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NZEB target for existing buildings: case study of historical educational building in Mediterranean climate

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Abstract

A key element of the Energy Performance of Building Directive 2010/31/EU is the introduction of nearly zero energy building (NZEB) standard for new constructions. However, considering the very low rate of new built volume, the major change for achieve the sustainable grow of the European economy, appears to be the renovation of existing building stock. But, is it possible to reach very low or nearly zero energy standard during refurbishment design?

Proposed paper tries to answer this question, evaluating if the refurbishment of historic architectures to very low energy need is possible and economically feasible. With reference to a case study, this paper investigates the cost-optimal energy refurbishment of a Renaissance-style palace, located in the center of Naples, South Italy.

The adopted methodology consists of various steps. Firstly, a model of the building has been accurately built and calibrated. Then, it has been used to evaluate possible interventions concerning both the envelope and the energy systems. The best solutions, chosen according to the European methodology of cost-optimality, have been combined in a last simulation. The results show that great energy savings as well as economic and environmental improvements are possible, although heritage buildings present a less flexibility in the proposal of energy efficiency measures.

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Keywords: Historical buildings; Dynamic simulation; Energy retrofit; NZEB; Cost-optimal; Calibration of energy models.

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1. Introduction: energy efficiency and historic buildings

The aim of the European Council is to reduce the greenhouse gas emissions by 80-95% by 2050, compared to levels of 1990. About it, a better construction activity and use of buildings would influence the 42% of final energy consumption and about 35% of CO_2 emissions [1].

Given the low turnover rate of the building stock, the greatest challenge is the refurbishment of the existing buildings, even more than the construction of nearly zero energy buildings; recent statistics, indeed, reveal that 14% of EU-27 building-stock dates before 1919, about 12% between 1919 and 1945.

For what concern historic buildings, at present time, the only European regulation, dealing with Architectural Heritage, is the "Convention for the Protection of the Architectural Heritage of Europe" [2] which does not provide limits about the energy performance of historic buildings. For this reason, energy retrofit is not mandatory for historical buildings and these are excluded from the energy regulations measures if the refurbishment induces prejudice of the historical value.

Nomenclature

A_{month}	mean of the monthly utility bills
ACH	air changes for hours (volume/h)
CE	Exercise costs (€)
$CV(RMSE_{month})$	coefficient of variation of the root mean squared error (%)
DPB	discounted pay-back period (years)
EP	primary energy demand (kWh or MWh)
ERR_{month}	error in the monthly consumption (%)
ERR_{year}	error in the annual energy consumption (%)
M_{month}	measured electric consumption (kWh)
N_{month}	number of utility bills in the year
NPV_{20}	Net Present Value (lifetime equal to 20 years) (€)
RMSE	mean squared monthly error
S_{month}	simulated electric consumption (kWh)
S/V	dispersing surface to conditioned volume ratio(m^{-1})
U	thermal transmittance value ($W/(m^2 K)$)
U_w	window transmittance value ($W/(m^2K)$)
V	volume (m^3)

A number of previous studies provided examples in which the possible coupling of protection of Cultural Goods and sustainability of the renovation design have been developed suitably. With reference to warm climates, De Berardinis et al. [3] have investigated various masonry buildings damaged by the 2009 earthquake in Abruzzo. Ascione et al. [4] applied the cost-optimal analysis of energy conservation measures to an ancient building (XV century) located in Naples. Dalla Mora et al. [5] and Bellia et al. [6], have proposed other examples of energy-oriented refurbishments of historical buildings, Papadopoulos et al. [7], for a medieval tower in Northern Greece, recently converted in a museum, Pisello et al. [8] have investigated the energy refurbishment of 'Palazzo Gallenga Stuart', a historic university building located in Perugia. About the achievement of NZEB target on a historic building for tertiary use, Mauri [9] has shown that by retrofitting the existing with common technological solutions in Agrigento, it is possible to reduce energy of about 30%. However only using on-site renewable sources, the budget can ensure the achievement of the NZEB target.

For what concerns the methodology of analyses, few works study refurbishment solutions through the use of dynamic simulation and indoor climate measurements. Ascione at al. [10] used EnergyPlus to model historic buildings in Benevento. Todorovic et al. [11] proposed a holistic and sustainable approach for the refurbishment of the Aviation

Museum in Belgrade, by using Building Energy Simulation and renewable energy implementation. A more complex building, Albergo dei Poveri in Genoa, was recently studied by using the semi-dynamic approach by Franco et al. [12]. More recently, Cornaro et al. [13] used a commercial tool, IDA ICE4.5, in order to build a re-liable model of a complex historic building, Villa Mondragone, in Rome.

Starting from the previous considerations, this study has the main aim of evaluating the potential energy efficiency measures that can be applied to a real case study building, characterized by evaluable historical features. The proposed approach can be schematized by means of three main steps:

a. accurate building modeling by means of hourly energy simulations;
b. calibration and validation of the simulation model;
c. investigation of potential energy savings and environmental benefits, by evaluating their economical profitability, through the methodology of the cost-optimal approach for the decision-making.

2. Palazzo Gravina: history and description

The chosen case study is one of the administrative and didactic buildings of the Department of Architecture of University of Naples, presently known as “Palazzo Gravina” (figures 1a, b, c). The building is a Renaissance-style palace, located just at the border of the Roman City, in Via Monteoliveto, in the San Lorenzo district of Naples (Italy). Since 1940, it has housed the Faculty of Architecture of the University of Naples. Palazzo Gravina is located across the street and a few meters north of the sleek and modern Post Office, well-known all around the World for its architectural value (figure 1d).

Fig. 1. Palazzo Gravina: overview (a), main façade (b), courtyard (c), near post-office (d)

The main facade, on Via Monteoliveto, has a rusticated stone brick base for a first floor. The second floor has marble-framed windows, surmounted by circular niches with busts (figure 1b). The tall windows rise on a marble cornice, and are separated by piperno rock pilasters with mixed Doric-Corinthian capitals. The palace underwent restorations after a fire during the Neapolitan revolution of 1848 by means, a third floor with balconies was added in the 19th century, but these were removed in the 20th century.

3. Methodology

As said, the method consisted of three steps. The first phase regarded an accurate survey of the building, carried out through the study of historical documents, careful in-field investigations and visual inspection.

The second step consisted in the definition of the building model, by using a whole building simulation software. Evaluable examples of application, through different numerical methodologies, are discussed in many studies, referred to particular criticalities [14] or components [15] of the thermal envelope, the whole building thermo-physics [16, 17], HVAC systems and equipment and renewable sources [18, 19].

In order to simulate reliable energy performances, the numerical model of “Palazzo Gravina” has been created according to the procedures of “tailored ratings”, as defined by the international standard UNI EN 15603 [20]. As proposed by the M&V Guideline [21], with the “Whole Building Level Calibration with Monthly Data”, the output of simulations have been compared to the measured energy data, by determining the deviation and the relevant uncertainty. Finally, the calibrated model was then used to evaluate the annual energy performance of the present situation and of the various alternatives for the energy refurbishment.

3.1. Building modeling for hourly energy simulations

The building model has been defined by using EnergyPlus v8.4 [22], with the graphical definition of the geometry, dimensions and positions of the thermal envelope assigned by means of the program interface Design Builder [23].

Climate

The city of Naples is inside the Italian Climatic Zone “C”, characterized by 1316 Heating Degree-Days (baseline 20°C). The city has a moderate climate, typical of the Mediterranean areas, characterized by warm summers and not cold winters. Summary information are reported in Table 1 [24].

Table 1. Climate characteristics.

Latitude	{N 40° 50'}
Longitude	{E 14° 18'}
Elevation (m) above sea level	72
Maximum Dry Bulb Temperature (C)	35.0° (Jun 12)
Minimum Dry Bulb Temperature (C)	-3.0° (Mar 12)
ASHRAE Climate Zone	3C

Layout

The investigated edifice has a square shape, a global elevation of three usable floors above the ground (by including the level in contact with the ground), an overall height of about 15.0 m.

The definition of the model is shown in figure 2, with reference geometrical model with Design Builder (a) and real building (b).

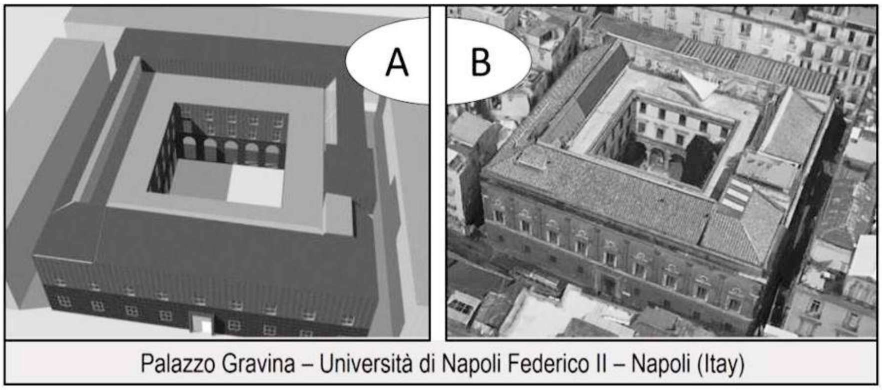

Fig. 2: The building model in Design Builder (a) and the real building (b)

The planimetry dimensions are 53.5 m × 54.0 m. In the middle, there is a courtyard of about 21.5 m × 21.5 m. The "surface to volume ratio"(S/V) is equal to 0.26 m^{-1}. Table 2 provides the main building data for each façade.

Table 2. Building characteristics and Window–wall ratio of the vertical envelope.

Total Building Area		**5677.2 m^2**	**Total building volume**			**≈ 21808 m^3**
Net Conditioned Building Area		4698.5 m^2	Height of building			≈ 15.0 m
Unconditioned Building Area		978.7 m^2	Surface to volume Ratio			0.26 m^{-1}
		Total	North	East	South	West
Gross Wall Area	m^2	3781.2	1029.4	922.1	923.0	902.8
Window Opening Area	m^2	980.9	289.9	274.1	153.4	263.6
Gross Window-Wall Ratio	%	25.9	28.2	29.7	16.5	29.2

Materials and windows

The building structures are described in the following bulleted list:

- ✓ The external walls have composite structure, with 3 layers: the external one is made of granite (6.0 cm), tuff of high density (50 cm) and a cement/lime plaster (4.0 cm). The U_{value} has been estimated around 0.97 W/m^2K.
- ✓ The horizontal structures have 80 cm (average value, by considering the vaults' shape) of lime and sand layer, a layer of 19 cm with cement basis and 10 cm of roof tiles or ceramic tiles The overall modeled U_{value} is around 0.34 W/m^2K, for both the floor on the ground and the roof structure.
- ✓ The windows have a painted wooden window frame, with a single layer of clear glass of 3.0 mm. The overall U_w is around 6.26 W/m^2K, with a SHGC equal to 0.858. All windows are provided with shading systems. In detail, the ones situated on the second and third floors have internal slats (blind with medium reflectivity), while the skylights positioned on the roof's block have external dark weaved drapes.

Activities

The building hosts some classrooms and administrative offices of the Department of Architecture of University of Naples. Indeed, in order to define reliable thermal loads into the building model, two different typologies of thermal area have been created classroom and office. The air change rate has been fixed to 1.5 ACH; this value has been considered reliable by taking into account the voluntary openings of windows and door, as well as the poor airtightness of the present thermal envelope.

HVAC System

Presently, the building has indoor fan coils fueled only during the heating season by means of the hot thermal-vector fluid produced by gas boilers. Indeed, the summer cooling is not presently provided. A detailed model of HVAC system has been adopted: it presents an old fabricated high temperature boiler (nominal efficiency = 0.83, constant discharge temperature of 70°C, nominal capacity of 740 kW) and fan coil units (fan efficiency = 0.7, pressure head = 150 Pa, Air Flow = 3 m^3/s; pumps' motor efficiency: 0.9).

For what concerns the heating program, according to the Italian law for the climatic zone C, the heating periods starts at the half of November and terminates at the end of March. Obviously, weekends and national holidays have been considered. The building is heated at 20°C from 8.00 am to 6.00 pm, from Monday to Friday.

3.2. Sensitive analyses to the boundary conditions

According to the standard EN 15603 [20], in this study, the Tailored Rating has been applied. In this regard, the transient energy simulation is much more suitable and precise compared to methods based on steady state heat transfer algorithms. Of course, various algorithms for the heat transfer can be adopted. In this work, simulations at different time-steps of calculation, have been carried on, mainly using two algorithms:

- Conduction Transfer Function algorithms (CTF),
- Conduction Finite Differences algorithms (ConFD).

Finite Differences (ConFD) provide completely the spatial heat transfer through the building surfaces, by identifying the temperatures at each node of the thermal envelope, so that the thermal field is completely determined. Compared to CTF, the required calculation power is higher, as well as the simulation time.

For this reason, a sensitive analyses at the boundary conditions has to be performed, in order to ensure the maximum precision, combined with the minimum simulation time. By considering the results (Table 3), it's evident that the optimal solution is the one with a number of time-steps equal to 4.

Table 3. Simulation times and percentage difference with ConFD simulation

Number of time steps	Percentage difference (electric) [%]	Percentage difference (gas) [%]	Simulation time [min]
ConFD Time-step 2	**---**	**---**	**180**
CTF Time-step = 2	1.74	0.06	15
CTF Time-step = 4	- 0.05	- 0.25	18
CTF Time-step = 6	- 0.55	- 0.29	20
CTF Time-step = 12	- 0.61	- 0.03	40
CTF Time-step = 60	0.02	0.15	80

3.3. Energy audit of the building

The annual energy demand for the space heating, calculated for a unitary floor area, is equal to 33.1 $kWh_{PRIMARY}/m^2$, by including the electric energy required by the auxiliaries (i.e., fans and pumps). In order to convert all energy vectors and sources in primary energy, with reference to the electricity, a primary energy conversion factor equal to 0.46 $kWh_{ELECTRIC}$ / $kWh_{PRIMARY}$ [25] has been assumed.

The above-reported energy demands imply an annual cost equal to 42'769 €. With reference to the environmental impact of the present building, emissions of equivalent CO_2 equal to 121.6 tons $CO_{2\text{-equiv}}$ have been calculated, for the space heating, by taking into consideration the LCA emission factors, for electricity and gas, reported by the Covenant of Majors for Italy [26] and thus for Natural Gas: 0.237 ton CO_2/MWh, and for electric energy: 0.708 ton CO_2/MWh.

3.4. Calibration and validation of the numerical model

After the assignment of input data into the numerical model and the running of the simulation, then the outcomes have been compared by the measurements of energy billings paid by the University of Naples Federico II. In particular, monthly values of the supply contract 2015 have been taken into consideration for the comparisons.

With reference to the annual electric demand, by taking into account the average value of electric efficiency of the Italian conversion system and by considering the net conditioned building area (4’698 m^2), the annual electric demand is equal to around 45.5 kWh/m^2. With reference to the annual space heating demand for the microclimatic control (around 160 MWh), there is a consumption of 34.1 kWh/m^2 for a unitary floor area.

Two statistical indices have been used for the calibration. More in detail, the error in the annual energy consumption $EER_{average\ year}$ and the coefficient of variation of the root mean squared error CV ($RMSE_{month}$), calculated as in equations (1) and (2):

$$EER_{average\ year} = \frac{\sum EER_{month}}{N_{month}} \quad (1)$$

$$CV(RMSE_{month})(\%) = \frac{RMSE_{month}}{A_{month}} \times 100 \quad (2)$$

With reference to Eq. (1) EER_{month} is the error in the monthly energy consumption and N_{month} is the number of monthly utility bills in the year. In Eq. (2), RMSE is the mean squared monthly error and A_{month} is the mean of the monthly utility bill.

Typically models are declared to be calibrated if these produce $ERR_{average\ year}$ within ±10%,CV ($RMSE_{month}$) within +10%. Annually, the ERR_{year} is -1.22% for the electricity and 0.03% for gas. Meanwhile the CV ($RMSE_{month}$) has been calculated only for the electricity demand, being the gas billings not coincident with the months. This is equal to 5.85% and, finally, all comparisons reveal a convergence fully acceptable.

4. The energy retrofit of the building

In this section the performances of a set of retrofit actions, singularly analyzed and then coupled, have been evaluated. In particular, the primary energy saving (ΔEP) and the avoided carbon dioxide equivalent emissions (ΔCO_2) have been calculated.

With reference to the economic indicators, by assuming for the electricity a standard price equal to 0.234 €/$kWh_{ELECTRIC}$ and for gas a standard price of 0.095 €/kWh_{GAS}, according to [27], the following indicators have been calculated:

- reduction of exercise costs(DCE), cost of the saved kWh of primary energy;
- discounted payback time (DPB) of the energy efficiency measure (EEMs).

4.1. Suitability of common EEMs with cost optimal analyses

In the reference state, the building primary energy demand, for the space heating, is equal to 156 MWh. In order to improve the use of energy, a set of EEMs, chosen in order to be respectful of the historical value, has been tested, by singularly considering:

- Insulation of vertical envelope, by adding 30 mm of vacuum insulation panels, on inner side walls. The U value is reduced at 0.28 W/m^2K (-70%).
- Additional thermal insulation, by means of 12 cm of polyurethane, on the roof structure. The slab transmittance is reduced at 0.15 W/m^2K (-56%).

- Replacement of windows, by adoption of a low-emissive glass of 6.0 mm with a cavity filled with 13.0 mm of Argon with an average $U_{windows}$ of 1.6 W/m^{2}K. The systems include wooden/aluminum frames and external shading systems with high-reflective slats, automatically activated.
- Design of a condensing hot water boiler.

The results in Table 4 show that windows seem to be critical elements of the present building envelope. Indeed, the substitution of the present ones allows a considerable saving every year in terms of energy (40.2%) and operational costs (39.9%). On the other hand it's possible to note that the additional insulation of the roof doesn't imply a significant impact. Furthermore, the insulation of the vertical opaque implies an improvement lower than what expected. Moreover, the replacement of the old boiler with a new condensation gas heater could improve the energy saving (32.8%) and consequently costs and emissions of about the same percentage.

Table 4. Energy, environmental and economic analysis of efficiency measures

EEM	ΔEP [kWh/m^{2}year]	ΔCE [€/year]	ΔCO_2 [t CO_2 / year]
Vertical insulation	5.35 (13.8%)	2’405 (13.6%)	6.09 (13.4%)
Roof insulation	0.39 (1.01%)	178 (1.00%)	0.46 (1.00%)
Double layer windows	15.6 (40.2%)	7’034 (39.9%)	17.85 (39.2%)
Condensing boiler	12.7 (32.8%)	5’672 (32.1%)	14.15 (31.1%)

The choice of the best EEMs to apply to the building has been evaluated through the cost optimal analyses, as it is shown in the Delegated Regulation 244/2012 [27]. Here the used equation for the macroeconomic calculation has been reported, and thus also the cost of greenhouse emissions has been taken into account, as proposed in (3).

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) + C_{c,i}(j) - V_{f,\tau}(j) \right] \tag{3}$$

With reference to equation (3), Cg is the global cost depending of the interested period of analyses τ and sum of the investment cost C_I, the annual costs $C_{a,i}$ actualized in the years thanks to the discount factor Rd and the emission costs $C_{c,i}$. In the equation, also the residual value (V_f) of the measure (j) appears, but in this work it hasn't been taken into account, in order to be conservative.

The study has been performed according to installation costs typical for the Italian market, in particular the official tariffs of 2013 for public works in the Campania Region [28]. For all the energy efficiency measures taken into account, a public incentive can be obtained, according to Ministerial Decree 28/12/2012 [29].

The emission cost of carbon is calculated multiplying the amount of annual emission for the unitary price of each ton of equivalent CO_2 produced in that year: the costs of emissions are 20 €/ton until 2025, 35 €/ton until 2030 and 50 €/ton after 2030 [27]. All used data are reported in Table 5.

Table 5. Costs for each energy efficiency measure analyzed

EEM	Cost [€/m^2 or €/number]	Quantity [m^2 or number]	Incidence of labor [%]	Investment cost [€]	Investment cost (- funding 40%) [€]	Emission cost [€]
Vertical insulation	42.00	2386 m^2	50 %	150’318 €	90’191 €	33’103 €
Roof insulation	60.00	1793 m^2	10 %	118’338 €	71’003 €	37’147 €
Double windows	365.00	546 m^2	15 %	229’183 €	137’510 €	24’289 €
Condensing boiler	16’000 €	1	10 %	17’600 €	10’560 €	28’248 €

In Figure 3, it can be seen that the global cost for the base building is around 400 k€ and it is the threshold used to accept or reject the solution considered.

For this reason, the EEMs combined in the last simulation have been: a) the substitution of the boiler and b) the replacement of windows, although the investment cost of these ones is the highest in the study (138 k€). The C_g, for each solution, considers a discount rate of 3% (safety scenario). As suggested in [27], for non–residential buildings, the global cost has been calculated with a lifespan of 20 years.

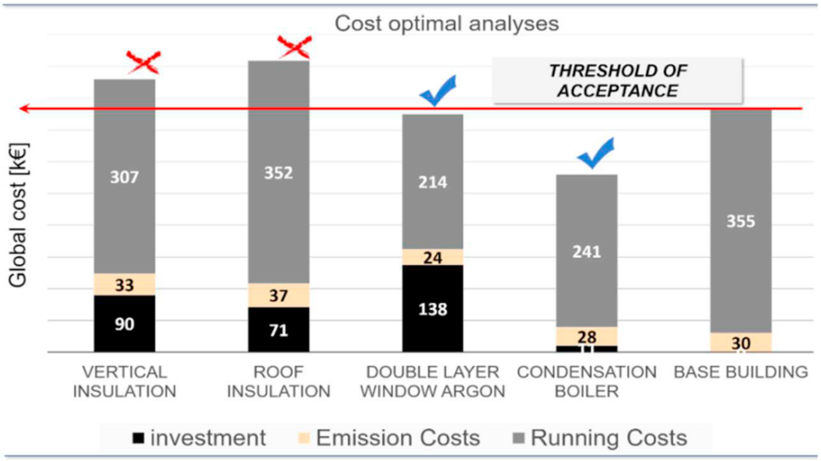

Fig. 3. Calculation of the global cost for the analyzed energy efficiency measures

4.2. Combined refurbishment actions: investigation of feasibility

In this section, on the basis of the results achieved, a last simulation combines the installation of a condensing hot water boiler and the replacement of windows.

In detail, the new energy request for the space heating appears 59% lower than the present one and it is possible to save 10’291 €/year with $\Delta CO_2 \approx 56\%$.

The investment cost of the combined energy efficiency measures is around 148 k€, just considering the total amount of the incentive, achievable in five years. Several scenarios have been considered for the discounting rate as specified in Table 6. A negative value implies that the annual cost of energy increases more than the inflation, so that the investment in energy efficiency becomes more convenient.

Table 6. DPBs and NPV20 for the five types of scenarios analyzed

	Discount Rates [%]	Discounted Pay Back [years]	Net Present Value $_{20\ years}$ [€]
High Risk Scenario	R_d = -5%	6	333’819
Medium Risk Scenario	R_d = -3%	7	239’298
Neutral Scenario	R_d = 0%	8	141’760
Safety Scenario	R_d = 3%	10	77’731
High Safety Scenario	R_d = 5%	12	46’925

In the neutral scenario, the SPB is 8 years and this is very favorable if compared to the lifetimes of the chosen energy efficiency measures. The NPV_{20} is equal to 141’760 €. Obviously, better results are obtained with the medium and high-risk scenarios, when the DPBs are respectively 7 and 6 years. The meaningful consideration is that in a high safety scenario, with a net discounting rate of 5%, the investment could be still convenient, because it has a Net Present Value after 20 years equal to 46’925 €.

4.3. Implementation of space cooling for the summer season

This section is dedicated to an investigation performed to evaluate the possible improvement of the indoor comfort, with reference to the cooling season, and thus from 15th of May to 30th of September.

As first step, by considering the refurbished building, the mean values of the air temperature have been plotted in figure 4a. The range of indoor air temperatures, by considering merely the occupancy hours, has a mean value of 29.4°C, with a peak of around 34°C. By assuming a comfort temperature, in the summery boundary conditions, equal to 26°C, the study reveals that for the 79% of the occupancy hours, in summer, the air temperature in the building is not comfortable.

The great amount of discomfort hours has suggest to verify the effectiveness of installation of two commercial air-cooled chillers, each one with a nominal cooling capacity of 255 kW. The selected chillers use scroll compressors, suitable for the air-conditioning and proper for operations with high energy efficiency ratios also at part load conditions, with a reference EER, at the rated conditions equal to 2.8 $Wh_{THERMAL}/Wh_{ELECTRIC}$. The overall estimated cost, by considering price of the system and labor, according to the Italian market, has been estimated around 112'000 €.

By means of summer active cooling of the building, as shown in figure 4b, the discomfort hours can be reduced (i.e., 3% of the total occupancy period).

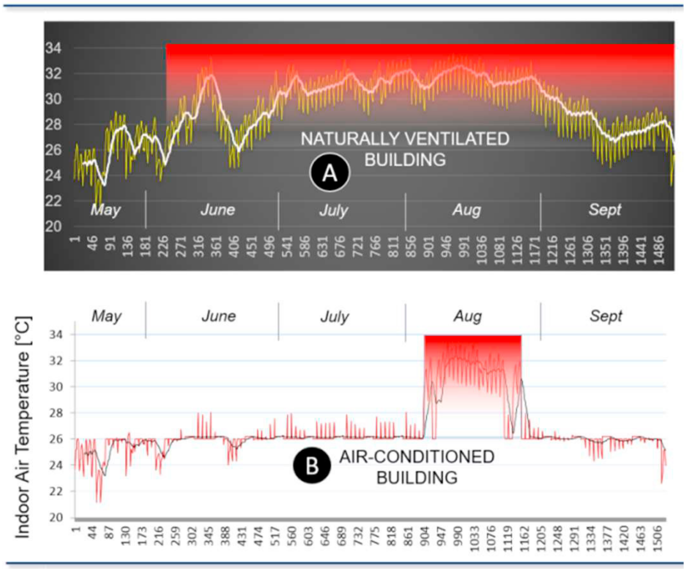

Fig. 4. Air temperatures: A) Palazzo Gravina naturally ventilated, B) building with air-cooled chiller

Even if the investment costs have been evaluated, of course a technical-economic feasibility study cannot be performed. Indeed, at the present moment, the space cooling is not provided, so that, also for what concerns the running costs, this installation and building improvement will increase the operational costs of the buildings.

5. 5. Further development of the investigation

With reference to the improvement of thermal and energy performances of Palazzo Gravina, as well as for reducing its impact on the overall energy balance, a further study is, at now, focused on two up-to-date topics, and thus:

- *Installation of PV*: it is analyzed the need of supply clean and renewable energy for supporting the energy demand of the building, by taking into consideration also the architectural peculiarities and thus the historical value.
- *CFD analyses*: in order to improve the indoor uniformity conditions, a new disposition of air terminals into the rooms of the second floor is under investigation, because the thermal stratifications, presently, induce high energy needs, in order to have thermal comfort also in the occupied zone.

In figure 5, the draft of the PV design is proposed, by comparing the achievable energy conversion to the electricity need of the building. PV technologies are quite suitable for the specific climate and by considering the building use. Indeed, the high solar radiation in Naples, all year around, as well as the conditions of sun-exposure of the building, as well as the slope of the pitched roof, allow to install 3 sub-fields of crystalline silicon photovoltaics on the roof of the building. It allows the specific conversion of around 1385 (averagely) $kWh_{eletricic}/kW_p$. The installable peak power is 61 kW. The interested sides of the pitched roof are the south-east and south-west ones. The overall energy conversion from photovoltaics is 84’528 kWh, while the building annual electricity demand is 239’993 kWh (after the refurbishment). Practically, the integration from solar renewables can be around the 35% of the electric requests.

About it, presently it is much more convenient the self use of electricity converted on site compared to its supply to the grid. By considering the contemporaneity of production and demand (because of the diurnal use of the building and the small size of PV installation), it can be considered that the most part of energy from photovoltaics, with some exceptions in full-summer, will be used by the building itself. By assuming a specific cost of electricity equal to 0.234 €/kWh, according to the Eurostat indications for Italy, and a cost of PV technology of 1’600 €/kW_p (this is a common price for sizes of 50 – kW_p), the installation can be repaid, according to a Simple Payback calculation, in around 5 years. Of course, this time can be shortened if incentives are considered.

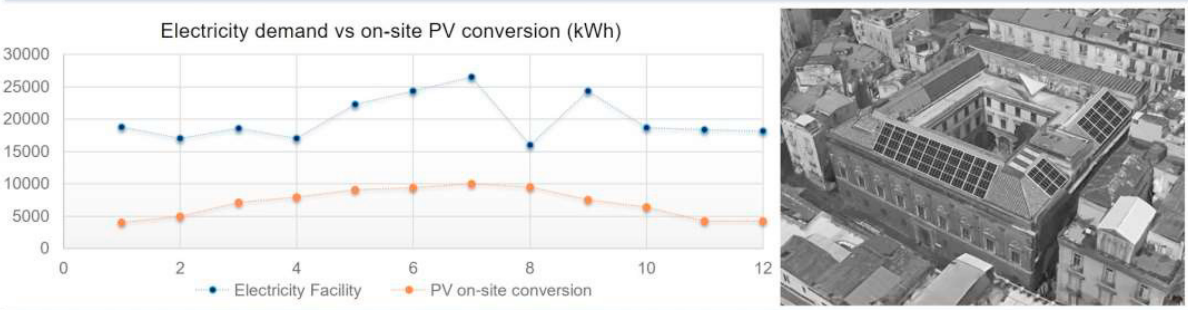

Fig. 5. Comparison among the energy requests of the building and the conversion from on-site photovoltaics (left side) and layout of its installation (61 kWp) on the building pitched roof (right side*)*

Considering the potential energy and economic savings and the effect of integration of renewable resource, Palazzo Gravina case study shows that the cost-effective energy retrofit of the existing building stock into very low energy building or nZEBs is not a dream, but it is possible and fundamental in the long path towards sustainability.

As aforementioned, a last investigation concerns the indoor conditions of air temperature, mainly for what concerns the avoiding of too accentuated thermal stratifications that, presently, make higher the energy demand for heating. Indeed, at the second floor of the building, in order to have 20°C in the occupied zone, much higher temperatures are verified in the upper volume of the classrooms, characterized, often, by an inner height of about 6 m. At the present moment, the fan coils are mainly located on the partition walls between classrooms and corridors. This not allows uniformity, because:

- the main thermal losses are generated on the opposite walls, near the perimeter walls and windows.
- the height of the rooms, on the side of the fan coils, is the highest.

Finally, we are studying to place fan coils on the opposite side (Figure 6B), by means of deep CFD investigations.

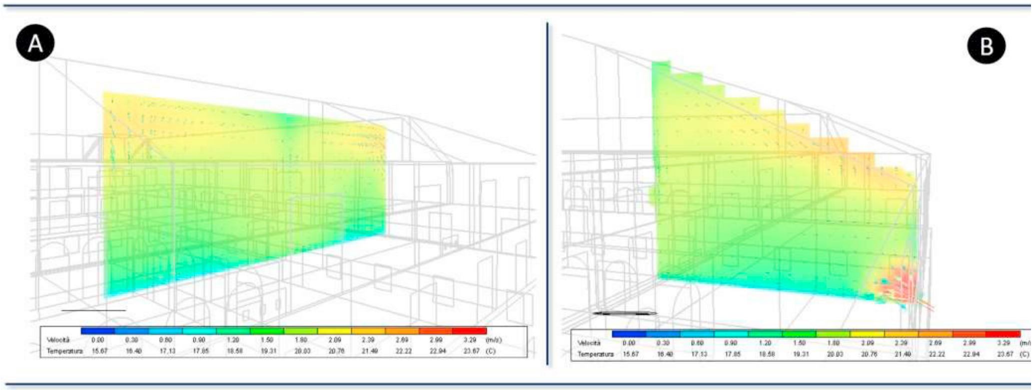

Fig.6. CFD investigations concerning new position for fan coils in classrooms. A) longitudinal and B) cross plots of thermal conditions, according to the repositioning of air terminal on the opposite side

6. Conclusions

This paper proposes the application of dynamic simulation tools to evaluate the energy performance of Palazzo Gravina. It is a historic building of great artistic value, property of the University of Naples Federico II. The evaluation regarded the actual performance of the mansion and four possible refurbishment interventions with minor impact on the historical value of the building. The cost optimal methodology has been adopted to choose the best retrofit scenario. A commercial dynamic simulation tool was successfully applied to build a reliable and accurate model; documental data were used to accurately calibrate the numerical model obtaining a ERRyear of 1.22%. Then the model has been used to experiment the effect of various refurbishment actions for the envelope and the plants. The most suitable combination of energy efficiency measure is the replacement of windows with low-emissive ones and the replacement of the boiler with a condensing one. In this way, the annual primary energy demand for the microclimatic control can be reduced of around 59% and the greenhouse emissions of around 57%. The total cost of the package is around 148’000 €. By considering the “neutral scenario” (i.e., discounting rate and annual increment of energy prices assumed equal to 3%), the calculated DPB is 10 years and the NPV20 is positive.

Further investigations concerned:

- installation of a chiller, in order to improve the thermal conditions in summer;
- improving of indoor uniformity, by moving the in-room terminal on the perimeter walls of the building;
- installation of 61 kWp of photovoltaics on south-east and south-west exposures of the pitched roof.
- All these investigation seem feasible, even if these require a further deepening.

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