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On the cost reduction of a nearly zero energy multifamily house in Italy: technical and economic assessment

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Abstract

Two important issues concerning NZEB development are: from one side to guarantee specific heating-cooling balance for each climatic condition, taking into account thermal comfort and indoor environmental quality, and from the other side to enhance the reduction of construction and management costs, ensuring the fulfillment of NZEBs standard requirements. In this paper these two aspects have been analyzed. Numerical analyses under transient thermal conditions demonstrated that passive design (night ventilation and shadings) allow to minimize the overheating risk in summer season and consequently to avoid the installation of an active cooling system: up to 65% average cooling demand reduction can be obtained; 1.5 air change rate of night ventilation allowed to reduce the overeating risks to 16 hours only. Furthermore, the development of low-cost technical solutions in the construction phase guarantees up to 25% reduction of investment costs and high final savings, considering operational costs over the entire building life cycle (50 years). The Net Present Value of the four scenarios range from 63 €/m^2 to 140 €/m^2

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Building sector accounts for the largest part of energy consumption and gas emissions at local and global level, but it represents on the other side a huge potential for energy savings [1,2]. According to the EU Directive, new public and private buildings will have energy performance close to zero (NZEB) starting from respectively 01/01/2019 and 01/01/202 [3], with requirements and compliance to be defined at European Member State level. Despite the common guidelines provided by the European Standards, NZEB definitions are subject to different interpretations and there are still ambiguities and misalignments in the implementation phase of the NZEB concept at national level due to the climatic, social, technological and economic differences among countries [4]. According

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to this, a minimum common threshold for energy efficiency cannot be easily identified for all the Member States. NZEB buildings should provide specific heating-cooling balance for each climatic condition, taking also into account thermal comfort and indoor environmental quality [5-6], but, currently, these last two aspects are still poorly considered in European Countries [7]. Another issue concerning NZEB is related to construction costs: although many researches and demonstration actions proved the achievement of NZEB targets, the design choices are not always proven to be cost effective both from an environmental and economic perspective [8]. Among the different building types, high importance is given to the development of residential NZEB buildings, which account for about the 75% of the total European Building stock [9]. In the residential sector, the issue of cost reduction of new NZEBs is particularly crucial for social housing, where the economic aspect is relevant, due to limited financial resources.

The Italian law fixes several requirements for new buildings, that can be reached through different strategies, technologies and operational means [10]; however, since the beginning of 2018, minimum requirements buildings and NZEBs must comply with same requirements for energy systems and renewable energy sources, the only difference consists in the slightly tighter requirements for the thermal insulation levels of NZEB components. Since 01/01/2018, in accordance to [11], energy performance of minimum requirements buildings and NZEB buildings will vary only in terms of small differences in transmittance values. This implies that very small cost differences can be expected between a conventional and a nearly zero-energy building, creating favorable conditions for NZEB proliferation. On the other side this situation calls for reduction of cost construction of new multifamily houses to achieve the high energy targets, especially in the social housing sector, characterized by strong economic restraints.

The objective of this paper is to preliminary explores the possibility of reducing construction costs keeping high energy target in new multifamily buildings, in the framework of the activities of CoNZEBs (Solution sets for the cost reduction of new Nearly Zero-Energy Buildings) Project [12]. The Project is funded by the European Union in the framework of the Horizon 2020 Program and aims at identifying and evaluating technology solution sets, leading to significant cost reductions of new Nearly Zero-Energy Multi-Family Houses (MFH). To achieve the objectives, cooperation with housing associations allows for an intensive interaction with stakeholders and tenants is implemented. The project starts by setting baseline costs for conventional new buildings, currently available NZEBs and buildings going beyond such levels. It analyses planning and construction processes to identify possible cost reductions.

2. Methodology

The study was carried out according to the following process:

a) Identification of a real nearly zero energy multifamily house, with the involvement of planners and designers, in order to catch their view about design criteria and more suitable technologies for high energy performing buildings;
b) Detailed technical and economic analysis to assess energy performance and disaggregated energy related costs respect to the overall construction costs;
c) Advanced dynamic simulations to assess the impact of a microclimatic conscious design and to identify possible passive solutions for specific energy services;
d) Identification of low cost technologies and assessment of energy and economic performance according to the national building code and to a life-cycle cost approach.

2.1. Design criteria and background

The case study is located in Prato, town in the centre of Italy, and was commissioned by the social housing company Edilizia Pubblica Pratese. The aim of the company is to realize new buildings with high energy performance, low environmental impacts and low investment and maintenance costs. The building is located in the outskirts of the city and represents an example of urban renewal connecting two separate built areas. It is a mixed-use building with three residential floors and a public space at the ground floor (civic centre). Different apartment sizes have been designed according to the needs of the final users. The L-shaped building is provided with a garden and a private parking, guaranteeing a clear separation between pedestrian and vehicular traffic. A pedestrian colonnade on the ground floor visually connects the public square in front of the building with the private green area.

The white linear and compact façades are marked by balconies and glazed railings. Brise-soleils are installed on staircases to prevent overheating. Reduction of energy consumption and/or construction costs was achieved by means of an adequate planning from different perspectives: simplified design (i.e. use of continuous façades); outdoor parking instead of underground parking; implementation of bioclimatic criteria; use of recycled materials.

Firstly, the design and technological choices have been simplified as much as possible in order to avoid extra costs. For example, the use of continuous façades allows to reduce thermal bridges. Furthermore, outdoor parking instead of underground parking have been chosen for lowering construction costs and rents for users. Secondly, bioclimatic criteria have been implemented in the design phase, with particular attention to summer comfort. Finally, recycled materials from the local textile companies have been used for the thermo-acoustic insulation.

Fig. 1. Building case study. Building portion highlighted in red for overheating calculation

2.2. Building description

The case study is a multi-family building, designed and built in compliance with NZEB indicators as defined in [10]. It consists of 29 flats distributed on 4 floors, served by four staircases. The net area of each apartment ranges between 45 and 95 m^2, with a total area of 2127 m^2 and a total volume of 5743cm^3. The ground floor is occupied by private cellars, utility rooms and the public civic centre.

In order to set standard characteristics and operation, some modifications of the original design were carried out. Concerning the building structure, the multilayer envelope is composed by two brick walls with an EPS thermal coating. Similarly, also the ground floor and the rooftop are insulated with a layer of XPS being respectively 8 cm and 12 cm thick. Argon-filled double-glazed windows with aluminum frame are installed. In the original building plan, thermal insulation of the envelope components was higher than standard NZEB values; hence the U values [W/m^2K] were adjusted to: 0.26 (roof), 0.28 (wall), 0.28 (ground floor), 1.46 (window). Independently from equipments and occupant in real apartments, for the reference building the internal gains are set to 5 W/m^2 for sensible heat and 2.5 W/m^2 for latent heat, according to Italian standards[13]. The building is naturally ventilated and, according the national building code, an air change rate of 0.3 h^{-1} is considered. The centralized heating system consists of the following sub-systems: the room-controlled floor emission system, is fed by a 171 kW air water heat pump and a 94 kW condensing boiler, acting as a back-up system when outdoor temperatures drop below the working conditions of the heat pump. The cut off temperatures of the heat pump are 3°- 45°C and its coefficient of performance (COP) in standard conditions is 3.28. The heat supply systems are coupled to a 2000 liters inertial tank storage. The condensing boiler is also used for the domestic hot water (DHW) production. Renewable energy sources coupled to the energy systems consists of 30 m^2 solar thermal collectors for DHW production and a 22 kW_p poly-crystalline PV system (142 m^2) both mounted on the tilted roof, on the south-east and south-west oriented pitches. No mechanical ventilation and cooling systems are installed, according to construction standards in most

Italian buildings, especially in the social housing sector. Artificial lighting in residential buildings is not taken into account in the energy performance scheme and certification in Italy.

2.3. Construction costs analysis

From the economic point of view, construction costs can be categorized as shown in Table 1. Total construction cost is 3,484,000 €, which corresponds to 1,638 €/m^2 of net floor area. The economic analysis of the cost-optimal scenarios will focus on the reduction of those costs which have an impact on the building energy performance. According to this, starting from the cost categories shown in Table 1, it can be stated that: the costs of structures are fixed; most of the architectural costs are adjustable (in particular those related to the building envelope); only costs of heating and DHW systems have been modified; costs of renewable energy systems have been considered as fully modifiable. Disaggregated energy related costs for each construction category are also shown in Table 1. According the table, only 832,927€, 24% of the total construction costs, can be reduced by applying more energy efficient solutions, which corresponds to 392 €/m^2 of net floor area.

Table 1. Total and energy related construction costs

Costs	Structure	Architectural components	Systems	Renewable sources
Total [€]	996,624	1,614,058	814,915	58,140
Incidence on total [%]	29	46	23	2
Energy related [€]	0,00	526,687	248,100	58,140
Incidence on total [%]	0	63	30	7
Unitary cost [€/m^2]	0	248	117	27

3. Calculation

3.1. Overheating risk analysis

This task was carried out to assess if an active cooling system is necessary in tight and highly insulated buildings or, on the contrary, adequate management and design criteria can provide a comfortable built environment. Numerical analyses were hence carried out under transient thermal conditions, using the well-known and calibrated software TRNSYS [14]. To reduce the calculation time requirements, the analysis was carried out in the three floors of the building portion highlighted in red in Figure 1 (8 apartments). The simulations were run for the summer season, which is not standardized in Italy and thus was conventionally considered between 01/05 and 30/09. Given the geometry and the construction technology of the building, design parameters to assess the thermal comfort were: the solar shading of transparent surfaces and the night ventilation. A parametric analysis was hence carried out, considering solar factor reductions ranging from 0 to 0.8, and air exchange rate due to extra ventilation from 9.00pm to 8.00am ranging from 0.3 to 1.8 h^{-1}. The first set of dynamic simulations allowed to calculate summer heat loads, able to provide more accurate than the ones achieved with quasi-steady-state tools recommended by the Italian Standard. In the next stage, the operative temperature was calculated as performance indicator of building overheating in thermal free floating, according to the procedure defined in the relevant standard [15].

3.2. Formulation of low cost solutions

Four scenarios have been modeled both modifying the components of the building envelope, the typology of the energy systems and the amount of PV panels and solar thermal collectors (respectively PV and ST in Table 3). Basically, in all the four scenarios the multilayer envelope with thermal coating has been replaced by blocks of autoclaved aerated concrete. This solution allows to construct an almost seamless wall using thin-bed mortar. In addition, mono-block windows have been installed: it is an integrated and prefabricated system which includes frame and glass, insulated rolling-shutter casing, side jambs and sill. All the scenarios do maintain the same transmittance values as the base case (minimum NZEB requirements) except for scenario 2 where the thermal insulation thickness of the external wall and rooftop has been increased for improving the energy performance (Super-NZEB). Differences among scenarios are summarized in Table 2. It must be noticed that Scenario 3 does not fully respect Italian law requirements: energy produced by renewable sources cannot be directly used for heating/cooling by joule effect.

Table 3. Characteristics of the four scenarios

Scenario	Envelope	Energy supply system		Heating emission system	Renewable energy system	
		Heating	DHW		ST [m^2]	PV [m^2]
Base case	NZEB	Heat pump	Boiler	Floor heating	30	142
1	NZEB	Boiler		Radiators	50	142
2	Super- NZEB	Boiler		Radiators	41	142
3	NZEB	-	Boiler	Electric Radiators	50	175
4	NZEB	Heat pump		Radiators	0	142

3.3. Energy performance and costs analysis

The energy performance calculations of the different building configurations are carried out with EDILCLIMA [16], a calculation tool certified by the national body in charge of software usable for the Italian energy certification scheme. The tool is based on a quasi-steady-state calculation method with monthly heat balance and utilization factors in accordance with relevant national and EU standards. The annual energy is computed for the following energy services: space heating, ventilation, domestic hot water production. The economic analysis was carried out based on the requirements of relative European Standard [17] taking into account: costs and lifetime of technical solutions implemented in the building configurations, costs for the used fuels, national economic indicators. The net present value (NPV) was selected as key performance indicator.

4. Results

In the first set of simulations the overheating risk was evaluated to assess the need of active cooling, applying different conditions of solar shading and extra night ventilation in the 8 flats. Two performance indicators were taken into consideration: the net cooling demand and the operative temperature. High reduction of summer heat loads were obtained: up to 65% average demand reduction between the conditions of 0 and 0.8 solar shading coefficients and up to 53% between conditions of 0 and 1.5 h^{-1} of night ventilation. Secondly, according to the thermal mitigation potential, the operative temperature hourly trend was calculated to assess the overheating risk, referring to the limits of the relevant standard [15]. In this standard three categories of thermal comfort are defined depending on the percentage of satisfied users: 90% of satisfied occupants in the first category and respectively 80% and 65% in the second and third categories. In figure 2 and 3, hours of discomfort complying with the first category of adaptive thermal comfort are shown. The two NZEB and Super-NZEB envelope configurations were compared and two conditions of natural ventilation were analyzed: a fixed value of 0.3 air exchange rate (ACH) in figure 2a and 1.5 ACH of additional night ventilation in figure 2b. The solar shading coefficient in both cases was set to 0.8.

Figure 2 shows that overheating occurred in 1985 hours as an average in the 8 flats for the NZEB configuration; the Super-NZEB envelope causes an increase in overheating of about 30% (2580 hours); 1.5 ACH of additional ventilation reduced on average the overheating risks to respectively 70 hours and 200 hours for the NZEB and Super-ZEB buildings. This proves that an active cooling system might be not necessary if an adequate design and management of passive strategies is carried out.

Results complying with the second category of the relative standards are even more promising. As a matter of fact, for the NZEB configuration in free floating, the discomfort hours reduced from 1400 to less than 100 hours adding the 1.5 ACH of additional night ventilation.

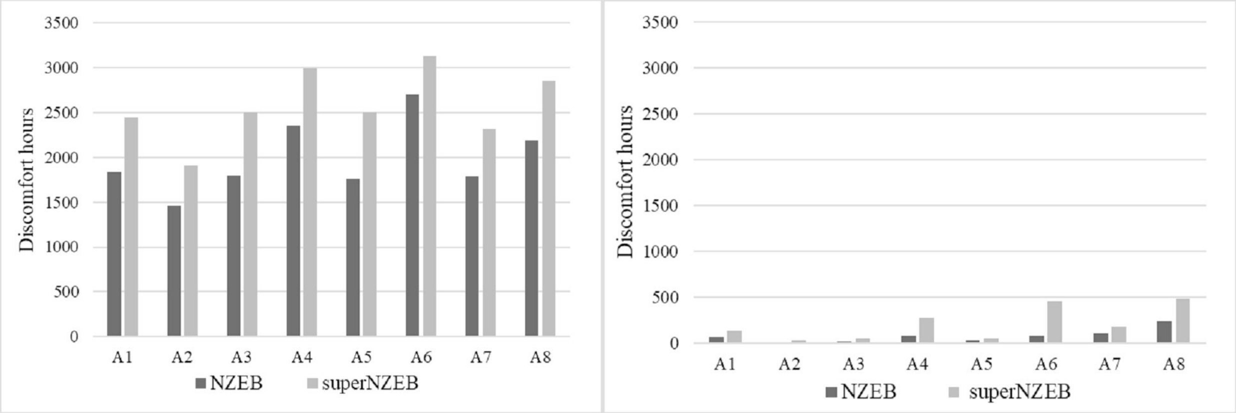

Fig. 2a and 2b. Variation of discomfort hours applying different transmittance of the building envelope (NZEB and Super-NZEB) and different ventilation conditions (0.3 ACH and 0.3 + 1.5 ACH extra night ventilation)

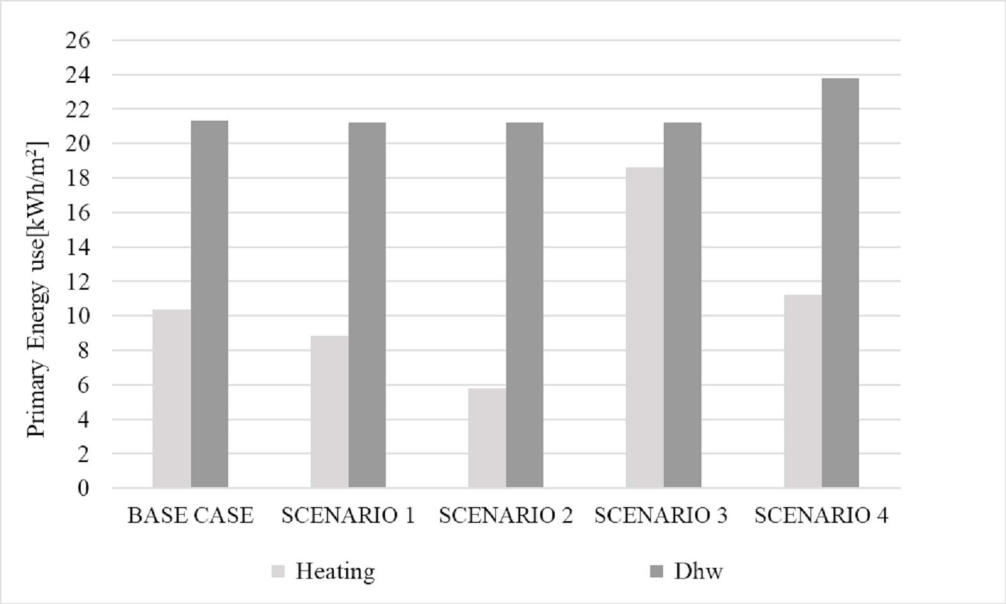

Fig. 3. Primary energy demand

According to the above findings, primary energy demand is presented for the space heating and DHW in fig. 3. DHW results do not significantly differ from each other, only scenario 4 presents a 11% increase. Heating demand presents higher variability, ranging from 5.8 kW/m^2 of scenario 2 to 18.6 kW/m^2 per year of scenario 3.

Results of the life cycle cost analysis are shown in Figure 4 and they are expressed in terms of incremental and actualized savings compared to the base case on 50 years expected lifetime of the building. The global economic indicator is the Net Present Value (NPV) based on: cost and lifetime of the installed products; 2% inflation rate, in in line with the pre-crisis period in Italy and target for the next years; 1.5% discount rate according to the evolution of the current European Interest Rate Swap (EURIRS). Disaggregated evolution costs of energy, maintenance and products were not taken into account, because no reliable predictions are available in the country. Results show that all the scenarios guarantee long term economic savings compared to the base case.

The most profitable scenario is number 2: despite it presents higher initial investments compared to the other scenarios and more frequent and considerable costs for systems replacement, energy costs for fuels are very low, causing final savings up to 55% higher than scenario 3. On the opposite, the least remunerative is scenario 3, which implies the use of electric radiators and therefore it presents the highest energy costs for fuels among the four scenarios.

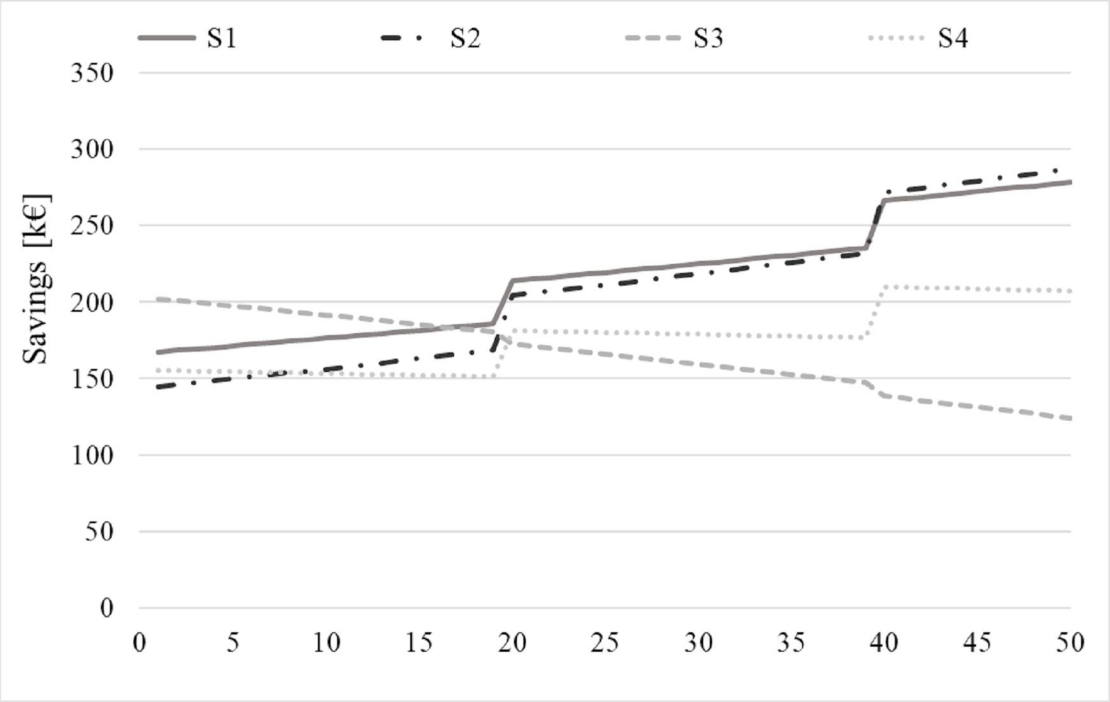

Fig 4. LCC analysis

Table 4 summarizes main data of the 5 scenarios comparing primary energy, energy related construction costs and NPV. Scenario 2 has the lowest overall primary energy, scenario 3 has the highest. Concerning the costs, the proposed solutions decrease the base case between 17% (Sc.2) to 24% (Sc.3). NPV of the 4 scenarios range from 58 €/m^2 (Sc. 3) to 135 €/m^2 (Sc. 2).

Table 4. Comparison among the five scenarios: Primary energy demand, Energy related construction costs and NPV

Scenarios	Envelope	Primary energy demand [kWh/m^2]			Energy construction costs [€]	Construction costs reduction [%]	NPV [€/m^2]
		Heating	DHW	Global non renewable			
Base case	NZEB	10.36	21.34	14.18	392	-	-
1	NZEB	8.88	21.23	14.70	316	-19%	131
2	Super- NZEB	5.78	21.24	13.33	326	-17%	135
3	NZEB	18.59	21.21	20	299	-24%	58
4	NZEB	11.23	23.78	9.70	321	-18%	97

5. Conclusions

In this paper, a cost-effective Italian nearly zero multi-family houses was analyzed to find other technical solutions for further construction cost reductions. Initially, passive solutions for reducing overheating risks in highly insulated building were simulated and low-cost technologies for optimizing performance and costs of NZEB buildings were proposed. The first set of analysis demonstrated that an accurate passive design strongly reduces the discomfort hours during summer, in an acceptable range according to relevant standards. In a second stage, solutions for additional cost reductions were identified and 4 scenarios were defined to assess energy and cost performance in a life-cycle cost approach. Results show that energy performance and energy related construction costs are inversely proportional: the lowest heating demand of scenario 2 corresponds to the highest energy related investment cost while the situation is opposite for scenario 3. On the contrary, a long-term economic analysis (50 years), based on a life cycle approach, demonstrated that scenario 2 is much more profitable than scenario 3, due to the lower energy costs for fuel over the life of the building. These findings suggest that design and construction of high performing buildings should be accurately evaluated in terms of initial, operational and maintenance costs to define the optimal configuration.

Acknowledgements

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