the considered locations (left) and properties of the building envelope (right).

City	HDD	Solar irradiation				
		S	E	N	W	Hor.
	[°C·d]	[kWh m^{-2}]				
TO	2617	930	1030	505	559	1354
RM	1415	1057	867	547	828	1603
AG	729	1177	929	576	889	1762

Wall				Window	
U	M_s	$\|Y_{ie}\|$	κ_i	U	$g_{gl,n}$
[W·m^{-2}K^{-1}]	[kg·m^{-2}]	[W·m^{-2}K^{-1}]	[kJ·m^{-2} K^{-1}]	[W·m^{-2}K^{-1}]	[-]
0.26	260	0.04	49.5	1.4	0.67
0.29	259	0.05	49.6	1.8	0.67
0.43	258	0.09	50.1	3.0	0.75

Hourly profiles of the internal heat gains and the ventilation flow rate were determined according to national specification UNI/TS 11300-1 [15] for residential buildings. The overall sensible internal heat gain, obtained as the mean value of the weekly profile, has a value of 5.30 $W \cdot m^{-2}$ (for a residential apartment of 75 m^2). As specified by the Italian legislation, continuous operating schedules were assumed during the heating and cooling seasons. The set-point temperature was fixed at 20 °C and 26 °C for heating and cooling, respectively. The solar shading devices are considered in function when the hourly value of solar irradiance exceeds 300 $W \cdot m^{-2}$.

3.2. Calculation model and assumptions

The software *DesignBuilder* (version 5.4.0.014), based on *EnergyPlus* (version 8.9.0 released on 31/03/2018), was used to run dynamic simulations and define the energy need of the case studies. The views of the case studies and the main geometric features are shown in Table 2.
The overall energy performance was evaluated in terms of non-renewable primary energy, using equation (2).

$$EP_{\mathrm{gl}} = \frac{EP_{\mathrm{H,nd}}}{\eta_{\mathrm{H,u}} \cdot \eta_{\mathrm{H,g}}} \cdot f_{\mathrm{p,nren,gas}} + \frac{EP_{\mathrm{C,nd}}}{\eta_{\mathrm{C,u}} \cdot \eta_{\mathrm{C,g}}} \cdot f_{\mathrm{p,nren,el}} \quad (2)$$

The technical building system were characterised in compliance with MD 26/06/2015, considering the mean seasonal efficiency of the heating/cooling utilisation subsystems (i.e. heat emission, control and distribution) $\eta_{H/C,u}$ equal to 0.81, and the mean seasonal efficiencies of the generation subsystem for heating $\eta_{H,g} = 0.95$ and for cooling $\eta_{C,g} = 2.50$. Specifically, gas condensing boiler and electric chiller were assumed as reference generators for heating and cooling, respectively. Two types of energy carrier were considered in the current analysis: natural gas and electricity with non-renewable primary energy conversion factors $f_{p,nren}$ equal to 1.05 and 1.95, respectively, according to MD.

4. Results

4.1. Legal requirements

The verification of the two parameters prescribed by the Italian legislation is shown in Table 2 and in Table 3. The compliant WWR configurations are shown in green. To calculate the summer solar effective collecting area of the building ($A_{sol,sum}/A_f$), the solar irradiance of main orientation was determined according to EN ISO 52010-1 [16]. Table 3 highlights that, using building elements having the same characteristics as the notional reference building, it is possible to increase WWR up to 40% in Turin, 30% in Rome, and 10% in Agrigento.

Table 2. Main geometric features of reference room and mean overall heat transfer coefficient by thermal transmission H'_T [$W \cdot m^{-2} K^{-1}$].

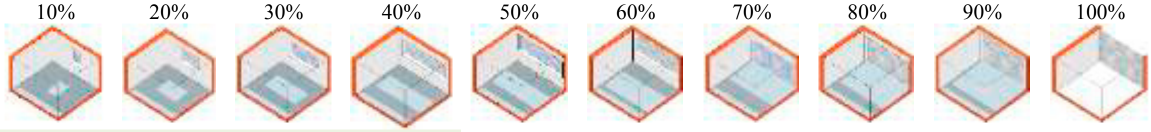
WWR	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
										
TO	0.37	0.49	0.60	0.72	0.83	0.94	1.06	1.17	1.29	1.40
RM	0.44	0.59	0.74	0.89	1.05	1.20	1.35	1.50	1.65	1.80
AG	0.69	0.94	1.20	1.46	1.72	1.97	2.23	2.49	2.74	3.00

Table 3 shows that with configurations of total solar energy transmittance of the transparent part of the element in presence of a shading device of $g_{gl+sh} = 0.15$ is always possible to realize more glazed area.

Table 3. Summer solar effective collecting area ($A_{sol,sum}/A_f$) of different configurations.

WWR	South						East						North			West					
	TO		RM		AG		TO		RM		AG		TO	RM	AG	TO		RM		AG	
[%]	0.15	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.15	0.35	0.67	0.67	0.75	0.15	0.35	0.15	0.35	0.15	0.35
10%	0.006	0.014	0.006	0.015	0.005	0.012	0.009	0.020	0.007	0.016	0.006	0.014	0.019	0.018	0.018	0.004	0.010	0.007	0.015	0.005	0.013
20%	0.013	0.030	0.014	0.032	0.011	0.026	0.019	0.044	0.015	0.036	0.013	0.031	0.042	0.039	0.039	0.010	0.023	0.014	0.034	0.012	0.028
30%	0.020	0.046	0.021	0.050	0.017	0.040	0.029	0.068	0.024	0.055	0.020	0.047	0.065	0.061	0.060	0.015	0.035	0.022	0.052	0.018	0.043
40%	0.027	0.062	0.029	0.067	0.023	0.054	0.040	0.092	0.032	0.074	0.027	0.064	0.088	0.082	0.081	0.020	0.048	0.030	0.070	0.025	0.058
50%	0.034	0.079	0.037	0.085	0.029	0.069	0.050	0.117	0.040	0.094	0.035	0.081	0.112	0.104	0.103	0.026	0.061	0.038	0.089	0.031	0.073
60%	0.041	0.097	0.045	0.104	0.036	0.084	0.062	0.144	0.049	0.115	0.042	0.099	0.137	0.127	0.126	0.032	0.074	0.047	0.109	0.038	0.090
70%	0.049	0.114	0.053	0.123	0.043	0.099	0.073	0.170	0.058	0.136	0.050	0.117	0.162	0.151	0.150	0.038	0.088	0.055	0.129	0.045	0.106
80%	0.057	0.132	0.061	0.143	0.049	0.115	0.084	0.196	0.068	0.158	0.058	0.135	0.187	0.174	0.173	0.043	0.101	0.064	0.149	0.052	0.122
90%	0.064	0.150	0.069	0.162	0.056	0.130	0.095	0.222	0.077	0.179	0.066	0.153	0.212	0.197	0.196	0.049	0.115	0.073	0.169	0.060	0.139
100%	0.072	0.167	0.077	0.181	0.062	0.145	0.107	0.249	0.086	0.200	0.074	0.172	0.237	0.221	0.219	0.055	0.128	0.081	0.189	0.067	0.155

In general, the configuration of WWR for g_{gl+sh} =0.35 which allows to satisfy the requirements of MD is between 10% and 20% of WWR. In accordance with the provisions of the decree the solar shading devices are not installed on the windows at North.

4.2. Energy performance and peak power

The energy performance of 70 configurations of the case study was calculated for three Italian locations characterized by different climatic conditions (for a total number of 210 simulations).

The configurations concern the progressive increase of WWR, the use of two different types of solar shading with different energy performance characteristics and different orientations of the reference room, representing the case study.

The trends of heating and cooling energy performance for configurations of glazing and shading device having the same g_{gl+sh} value are shown in Fig. 1.

For all the case studies and for all the locations, with the only exception of Turin for the northern front (configuration WWR of 10%), the energy need for cooling is higher than the one for heating.

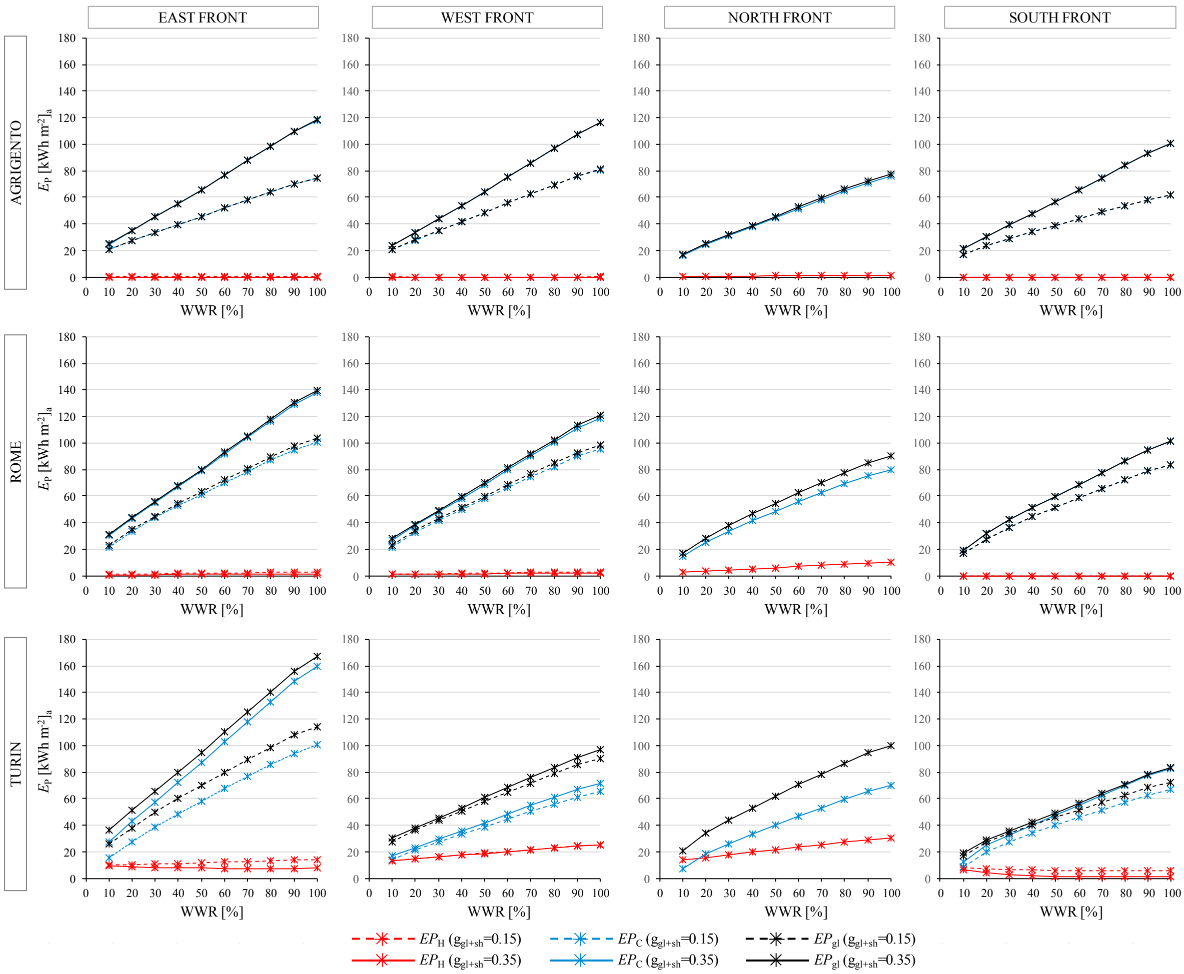


Fig. 1. Cooling, heating and global energy performance of the analyzed configurations.

The results show that window-to-wall ratio and energy needs are directly related. For example, for Turin and for configurations of glazing and shading device with g_{gl+sh} = 0.35, differences of total energy needs of 357% for the East front, 222% for the South front, 385% for the North front, and 340% for the West front occur increasing WWR from 10% to 100%. These percentages significantly increase for the locations of central and southern Italy where the energy needs for heating are nearly zero while the energy needs for cooling have a significant weight.

For all the analyzed locations, the effect of WWR on the East front is very pronounced, followed by that on the West. The use of a high performance shading device has a positive effect on the energy need for cooling. In general, for any WWR configuration the use of best performing shading device decreases the energy needs for cooling: for Agrigento, for all orientations, the energy benefits increase for large glazed surfaces; for Turin the best energy benefits are for WWR between 10 and 20%; in conclusion at Rome in the East and West front the trend is similar to that for Turin while at South is similar to Agrigento.

The best performing shading device (g_{gl+sh} = 0.15) has a greater impact on the energy performance of buildings in the following order East > South > West.

In Turin the reference room on East and North fronts shows higher values of EP_{gl}. By contrast, the reference room acts differently on the fronts West and South where instead the EP_{gl} referred to Turin has lower values compared to other locations.

Fig. 2 shows results related to peak power. For all case studies, and for the different examined WWR configurations, the results indicate that the increase of the energy performance of shading device has a twofold and opposite effect. On the one hand, there is a substantial reduction of the cooling demand of the reference room and on the other a slight increase of the energy need for heating. In general, for all localities and orientations (with exception of the North front) the use of large windows increases both the heating and the cooling peak loads.

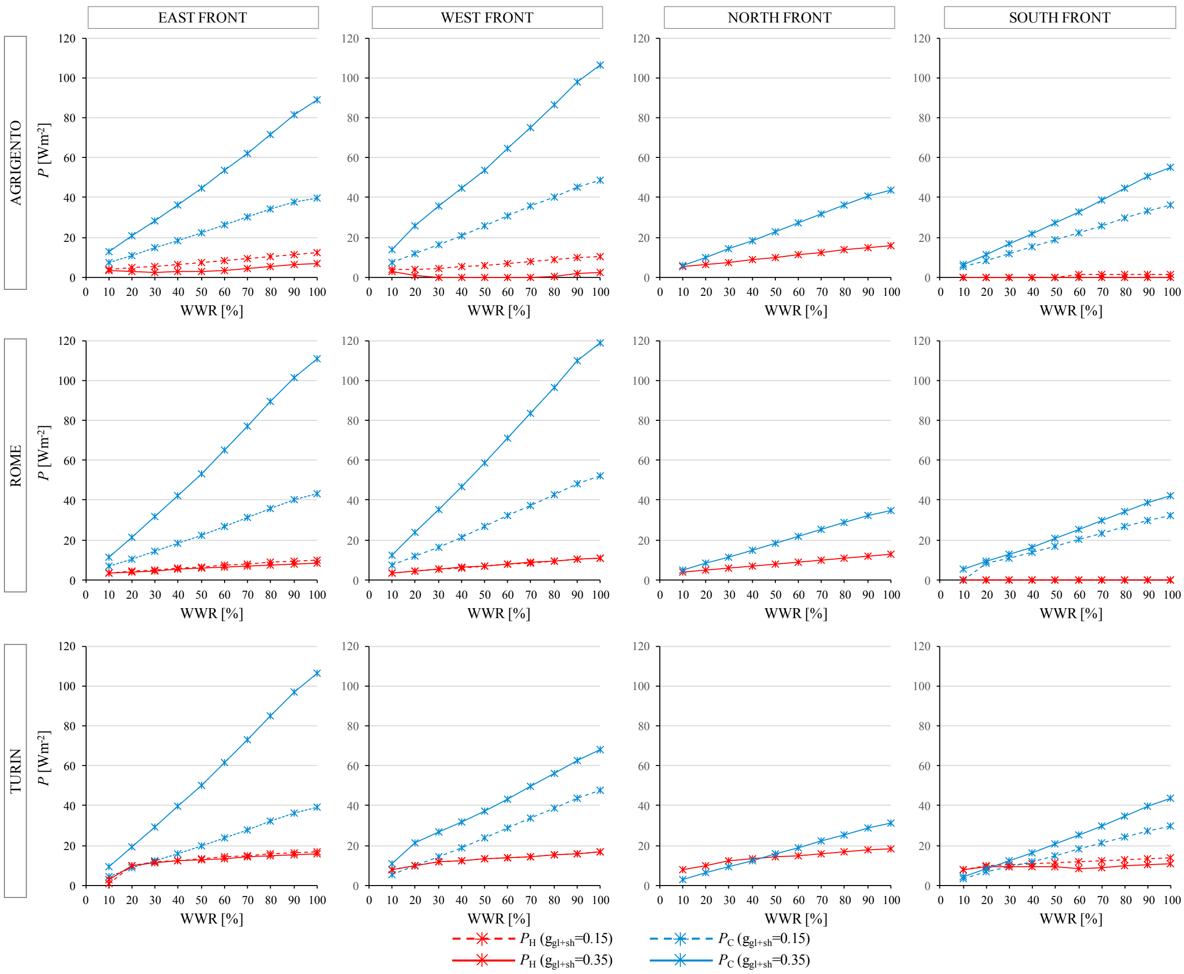


Fig. 2. Cooling and heating peak power of the analyzed configurations.

5. Conclusions

In order to achieve the nZEB target it is not a good design practice to increase the WWR ratio. Moreover, the orientation of the windows has a significant impact on the energy performance of the building.
For a single reference room with only one external wall a WWR range from 0 to 100% was tested to investigate its effect on the energy need. The results show some common trends for all the considered climates.
In general, for all localities and orientations, the use of large windows increases both the heating and cooling energy need and the peak power. For all orientations and localities, the WWR with minimum EP_{gl} is always equal to 10%. The weakest link of the nZEBs design concerns the cooling energy performance. It is always a good practice to use a high-performance shading device to reduce the overall energy demand despite it negatively effects on the heating energy behavior of the building (which as seen, however, has a low percentage incidence). Therefore, in the design of nZEBs, it is important to consider the orientation fronts of glazed surfaces, the solar and thermal properties of windows and the shading devices properties in addition also to the reduction of internal heat loads (such as lighting, equipment, etc). Future studies will examine further configurations of the reference room with expanded thermal envelope also including ground floor or roof. Other glazing properties will also be considered. The lighting service that is strongly dependent on the characteristics of glass and solar shading will also be taken into consideration. Considering the solar contributions for each orientation it will be investigated the method of reaching the optimum configuration combining all four sides of a building.

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