E3S Web of Conferences **197**, 02003 (2020) https://doi.org/10.1051/e3sconf/202019702003
75° National ATI Congress

Historical analysis and refurbishment proposal of the “Red schools” in Viterbo

Giada Romano[1], *Elisa* Pennacchia[1], and *Sofia* Agostinelli[2]

[1]Department of Planning, Design and Technology of Architecture, Sapienza University of Rome, Via Flaminia 72, 00196 Rome, Italy
[2]Interdepartmental Centre for Landscape, Building, Conservation, Environment (CITERA), Sapienza University of Rome, Via A. Gramsci, 53-00197 Rome, Italy;

Abstract. To hinder climate change, EU legislation requires that by 2020 each European state achieves the objectives set by the 2020 Climate and Energy Package. Particular attention is paid not only to new constructed buildings, the so-called Near Zero Energy Buildings, but also to the existing building stock: in Italy in fact, in addition to the National Action Plan to increase the NZEB buildings (PANZEB), the Strategy for Energy Renewal of the National Real Estate Park (STERPIN) is planned. The aim of the thesis work is a primary school built in 1938 within the historical centre of Viterbo. The work touched on three different areas of design: the design of the internal and external spaces, annexed to the school building, finding solutions for a flexible and functional distribution in line with the theories of modern pedagogy, moving from a school of homologation to a school of diversity enhancement.
This was joined by a study concerning the original elevations and constructive features, bearers of historical and aesthetic values, which resulted in the proposal for conservative restoration of the Terranova plaster and the original iron-window profiles.
Finally, attention was paid to energy upgrading and efficiency, in line with regulatory provisions.
The interventions did not only concern the building envelope (through a thermal upgrading of the original iron-windows, the insulation of the flat roof and the indoor thermal coat of the perimeter walls), but also the system (through the replacement of the boiler with a heat pump, integrated with the photovoltaic system placed on the roof, the inclusion of thermostatic valves and lighting design with the replacement of fluorescent lamps with LED ones).

1. Introduction

The European Community has clearly drawn its goals in terms of environmental sustainability, indicating ambitious targets for reducing energy consumption, emissions and increasing the use of RES [1–27].

Building sector nowadays is responsible of more than 40% of total energy consumption in the European Union [2]. Imposing consumption limits on new buildings alone is not enough to reach the objectives, required by the policies of mitigating the harmful effects that buildings have on the environment [3]. Deep renovation rates and adaptation in the energy carriers will be required, leading a large majority of dwellings to use renewable heating sources (electricity, district heating, renewable gas or solar thermal) [4], more efficient products and appliances, smart management systems of buildings and all energy uses.

As for renewable energies, the European Commission has stated that the renewable energies in 2030 will top 32% of overall energy consumption; the production of electricity from RES will be greatly enlarged, with new systems that will be installed first of all on the built environment [5–6–24], meanwhile, electrification of the energy system will be gained on a large scale. The introduction of alternative energy sources for supply will require careful management of flexible loads (DSM - Demand Side Management) to improve efficiency and make the network stable, even facilitated by introduction of storage, when possible [7].

In this scenario, the defensive attitude that resulted in the attempt to exclude historic buildings from any obligation has changed and has developed into a more constructive approach, that, together with the desire to preserve buildings, also consider the possibility to use them efficiently [8–9]. Therefore, guidelines and good practices must be applied for a correct energy refurbishment of the building heritage, to adapt it to the needs of contemporary use and to climate change [10]; if feasible, efforts should be made to get to the nZEB standard [11–13], with a renovation that also considers the Indoor Environmental Quality (IEQ) [14] and the utilization of RES, introducing automation systems to manage flexible loads [15,16]; for buildings subject to constrain, it is necessary to find the way to improve their performance preserving the historical and architectural values [17–19]. As for the urban environment, however, it is better to use those energy carriers that reduce local pollutant emissions [20–22–25–26].

This paper reports the details of a renovation of a primary school, in a building subject to protection. Referring to the national and international energy framework described above, the design team listened to the costumer’s requests: so that, the work touched on three different areas of design: the design of the internal spaces, the external ones attached to the school building, going to find solutions for a flexible and functional distribution in line with the theories of modern pedagogy, passing from a school of homologation to a school for the enhancement of diversity.

The design choices have aimed not only at the research for environmental comfort, but also at energy efficiency, the reduction of polluting emissions, the electrification of public services and the use of RES.

 https://doi.org/10.1051/e3sconf/202019702003

2. Building features and energy status quo

The school building, now used as a primary school, was built in 1938 in the eastern part of the historical centre of the city of Viterbo, based on the project by the Technical Office of 1936. The complex, which annually hosts about 580 students, consists of 2 floors above the ground and one partially underground, and it has a global surface area of 3,200 m^2 of which approximately 1,870 m^2 are covered and about 1330 m^2 are uncovered (Figure 1). From the point of view of urban planning, between via del Bottalone and piazza Concetti Luigi, the school borders with the church of Santa Maria della Pace (Figure 2), while from the architectural point of view it has a very irregular conformation that follows the development of the blocks where it was built: the corner solution is unusual with the mute façade of the clock tower between via Vetulonia and via della Verità (Figure 3).

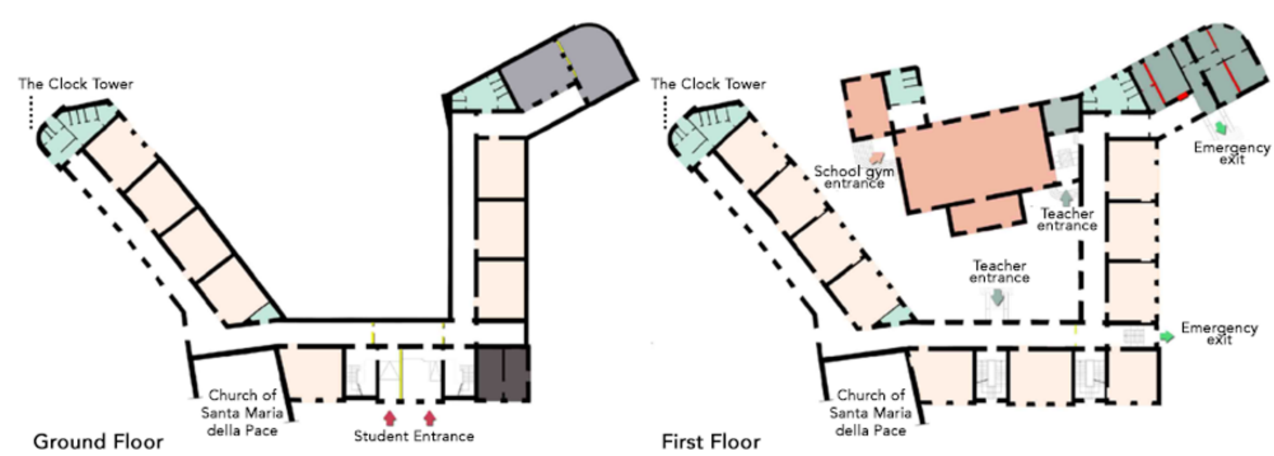

Fig. 1. Plans of the current state of the Ground Floor and the First Floor.

a b

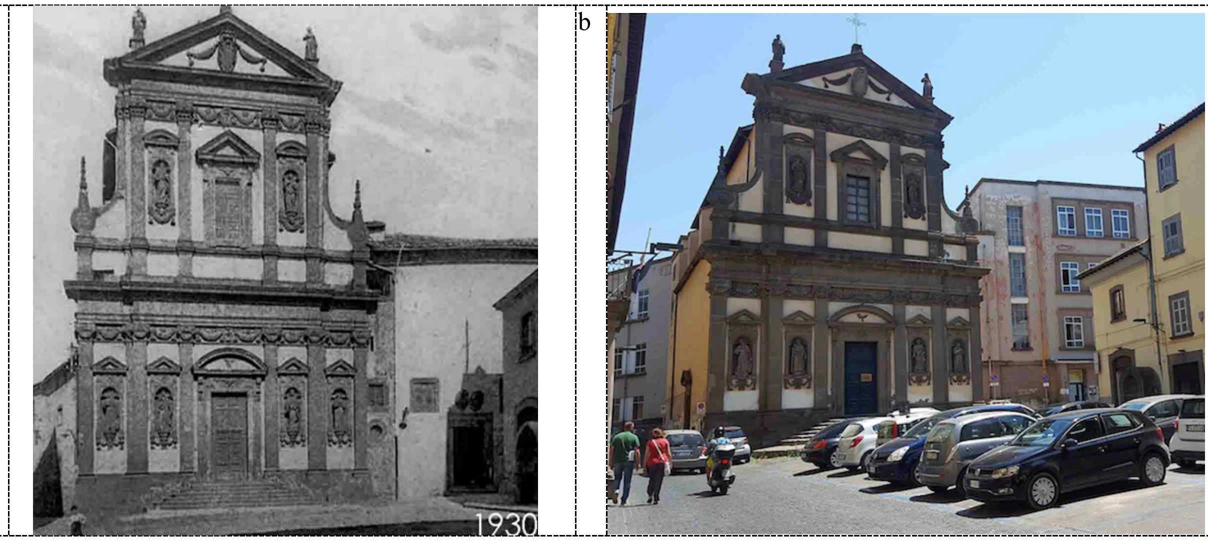

Fig. 2. Church of Santa Maria della Pace and school (a) year 1930; (b) today.

Fig. 3. The Clock tower **(**a) year 1949; (b) today.

Historical-critical recognition is an essential premise for the conservation of this building. The school was, and still is today, a training and education centre for the Viterbo community. The name "red schools", which has always been used, underlines the fact that it is present in the collective memory: a unique building, set between a baroque church and medieval streets. Despite this, the building's vulnerability derives both from its physical fragility but, above all, from its overexposure to use. These reasons, combined with the total absence of maintenance interventions over the years, makes the progress of an already rapid aging.

The data used for dimensional and energy analysis were got through non-destructive in-situ investigations, in addition interviews were carried out with the maintenance technicians of the structure and all the documentation relating to the construction process of the building was consulted, obtained thanks to the material present in the Archive of the Civil Engineers of Viterbo and in the Historical Archive of the Municipality of Viterbo as well as using bibliographic sources on the subject.

The first project included a concrete structure but, during the construction, a structural solution in load bearing wall in stones of peperino was then chosen (coming from the quarry of the "Pallone" about 10 km from Viterbo) among which, every 80 cm, two rows of solid bricks are arranged in horizontal courses, bound together by cement mortar (figure 4a). The ground floor and those of the upper levels are of the "Berra" type (figure 4b): mixed floors in reinforced concrete characteristic for the structure with triangular holes, while the roof is of the "Stimip" type (figure 4c): in tile and concrete, but the concrete slab is replaced by massive slabs that form a hollow block.

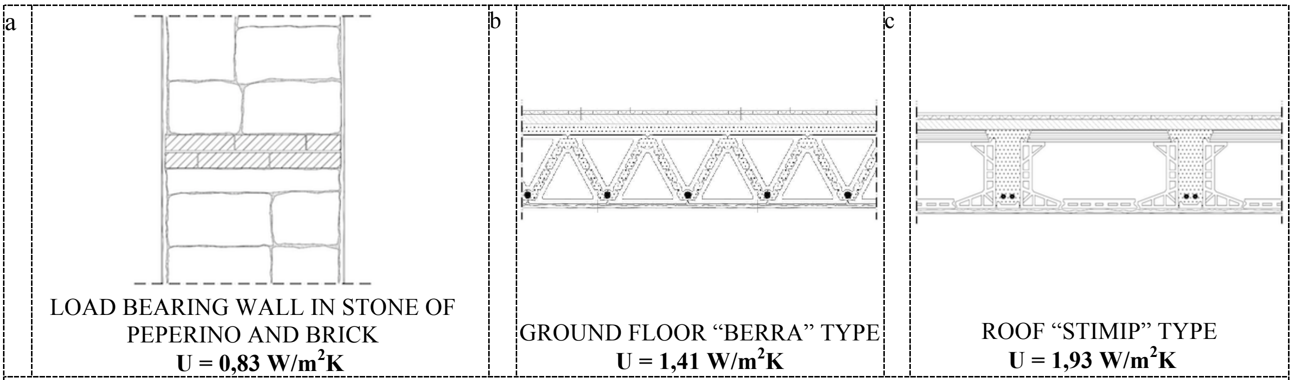

Fig. 4. Abacus of constructive elements **(**a) load bearing wall in stone of peperino and bricks; (b) ground floor BERRA type; (c) roof SIMIP type.

Table 1 shows the area of the walls and the windows related to their orientation and their thermal transmittance.

Table 1. Building Wall and windows orientation [m^2] and U-values [W/m^2K].

Wall Orientation	Total opaque area	Thermal transmittance	Total glazed area	Thermal transmittance
N	131,2	0,83	0	0
NE	93,4	0,83	8,9	2,43
E	121,3	0,83	20,3	2,43
SE	65,3	0,83	12,3	2,43
S	65,3	0,83	23,9	2,43
SW	0	0	0	0
W	207	0,83	24,1	2,43
NW	97	0,83	0	0
Ground floor	1425	1,619	-	-
Roof	1425	1,561	-	-

The original windows, still present in the building, are made of iron. The iron-windows manufacturing process allowed the development of numerous types of profiles that can be assembled in different combinations; the openings used in this case are hinged, with two doors, with tilting windows and joined to fixed parts (Figure 5). The advantages of the iron-windows compared to the wooden structures are many i.e. the greater surface area useful for lighting, incombustibility, lower sensitivity to atmospheric agents and longer duration of the window.

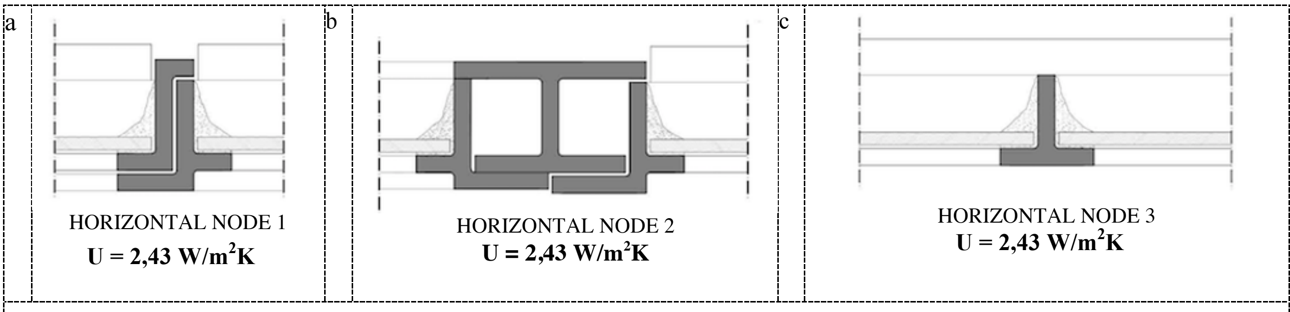

Fig. 5. Abacus of the windows (a) hinged, with two doors; (b) tilting, with two doors; (c) joined with fixed parts.

As regards the system equipment of the school building, from a project of 1936, this was equipped with a heating system with coal burner; in 1953 the original burner was replaced with a completely automatic oil-fired one.

Based on this set of information, a building model was built using Stima10-TFM software, which implements the procedures of the UNI 7357/74 for the calculation of winter peak thermal loads, the Transfer Function Method (TFM) ASHRAE for the calculation of summer thermal loads and procedures of UNI/TS 11300 (UNI EN ISO 13790 national adoption) for the calculation of energy needs.

Table 2 shows the ideal energy consumption before intervention with the share between transmission losses, ventilation losses, solar gains and internal gains.

Table 2. Ideal energy consumption.

		Before
Transmission losses	[kWh/m^2]	154,6
Ventilation losses	[kWh/m^2]	15,6
Solar gains	[kWh/m^2]	35,4
Internal gains	[kWh/m^2]	16,6

The building consumptions model due to heating, hot water and lighting was validated by comparison with the data from energy bills given by the head teacher [23-26]. According to energy labelling, the building belongs to category F since its $EP_{gl,nren}$ consumption is 243.7 kWh/m^2y; the renewable fraction reaches 3.9%.

Table 3. Primary energy consumptions.

		Heating	Hot water	Lighting	Total
Renewable	[kWh/y]	562	32	27,238	27,862
Fossil	[kWh/y]	575,978	1,150	113,084	690,213
Total	[kWh/y]	576,570	1,182	140,322	718,075
Renewable fraction	%	0.1%	2.7%	19.4%	3.9%

3. Intervention strategies

Having made the necessary considerations, it was decided to proceed with a project aimed at confirming the historical-architectural presence of the building in the urban context and, at the same time, guaranteeing its necessary functional renewal dictated both by the evolution of educational needs and by the technological ones. This is combined with a plant and energy refurbishment as an essential modification to the use of the building and, consequently, to its conservation.
Starting from the results of the analysis and the study of the reference standards, a series of interventions in different areas have been hypothesized:

- on the interior spaces the proposal is to create new learning spaces through flexible and functional furniture; in this way the school spaces are adapted to the needs of modern pedagogy;
- the outdoor spaces, currently empty and with no identity, are enhanced through the insertion of an urban garden that can be used both by students to encourage them to be in contact with nature and by the inhabitants of the neighbourhood; from an environmental point of view, the percentage of permeable external floor is increased and food can be produced without the use of chemicals.
- energy requalification both on the building envelope with the replacement of the glass, the insulation of the roof slab and the internal insulation on the perimeter walls; and on the systems, with the introduction of a photovoltaic system on the roof for on-site production of electricity.

Due to the flexibility of the spaces, the project proposal is to create learning areas equipped with flexible and functional furnishings, also in relation to the chromatic variation (yellow promotes the activity of the left hemisphere and stimulates study and concentration; green encourages reflection and calm; blue is the colour of intuition and extra-sensory perception; orange stimulates activity, positivity and movement). The flexible classroom allows the school to overcome the homogenization through the freedom of action and the active involvement of the students, it also allows to highlight the distinction between the theoretical lesson and the laboratory activity and to create multi-functional spaces necessary for the new needs of teaching.

The outdoor spaces, currently empty and without identity are enhanced through the inclusion of an urban garden accessible both by students and the population of the district: this strategy aims to raise awareness of environmental and nutritional issues and encourage socialization.

As regards the building envelope, in order not to alter its original appearance, the proposed solution for perimeter walls is the insertion of an internal insulation layer with the "Aeropan Fast" panel, consisting of an insulator nanotechnology in Airgel coupled with a breathable membrane in polypropylene reinforced with glass fiber: this insulating panel has a thermal resistance of 2,01 m^2K/W and a thermal conductivity at 10°C of 0,015 W/m*K for a thickness of 30mm; the intervention aiming at the roof floors provides for the application of an insulating layer (for the covering layer) made of polyurethane panels with a thermal conductivity at 10°C of 3,84 W/m*K for a thickness of 100mm and the replacement of the existing flooring with one in marbles.

As far as windows are concerned, instead, it was decided to intervene through a conservative refurbishment of the original iron-windows but with the replacement of the single glass with a 4-9-4 (mm) double glazing with Argon. These iron-windows are essential to maintain the character and the historical and architectural value of the whole building; this choice is also joined by a series of economic and environmental reasons linked to the conservation of the incorporated energy and the reduction of environmental costs associated with the disposal of the elements.

Table 4 summarizes the U-values of the building envelope components, comparing the existing situation with the intervention proposals.

Table 4. U-value of building components [W/m^2K].

Description	Existing situation	Intervention proposal
Vertical building envelope	0.83	0.30
Ground floor	1.41	0.23
Roof	1.56	0.24
Original windows	2.43	1.60

With regard to systems, the introduction of a reversible air-cooled compression heat pump, with a total peak thermal power required of 100 kW for the winter heating as a priority generator, replacing the existing boiler was hypothesized. The reduction of the winter thermal load obtained with thermal insulation interventions allows existing radiators to be maintained as terminals of the heating system with the introduction of thermostatic valves as a regulation system.

Regarding the lighting system, the replacement of fluorescent lamps with suspended LED lamps was hypothesized, with the introduction of an automatic shutdown system equipped with presence sensors.
On the flat roof of the school building the installation of a photovoltaic system has been hypothesized: this is composed of monocrystalline silicon panels with a peak thermal power of 0,150 kW/m^2, lying horizontally on the roof, for a total area of 700 m^2.

Table 5 shows the ideal energy consumption after intervention with the share between transmission losses, ventilation losses, solar gains and internal gains.

Table 5. Ideal energy consumption.

		After
Transmission losses	[kWh/m^2]	63,6
Ventilation losses	[kWh/m^2]	15,0
Solar gains	[kWh/m^2]	15,9
Internal gains	[kWh/m^2]	9,0

According to the energy labelling, the building belongs to category B since its $EP_{gl,nren}$ consumption is 80.9 kWh/m^{2}y; the renewable fraction reaches 36.5% considering the aero-thermal energy of the heat pumps and the electricity produced by the photovoltaic system. Those quantities are depicted in Table 6.

Table 6. Primary energy consumptions.

		Heating	Hot water	Lighting	Total
Renewable	[kWh/y]	90,177	444	36,011	126,572
Fossil	[kWh/y]	190,925	550	28,598	220,073
Total	[kWh/y]	281,042	994	64,609	346,645
Renewable fraction	%	32.1%	44.7%	19.4%	36.5%

4. Conclusions

In light of what was said in the intervention strategies, it can be stated that the benefits deriving from the choices made are not only of an energy, and consequently economic, field. They are also at an environmental and social level. In this last aspect, the flexibility of the interior spaces and the creation of equipped green areas, usable by students but also by other citizens, promotes aggregation and socialization, important in the age of the individual growth.

From an environmental point of view, the choice of advanced system devices, already designed to be connected to the photovoltaic system, makes the exploitation of renewable energy resources possible.

At the energy level, the reduction in net demand is evident in terms of heating: in the winter case, the current situation goes from a thermal load of around 1'200'000 MJ (in January) to the post-intervention situation in which the same load does not exceed 490,000 MJ. This means, in percentage terms, a 59% reduction in the net energy demand for heating.

References

[1] European Commission 2018 *A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy*

[2] Eurostat 2017 Database - Eurostat *risk poverty Soc. exclusion*

[3] Battisti A 2016 Guidelines for energy efficiency in the cultural heritage *TECHNE - J. Technol. Archit. Environ.* **12** 65–73

[4] Nastasi B 2019 Hydrogen policy, market, and R&D projects *Solar Hydrogen Production: Processes, Systems and Technologies* (Elsevier) pp 31–44

[5] Mancini F and Nastasi B 2020 Solar Energy Data Analytics: PV Deployment and Land Use *Energies* **13** 417

[6] de Santoli L, Mancini F and Astiaso Garcia D 2019 A GIS-based model to assess electric energy consumptions and usable renewable energy potential in Lazio region at municipality scale *Sustain. Cities Soc.* **46** 101413

[7] Mazzoni S, Ooi S, Nastasi B and Romagnoli A 2019 Energy storage technologies as techno-economic parameters for master-planning and optimal dispatch in smart multi energy systems *Appl. Energy* **254** 113682

[8] Battisti A and Tucci F 2014 Technological energy and environmental refurbishment of historical Italian libraries *Techne J. Technol. Archit. Environ.* **0** 90–108

[9] Hausladen G and Tucci F 2017 Technological culture, the environment and energy: The outlook for research and experimentation *TECHNE* **13** 63–71

[10] Mancini and Lo Basso 2020 How Climate Change Affects the Building Energy Consumptions Due to Cooling, Heating, and Electricity Demands of Italian Residential Sector *Energies* **13** 410

[11] de Santoli L, Lo Basso G, Astiaso Garcia D, Piras G and Spiridigliozzi G 2019 Dynamic Simulation Model of Trans-Critical Carbon Dioxide Heat Pump Application for Boosting Low Temperature Distribution Networks in Dwellings *Energies* **12** 484

[12] Roversi R, Cumo F, D'Angelo A, Pennacchia E and Piras G 2017 Feasibility of municipal waste reuse for building envelopes for near zero-energy buildings *WIT Trans. Ecol. Environ.* **224** 115–25

[13] Piras G, Pennacchia E, Barbanera F and Cinquepalmi F 2017 The use of local materials for low-energy service buildings in touristic island: The case study of Favignana island *2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe)* (IEEE) pp 1–4

[14] Mancini F, Nardecchia F, Groppi D, Ruperto F and Romeo C 2020 Indoor Environmental Quality Analysis for Optimizing Energy Consumptions Varying Air Ventilation Rates *Sustainability* **12** 482
[15] Mancini F, Lo Basso G and de Santoli L 2019 Energy Use in Residential Buildings: Impact of Building Automation Control Systems on Energy Performance and Flexibility *Energies 2019, Vol. 12, Page 2896* **12** 2896
[16] De Santoli L, Mancini F and Basso G L G Lo 2019 Analysis on the potential of an energy aggregator for domestic users in the Italian electricity system *AIP Conference Proceedings* vol 2191 p 020062
[17] De Santoli L, Mancini F, Clemente C and Lucci S 2017 Energy and technological refurbishment of the School of Architecture Valle Giulia, Rome *Energy Procedia* vol 133 pp 382–91
[18] Mancini F, Clemente C, Carbonara E and Fraioli S 2017 Energy and environmental retrofitting of the university building of Orthopaedic and Traumatological Clinic within Sapienza Città Universitaria *Energy Procedia* vol 126 pp 195–202
[19] Mancini F, Cecconi M, De Sanctis F and Beltotto A 2016 Energy Retrofit of a Historic Building Using Simplified Dynamic Energy Modeling *Energy Procedia* vol 101 pp 1119–26
[20] Cumo F, Curreli F R, Pennacchia E, Piras G and Roversi R 2017 Enhancing the urban quality of life: A case study of a coastal city in the metropolitan area of Rome *WIT Trans. Built Environ.* **170** 127–37
[21] Piras G, Pini F and Astiaso Garcia D 2019 Correlations of PM10 concentrations in urban areas with vehicle fleet development, rain precipitation and diesel fuel sales *Atmos. Pollut. Res.*
[22] Astiaso Garcia D, Cumo F, Pennacchia E, Stefanini Pennucci V, Piras G, De Notti V and Roversi R 2017 Assessment of a urban sustainability and life quality index for elderly *Int. J. Sustain. Dev. Plan.* **12** 908–21
[23] Manfren M and Nastasi B 2020 Parametric Performance Analysis and Energy Model Calibration Workflow Integration—A Scalable Approach for Buildings *Energies* **13** 621
[24] Corrado V, Murano G, Paduos S, Riva G 2016 On the refurbishment of the public building stock toward the nearly zero-energy target: two Italian case studies *Energy Procedia* **101** 105-112
[25] Graham-Hanssen K 2014 Existing buildings – Users, renovations and energy policy *Renewable Energy* **61** 136-140
[26] Lu M, Lai J H K 2019 Building energy: a review on consumptions, policies, rating schemes and standards 10th International Conference on Applied Energy (ICAE2018) *Energy Procedia* **158** 3633-3638
[27] Santamouris M, Cartalis C, Synnefa A, Kolokotsa D 2015 On the impact of global warming on the power demand and electricity consumption of buildings – a review *Energy and Buildings* **98** 119-124