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Rossella Roversi, Fabrizio Cumo, Elisa Pennacchia, and Valentina Sforzini

Energy and acoustic efficiency technical solutions assessments. The case study of the Italian Chamber of Deputies office building

Rossella Roversi[1, a)] Fabrizio Cumo[2, b)] Elisa Pennacchia [2, c)] Valentina Sforzini[2, d)]

[1]CITERA, Interdepartmental Centre for Territory, Building, Conservation and Environment, Sapienza University of Rome, Italy;
[2]DPDTA Department of Planning Design and Technology of Architecture, Sapienza University of Rome, Italy

[a)]Corresponding author: rossella.roversi@unibo.it
[b)]fabrizio.cumo@uniroma1.it
[c)]elisa.pennacchia@uniroma1.it
[d)] valentina.sforzini@uniroma1.it

Abstract. Energy efficiency in existing buildings is a capital issue in Italy. Retrofitting interventions on buildings of historical and artistical interest have particular constraints and challenges. The present contribution deals with the description of the project and final results analysis of an experimental campaign of energy efficiency and acoustic improvement of a significant sixteenth-century building located in Rome, seat of the Chamber of Deputies of the Italian Parliament.

INTRODUCTION

In the field of functional reconversion and technological-environmental requalification of the existing high testimonial value building heritage, the research state of the art is now quite extensive. However, it is not sufficiently systematized, the involved scientific sectors are many and often remain separate so the solution of problems occurs from partial and sectoral points of view [1].

The Italian building heritage is largely made up of old buildings in need of redevelopment, for instance as regards the energy aspects: more than 50% of the buildings stock dates back to before L.376/76 (Standards for the containment of energy consumption for thermal uses in buildings), and those of historical interest are about the 8% of the total (CRESME SAIENERGIA Report, based on ENEA data).

With Legislative Decree 311/2006 (Corrective and supplementary provisions to Legislative Decree 192/2005, and in implementation of Directive 2002/91/EC on the energy performance of buildings), the Italian legislator began to push on the recovery issues and no longer only new construction issues, aware that the best results for the reduction of consumption and CO_2 emissions in buildings with negative effects on climate change would be obtained precisely on this front, numerically much more significant.

However, in Italy, historical heritage is excluded from energy efficiency obligations when the compliance with the requirements would imply an unacceptable alteration of their historic and/or aesthetic characteristics: those derogations derive from mandates given to Member States in 2013 by Directive 2010/31/EU (art. 4, paragraph 2) establishing that competent authority decides whether the intervention represents an alteration of the historical and artistic value of the good or not (in Italy, the Superintendence for Archaeology, Fine Arts and Landscape).

The increased awareness about energy issues is also confirmed by the Ministry for Cultural Heritage and Activities (MIBACT), which presented the "*Guidelines for the improvement of energy efficiency in cultural heritage*" in 2015. The guidelines provide indications for the evaluation and improvement of the energy performance of the cultural and

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protected heritage in historical centres and of the rural architecture, with reference to the Italian regulations on energy saving and efficiency of buildings [2].

The interventions on buildings belonging to the historical heritage, and even more if subjected to the constraints of the Superintendence, must provide an approach substantially different from that normally applied on buildings of recent times. A balance is necessary between the opportunity to maintain the historical memory of the building and the possibility of energy upgrading, in order to obtain a satisfactory result from both points of view.

The maintenance of the testimonial value of ancient buildings may make inapplicable some methodologies of evaluation and analysis designed for recent constructions, as well as the legal limits normally set for more recent interventions often cannot be met unless they excessively alter the architecture. The opportunity to adapt internal comfort to the current demands of users and the containment of operating costs, especially in public buildings, are other important issues that affect historical buildings [3,4]. Moreover, the increasingly need to re-functionalize this part of the existing building stock, particularly relevant in terms of diffusion on the territory, especially in the Italian scenario, pushes the construction sector to investigate the energy behaviour of old buildings, with a view to intervening with an appropriate approach, in order to identify solutions for a conservative energy requalification [5].

OBJECTIVES OF THE RESEARCH

This paper refers about the research activities carried out within the framework of the Collaboration Agreement "Monitoring and Energy Measurements of High Performance Buildings. Comparison between calculation data and actual data" between the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) and the Territory Building Restoration Environment Interdepartmental Center (CITERA) of the Sapienza University of Rome. It is part of the "Studies on the energy requalification of the existing park of public buildings aimed at achieving the definition of nearly zero energy buildings (nZEB)" project of the Italian Ministry of Economic Development, that on December 21st 2016 signed with ENEA a Programme Agreement for a financial contribution for the implementation of the activity lines of the 2015-2017 “Three Year Plan for Research and Development of General Interest for the National Electric System”.

A case study has been identified, representative of the types of buildings used by Italian Public Administration offices, located in Italian climate zone D: the Ex Banco di Napoli building (Former Bank of Naples), listed by the Superintendence, is currently the seat of the administrative offices of the Chamber of Deputies of the Italian Parliament (Fig. 1). The building complex has been chosen as the pilot of a global set of interventions to be carried out in the seven palaces of the Chamber of Deputies in five years.

The first goal of the research was the calculation of the energy requirements of the building [6], conducting the energy analysis through a dynamic simulation software, in order to evaluate the correspondence between the estimated energy data and the actual behavior data. The real behaviour and energy consumption assessment consisted in the study of the whole external envelope and all the technological systems and devices that located inside it, proceeding therefore to the collection of data through analysis of available documentary material, inspections, interviews with personnel and monitoring of meters [7]. Consequently, an energy simulation has been performed evaluating all the energy end uses of both thermal and electric energy, in summer and in winter. The simulation results of the energy model were compared with the real consumption data coming from the analysis of three years of energy bills (electricity and gas), normalized with the climatic data of the corresponding years, to assess the adequacy of the model.

Hence, the model was used to complete the energy diagnosis by hypothesizing technical improvements to be realized for the transformation into nZEB of the building [8,9], according to the simultaneous compliance with all the technical standards and regulations concerning nZEB for Public Administration buildings and evaluating not only technical feasibility, but also economic feasibility.

The second objective was to test the use of some of the best existing and not invasive technologies in the field of internal insulation, low emissivity windows and reflective films, in such a delicate historic context. The building was used as a laboratory to assess the effectiveness of the single intervention with the final aim to use the more efficient of them in other Chamber of Deputies buildings. A deliberately partial efficiency and acoustic intervention was carried out, applying different technical solutions in several rooms and not intervening in some others to use them as initial references for the thermo-hygrometric and acoustic performance confrontations.

THE EX BANCO DI NAPOLI CASE STUDY

The palace is located within the historic urban centre of Rome, between Via del Giardino Theodoli, via del Parlamento and via del Corso. It is called “Ex Banco di Napoli” because it housed a bank and it still preserves the old bank counters furnishings.

The Ex Banco di Napoli complex, in its current planimetric, volumetric and decorative configuration, dates back to the nineteenth century and consists of three pre-existed blocks, internally connected to each other, clearly distinguishable by shape, arrangement of openings and finishings. The buildings are made of load-bearing masonry, with strong brick wall thicknesses. The main body, which can be accessed from Via del Parlamento, is characterized by an internal courtyard covered by a large roof window (chiostrina), while the two secondary buildings have small internal courtyards that allow ventilation and lighting for the rooms located far away from the streets.

FIGURE 1. View of the corner of the Ex Banco di Napoli building between Via del Corso and Via del Parlamento.

Objective 1: Building Energy Model Developing

The mapping and survey phase of the complex was initially set up by finding data and information aimed at creating a 3D model in a BIM (Building Information Model) environment, using the Autodesk Revit software. It has not been possible to use an energy diagnosis program integrated in the BIM because currently the available ones are not considered sufficiently reliable by ENEA. The BIM model was therefore used essentially to divide the building into thermal zones (6 zones), to create an abacus of windows and walls and to simulate the managing information process of the building during its entire life cycle [10,11].

The Transient System Simulation Tool (TRNSYS) software was chosen for the energy diagnosis. The first part of the software is an engine that reads and processes the input file and provides utilities that determine, among others, thermophysical properties. The second part of TRNSYS is an extensive library of components whose particularity is that they are constructed in such a way that users can modify them or write their own, extending the capabilities of the environment. This flexibility is very useful in existing buildings modelling because their components may be very differentiated and not standardisable.

Building envelope characteristics, air conditioning systems and domestic hot water production

The structure of the building is made up by bearing stone masonry with a thickness of about 40 cm. The vertical opaque closures are not insulated and are externally covered with plaster, enriched by decorative patterns. The average thermal transmittance of the opaque structure is estimated in 1.15 W/m2K.

Windows, of different sizes, are all composed of a wooden frame with thermal break with double 4-12-4 glazing. All windows have sun screens consisting of shutters. The glazed elements total surface area is 450 square meters.

Roofs are not thermally insulated and differ in practicable and not practicable (Tab. 1).

TABLE 1. Average transmittance of the envelope elements, in W/m^{2}k

Envelope Elements	Transmittance
External walls	1,15
Windows	3,74
Roof	1,51
Ground floor	1,34

There are several systems for the production and distribution of heat transfer fluids in the building complex [12]. There are 4 traditional methane boilers located on the roof, type Bongiovanni BONGAS 2/14, nominal capacity 263.3 kW each. They also provide domestic hot water to complement the system of 13 solar collectors located on the roof, Via del Parlamento side. The total surface area of the collectors is 26 square meters with a total production of about 4000 kWh/year. The cooling plant is made up by two heat pumps located on the roof, model 30RQ 0402-0129-PEE, cooling capacity of 362 kW each. For the three bodies of the building complex there are three different Air Handling Units and an additional one is located on the basement. So, the fan coil systems and the batteries of the Air Handling Units are powered by the two heat pumps and three Variant Refrigerant Flowplants (VRF).

The TRNBuild model

As already mentioned, the simulation model used to carry out the dynamic energy diagnosis for the Ex Banco di Napoli building was developed with the TRNSYS software. The model of the building's actual state and its energy diagnosis have been constructed following the directives imposed by the UNI/TS 11300-1 standard "Determination of the building's thermal energy requirements for summer and winter air conditioning" and using TRNBuild.

The thermal zones to be analysed during the study were identified. The division of the various floors into thermal zones has been carried out in accordance with the UNI/TS 11300-1 standard: each portion of the building, conditioned at a given temperature with identical modes of regulation, constitutes a thermal zone. Following this definition it was possible to divide the whole building into 63 thermal zones. Once the division of the building in thermal zones had been defined, the characterization of each of them was carried out, determining the properties indispensable for the calculation of the thermal regime inside the building.

Through the "WallType Manager" option, TRNBuild allows the model developer to create new wall packages that have the desired features. Therefore, using the software tool, the external and internal wall packages have been implemented, as well as the intermediate floors, the foundation floor, the roof and the windows belonging to each thermal zone.

The windows in the building were modelled using the "Windows Type Manager" function, which allowed the thermal characteristics of the glass in the building to be defined.

The internal loads represent the contributions of sensitive and latent heat to the conditioned environments coming from the inside of the same environments. Generally they are due to: occupancy (ISO 7730 called "Rates of Heat Gain from Occupants of Conditioned Spaces"), lighting, machinery that in operation reach temperatures higher than the ambient.

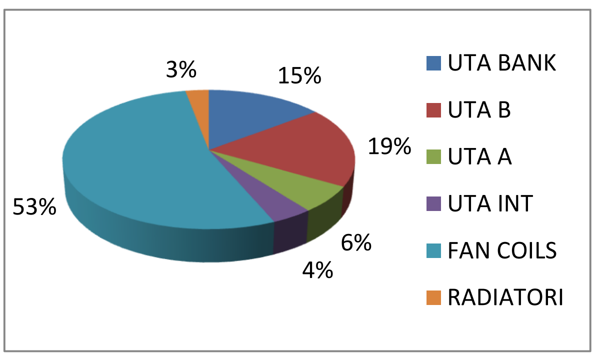
In the developed model, the set point values of the temperature and relative humidity, as well as the thermal power of the heating and cooling system, are established directly within the simulation model on TRNSYS Simulation Studio which communicates with the TRNBuild and receives them as external input. In the "Ventilation Type Manager" it was possible to set the temperature and relative humidity of the ventilation air [13,14].

Results of the energy analysis of the building and validation of the energy model

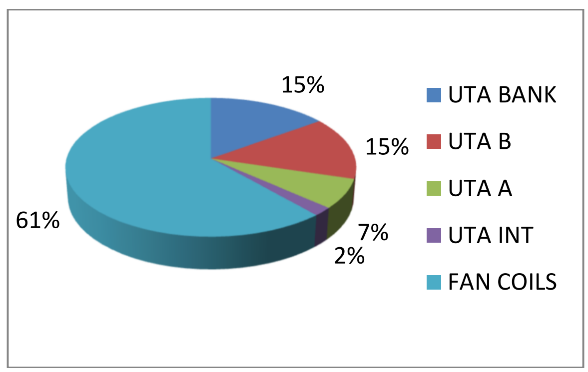
The analysis carried out through the described model, returns the consumptions deriving from the conditioning of the rooms, highlighting the distribution of the electrical and thermal consumption in the various thermal zones (Tab. 2). The results show a different weight of the winter season consumption compared to the summer season consumption of the overall building complex. In particular, the thermal energy requirement is of about 1140 MWh/year and the cooling energy requirement is about 530 MWh/year. To ensure thermal comfort in air-conditioned rooms, fan coils weigh 9 % for heating and 22 % for cooling more than the Air Handling Unit. The electricity consumption of the air conditioning is about 56% of total electricity consumption.

TABLE 2. Annual heating and cooling energy consumption, divided according the different AHUs, fan coils and radiators, in MWh

Annual energy allocation		
	Heating (MWh)	**Cooling (MWh)**
AHU BANK (nominal capacity 17,500 mc/h)	127.07	79.36
AHU of wing B and C (nominal capacity 12,500 mc/h)	161.53	77.77
AHU of wing A (nominal capacity 6,000 mc/h)	53.27	36.46
AHU INT underground level (nominal capacity 6,000 mc/h)	34.85	10.37
FAN COILS	463.25	325.57
RADIATORS	25.45	-
TOTAL	1137.71	529.53



a)



b)

FIGURE 2. Annual distribution of thermal energy (a); annual distribution of cooling energy (b).

Comparing the annual consumption resulting from the air conditioning with the actual consumption reported on the bills, it was possible to validate the model created: the objective of the model calibration is to match the energy signatures obtained from the operational evaluation and the evaluation simulated with the model.

The percentage difference between the results obtained from the two evaluations is very low, with an average value of around 1.07 % for the 2014 season, an average value of 0.79 % for the 2015 season and an average value of 0.48 % for the 2016 season. In addition, all seasons have a maximum deviation between simulated data and bills of just over 3 % for a few months only. Therefore, it can be said that, for the energy consumption sector, the building model modelled by TRNSYS is representative of the building real behaviour.

Dynamic simulation of the energy behaviour of the Ex Banco di Napoli

Following the validation of the results of the dynamic model, several simulations were carried out aiming at assessing the costs and benefits of efficiency measures to make the building an nZEB.

Because of the architectural and cultural value of the external walls and the resulting constraints in place, some interventions to improve the efficiency of the external building envelope could not be carried out and it was therefore not possible to reach the nZEB standard, despite the respect of almost the totality of the parameters. For instance, through the proposed intervention of installation of a 36 kWp PV system (higher than the limit value required), integrated with the generation of thermal energy through heat pumps and VRF systems, the requirements on the consumption of thermal energy from renewable sources and the consumption of energy from renewable sources are met. In Table 3, two examples of technically feasible interventions on the building and their economic payback times are reported.

TABLE 3. Simulation of benefits and costs of two hypotheses of intervention on the Ex Banco di Napoli

Global Energy Performance before interventions 112,5 KWh/m^{2}year			**C Energy class** (UNI TS 11300)
Interventions proposals			
Solution 1		**Solution 2**	
Intervention	**Cost (€)**	**Intervention**	**Cost (€)**
Solar film for windows	55,600	Windows replacement	108,00
Boilers substitution	141,840	Boiler substitution	141,840
Vertical closures insulation	121,078	Vertical closures insulation	121,078
LED lights	25,000	LED lights	25,000
Total cost (€)	**343,518**	**Total cost (€)**	**395,918**
Return on Investment (years)	**15.2**	**Return of Investment (years)**	**20,1**
Global Energy Performance after intervention (solution 1, as better performance/cost balance) 80.25 KWh/m^{2}year			**A1 Energy Class** (UNI TS 11300)

Objective 2: experimental intervention of energy and acoustic efficiency and testing of the effectiveness of non-invasive technologies

The Ex Banco di Napoli building complex has a considerable historical and architectural value and is in a good state of maintenance. With regard to the internal comfort, it takes advantage of the considerable consistency of the external wall masses: they ensure good thermal inertia, whose effectiveness is however different depending on the exposure of the different fronts.

The main front, which hosts the entrance to the complex, is located on Via del Parlamento and it is exposed to South; the road is wide so the front, especially near the corner with Via del Giardino Theodoli, is subject to heavy sunshine exposure especially in the middle hours. The northern exposure of the offices overlooking Via in Lucina makes them the coldest of the whole complex, with considerable differences in internal temperature compared to those overlooking Via del Parlamento. The heating system consists of fan coils placed in niches under the windows: the very deep niches are the main weakness of the outer shell of the complex. Another element of strong criticality from a thermal point of view is the glass covered chiostrina, where the old bank counters are preserved. The main problem, complained by the employees working in the offices, is the noise coming from Via del Corso, that is a very busy road.

The different materials and types of solutions have been selected on the basis of the detected criticalities and calibrated according to the construction peculiarities of the building, while respecting the need to preserve the aesthetic aspect and avoiding overly invasive interventions (Fig. 3). Many interiors have stucco decorations and wooden frames on the walls and ceilings; others have painted wooden ceilings. Therefore, it has been avoided to intervene where the increases in thickness, due to the construction of internal coats, would have led to alteration of the designs of the decorations or too high costs of restoration. The building interventions carried out on the building envelope in order to improve its energy efficiency, can be summarized in the following Table 4.

FIGURE 3. Interventions implemented in second floor of A wing (main body facing Via del Parlamento) and Third floor of BCD wings

TABLE 4. Pilot interventions implemented on the Ex Banco di Napoli building complex.

FLOORS	ROOMS	INTERVENTIONS
1° wing A and 2° wings BCD	7658 – 7659 – 7660 – 7661	OVERCOAT INTERNAL INSULATION of perimetral walls with particular attention paid to the niches behind the fan coils (Corkpan panels)
	7663 – 7664 – 7666	OVERCOAT INTERNAL INSULATION (insulating plaster)
	7658 – 7659 – 7660 – 7661 – 7662	DOUBLE GLAZING (Pilkington K Glass N)
2° wing A and 3° BCD	7683 – 7684 – 7685 – 7686 - 7630	OVERCOAT INTERNAL INSULATION of perimetral walls with particular attention paid to the niches behind the fan coils (Corkpan panels)
	7688 – 7689 - 7691	OVERCOAT INTERNAL INSULATION (insulating plaster)
	7684 – 7685 – 7686 – 7630	DOUBLE GLAZING (Pilkington K Glass N)
	7511 – 7512 – 7510 – 7509 – 7508	REFLECTIVE FILMS 3M SUN CONTROL EXTERIOR
	7683	DOUBLE GLAZING (Pilkington Energikare triple)
3° wing A	7531-7532- 7533 – 7534 – 7535-7531	SUSPENDED CEILING RIGID PANELS (Gess fon Bio and KNAUFF)
	7533 – 7534 – 7535 – 7536 - glass cover of the internal chiostrina	3M SUN CONTROL EXTERIOR REFLECTIVE FILMS

Thermo hygrometric measurements

Outside the Ex Banco Napoli palace, measurements were carried out both at street level, in Via Del Giardino Theodoli, and on the roof, where the external air intake units of the Air Handling Units are located.

Inside, several rooms were sampled for each floor. Room 7665, where no work was done, is used as a reference room.

The *ex-ante* measurements were carried out on 14th and on 21st July 2017. The *ex-post* thermo-hygrometric measurements were carried out on 13rd and 15th September 2017, after completed the efficiency works.

It should be premised that the air conditioning system was able to maintain even in *ex-ante* conditions the environmental parameters within the comfort range (temperature = 26°C 1; relative humidity = 50%5). However, in the *ex-post* monitoring data in summer, the room not affected by the works recorded the highest temperature data of all the other rooms, regardless of the exposure, while in the *ex-ante* data this room had a temperature in line with the other rooms.

This leads to the conclusion that the increased insulation of the building envelope, is useful also in summer season to decrease the internal heat loads with a consequent decrease in the measured internal temperature of the order of at least 0.5 ° C. Finally, measurements were carried out in the bank's area to validate the effectiveness of the reflective films installed on the bank's transparent cover. The thermo-hygrometric measurements showed that the use of such films prevents the establishment of the greenhouse effect in the chiostrina almost completely. The data fully confirms the manufacturer's certification that the use of the films in question ensures a reduction in the input of radiation in the wavelengths UVB-visible-infrared close by 15%.

Acoustic measurements

The acoustic measurements were made with the help of a portable sound level meter on 15th September 2017 evaluating the difference in sound pressure between the inside and outside of the rooms where the windows on the side of Via del Corso were replaced (where there is the loudest noise caused by vehicular traffic). The room 7495, where the window has not been replaced, was also measured to have a reference on the improvement of the acoustic comfort of the environments.

As shown in Table 5, the transition from traditional double glazing to low-emission double glazing reduces external noise by 4 db, while the triple glazing positioned in the 7683 room reduces the sound pressure level by as much as 11 db. Room 7683 has the best thermal performance also in the thermo-hygrometric data.

TABLE 5. Noise reduction after the substitution of the old windows (38 db)

Floor/Wing	Room number	Windows soundproofing
2 - BCD	7658	42 db
2 - BCD	7659	42 db
2 - BCD	7660	42 db
2 - BCD	7661	42 db
3 - BCD	**7495 no windows replacement**	**38 db**
3 - BCD	7683 triple glazing windows	49 db
3 - BCD	7685	42 db
3 - BCD	7685	42 db

CONCLUSIONS

The particular construction systems and components that characterize the historical buildings and that can vary greatly from one building to another, makes it difficult to develop a reliable energy model. The starting point for energy requalification is the correct and complete analysis of the actual state, an essential premise and at the same time an integral part of the requalification and recovery project itself. This implies a priority importance of the quality of the incoming data and therefore of the methodologies and technologies underlying their acquisition. The experimentation carried out on the Ex Banco di Napoli building shows how it is possible to create a validated energy model to carry out dynamic simulations of various requalification scenarios.

The efficiency interventions implemented in some rooms of the building complex and the monitoring of the situation *ex-ante* and *ex-post*, have led to appreciable results in terms of increased performances. In addition, it was possible to test some products on the market, verifying their effectiveness even in the case of unconventional use. As regards films, for example, it was possible to demonstrate how they work with equal performance both vertically (on the windows) and horizontally (on the skylight of the chiostrina), a case not covered by the manufacturer tests. Sometimes, however, as in the case of the use of cork insulation, the implementation of the interventions has proved particularly difficult because of the interference of the laying operations with the work of the employees of the offices concerned. In addition, it should be taken into account that some of these interventions would not have been possible in rooms where there is an important decorative apparatus.

a) b)

FIGURE 4. The Ex Banco di Napoli façade facing Via del Parlamento (a); the glass covered internal chiostrina (b).

By virtue of the derogations allowed for buildings with a strong historical value in the event that compliance with energy requirements could unacceptably alter their distinctive features, we must strive for the concept of “improvement”, rather than “compliance” with the high minimum standards. On the other hand, the derogation should not discourage possible and compatible interventions. In fact, technological innovation has made great progress in the plants and the envelope efficiency, in the inclusion of renewable sources and in the reduction of climate-changing gas emissions. Rather than just retrofitting we may also speak of "energy restoration" [15]: the pursuit of the quality and environmental well-being through the rational use of energy, necessarily involves an integral view of the problems and a coordinated response that allows to manage the complexity of the design process and to build synergies between the different engaged actors.

Interventions on exemplary architectures are multiplying and therefore the state of the art, while respecting the criterion of "case by case", provides a repertoire of case studies really solid and abundant.

In addition to bringing a significant improvement in the conditions of well-being perceived by users, the interventions of energy and acoustic efficiency lead to a reduction in the phenomena of degradation, also to protect the works of art that are often preserved in the building, and increase the attractiveness of the architectural asset, including for the real estate market.

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Environment) Sapienza University of Rome; Programme Agreement Ministry of Economic Development – ENEA; Annual Implementation Plan 2016 Area D: Energy efficiency and energy savings in electrical end uses and interaction with other energy carriers Research Topic: Nearly Zero Energy Buildings (nZEB), Project D.2.1: Studies on the energy requalification of the existing park of public buildings (schools, hospitals, central PA offices and local) aimed at achieving the definition of nearly zero-energy buildings (nZEB), Objective e.1: High performance building energy measures. Comparison between calculation data and actual data.

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