Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Transformation of a historical building into a Nearly Zero Energy Building (nZEB)

Transformation of a historical building into a Nearly Zero Energy Building (nZEB)

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Abstract. The European Commission strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050 outlines main strategic blocks to maximise the benefits of energy efficiency, including zero emission buildings and to maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply. The following EU Climate Target Plan 2030 underlines, once again and even more urgently than in 2050, the strong need to build a modern, sustainable and resilient Europe, and this high objective means cleaner air, more energy security and more energy-efficient buildings. Looking at these European directives, Italy has signed the PNIEC, with whom intends to pursue an indicative target of reducing consumption by 2030 equal to 43% of primary energy and 39.7% of final energy compared to the PRIMES 2007 reference scenario. To achieve this goal, particular attention is paid to the existing buildings such as Palazzo De Simone. This historical building, built in the eighteenth century on a project by the architect Raguzzini, located in Benevento (BN), is now home to four different uses: the De Simone Theatre, the De Simone Chapel, a faculty of the University of Sannio and the Conservatory of Benevento. Starting from an extensive historical research, as well as from a series of non-destructive in-situ surveys and environmental measurements, it has been possible to create a satisfactory analysis framework. Later, the design objectives have been identified and, starting from these, design strategies and solutions have been formulated. It has been decided to act at a global level with a conservative restoration in compliance with the constraints imposed by the Superintendence, and at a specific level first on the building envelope, leaving the systems unchanged, then on the systems, leaving the envelope unchanged. Finally, crossing the results, the transformation of the historical building in a nZEB has been obtained, in compliance with the legislative constraints imposed by the national regulations.

1. Introduction

To tackle climate change, energy sustainability is the key objective that EU countries set to achieve by 2020 [1] and continue to pursue with the European Green Deal [2] and the NextGenerationEU recovery plan [3], through which they aim to make Europe a climate-neutral continent by 2050. The European Commission proposes to reduce greenhouse gas (GHG) emissions by at least 55% within 2030 compared to 1990, well above the current target of at least 40% for 2030 [4,5].

Italy for Climate's processing of data on emissions for March and April 2020 estimates a decrease in CO_2 emissions from fossil fuels of about 17% compared to the same months of 2019, equal to about 5,7 million tons of CO_2 less, in response to the measures put in place to fight the pandemic [6], data that highlight the importance of implementing green and low carbon policies today to avoid that the years to come are characterized by a new exponential growth of GHG emissions. Italy is currently pushing hard on the need for green and low carbon criteria, in order to achieve the energy savings to be reached in the period 2021-2030 pursuant to article 7 of the EED Directive, aiming to incentivize strategies to improve the energy performance of the building stock [7], a sector responsible today for 40% of energy consumption and 36% of GHG emissions of the European Union [8]. Legislative Decree 48/2020 transposes Directive (EU) 2018/844 on energy performance in buildings and Directive 2012/27/EU on energy efficiency [9]: among the main objectives of the directive are to accelerate the economically

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efficient renovation of existing buildings and integrate long-term renovation strategies in the building sector to encourage the mobilization of economic resources and the construction of zero-emission buildings by 2050 [10].

Why this happens, models and strategies to increase the use of local and renewable energy sources (RES), or new technologies such as the heat pump (HP) [11], play a key role in improving energy independence and the sustainability of areas and buildings [12,13]. Recent technological advances place photovoltaics among the most cost-effective electricity generation technologies [14], and photovoltaics have a low impact when integrated into existing buildings [15].

The energy requalification of historical buildings is an interesting challenge that links the historical-artistic sphere to the technological-plant engineering one with the ultimate aim of improving energy efficiency and environmental comfort [16,17]. In fact, it is necessary to make very intense efforts to maintain the architectural identity and its balance with the refurbishment intervention [18]. This is especially true in Italy where a large part of the national building heritage dates back to the pre-modern and modern age. Most of these buildings, in fact, offer thermal performances that are inadequate to the current needs in terms of energy efficiency, thermo-hygrometric comfort as well as seismic safety [19]. Beyond this criticality, even where the durability of the materials is preserved [20], the design of these buildings involves a high energy consumption, a spatial arrangement not adequate for modern needs as well as neglecting many mandatory requirements according to the current regulations [21].

Moving towards reduction of consumption or the nZEB standard is an achievable goal if an integrated renovation is coupled with a critical analysis on the side of energy production and thermal management strategies [22, 23]. To do this, a simplified dynamic energy modelling of the building has been created, which allowed for a preview of the effect of the changes on the building envelope and plant systems [24].

The Palazzo De Simone in Benevento, conceived as an eighteenth century mansion, then expanded with the construction of a church, subsequently transformed into a college and then modernized and reorganized to accommodate multiple activities, today is overall in poor maintenance conditions. It is currently home to four different uses: the University and the Conservatory regularly in use, the De Simone theatre, owned by the Municipality of Benevento, which occasionally hosts events and the Church of the former college, currently owned by the University, which is closed off to the public, in poor maintenance conditions and totally devoid of windows.

The intent of the study has been to evaluate the thermo-hygrometric comfort, the indoor air quality and the energy performance of the various users of the building with the aim of finding strategies for a global technological-plant improvement such as to make the building compliant with the nZEB legislative standards [25], without exceeding the restrictive constraints imposed by the Superintendence to preserve its historical value, and also referring to similar studies on existing buildings [26], historical and non-historical, seats of schools [27-29], offices and university faculties [30,31], theatres [32] and churches [33,34]. Although starting from an original average energy performance for each of the intended uses, the various simulations have shown that it would be possible to achieve a good reduction in energy needs by making minimal changes in the management and control of systems (HVAC and electrical system). These benefits are further reduced, with higher costs and in accordance with the directives of the Superintendence, updating the technological components of the building envelope. Even more with the combination of all simulated interventions which, all together, allow the achievement of the standards legislation for requalification from a nZEB perspective.

This study also shows how a correct approach to the refurbishment of the existing building heritage can lead to relevant results in terms of improving energy performance in accordance with the conservation of the architectural characteristics of historical buildings.

2. Building features and energy status quo

Palazzo De Simone is one of the historical buildings in Benevento which has been partially restored and used for new uses. In the eighteenth century, the Marquis De Simone had the bourgeois building for his family built on a project by the architect Raguzzini (figure 1).

From 1931 the building became the seat of the Collegio De La Salle. This change in intended use led to a series of expansion and modernization works of the whole building. When the works were completed, very little remained of the noble eighteenth century palace with a Raguzzini's design. In its place stood an imposing four-storey building which lost its size completely, while maintaining the original structure and the layout of the façade [35] (figure 2).

Figure 1. Façade of Palazzo De Simone in its eighteenth century layout - watercolour drawing (image source: Diocesan Archives of Rome, Collegio De La Salle fund, "Trial of the Anonymous Society of Beni Stabili against the Municipality of Benevento").

Figure 2. Ground floor plan and main façade of Palazzo De Simone straightened from a photo taken from Piazza Arechi II in its current condition.

The entire building was affected by restoration, re-functionalization and structural consolidation works in 1983 following the Irpinia earthquake, that brought it to its present structure. Today the building, with approximately 10,000 square meters of gross surface area, houses:

- on the first two floors of the northern wing the De Simone Theatre, a municipal theatre with a capacity of 220 seats that occasionally hosts cultural events, to which the De Simone Garden is annexed;
- in the two upper floors of the same wing there is the De Simone Chapel, owned by the University of Sannio, but currently unused and unusable because of the degraded condition and alteration prevailing in its status;
- in the central part, which develops around the two internal courtyards, there are the library and some offices belonging to the Economics Department of the University of Sannio;
- in the southern wing the "Nicola Sala" Conservatory of Benevento.

3. Materials and methods

3.1 Methodology

The methodology followed in this work includes analysis of thermo-hygrometric comfort, indoor air quality (IAQ) and an evaluation of energy performance (EP). The comfort and energy aspects have been estimated through numerical simulations, according to established procedures, technical standards and other official international references.

The thermo-hygrometric comfort, the indoor air quality and the energy performance of the building have been evaluated and compared in the four different variants performed with the same calculation criteria: (1) the building in its current state; (2) the building with refurbishment and/or substitution of the components of the building envelope; (3) the building with redevelopment and/or replacement of the HVAC and electrical systems; (4) the building with the crossing and the sum of the interventions made in case (2) and (3).

The methods applied in this research are detailed in sections 4.3-4.5.

The thermo-hygrometric comfort and the IAQ have been evaluated through the indices and procedures specified in the technical standard EN 16798-1 [36].

From the point of view of energy performance, reference has been made to the technical standard EN ISO 52000-1 [37], according to which the overall energy performance of a building is the calculated or measured quantity of weighted energy necessary to meet the associated energy demand the typical use of the evaluated object: this includes the energy used for heating, cooling, domestic hot water production, lighting, transport of people or things etc.

As in the Inter-Ministerial guidelines [38] the energy performance of the building has been calculated and expressed in terms of total annual non-renewable primary energy normalized for the net conditioned area. The actual energy services of the existing building have been included, while in the refurbishment interventions, cooling and domestic hot water have been also considered. In the calculation of energy performance, the production of electricity from technologies that use RES (photovoltaic system and heat pumps) has been distributed in proportion to the electricity demand of each user. The non-renewable primary energy conversion factors of the energy carriers applied in the assessment of the EP are the Italian national values established by the above-mentioned Inter-Ministerial decree of 26 June 2015.

The data necessary for the analysis of the building have been obtained through archival investigations, by consulting the documentation relating to the construction process of the building, filed with the Superintendence of Archaeology, Fine Arts and Landscape for the provinces of Caserta and Benevento and in the Archive of Civil Engineers of Benevento. To confirm the documentation found, non-destructive in-situ investigations (thermography) and environmental measurements (temperature, relative humidity, air quality [39]) have been also led.

The thermography investigations have been executed on 26/01/2018, from 15:45 to 16:30, with air temperature of 13.5 °C, relative humidity of 61%, clear sky and no wind and on 27/01/2018, at 15:00, with air temperature of 6.5 °C, relative humidity equal to 95%, overcast sky and no wind.

3.2 Current condition of the building envelope

In general, the opaque structures of the building envelope, in accordance with the construction techniques of the time, do not have an insulating layer. The perimeter walls of the entire building are sack walls, with an overall thickness on the ground floor of 1.05 m. It is a facing masonry in blocks of stone and brick plastered and left exposed in some sections of the east elevation due to recent interventions. The slabs, reinforced during the 1983 works, are composed of double T beams for reinforcement in the intrados, metal mesh and mixed slab made of IPE 120 beams and reinforced concrete, to ensure good operation in the event of an earthquake. Beyond the good seismic behaviour, however, it has been noted that the ground floor lacks adequate waterproofing useful to protect it from the phenomena of alteration and degradation linked to the presence of humidity rising from the ground and also the roof slabs do not have an adequate protective thickness. The existing windows have a wooden frame and a glazed component with single glass, therefore they are ineffective both from the point of view of thermal and acoustic insulation.

From the analysis of the construction technologies and the thermo physical characteristics of both the opaque and transparent components, data to underline emerge: first of all, the study of the vertical opaque structures has highlighted how, in its current condition, its transmittance falls within the limit values imposed by 2021 in the DM 26/06/15 [38].

However, considering the energy performance of the building, it should be noted that the envelope in the winter season is not sufficient to ensure a good level of indoor comfort.

As regards the horizontal structures, none of the elements have a sufficient transmittance to make it fall within the parameters required by the aforementioned Ministerial Decree and, above all, none of the ground floor, flat roofs and pitched roofs have an insulation layer suitable for protecting the structures from the indoor formation of mould and condensation.

Finally, from the analysis of the stratigraphy of windows and doors, it can be seen that these are now obsolete compared to the modern technologies and scarce, not only from a regulatory point of view but also and above all for the thermal and acoustic insulation.

3.3 Current condition of the systems

The current plant configuration includes diversified systems serving the four building destinations:

- the Theatre is equipped with a winter heating system (simulated system based on the minimum requirements for the reference building);
- the Chapel is currently lacking in winter and summer air conditioning systems;
- the University is served by a winter heating system with two gas heat generators and a series (16) of small summer air conditioning systems with direct expansion type heat pump;
- the Conservatory is served by a heating system with two gas heat generators (for similarity with the winter behaviour of the University).

From the analysis of the layout of the systems and of the types of production, distribution, regulation and emission systems currently present in the building, it is undoubtedly a good strategy to have separated the four users and to have therefore distinguished the four production: first of all this strategy is useful to reduce management costs and to make an objective quantification of consumption, moreover it has avoided to create a distribution and channelling network that is too complex, and therefore more difficult, to access for inspections and maintenance interventions of different kinds.

The characteristics of the systems currently present are in line with the period of construction (1980s of the last century).

The electrical system of each intended use (with the exception of the Theatre where an autonomous system for stage lights is added and of the Chapel where there are no light bulbs) is now clearly compliant with current regulations: however, it must be considered that the Tubular fluorescent bulbs, which fall into the category of discharge bulbs, have evolved and those installed with a diameter of 38 mm are to be considered obsolete, large and by now scarcely used.
The important differences in terms of use of the buildings should be emphasized: the University and the Conservatory have a period of occupation of the building (in terms of working hours and days of activity) almost daily, the Chapel is currently unusable and the Theatre is used only for sporadic events organized by the Municipality.

Based on this set of information, a building model has been built using a simulation tool developed by the Research Group which allows a single zone dynamic simulation and which implements a finite difference simulation algorithm [24].
The building model was validated by comparison with the data from energy bills.
According to energy labelling, the building in its current state belongs to category D since its $EP_{gl,nren}$ consumption is 174.9 kWh/m^2y; no renewable fraction is now available.

4 Results and discussion

Starting from the analysis of the existing situation, the main design objectives have been identified, in line with the intent of transforming Palazzo De Simone into a nearly zero energy building:

- minimize the environmental impact of Palazzo De Simone;
- ensure a high level of microclimatic comfort and good air quality in the rooms;
- ensure the conservation and integrity of the property while preserving its historical character;
- improve the energy performance of the building, reducing energy requirements and consequently management costs.

Two macro intervention hypotheses have been therefore formulated to be applied globally:

- conservative restoration of the façades by:

  - the disinfection and removal of microorganisms, algae, fungi and lichens;
  - spray and dry cleaning;
  - grouting with reintegration of lacks, flaking or disintegration;
  - the removal of spontaneous weed vegetation;

- installation of masonry dehumidification systems for problems related to water rising from the ground: rising damp is due to the ability of water to penetrate into the walls and rise upwards through the capillaries present in the constituent materials of the walls. This physical mechanism is triggered by electrical forces that the walls exert on the water molecules present in the ground in contact with the masonry, subject to electrify. To neutralize this phenomenon, there is a non-invasive and totally biocompatible system: a small appliance (28x17x6cm) is installed inside the building to be connected to a plug. This device neutralizes the electrical charge of the water present in the ground thus interrupting the rising of new water. The moisture present is gradually expelled through spontaneous evaporation;

and other hypotheses of intervention to be carried out in an appropriate manner according to each of the four intended uses (figure 3).

4.1 Intervention strategies for the building envelope

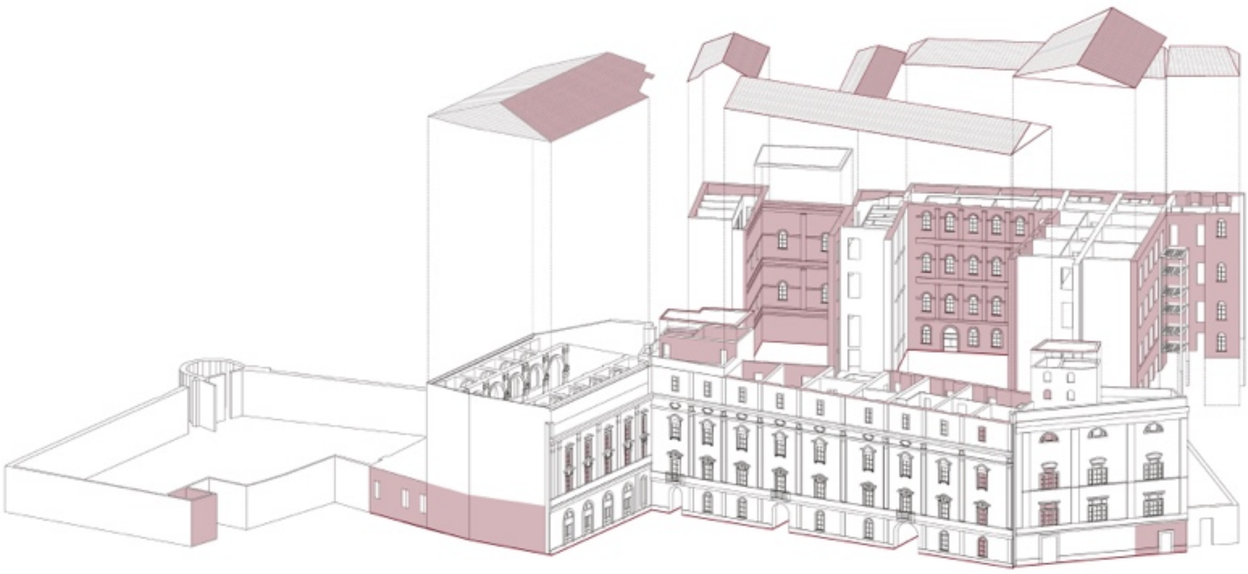

Figure 3. Axonometric exploded view and design strategies

The following interventions have been hypothesized limited to the building envelope:

1. replacement of windows, with windows equipped with double low-emission glass;
2. insulation of horizontal structures, both in contact with the ground and for roofing; it has been decided to use the innovative raw material *neodur*; for the bottom floor the choice has been to insert the insulating layer below the marble floor, in compliance with the historical and architectural constraints of the building; for the roof it has been chosen to add the insulating layer from the outside, considering this the most suitable solution to eliminate thermal bridges and the risk of interstitial condensation;
3. insulation of vertical opaque walls; although the value of the transmittance was already low enough, an internal insulation intervention with the same material identified for the horizontal structures has been still hypothesized.

4.2 Proposed solutions for the building envelope

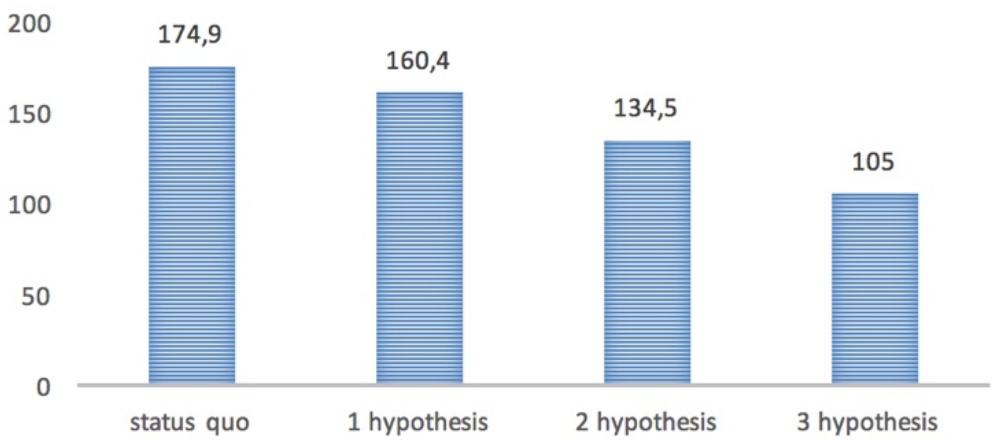

Figure 4. Primary energy consumption [kWh/m^{2}y] for the interventions on the building envelope.

As a first hypothesis of intervention, it has been deemed necessary to replace the windows and doors by evaluating which were the construction technologies of the transparent vertical structure that were

more efficient than the needs of the building (it is essential that the windows chosen for the conservatory and theatre have good levels of acoustic insulation, as well as than thermal).
The choice therefore fell on low-emission double-glazed windows, for the theatre and the conservatory also soundproofing and sound-absorbing.
In conjunction with the replacement of the selected windows, in hypothesis 2 improvements have been made in the insulation of the horizontal structures, both in contact with the ground and as a roof. The innovative raw material *neodur* has been chosen, whose substantial evolution consists in the winning combination between the expanded polystyrene (EPS) polymer, which is obtained from natural resources, and a natural organic product: graphite. This, encapsulated within the cellular structure, absorbs and reflects heat radiation, significantly improving the insulating performance of the material. It is a material permeable to water vapour but, at the same time, impermeable to water: the permeability to water vapour means that moulds do not form inside buildings insulated with polystyrene; instead of water, the absorption by capillarity of this material comes to nil.
In the third hypothesis of intervention, the benefits obtained from the replacement of the windows and the insulation of the horizontal structures have been added together with the attempt to improve the vertical structures as well. Although from a thermal point of view these already fall within the required parameters (and therefore for the purposes of energy requalification they could be considered satisfactory) to obtain an improvement in the overall energy performance in the winter season it is also necessary to modify these structures: the choice was therefore that to make an inner thermal coat (figure 4).
The internal thermal coat removes the problem of condensation, thermal bridges, humidity and mould. Above all, it offers good thermal insulation depending on the chosen materials, also acoustic (the changes made to the building envelope in the modelling, have been made excluding the part of the envelope of the De Simone Chapel and the De Simone Theatre due to the exceptions expressed in the Attachments of the Ministerial Decree). To make a thermal coat it is better to prefer natural materials because artificial ones tend to favour the formation of mould and therefore to be toxic, for this reason it has been chosen to make it with the same insulating material used for horizontal structures.
The table below shows the comparison between the transmittance values of the existing structures and those hypothesized by intervention (Table 1).

Table 1. U-value of building components.

	U [W/m^{2}K]	
Description	Status quo	Proposed solutions
Vertical building envelope	0.34	0.17
Ground floor	1.03	0.37
Roof	1.15	0.31
Original windows	3.62	1.03

The combination of these interventions on the building envelope allows to reach the energy class B based on the non-renewable primary energy parameter (a reduction of 40% compared to the current state) with the value of $EP_{gl,nren}$ = 105 kWh/m^{2}y with an average energy performance of the building in the winter season and a good performance in the summer season.

4.3 Intervention strategies for the HVAC and electrical systems
Regarding the systems, four other intervention hypotheses have been formulated:

1. improvement of the regulation system, with the introduction of suitable systems for temperature control for each room;

2. replacement of the light bulbs now used in the building with LED ones; to these, for the University and the Conservatory, it has been decided to associate a motion and presence detection system to adjust the brightness based on daylight and movement in the rooms;
3. replacement of heat generators with the introduction of high-efficiency silenced heat pumps;
4. introduction of a photovoltaic system for the in-situ production of electricity from renewable sources; for the roof covering, 540 m^2 will be replaced with tiles with integrated photovoltaic system, in a position not visible from the ground level.

4.4 Proposed solutions for the HVAC and electrical systems

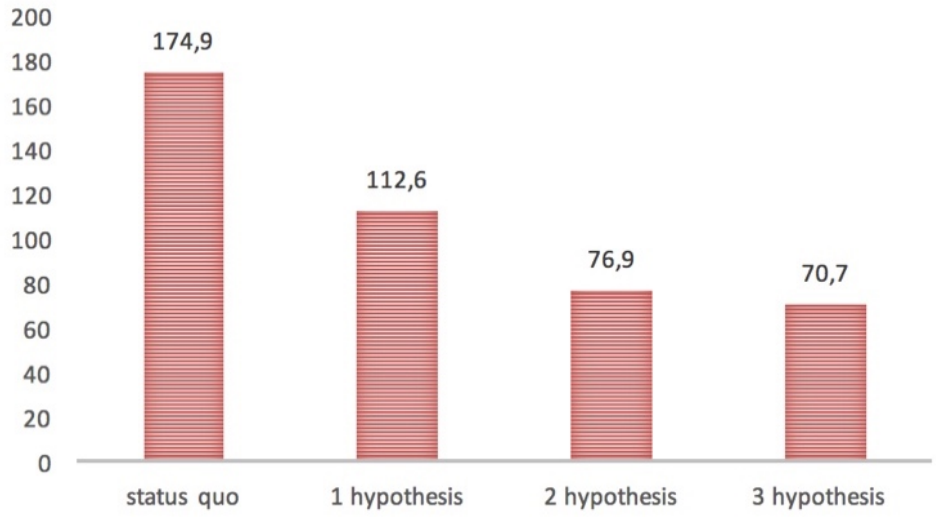

Figure 5. Primary energy consumption [kWh/m^2y] for the interventions on the HVAC and electrical systems.

In the first hypothesis of intervention, an attempt has been made to leave the production system unchanged by making a change to the heating subsystem: in all terminals present in the University and in the Conservatory (in this case the less performing radiators have been replaced and new radiators have been integrated in environments that do not have them) it has been decided to install thermostatic valves coupled to the electronic thermostatic heads that regulate the inflow of hot water from the radiator based on the ambient temperature and to the set programs. They also make it possible to adapt the thermal comfort needs to the user's needs, obtaining significant savings on heating costs.
As for the electrical system, the existing light bulbs have been replaced with LED ones of a smaller diameter (T8=26mm): these light bulbs are energy-saving, they reduce consumption and consequently the costs in the bill and also guarantee a long life. To these lamps, for the University and the Conservatory, it has been decided to associate a motion and presence detection system to adjust the brightness based on movement in the rooms and daylight.
In hypothesis 2 of intervention, with the changes made to the regulation subsystem in the previous hypothesis, it has been decided to intervene with the replacement of the heat generation machines: a high silenced efficiency heat pump has been installed for each of the users. These heat pumps are reversible outdoor machines for the production of high efficiency chilled/heated water, with axial fans and external copper coils with aluminium fins. In cold operation, it is also possible to produce hot water for free. The base, the structure and the panelling are in galvanized steel treated with anti-corrosion polyester paints, therefore suitable to be placed on the ground floors but for the Theatre, the replacement would require a modification of the roof covering of the thermal plant to be substituted with a grid for ventilation.

In addition to the changes to the layout of the heating and electrical system expressed in the previous hypotheses, in the third hypothesis of intervention, the production of electricity is inserted through powered systems from renewable energy sources (RES). According to the calculations carried out with respect to the global surface of Palazzo De Simone, at least 60kW of energy produced from RES are required, reached and exceeded, through the aero-thermal energy of heat pumps and photovoltaics which together allow to satisfy one of the two legislative obligations which a building must undergo in order to be classified as nZEB. For the roof covering, 540 m^2 have been replaced with tiles with an integrated photovoltaic system. This photovoltaic system transforms the roof of the building into an electricity generator without changing its appearance and allows the preservation of historic centres without giving up the use of renewable energy (figure 5).
An evaluation of the improvement measures limited to the plant systems alone has made it possible to reach the energy class A1 with a reduction of 59% of the non-renewable primary energy parameter and an average quality of the performance of the building in the winter season and a good quality of performance in the summer season.

A comparison between the improvements deriving from the interventions on the building envelope and those on the systems (figure 6) highlights how it is more convenient to privilege interventions on the systems, leaving out those on the building envelope, if you have to choose the preferred strategy for energy efficiency at a lower cost and in compliance with the constraints imposed by the Superintendence.

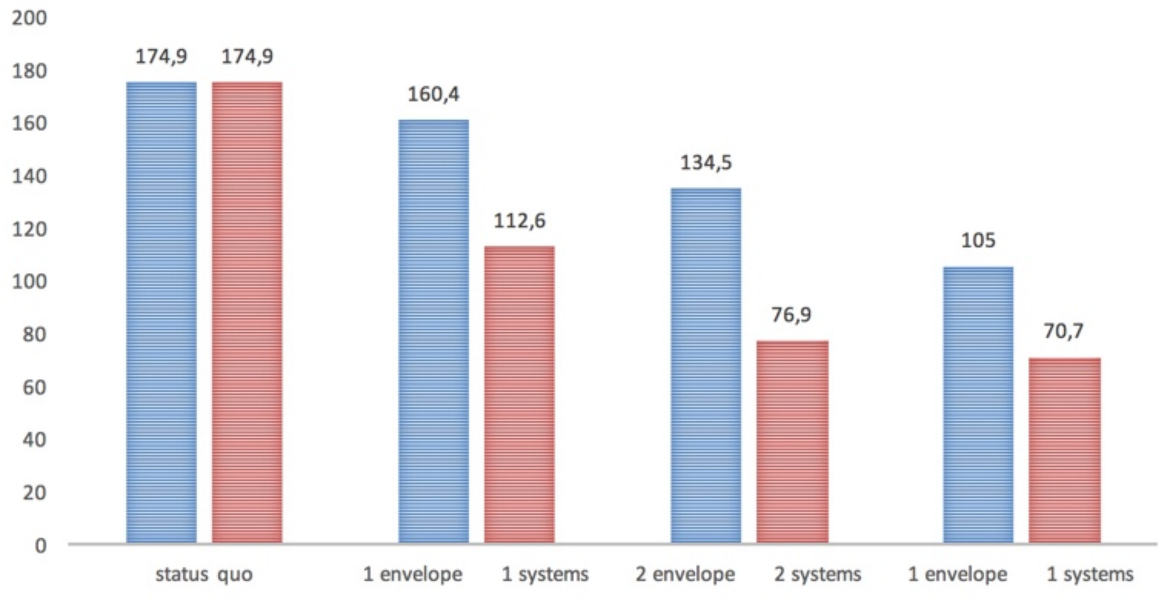

Figure 6. Comparison of the primary energy consumption [kWh/m^2y] for the interventions on the building envelope and the intervention on the HVAC and electrical systems.

However, assuming the joint implementation of all the proposed interventions, the Palazzo De Simone undergoes a major first-level renovation ensuring that all the regulatory requirements, provided by the Ministerial Decree of 26 June 2015 on the "minimum requirements" to obtain the near zero energy building qualification [25], are respected.

4.5 Data crossing between the intervention on the building envelope and on the HVAC and electrical systems
The design solution to achieve the nZEB goal is formed by combining the interventions provided for on the building envelope with those for the plant systems.

Summarizing on the building envelope, we proceeded with:

- the increase in the thickness of the ground and roof floors inserting an adequate layer of thermal insulation of the horizontal structures;
- total replacement of all windows; and finally
- the increase in the thickness of the vertical perimeter structures, for the creation of an internal thermal coat;

while on the plant system the following interventions have been envisaged:

- the modification of the regulation and emission subsystems with the addition of components for thermal control in each room;
- the global replacement of light bulbs with the addition of elements for controlling movement and presence in individual spaces according to their use, with consequent savings on electrical consumption;
- heat pumps in place of existing heat generators (with consequent structural reinforcement of the roof slab and adaptation of the rooms that house the existing thermal plants); and at last:
- the insertion of a grid-connected photovoltaic system on the roof by partially replacing the existing mantle with tiles equipped with an integrated photovoltaic system. Thanks to this, the energy needs of the whole Palazzo De Simone are half covered by renewable energy sources and grid-connected, i.e. connected in parallel to the public electricity grid, to cede the excess electricity, capable of reducing the energy needs of other buildings.

According to energy labelling, the building belongs to category A3 since its $EP_{gl,nren}$ consumption is 36.6 kWh/m^{2}y; the renewable fraction reaches 55% considering the aero-thermal energy of the heat pumps and the electricity produced by the photovoltaic system. Those quantities are depicted in Table 2.

Table 2. Primary energy consumptions.

		Heating	Lighting	Total
Renewable	[kWh]	204684	107024	311708
Non-renewable	[kWh]	287885	77505	380308
Total	[kWh]	492569	184529	692017
Renewable fraction	%	41.6%	58%	55%

5 Conclusion

In this study the issue of energy requalification of historical buildings has been addressed. For these buildings it is generally possible to derogate from compliance with the legislation on energy saving. However, in respect with historical and architectural constraints, interventions are still possible to improve thermal-hygrometric comfort, IAQ and energy performance of the building, which allow to use it with lower costs for energy supply and with greater environmental comfort.

It has been demonstrated how each intervention, taken individually, already brings in itself an improvement in the overall performances of the building: this highlight the general steps to achieve the goal and also the benefits that are brought to the building. Therefore, in the event that the necessary funds are not available to carry out the project in its entirety, on which intervention the economic effort should be concentrated more to refurbish the Palazzo di Benevento from an energy and comfort point of view.

However, it is thanks to the combination of all the interventions on the building envelope and on the engineering systems that it is possible to reach the energy class A3 and, from a procedural point of view, to see all the requirements met thanks to lower values compared to those of the reference building formed by the software (with the same geometry, orientation, territorial location, intended use, surrounding situation and thermal characteristics of the envelope). So that, the parameters imposed by Italian law are observed and the historical Palazzo De Simone could be defined as a "nearly zero energy building (nZEB)".

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