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Energy efficiency measures for an existing residential building in Italy. Improvement of energy certification and fulfilling of the nZEB standard

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ABSTRACT

The current World situation is particularly complex and heavy, from many points of view, among which energy and socio-economic ones. The COVID-19 pandemic, besides causing a health crisis, has brought out, even more, the need to reduce emissions for a healthier environment. The role played by the existing building stock is fundamental, as it is responsible for 36% of CO_2 emissions in Europe. The proposed work aims to define some energy refurbishment interventions, for a residential building in south Italy, regarding the building envelope, the heating and cooling systems, and the addition of systems from renewable energy sources in order to improve its energy labeling. The methodological approach has followed the guidelines for the energy certification of buildings in Italy. It was possible to evaluate the improvement in building energy labels according to the proposed efficiency measures, highlighting those which allow for a tax relief recently introduced by the Government. Finally, the addition of photovoltaic and solar collector systems was evaluated to allow even the fulfillment of nZEB standard.

Keywords: building energy performance, energy efficiency measures, labels, renewable energy, nZEB.

NONMENCLATURE

Abbreviations	
EPBD	Energy Performance of Building Directive
HVAC	Heating ventilation air-conditioning
Symbols	
U_{factor}	Thermal transmittance
$EP_{gl,nren}$	Energy Performance global non-renewable
COP	Coefficient of Performance
EER	Energy Efficiency Ratio

1. INTRODUCTION

In the last decade, the growth of global energy consumption is coming to a halt, indeed, in 2019 there was an increase of just about 1.6% compared to 2018. In EU, due to restrictions, primary energy demand has decreased by 1.1% while the share of renewable energy has risen by 1% compared to 2018 [1]. These data, although positive, are not enough. The economic and social situation suffered serious repercussions due to the COVID-19 pandemic. Several scientists have shown that the worsening of the population health affected by SARS-CoV-2 is connected to environmental conditions and the concentration of pollutants is a factor that increases people's mortality [2-3]. Setti *et al.* [4] evidenced the presence of SARS-CoV-2 RNA on PM and suggested to use it as indicator of epidemic recurrence. This is a clear indication that the reduction of emissions is a priority objective for our health and for the healthiness of the environment around us. A large part (36%) of European CO_2 emissions depend on the building sector and therefore, starting from 2002, it has enacted three versions of the Energy Performance of Building Directive: EPBD 2002/91/EU [5], EPBD Recast 2010/31/EU [6] and EPBD 2018/844/EU [7]. Growing attention is placed on the redevelopment of the existing building stock and on the need to reduce energy demand and increase the use of plants from renewable sources. To match European goals, recently, Italy has issued a Law which provides a 110% tax advantage in the form of tax credit incurred, until the end of 2021, for specific interventions in the field of energy efficiency, anti-seismic interventions, installation of PV or plants for charging electric vehicles in buildings [8].

Our study, consistently with the regulatory context, aims to redevelop an existing building, having constructive and structural characteristics typical of a 70's building in the Neapolitan area by proposing different energy efficiency measures. Specifically, the

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energy retrofits concern the transparent and opaque envelope, heating and cooling systems, renewable sources and these aim at improving building energy class.

Unlike other studies, this one, besides identifying interventions for the improvement of the energy class, underlines those which guarantee the new tax advantage introduced in Italy.

The main questions are: how much energy efficiency interventions limit the building energy demand? Which interventions, on the case study in question, can enable an energy class upgrade, and which one enables the tax advantage provided by Law? How the nZEB standard could be reached? These are crucial questions today in Italy, in the world of construction, and through this study are discussed in detail.

2. THE METHODOLOGY

2.1 The building case study

To obtain a reliable numerical model, fundamental for having reliable results, a 3D building model was built through the software DesignBuilder V6 [9], a graphical interface of EnergyPlus [10], a BPS (Building Performance Simulation) software employed to test and validate building energy performance.

The case study is a building located in Naples (Italic climatic zone C) [11] and it's constructive characterizes were deduced from a reference real building typical of the South Italy building stock of the sixties and seventies. The plan is quite rectangular, 30 m long and 12.5 m wide, and is repeated equally for the 4 floors of the building. Each floor has 4 apartments, for a total of 16 apartments. The net conditioned area is 1337 m^2 and the total volume is about 4070 m^3, while the overall height is 13.2 m and the inter-floor height is 3 m. As showed in fig.1, the longest façades are exposed to the northeast and southwest, and the blind shortest facades to southeast and northwest, respectively.

The thermophysical properties of the building envelope are coherent with the data provided by the following relevant Italian standards UNI TS 11300-1/2008 (abacus A3) [12] (the Official Italian Application of the ISO EN 13790 [13]) and the CTI recommendation R03/3 of Italian Thermo-technical Committee (abacus A5) [14] and are described below:

- A 0.30 m external wall with a thermal transmittance of 0.95 W/m^{2}K and composed of the following layers (starting from the outside): cement-based plaster 0.03 m, aerated bricks 0.12 m, air gap 0.05 m, lapillus block 0.08 m, lime plaster 0.02 m.
- A 0.44 m flat roof with a thermal transmittance of 1.0 W/m^{2}K, composed of a bituminous waterproofing membrane 0.01 m, lightweight concrete 0.15m, 2% reinforced concrete 0.06 m, reinforced concrete, and hollow tiles mixed slab 0.2 m, lime plaster 0.02 m.
- A slab on the ground of 0.30 m with an U_{factor} of 1.35 W/m^{2}K (tiles 0.015 m, lightweight concrete above reinforced concrete at 2% of iron, 0.08 m in total, reinforced concrete and hollow blocks mixed slab 0.20 m, a thin bituminous waterproofing membrane).

For what concerns the transparent envelope, all the windows have double glasses (U_{factor}= 3.2 W/m^{2}K) and old wood frames.

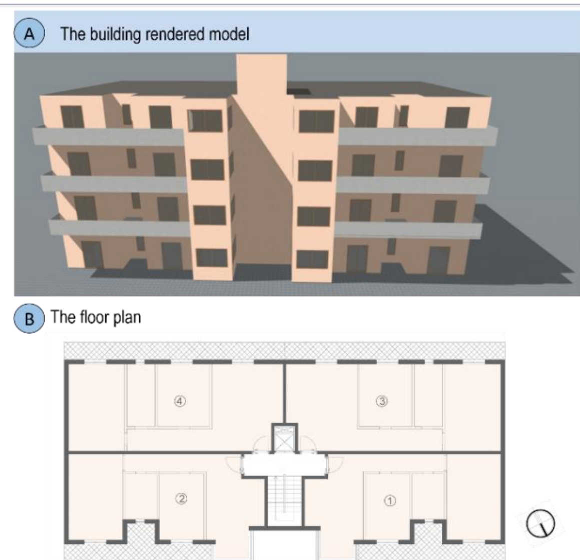

Fig 1 - (a) rendered view of the building model, (b) floor plan of the building

The microclimatic control during the heating period is guaranteed by in-room hot water radiators connected to a gas centralized boiler with an efficiency of 0.6, while during the cooling period, by DX split systems with an EER of 3.0.

The other boundary conditions were set accordingly to the conventional calculation method of the Standard EN 15603 [15], as detailed in section 2.2.

Two different calculation approach for the energy analysis were adopted in this study: a "conventional rating" approach for the energy label (section 2.2) and a "tailored rating" approach for the nZEB standard (section 2.4).

2.2 The calculation method for the energy certification

The energy building certification (APE) is mandatory in Italy [15, 16, 17] for new constructions and in case of a sale, donation, or rental, and assigns an energy class, from A4 to G (A4 = highest efficiency; G=lowest efficiency), based on a global energy performance indicator ($EP_{gl,nren}$). This index depends on the quality of the thermal envelope and efficiencies of energy systems for heating, cooling, and DHW, by excluding the renewable energy systems. The calculation approach for energy labels is not a "tailored rating" but a "conventional rating" (i.e., "asset" or "design") [15] which is based on the conventional boundary conditions listed below:

- Indoor temperature control of 24h, with 20°C constant temperature during the winter and 26 °C constant temperature during the summer.
- Endogenous gains (due to people, lighting system, and electric equipment): 5 W/m^2 (is an average value).
- Infiltration rate: 0.5 h^{-1}.

The considered heating period starts on November 15th and ends on March 31st as suggested by the Italian law (D.P.R. 74/2013 [18]) while the cooling period starts on June 1st and ends on September 30.

The energy class of the building is obtained by comparing the $EP_{gl,nren}$, with those of the reference building ($EP_{gl,nren,rif\ (2019/21)}$) [19] whose input data are reported in Table 1.

COMMON CONDITIONS		
Weather data	NAPLES - ITA IWEC Data WMO#=162890	
Heating setpoint [°C]	20	
Cooling setpoint [°C]	26	
	Reference building	Base building
Infiltration [h^{-1}]	0.5	0.5
Endogenous gains – [W/m^2]	5	5
HEATING, COOLING AND DOMESTIC HOT WATER SYSTEMS		
Heating system efficiency [-]	0.77	0.60
Cooling system EER [Wh_t/Wh_e]	2.075	3
Domestic hot water system efficiency η [-]	0.595	0.80
DHW Heating Systems	Gas Boiler	Electric Boiler
BUILDING ENVELOPE		
Thermal transmittance of the vertical envelope [W/m^2K]	0.34	0.95
Thermal transmittance of the roof [W/m^2K]	0.33	1.01
Thermal transmittance of the ground floor [W/m^2K]	0.38	1.35
Thermal transmittance of the transparent envelope [W/m^2K]	2.2	3.2
CONVERSION FACTORS		
Primary energy factor of Electricity		1.95
Primary Energy Factor of Natural Gas		1.05

Table 1 - Input parameters of the reference building and of the building case study

2.3 The energy efficiency measures

In Italy and in most of Europe it is necessary and urgent to intervene in the existing building stock and to propose solutions that reduce the energy demand of the buildings. Through this work, interventions were proposed for all three levers of energy efficiency, i.e. 1) transparent and opaque envelope, 2) heating and cooling systems and, 3) supply from renewable sources. The different solutions were finally combined to evaluate both the energy-saving and the energy class updates. Three different combinations of interventions were proposed for the building envelope:

1. Replacement of the windows with double Low-E glasses (U_{factor}= 1.7 W/m^2K) and PVC frames.
2. Replacement of windows as described at point 1) and external wall insulation with 0.10 m of rockwool (λ = 0.04 W/mK; c = 1030 J/kgK; ρ = 120 kg/m^3). The wall thermal transmittance results equal to 0.28 W/m^2K.
3. The interventions referred to points 1 and 2 were added to the thermal insulation of ground and roof floors, with 0.12 m and 0.10 m of extruded polystyrene, respectively. The U_{factor} of the roof floor would become 0.23 W/m^2K and those of the ground floor would be 0.28 W/m^2K.

The thermal transmittance of the refurbished envelope complies with the limit values established by [20], proper values to obtain a tax relief of 110% [8].

Two other configurations involve the replacement of the HVAC system:

4. Intervention number 4 concerns the replacement of the existing heating and cooling system with a VRF (Variable Refrigerant Flow) system having an EER equal to 3.2 and a COP of 4.01.
5. Configuration 5 combines the previous energy efficiency measures.

2.4 The nZEB standard

Starting from the refurbished building (configuration 5), to reach the on-site nZEB standard as suggested by Decrees 2015 [17] and Decree Law 28/2011 [21], two other interventions were proposed:

- The addition of a PV system of 27 kW: 75 monocrystalline panels of 360 W, inclination angle 10°, and azimuth 0°.
- The addition of a solar collector system of 12 vacuum panels, with inclination angle 45°, and azimuth 0°, by considering a daily DHW need of 40 l/person (2560 l/day whole building).

According to [21], in the case of new building construction or building refurbishment, the building energy demand must be covered by plants powered by renewable sources, to the extent of at least 50% for DHW production, and at least 50% of the sum of DHW and cooling and heating.

The numerical approach for the energy analysis, in this case, is the tailored rating method, and its boundary conditions and calibration were already widely described in [22].

3. RESULTS

3.1 The energy certification results

The energy class of the building can be evaluated by calculating the $EP_{gl,nren}$ index according to the Italian Ministerial Decree 26/06/2015 [17]. Fig. 2 reports the results of the energy analysis and compares the $EP_{gl,nren}$ of the base building with the $EP_{gl,nren,rif,standard\,(2019/21)}$ of the reference building. The base building has an energy class "D", typical of an energy inefficient building, while the configurations proposed, involves a reduction of the $EP_{gl,nren}$ and therefore the energy class update. The initial class is not too bad because of the presence of good cooling systems (typically, installed in recent years) and windows with double glasses.

Specifically, configuration 1, which provides for the replacement of the windows, however, determines the update of a single energy class, which means that it does not entail access to the 110% tax relief [8]. In any case, this intervention cannot benefit of the full incentives also because it is limited to a surface lower than 25% of the envelope. Moreover, the benefit is only possible with a two-energy class update and thus for Configurations from 2 to 5. All results are proposed in Fig. 2.

	EP - kWh/m²	Energy class
Reference building	71	-
Base building	114	D
Config.1	94	C
Config.2	74	B
Config.3	65	A1
Config.4	72	B
Config.5	57	A2

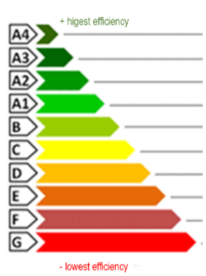

Fig 2 - $EP_{gl,nrel}$ of the reference building, base building and of the configurations proposed with respective energy classes

The following notes are provided:

- Configuration 2 provides for the replacement of windows and the addition of external wall insulation and allows the energy class update to B.
- Configuration 3 adds to Configuration 2 the thermal insulation of the roof, and of the ground floor, and provides for the transition to class A1. Indeed, even if the heating system is not very efficient, the thermal need is very low.
- Configuration 4, which consists of replacing the heating and cooling system, determines the update to class B with an $EP_{gl,nren}$ almost the same of Configuration 2.
- Finally, Configuration 5, which adds up all the interventions, results in a class update to A2. The results are consistent with those of Ascione *et.al.* [22].

Obviously, the choice between the proposed configurations is also calibrated to the economic availability of a possible owner aimed at retrofitting. Therefore, further study could be a cost-benefit analysis of the proposed solutions.

3.2 The nZEB

Taking into account the methodology described in section 2.4 (and thus a "tailored rating", in real conditions of building use), the building Configuration 5 (deeply retrofitted building), provides an annual electric energy demand (for heating, cooling, equipment, and lighting) equal to 47'765 kWh_{el}/year, and thus 36 kWh_{el}/m^2year. In detail:

- electric energy demand for space heating: 1'175 kWh_{el}/year (→ 0.9 kWh_{el}/m^2year);
- electric energy demand for space cooling: 8'885 kWh_{el}/year (→ 6.65 kWh_{el}/m^2year);
- electric energy for artificial lighting: 11'443 kWh_{el}/year (→ 8.56 kWh_{el}/m^2year).
- electric energy for plugs and equipment: 26'263 kWh_{el}/year (→19.64 kWh_{el}/m^2year).

The overall estimated electricity costs, annually, would be around 845 €/100m², by taking into account the price of electricity of 0.234 €/kWh_{el}.

With the integration of PV as aforementioned, the annual PV energy converted is 37'523 kWh_{el} and thus the net integration is 79% of the overall electricity demand.

Of course, energy storages would be suitable for improving the self-use. In fig.3, the monthly electric energy demanded by the building and the electric energy converted by the PV system is shown.

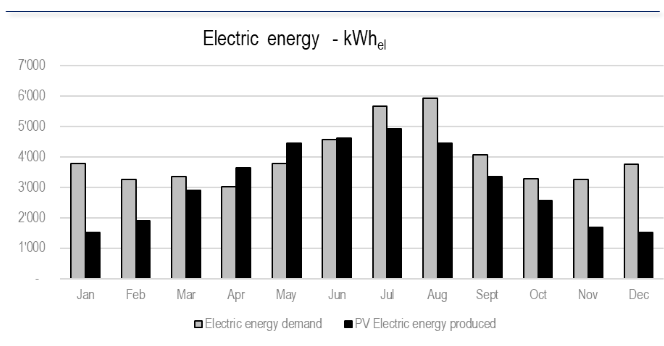

Fig 3 - Comparison of monthly trends between energy demanded and converted by the PV system

For what concerns the solar collector, the production is 27'982 kWh_{th}, and this will cover 80% of the annual demand of DHW.

4. CONCLUSIONS

Considering the very high building energy consumption of the Italian building stock, (compared to quite moderate climatic conditions, with warm winters and hot summers), the study demonstrates the possible energy savings that a typical residential building of south Italy can have after a deep refurbishment intervention. The consequences of various building energy efficiency measures were assessed, both considering the current Italian energy certifications and the nZEB standard. Two different methods of calculation were adopted, in the first case, the 'asset rating' approach and, in the second case the 'tailored rating approach'.

Therefore, by taking into account the Italian energy certification, 4 types of interventions guarantee the update of at least two energy classes, and all involve either a combined intervention on the envelope or the replacement of the heating and cooling system. Finally, according to [21] the on-site nZEB standard was achieved for the refurbished building, through the design of three technologies for the exploitation of renewables: aeraulic heat pumps, solar thermal systems, and photovoltaic system.

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