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Improving energy efficiency and Indoor Environmental Quality in the School of Mathematics at the Sapienza University campus in Rome

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Abstract. SDG 7 "affordable and clean energy" aims at expanding infrastructure and upgrading technology to provide clean and more efficient energy in all countries, encouraging socio-economic growth and helping the environment. Its implementation through legislative instruments led to the writing of the Sapienza Energy Plan and the Energy Implementation Program, which define a series of medium-term implementation strategies on buildings inside and outside the Sapienza University campus. Strategies aimed at the energy redevelopment of the building envelope to achieve the minimization of energy needs and the construction of PV systems as well as the technical and regulatory adaptation of existing HVAC systems to improve the environmental comfort conditions. By the requirements of current legislation, the Energy Performance has been quantified through the energy efficiency analysis of the building in its current state and post-interventions, led using a simulation on an energy diagnostic software. After the analyses, the refurbishment interventions have allowed defining the guidelines, in compliance with the contents of the Guidelines for the energy efficiency of cultural heritage and the PES, through a series of strategies aimed at the conservation and improvement of the building envelope and at improving the energy efficiency and the IEQ of the School of Mathematics.

1. Introduction

As part of measures to achieve both the 2030 targets and the almost complete decarbonisation of the civil sector envisaged in the Long Term Strategy (LTS) for 2050, it is therefore necessary to develop a mix of technical, fiscal and regulatory measures which promote the wider implementation of energy-efficient interventions and increase deep renovation [1].

According to research conducted by ENEA [2-3], most of the buildings on Italian territory, over 50%, date back to before the 373/76 law (law that had the purpose to limit the energy consumption for thermal uses in buildings) and only 2% fall into classes equal or higher than class C. The current problem, in the redevelopment of the existing, is to adapt to the requirements of the new regulations without however diminishing the value and the essence of the architectural element [4-5].

Very often when we talk about existing buildings, especially if they are historical, the interventions are in contrast with the characteristics and the memorable value of the building.

With regard to the increase in energy efficiency of the historic building heritage linked, according to the Code of Cultural Heritage D.lgs. 42/2004 [6], the lines to be followed must be based on respect for the character and essence of the building, in order to allow its conservation and transmission to future generations. The choice of technologies to achieve the efficiency goals must be particularly prudent; the interventions must not in any way compromise the appearance and the value of the building construction.

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In most cases, when the demand for comfort concerns old restored or only restored buildings, the interventions exhibit invasiveness and pervasiveness that do not protect the seriousness and respect of the design. Talking about the redevelopment of a historic building, we must not only think about the well-being in terms of user comfort or in terms of preserving what is contained within the building, but above all the choices of the technologies and facilities for the architectures historical [7].

The Gio Ponti's building is part of a particular field of buildings (historical and cultural buildings) exempted from reaching the performance limits established by the law; but this does not mean that is impossible, in respect of the building and the context, to improve its efficiency and reduce its emissions deriving from wide and sometimes improper and use of fossil fuels [8]. The purpose of this study was to improve the energy performance and consumption reduction, of a building worthy of respect in the consideration of its historical value [9].

The important of the energy analysis comes from the current building use that is in contrast with the original ones; consequently, it is necessary to adapt HVAC and electrical plants to the new functions, lowering the overall energy demand always respecting the occupants internal comfort standards [10].

The in-depth study of the building of the School of Mathematics within the Sapienza university campus fits right into this framework of short and medium-term interventions to increase energy efficiency and the use of RES, to reduce air pollution through different energy redevelopment proposals, which at the same time take into account their historical value and integrate with the campus context. Starting from historical analysis and direct analysis, the first phase of the research revealed that the School, designed by the Italian architect Giò Ponti, is equipped with "basic" systems, with common elements and characteristics, while there are “particular” architectural and engineering solutions useful for achieving micro-climatic and psycho-perceptive comfort in specific parts of the building. These design attentions are also demonstrated by a characterization of the building envelope to maximize the passive bioclimatic functioning of the building thanks to the positive effects of natural lighting and ventilation. Also, non-invasive in-situ surveys have been carried out in the building to measure temperature, relative humidity and air quality to evaluate the Indoor Environmental Quality (IEQ); the monitoring campaign has taken place over a year using the direct method, through specific instrumental analysis and with the integration of the data obtained by the Regional Environmental Protection Agency (ARPA) of the Lazio region.

The simulations have foreseen the modelling at first of the whole building and then as divided into 4 thermal zones, to investigate the energy performance of the individual parts before and after the improvements proposed on the building.

2. Building features and status quo

2.1 The historical and urban context

The establishment of Rome's campus for the “Regia Università di Roma” (then Sapienza University), between 1930 and 1935, represented a complicated process, deeply intertwined with the Italian political and economic situation at that time [11].

The School of Mathematics school is part of the building system of the University of Sapienza [12-13-14-15]. So, it is essential to analyze the behaviour of the entire complex and then focus on the single building [16-17].

The layout of the Sapienza is of the basilican type with a Latin cross, based on orthogonal axes that outline an internal regularity of the spaces, leaving the solution of the relationships with the various pre-existing structures and conditions at the edges; this layout culminates in the Rectorate square [18]. The entrance, which opens onto Piazzale Aldo Moro, invites you to enter through the high propylaea; once you have entered, walking along the central nave represented by the tree-lined avenue that descends with a slight slope, you reach the main square: opposite the imposing Palazzo del Rettorato and the statue of Minerva [19]. The distribution of the buildings is rigorously symmetrical, while the articulation of the volumes is free. In 1932 the "Consortium for the building layout of the Royal University of Rome" was established [20].

Originally the heating system was headed by a single heating plant, located within the perimeter of the University City, in a building built specifically to house it; the plant had a capacity of 8,800,000 cal/h with two hot water boilers at low temperature and pressure; the plant included three different distribution networks to bring heat to the Institutes [21].

The boilers were of the Velox type, modern at the time; they lent themselves well to satisfying the needs of a complex, where there was great variability in the demand for heat during the hours of the day.

In a subsequent phase, the super-heated water grid of Sapienza was connected to the Thermal Plant of the Umberto I Hospital, which provided for the overall district heating of the University Campus and the Hospital itself.

2.2 Sapienza University of Rome and School of Mathematics: current conditions of the plants

To date, the situation is that of the modern district heating grid, with superheated water. Inside the thermal plant (total thermal power 15 MWt) steam is produced and subsequently transformed into superheated water. The new Thermal Plant, inaugurated in December 2014, is located in the former Regina Elena complex and serves the complex and the University Campus. The construction of the plant was the last act of the University energy program and concludes a process that started with the redevelopment of the district heating network of the University City and with the creation of energy islands interconnected to the grid [22].

The superheated water is distributed to the sub-heating plants of the building; here, through a heat exchanger, of different power depending on the needs of the building, the hot water is prepared to be sent to the terminals with a flow temperature of 80°C and a return temperature of 60°C.

Not all buildings are reached directly by the heating network; some, such as for example that of Mathematics, rely on the sub-heating plant of another building, in this case at the Institute of Pharmaceutical Chemistry, which receives the supply of thermal energy through a secondary network.

<u>Electrical system</u>

The power supply of the University Campus provides for a multiplicity of supply points, some also in LV and referring to small users; currently, in fact, there are numerous electricity supplies (more than thirty) within the university city, sometimes even within the same building, originating from different and often no longer traceable reasons.

In this context, the need for adaptation (technical-normative) and energy efficiency is evident with the distribution loop of the Medium Voltage (MV) line to power the almost twenty MV/LV sub-stations in use and related to the campus buildings' university [23].

<u>PV systems</u>

Inside the University Campus, there are also PV systems for the production of electricity:

- Nursery - Peak power 6 kW and estimated production of 7,200 kWh;
- General Services - Peak power of 30.9 kW and estimated production of 37,000 kWh;
- Rectorate - Peak power 160 kW and estimated production of 218,620 kWh;
- Literature and Mathematics peak power 109.5 kW and estimated production of 142,620 kWh [23].

Current overall conditions of the building are discouraging, although the balance in terms of material authenticity is all in all fair.

Figure 1. Main façade of the School of Mathematics

3. Materials, Methods and Results

The final objective of this investigation, providing a general diagnostic picture from an energy point of view of the School of Mathematics, has been to highlight the correlation between the activity performed (function) and the suitability of the envelope to host this activity in full respect of the user and the preserved collections.

This objective has been achieved according to design steps divided into four different phases:

1) *Non-destructive monitoring and investigation*: possible investigations of the HVAC and electrical plants need to be compatible with the current use of the building. Therefore, non-destructive techniques should be used as much as possible in order to minimise interruption of the academic activity. Ambient measurement of the main thermal-hygrometric parameters will be performed in almost all the building rooms in order to evaluate the dynamic response of buildings;
2) *Indoor Environmental Quality measurement*: In situ monitoring of four airborne pollutants will be also performed in the main building areas to evaluate Indoor air quality according with a tailored protocol developed in Sapienza departments. The selected pollutants are CO_2, O_3, PM10 and TVOC;
3) *Energy modelling and Energy efficiency diagnoses*: from this first evaluation the energy class and the respective performance index will be highlighted, as the technical plants efficiency, the overall energy needs in the winter and in the summer and consequently the final consumption of primary energy. By analysing the consumption of primary energy it will be possible to evaluate which is the part due to heating by fossil sources, how much the amount due to lighting and the percentage of incidence of renewable sources on total primary energy consumption;
   From the analysis of energy consumption, intervention, proposals will be pointed out for the reduction of the latter.
   This is the final phase of the energetic building diagnosis model considering both the envelope and technical plants system. An accurate validation of the diagnosis results will be performed by checking the real energy consumption using gas and electric bills.
   The interventions will initially concern the passive performance of the building envelope and later the plumbing plants. Once the energy needs have been reduced, we will have a building with excellent performance from the constructive point of view, while the technical plant will not have a good efficiency value, as it is proportioned according to the technical plants requirements of more than 20 years ago.
   So the further result should be a substantial retrofit of HVAC and electrical plants, order to make it more efficient and commensurate with new regulation request and users needs.
   The interventions on the envelope should concern the vertical opaque closures, the floors, the roof and the fixtures, while for technical plants will be take into account lighting and thermal regulation systems. If possible some PV will be located on the building roof in order to achieve 20% of electric power and 50% of hot water production coming from renewable sources;
4) *Intervention guidelines*: at the end of the diagnostic investigations and the creation of the energy model, the guidelines describe the possible future improvement intervention.

3.1 Non-destructive monitoring and investigation

The School of Mathematics proceeds along a symmetrical north-south axis which starts from the front block (A) and culminates in the block of the tower of classrooms (B), set up according to an amphitheater structure [24]. Two semicircle blocks (C1 and C2), the wings, connect the latter to the body of the building that, in addition to the offices, houses the Library (Figure 2).

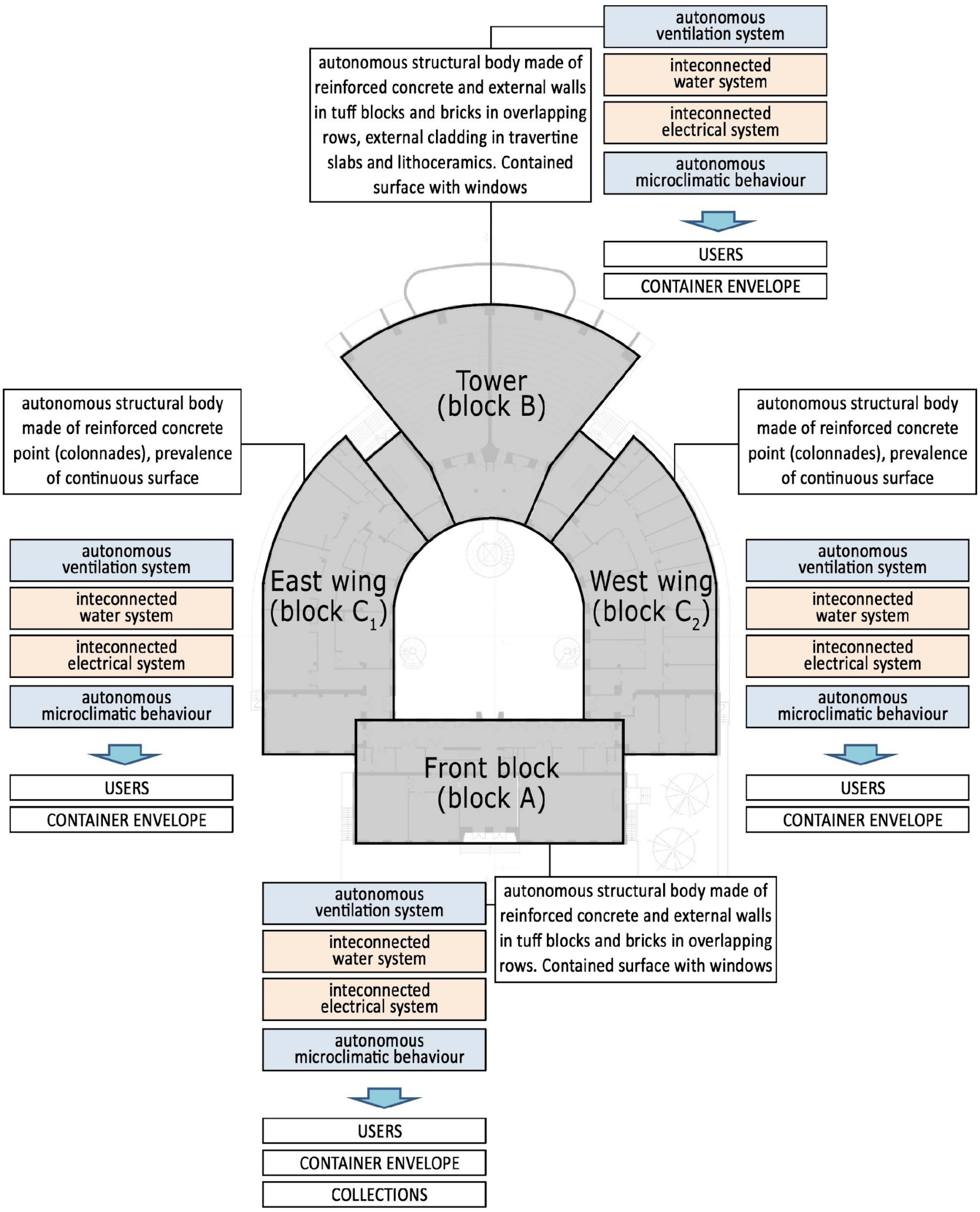


Figure 2. Layout of the spatial, plant engineering, compositional aspects (materials) of the building according to the three main blocks: front building, curved wings, tower of classrooms.

The entire complex is spread over three differently floors above ground with a gross area of 6570 m^2 (Table 1): the classrooms occupy 33% of the total area (2188 m^2), the offices 26% equal to 1713 m^2, the Library 497 square meters corresponding to 8% while approximately 1300 square meters intended for service distribution areas and 172 square meters, or 3% of the total area, are intended for technical rooms.

Table 1. building surfaces

	Surface (sqm)	Percentage (%)
Total surface	11216	100
Indoor surface	7940	70,8
Outdoor surface	3276	29,2

These specificities are demonstrated by a careful characterization of the envelope, by a careful calibration of the relationship between opaque and glazed surfaces (Table 2) in order to maximise the positive effects of natural lighting and natural ventilation, with integration of systems mechanical ventilation where necessary.

Table 2. building façade surfaces

North façade	Surface (m^2)	Percentage (%)
Total surface	937,3	100
Glazed surface	68,7	7,2
Opaque surface	869,6	92,8
South façade		
Total surface	1011	100
Glazed surface	200,2	19,8
Opaque surface	810,8	80,2
West façade		
Total surface	1186	100
Glazed surface	272	23
Opaque surface	914	77
East façade		
Total surface	1186	100
Glazed surface	272	23
Opaque surface	914	77

The structure is of the punctiform type made of reinforced concrete with continuous slab casting. The perimeter walls are in blocks of tuff alternating with parallel rows of red bricks. The tinted lime mortar plaster covers the entire external surface except for the main façade and the plinth which is covered in litho-ceramic. The average thickness of the external walls is about 80cm and that of the internal partitions of 10/15cm.

The building is equipped with essential technological systems, aimed at satisfying functional needs and achieving environmental comfort.

In particular, the building is equipped with electrical systems for the supply of motive power and lighting, heating systems (serving the entire building), cooling systems (serving some parts of the building), mechanical ventilation (serving some parts of the building) and domestic hot water systems. From the analysis it emerged that the building is equipped with plant systems dedicated to the "basic" use of the building that have common characteristics and elements, while for the different parts of the building (Figure 1) there are specific architectural solutions and plant engineering, useful for achieving environmental comfort and more generally for Indoor Environmental Quality (IEQ) according to the various activities carried out in each part of the building.

3.2 Indoor Environmental Quality measurement and results

In order to assess the Indoor Environmental Quality (IEQ) of the School of Mathematics, seasonal measurements of temperature, relative humidity and air quality have been carried out; the monitoring campaign took place in the summer, autumn and winter season [10-25]. Survey during spring was not possible due to the issuance of the D.P.C.M. of 8th March 2020 for the "Containment and management of the epidemiological emergency" throughout the national territory which has, among others, precluded access to the university for months). The direct method was used, based on measurements approached with specific instrumental analysis techniques, carried out during inspections over several days, and by integrating the obtained information with data detected by the "Regional Environmental Protection Agency" (ARPA) of the Lazio Region for the same days.

Comfort values assumed for the temperature are 20°C in the winter season and 26°C in the summer season, with a deviation of ± 1°C and for the relative humidity 50% with a deviation of ± 5% in both seasons.

The set of pollutants monitored to assess IAQ (Indoor Air Quality) consists of pollutants that allow us to describe both indoor and outdoor air quality. The following table shows a breakdown by class of air quality, obtained according to the concentration values of the pollutants.

Table 3. Concentration values of the pollutants and classification of air quality.

Classes	CO_2 [ppm]	TVOC [ppm]	PM_{10} [µg/m^3]
Hazardous	1,501 ÷ 5,000	0.431 ÷ 3000	141 ÷ 750
Unhealthy	1,001 ÷ 1,500	0.262 ÷ 0.430	91 ÷ 140
Moderate	601 ÷ 1,000	0.088 ÷ 0.261	31 ÷ 90
Good	340 ÷ 600	0.000 ÷ 0.087	0 ÷ 30

The goal of the research is the monitoring of IEQ; for this reason, we have decided to collect hourly average values by carrying out sampling of short duration.

The reference period has been fixed from 10:00 to 16:00. During the reference period, the sampling of the monitored parameters (VOC, PM10, CO_2) has been carried out with closed windows and by positioning the samplers in the centre of the room at a height of 1.50 meters and for a 30-minute time lapse.

All the probes for the thermo-hygrometric characterization have been fixed at a height of 1.00 meter from the floor; the equipment for determining the IEQ parameters have been positioned, for the duration of the sampling, at a height corresponding to the average height of the human upper respiratory tract. In order to identify the contribution of the external environment to the indoor concentration levels of the monitored pollutants, measurements of the same pollutants have been carried out almost simultaneously in order to acquire information about the extent of the external contribution.

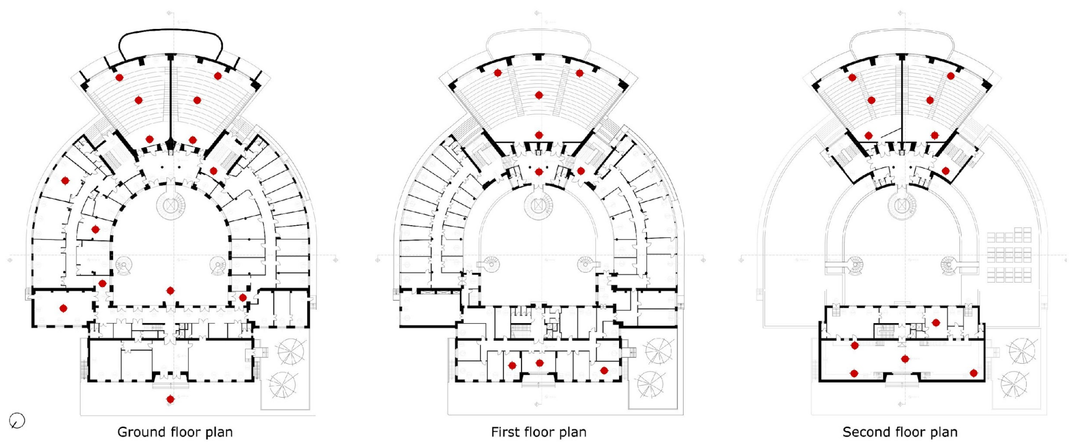


Figure 3. Measuring points (in red)

In the front block, specific attention has been paid to the library to investigate the levels of pollution not only with respect to human perception but also in the presence of the prestigious book collections: in the library, monitoring took place at various points, in addition to the central part, located at different heights (2.1 meters/4.2 meters/6.3 meters, starting from the entrance level into the room), in correspondence with the bookshelves; the offices and reading rooms around the library have been also analyzed. In the tower of classrooms, measurements have been concentrated in the tiered lecture halls (halls I, III, V); in this case the significant difference in height in each hall (4.2 meters' difference between the chair and the last step) made it necessary to carry out different measurements within the same room. A sample, among the various classrooms, has been chosen to monitor the situation of pollutants in the study room, located on the ground floor in the East curved wing C1.

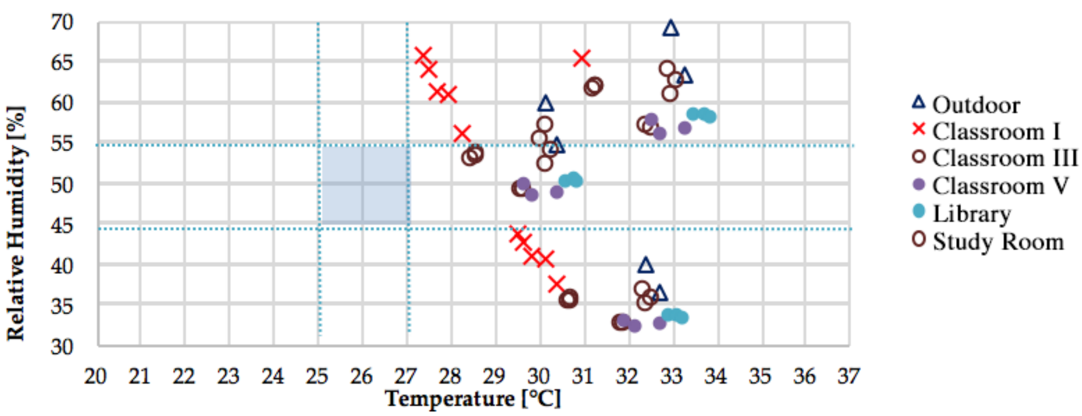
The summer monitoring campaign has taken place place in the presence of very few people (students and teachers) and in almost empty classrooms; the cooling system was generally off. There is no big difference between indoor and outdoor values (Figure 4).
The CO_2 values, as well as those of the VOCs, measured indoor and outdoor show good quality levels (blue band of the graphs), while the PM10 values are at a predominantly moderate quality level (green band).

Overall, all three pollutants detected are in acceptable quality classes both for human health and for the proper maintenance of the book collections conserved in the library; however, the conditions of thermo-hygrometric comfort were lacking in the rooms, in compliance with what was expected in the absence of a suitable cooling system.

The autumn monitoring campaign has taken place with the air conditioning systems turned off and the classrooms half full, given the start of the academic year in the month of September. Also in this case, similar parameters emerged from the outdoor and indoor surveys (Figure 5). The CO_2 values have been found halfway between good and moderate (blue-green band), the PM10 values within the moderate values level (green band), while those of the VOCs have been observed at a good level of quality (blue band). The parameters measured during the autumn season are slightly worse than in the summer, but still acceptable to guarantee human health and the correct maintenance of the book collections.

The expectations for the spring season are roughly the same, being the two seasons both of transition between summer and winter conditions.

The winter monitoring campaign has taken place with the air conditioning systems on and the classrooms half full (Figure 6). The CO_2 levels corresponded to an unhealthy quality class (orange band) in the study room, the only classroom full of students (80-90 people present during the monitoring campaign), while between good and moderate (blue-green band) in other environments. The PM10 values fall between the moderate and unhealthy levels for all environments (green-orange band), while the VOC levels, once again, are in the good range (blue band of the graph). It is closer to the conditions of thermo-hygrometric comfort in all environments with optimal levels in the library. In general, the slight deterioration of the quality classes of the pollutants detected in this period of the year - which in any case remains at acceptable levels, is justified by the high number of people present in the halls and classrooms, to which concur the closing of the windows and the air conditioning system switched on.



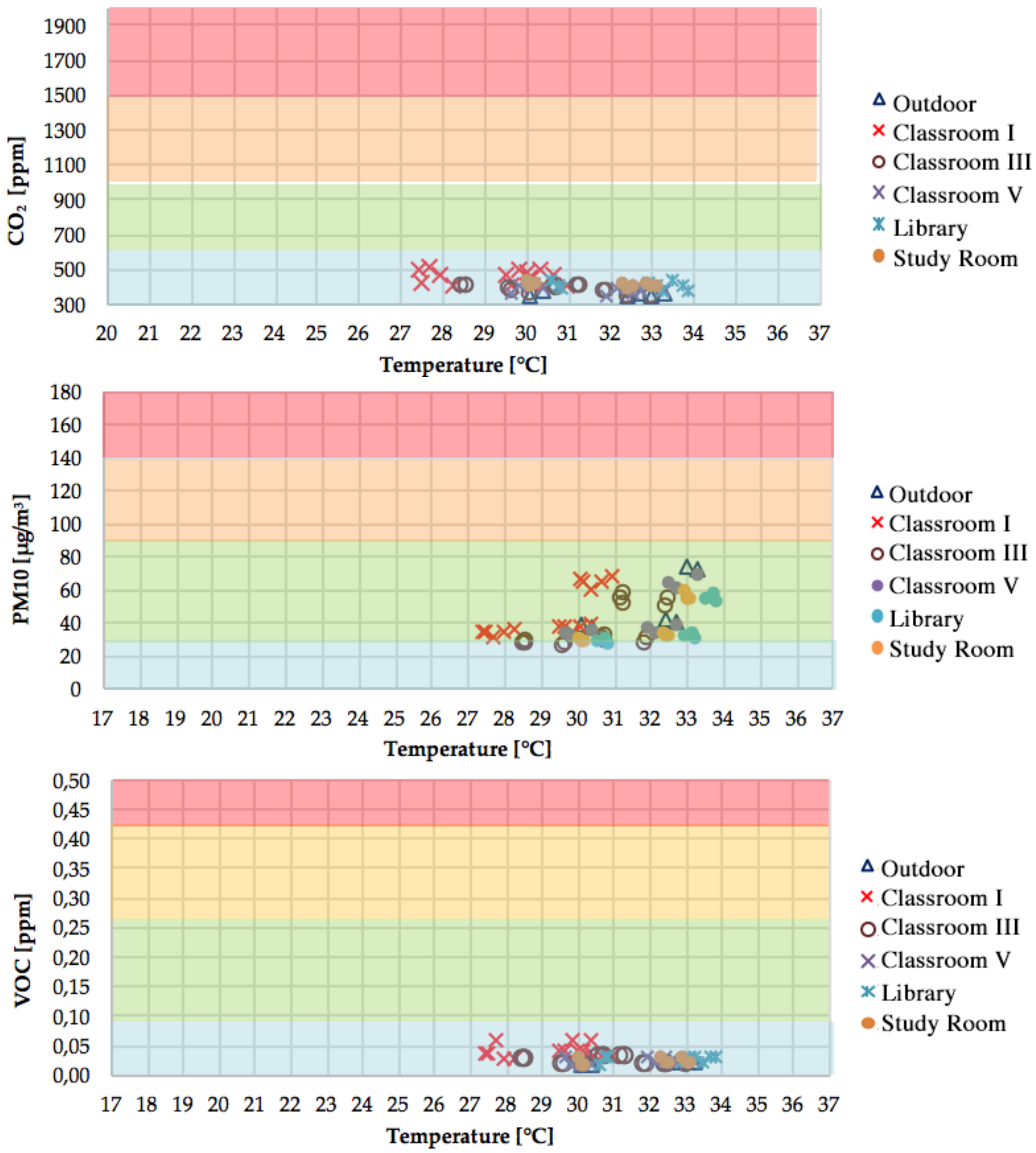
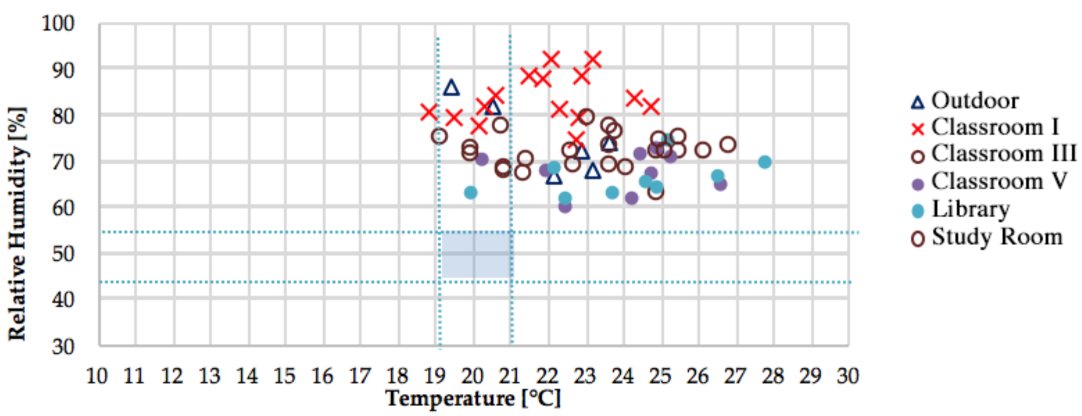


Figure 4. Results of measurements in the summer season



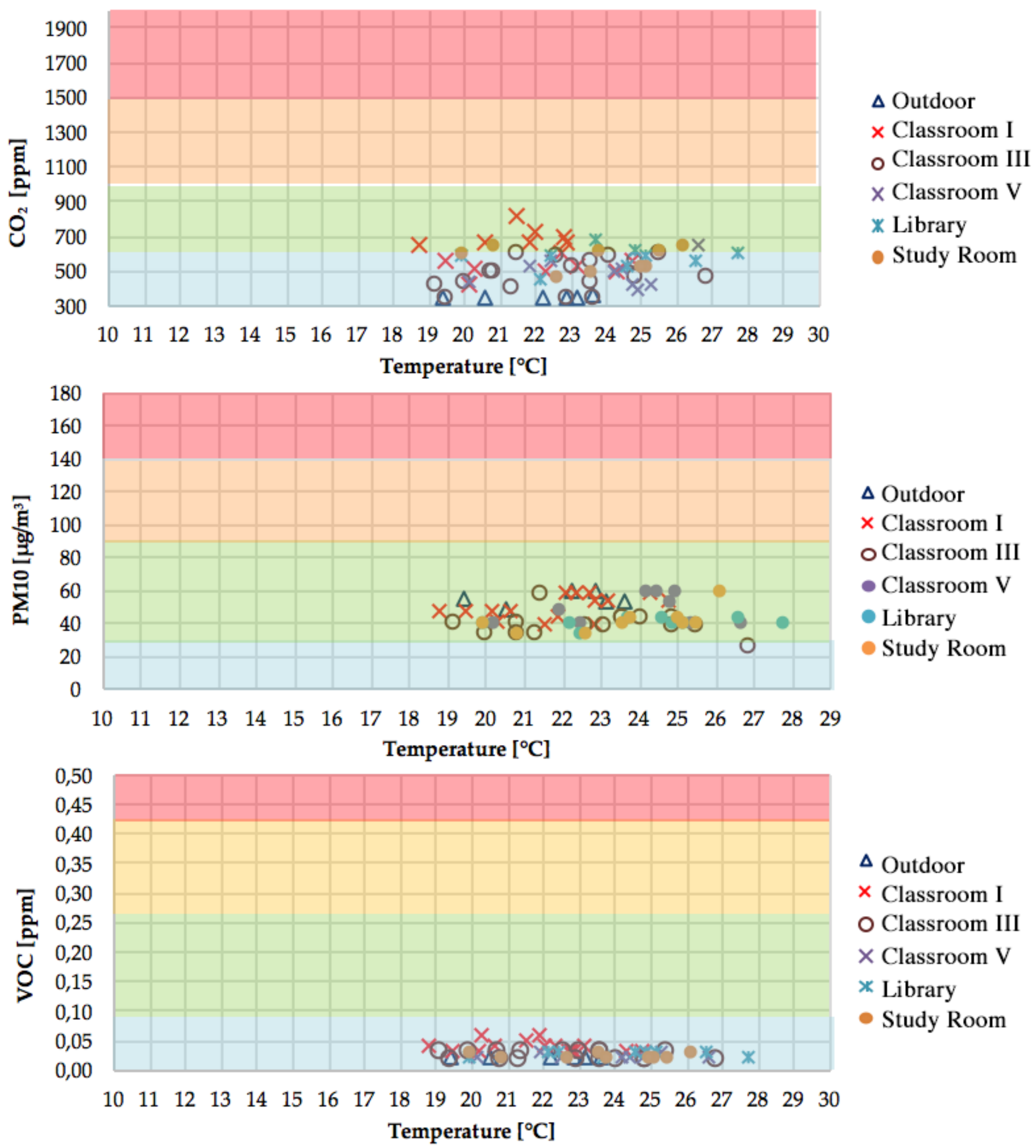
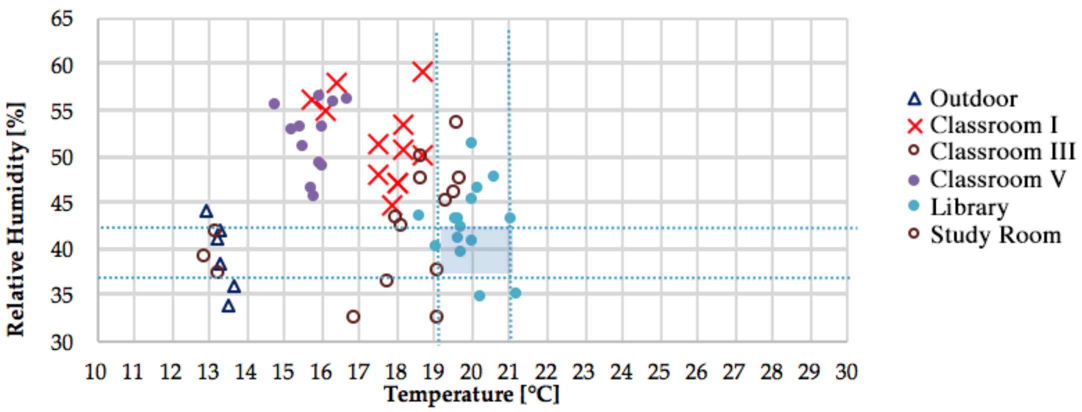


Figure 5. Results of measurements in the autumn season



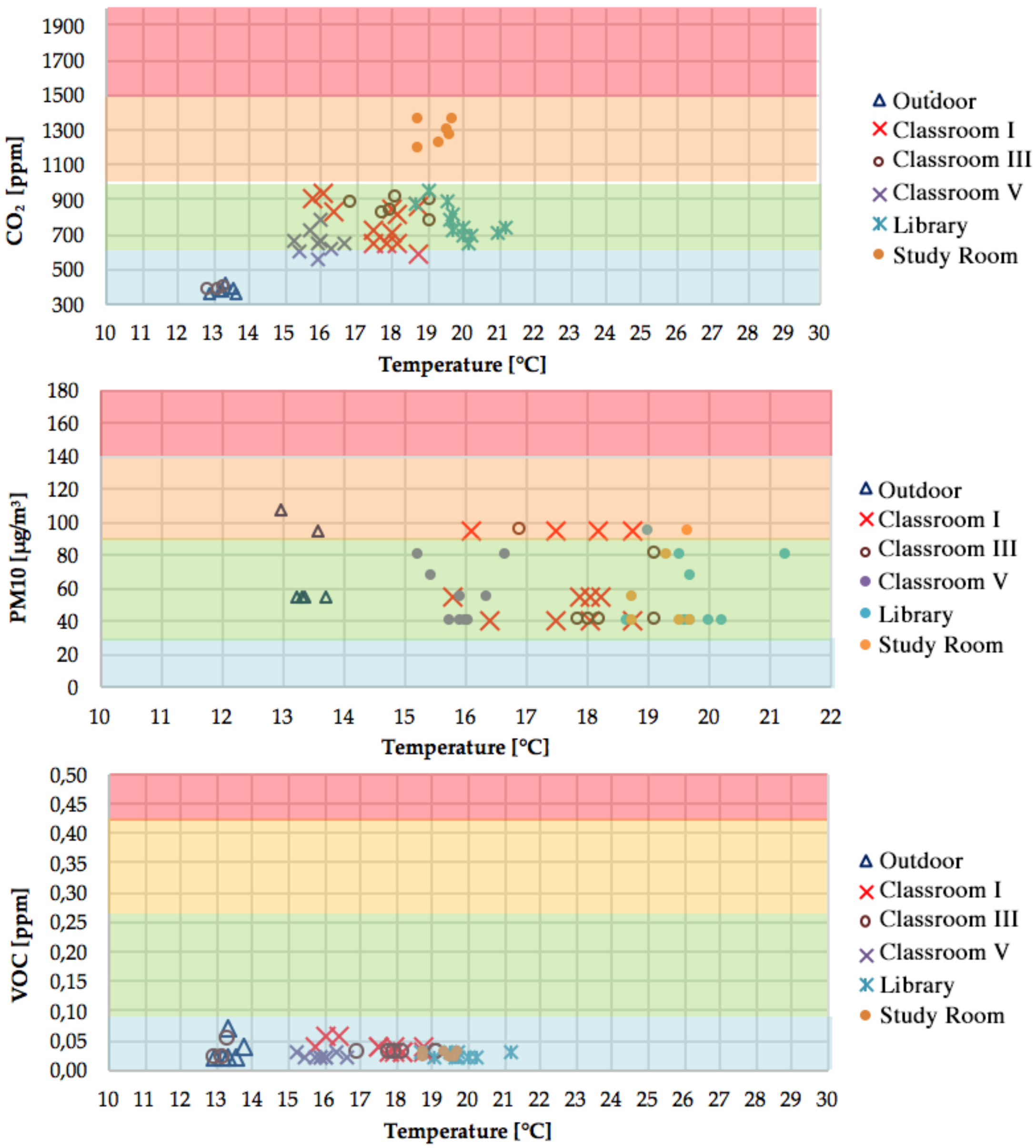


Figure 6. Results of measurements in the winter season

3.3 Energy modelling and Energy efficiency performance diagnosis

The School of Mathematics has been analysed, in its current condition, first in its entirety and subsequently simulated as divided into 4 thermal zones (Front building A; Tower of Classrooms B; Curved wings C1 East and C2 West) to investigate the energy performance of the individual parts in detail, in respect of Article 6 of Legislative Decree 192/2005. The energy services considered in the evaluation of the energy performance of the building are: winter air conditioning, production of domestic hot water (DHW), lighting and transport of people or things. The intended use according to Presidential Decree 412/93 is E.7: School buildings at all levels and similar).

The Energy Performance Certificate has been provided following the current legislation (Ministerial Decree of 26 June 2015) [26] provides for the calculation of energy performance in buildings, including the use of RES, the use of national technical standards UNI/TS 11300 [27-28]; these standards define the procedures for the Italian application of UNI EN ISO 13790:2008 and are aimed at all possible applications envisaged by UNI EN ISO 13790:2008: design rating, energy assessment of buildings through the calculation of standard conditions (asset rating) or in particular climatic and operating conditions (tailored rating).

For the simulation of the energy behaviour of the building envelope of the front building implemented with dedicated software, reference has been made to the results of the investigations and to the information collected during the inspections: listing of opaque structures includes floors, which have been modelled as brick-concrete elements of variable thickness between 35-40 cm, and perimeter walls, which have been modelled as tuff blocks alternating with parallel rows of red bricks, plastered with lime mortar, with the exception of the main and the rear façade which are cladded with travertine slabs and litho-ceramic, with an overall thickness of about 80 cm. Transparent surfaces are all single glazed, mostly windows with wooden frames, resting on travertine sills and without solar shading systems.

The energy services considered in the calculation of the energy performance for all the four blocks are winter air conditioning, production of domestic hot water (DHW), lighting and transport of people or things.

The heating system of these spaces is connected to the university campus district heating network, through a secondary branch that starts from a substation, and arrives in a technical room from which the backbones branch off through a distribution manifold and heat exchangers. Distribution boxes are housed in the basement near the block. The production of domestic hot water (DHW) for the toilets is produced locally using local electric boilers. Lighting fixtures in this part of the building are equipped with tubular fluorescent lighting lamps with an average diameter of 38 mm while the transport of people or things is entrusted to an electric lift, whose motor is at the top of the shaft, with automatic scrolling cabin doors.

In light of the information acquired, the calculation of the energy performance of the block A, in its current condition, has resulted in a non-renewable global energy performance index $EP_{gl,nren}$ = 87.6 kWh/m^2 per year, thanks to which the energy class of the building has been defined as corresponding to the E class. The winter energy performance index is of low quality, while the summer performance is of medium quality; the calculation of the energy performance of the Tower of classrooms B, in its current condition, has resulted in a non-renewable global energy performance index $EP_{gl,nren}$ = 123,7 kWh/m^2 per year, thanks to which the energy class of the building has been defined as corresponding to F class. Both the winter energy performance index and the summer performance index are of low quality; the calculation of the energy performance of the Curved wings C1 and C2, in its current condition, has resulted in a non-renewable global energy performance index $EP_{gl,nren}$ = 141,8 kWh/m^2 per year, thanks to which the energy class of the building has been defined as corresponding to F class. Both the winter energy performance index and the summer performance index are of low quality.

After the current condition energy performance analysis, a framework of possible requalification intervention has been hypothesized.

To understand which are the most effective strategies for improving the energetic behaviour of each block, a further simulation has been made on the software. The opaque structures of the building envelope remain unchanged as of the current situation; concerning the glazed surfaces, on the other hand, the replacement of the existing elements is recommended with thermal-break windows with open joint and low-emission double glazing, maintaining, where possible, the original frame, integrated with solar shading systems. For the main central window, where the conservation of the original window frame is expected due to its historical value, the insertion of a glazed counter-wall with a PVC frame is proposed.

The energy services considered in the calculation of the energy performance remained the same as the current condition: for the heating system, the building remains connected to the University campus district heating network, while for the heat generators high-efficiency silenced heat pumps are proposed, which also allow almost costless production of domestic hot water (DHW) for the toilets. Furthermore, about the distribution sub-system, the installation of thermostatic valves coupled to the centralized electronic thermostatic heads is proposed on each radiator to regulate the inflow of hot water based on the temperature of the single rooms.

For the electrical system the implementation of the PV system is suggested, placed on the roof, currently at the exclusive service of the adjacent building; for lighting, the replacement of the lamps with energy-saving LED elements is proposed and the insertion of timers for the automatic switch-off of the lights at pre-set times differentiated by areas, while the transport of people or things remains entrusted to the existing lift.

In light of the solutions proposed for the requalification of the block A, the calculation of the energy performance resulted in a non-renewable global energy performance index $EP_{gl,nren}$ = 74.8 kWh/m^2 per year, thanks to which the energy class of the building as corresponding to indicator A1, significantly higher than the initial one. The winter energy performance index is of high quality, while that of the summer performance remains of medium quality; for the requalification of the block B, the calculation of the energy performance resulted in a non-renewable global energy performance index $EP_{gl,nren}$ = 74.8 kWh/m^2 per year, thanks to which the energy class of the building as corresponding to the indicator C, higher than the initial one but lower than that of the the Front building A due to summer air conditioning and the share of RES from which it is served. Both the winter energy performance index and the summer performance index are of high quality; for the requalification of blocks C1-C2, the calculation of the energy performance resulted in a non-renewable global energy performance index $EP_{gl,nren}$ = 57,3 kWh/m^2 per year, thanks to which the energy class of the building as corresponding to the alphabetic indicator C, higher than the initial one. The winter energy performance index is of high quality, while that of the summer performance remains of medium quality.

4. Discuss and Conclusion

The results obtained starting from the IEQ analyses and the energy modelling and simulation allow us to propose intervention guidelines following the simulation of energy requalification and also the directive of the guidelines for improving energy efficiency in cultural heritage [29]:

For the conservation and improvement of the building envelope:

- No specific intervention on the masonry structures, except for periodic maintenance;
- Implementation of (indoor) mitigation systems for window frames belonging to those environments where it is necessary to improve the microclimate;
- Replacement of mechanical window opening systems where necessary.

More specifically, in the Front building (block A), as the main window is imbued with historical value, it is advisable to:

- add an internal glazed counter-wall with PVC frame;
- replace the glass part only, leaving the original frame;
- insert an air destratifier.

For the improvement of the HVAC systems:

In the Front Building:
- Installation of centralized thermostatic valves on all radiators;
- Library: creation of a horizontal barrier to limit rising air currents in the central area of the reading tables during the winter season;

In the Tower of Classrooms:
- Installation of centralized thermostatic valves on all radiators;
- Tiered lecture halls: requalification of the original thermo-ventilation system, especially taking into account its historical value;

In the Curved Wings:
- Installation of centralized thermostatic valves on all radiators;
- Study rooms: replacement of current systems serving individual rooms with a centralised heating/cooling system.

For the improvement of electrical systems:

- implementation of PV systems to support the existing electrical system;
- scheduled replacement of lighting with LED lamps;
- insertion of timers for automatic switching off of lights according to pre-established times and functions differentiated for external areas, common areas such as corridors, lobbies and classrooms.

As a result of this first part of the research, the School of Mathematics does not require radical alterations but instead does need to be revitalized so that its architectural features can be perceived and its original spaces, that now appear disjointed, can be recomposed.

Although the definition of the building improvement solutions is still in the in-progress and in-depth phase, this part of the research highlights how it's possible to achieve the improvement by integrating huge losses and by aligning the building envelope and existing plant systems concerning current regulations, based on critical, scientific, and philological considerations aiming at the refurbishment of the existing building stock required from the European legislation.

References

[1] MiTE (2021), Strategy for Energy Retrofitting of National Building Stock. Available online: https://energy.ec.europa.eu/system/files/2021-12/2020_ltrs_italy_-_en.pdf (accessed 26 May 2023)

[2] ENEA (2020), Rapporto annual 2020 – La Certificazione energetica degli edifice. Available online: https://www.enea.it/it/seguici/events/rapportoape_2020/RapportoAPE2020_esteso.pdf (accessed 26 May 2023)

[3] Energy Performance of Buildings (2020), Implementation of the EPBD Italy – Status 2020. Available online: https://epbd-ca.eu/wp-content/uploads/2022/03/Implementation-of-the-EPBD-in-Italy-2020.pdf (accessed 26 May 2023)

[4] European Commission (2020), Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee Of The Regions A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives {SWD(2020) 550 final}. Available online: https://eur-lex.europa.eu/resource.html?uri=cellar:0638aa1d-0f02-11eb-bc07-01aa75ed71a1.0003.02/DOC_2&format=PDF (accessed 26 May 2023)

[5] European Parliament and the Council of the European Union. "Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (Text with EEA relevance)". Off. J. Eur. Union L156/75, 2018

[6] GURI (2004), D.L. 22 gennaio 2004, n. 42 Codice dei beni culturali e del paesaggio, ai sensi dell'articolo 10 della legge 6 luglio 2002, n. 137. (GU Serie Generale n.45 del 24-02-2004 - Suppl. Ordinario n. 28). Available online: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazione Gazzetta=2004-02-24&atto.codiceRedazionale=004G0066 (accessed 26 May 2023)

[7] Ministerial decree 10 May 2001, Guidelines on technical and scientific criteria and the standards of functioning and development of museums (art. 150, par. 6 of Legislative Decree no. 112/1998 G.U. 19 Oct. 2001, no. 244, S.O.) Available online: https://www.gazzettaufficiale.it/eli/id/2001/10/19/001A8406/sg (accessed 26 May 2023)

[8] Romano, G; Mancini, F. (2022), Transformation of a historical building into a Nearly Zero Energy Building (nZEB) / - Journal of Physics. Conference Series. - ISSN 1742-6588. - 2385:1(2022), P. 012008. [10.1088/1742-6596/2385/1/012008]

[9] Mancini, F., Romano, G., Rosso, M. (2022). Technical issues, comfort, and energy efficiency, in Salvo, S. (ed.) The School of Mathematics at Rome's university campus, Gio Ponti 1935 pp. 265-294

[10] Nastasi, B; Mancini, F. (2022), Procedures and Methodologies for the Control and Improvement of Energy-Environmental Quality in Construction, Energies. ISSN 1996-1073. - 14:9(2021), P. 2353. [10.3390/En14092353]

[11] Mornati S. (1994-1995): "La sperimentazione nella costruzione della Città Universitaria di Roma (1932-35)". In: Rassegna di architettura e urbanistica;

[12] De Santoli, L., Mancini, F., Clemente, C. (2017), Energy and technological refurbishment of the School of Architecture Valle Giulia, Rome in Energy Procedia (Oxford: Elsevier B.V) pp. 382-391 - ISSN: 1876-6102
[13] Di Marco I., Pappalardo R., Santelli E. (2019), Riqualificazione paesaggistica ed ambientale degli spazi outdoor della Città Universitaria "La Sapienza". Sapienza Università di Roma, Roma
[14] Pensuti E., Verzari S. (2018), Riqualificazione energetica ed ambientale dell'Istituto di Chimica dell'Università di Roma - La Sapienza. Sapienza Università di Roma, Roma
[15] Fraioli S. (2016), Riqualificazione energetica ambientale: edificio della clinica ortopedica e traumatologica alla Città Universitaria. Sapienza Università di Roma, Roma
[16] Pini, F., Romano, G., Aureli, C. (2019), Energy refurbishment of the general physiology institute at Sapienza university campus, in: Journal Of Physics. Conference Series. - ISSN 1742-6588. - 1351:1(2019), pp. 1-8
[17] Mancini, F., Clemente, C. (2017), Energy and environmental retrofitting of the university building of Orthopaedic and Traumatological Clinic within Sapienza Città Universitaria, in Energy Procedia (Oxford: Elsevier B.V) pp. 195-202 - ISSN: 1876-6102
[18] Muntoni A. (2010): "La città universitaria di Roma (1933-1935)". In: A. Muntoni, Roma tra le due guerre 1919-1944. Architettura, modelli urbani, linguaggi della modernità, Rome: Edizioni Kappa;
[19] Bouilhet-Dumas S., Forest D. (2018), in Licitra S. (eds.): Gio Ponti archi-designer, Catalogue of the exhibition (Paris, October 19, 2018- February 10, 2019), Paris: MAD.
[20] Licitra S. (eds.) (2020); Gio Ponti, Köln: Taschen.
[21] AA.VV. (1935), La città universitaria di Roma – Numero speciale della rivista "Architettura – rivista del sindacato nazionale fascista architetti" diretta da Marcello Piacentini, F.lli Treves ed., Milano
[22] De Santoli L. (2011), Le comunità dell'energia, Macerata: Quodlibet;
[23] De Santoli, L. et al. (2017), PES Piano strategico energetico-ambientale di Sapienza (2017-2030) – Transizione verso un modello energetico e una economia decarbonizzati, Delibera 08 Giugno 2017, Sapienza Università di Roma, Roma;
[24] Neufert, E., Architects' Data, Italian edition, Hoepli publisher, 1999 Milan
[25] Mancini, F.; Nardecchia, F.; Groppi, D.; Ruperto, F.; Romeo, C. Indoor Environmental Quality Analysis for Optimizing Energy Consumptions Varying Air Ventilation Rates. Sustainability 2020, 12, 482. https://doi.org/10.3390/su12020482
[26] Interministerial decree 26 June 2015, Adaptation of national guidelines for the energy certification of buildings. Available online: https://www.mise.gov.it/index.php/it/normativa/decreti-interministeriali/2032968-decreto-interministeriale-26-giugno-2015-adeguamento-linee-guida-nazionali-per-la-certificazione-energetica-degli-edifici (accessed 26 May 2023)
[27] UNI Ente Italiano di Normazione Italian technical standard Number UNI/TS 11300-1:2014 — "Energy Performance of Buildings —Evaluation of Energy Need for Space Heating and Cooling." Available online: http://store.uni.com/catalogo/index.php/uni-ts-11300-1-2014.html (accessed 26 May 2023)
[28] UNI Ente Italiano di Normazione, Italian technical Standard Number UNI 10339:1995, "Air-conditioning systems for thermal comfort in buildings. General, classification and requirements. Offer, order and supply specifications." CTI – Cooling systems: design, installation, test and performances, 1995.
[29] MIC, Guidelines for improving energy efficiency in cultural heritage, Architecture, historic and urban centres, 2015. Available online: https://www.soprintendenzapdve.beniculturali.it/wp-content/uploads/2021/04/Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf (accessed 26 May 2023)