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Energy and environmental retrofitting of the university building of Orthopaedic and Traumatological Clinic within Sapienza Città Universitaria

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Abstract

To cope with climate change energy sustainability is considered the key target EU Countries set to achieve by 2020. Existing energy users such as building stock require huge efforts to be aligned to this goal. This is the case of the University of Rome "La Sapienza" campus since it was built even before first regulations on energy saving, i.e. Italian Law 10/91. Current energy classification assigns to them the energy efficiency class G, far from class A, the energy label to be achieved by 2020.
The purpose of the study is the energy refurbishment of the Orthopaedic and Traumatological Clinic Institute building located within the "Sapienza" University campus. It is a historical building of great architectural value, designed by Arnaldo Foschini in the 1930s. The proposed interventions entail the total renewal of the building envelope, investigated by thermographic surveys, along with the installations of new heating and cooling systems. The architectural redevelopment is according to Italian Law 338 of 14 November 2000 for the construction of temporary accommodations and residences.
The results obtained were analyzed to identify the best intervention strategy for a sustainable energy retrofitting of historical building, taking into account the preservation of its architectural values as well as making it fit for modern use.

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Keywords: energy refurbishment; energy efficiency; cultural heritage.

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1. Introduction

Building sector is one of the most responsible for CO_2 emissions causing poor air quality [1]. The implementation of European Directive 2009/29/EC in Italian context promoted specific incentive schemes aimed at building energy retrofitting including innovative technology [2]. Here, the energy refurbishment of the Orthopaedic and Traumatological Clinic Institute building located within the “Sapienza” University campus has been designed. Specific attention is paid to the fact that the case study is a protected building. This makes more complex the renewable integration and efficient thermal management in its refurbishment [3]. Because of its inclusion in the listed buildings group, a design proposal must be based on minimum intervention and reversibility [4,5] to preserve its architectural values. Façade material solutions and their physical properties play a key role in terms of local microclimate [6] and building energy performance [7,8]. As a consequence, on-site surveys along with bibliographic research are crucial to calibrate energy performance prediction during the building lifespan. Moreover, installing cutting-edge technologies in the building [9,10,11] such as local renewables when available in the surrounding areas [12], even if they are protected areas [13], becomes feasible after detailed status quo analysis [14,15].

As far as the building history is concerned, it was listed by the Ministry of Cultural and Environmental Heritage according to the Legislative Decree 490/1999 [16]. The driver of this energy refurbishment strategy is to demonstrate that improving building energy performance is viable without affecting architectural and landscaping values as recently shown in this growing research field [17] able to involve detailed energy engineering solutions such as storage [18] or fuel supply modification [19] as well as new meaning of restoration discipline [20].

2. Building history

Recently, Italian cities have followed the Covenant of Mayors call for implementing EU 20-20-20 targets in urban contexts. Protected areas and UNESCO sites were excluded from this initiative and city like Rome, with huge amount of cultural heritage, shows high potential in its rural-urban continuum [21,22] but, low renewable energy potential in its centre and restricted areas [23].

The University "La Sapienza" is located in the II District of Rome. In 1930-1931, the area between Via Regina Elena, Via del Policlinico and Via dei Peligni was assigned to the University by Mussolini's plan to build the new campus. In 1933 the construction works began and they ended in 1935. Marcello Piacentini designed the MasterPlan of the University City as well as the most representative building, i.e. the Rectorate. The campus, called Citta’ Universitaria, is composed by a main axis and a large square with the same proportions of the agonistic circus of Piazza Navona. The distribution of the buildings is strictly symmetrical, while at building scale each volume is independent, as shown in Figure 1. The Orthopaedic and Traumatological Clinic Institute building was designed by Arnaldo Foschini and built between 1933 and 1935.

It is located at the main entrance of the campus. It is made by a structural masonry covered by yellow lito-ceramics while, entrance and external staircases are made by travertine, as depicted in Figure 2.

a b

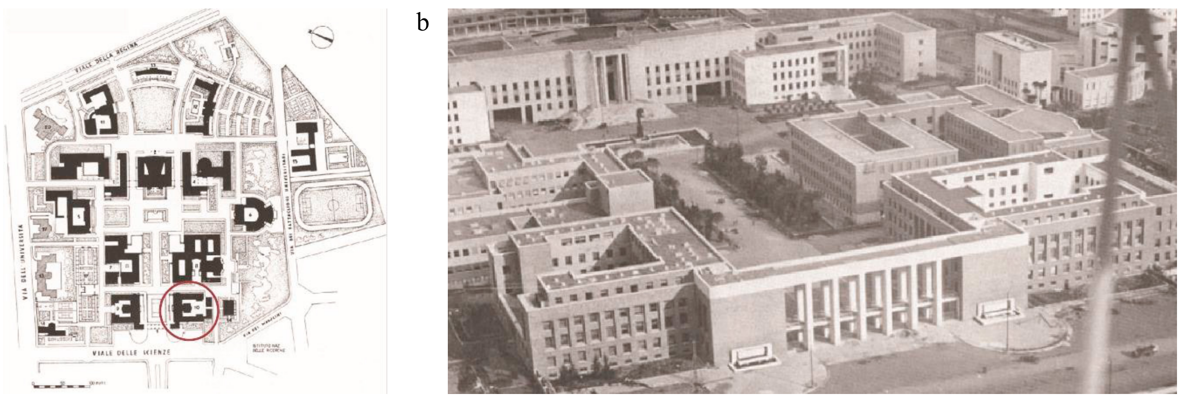

Fig. 1. Città Universitaria (a) plan; (b) view.

a b

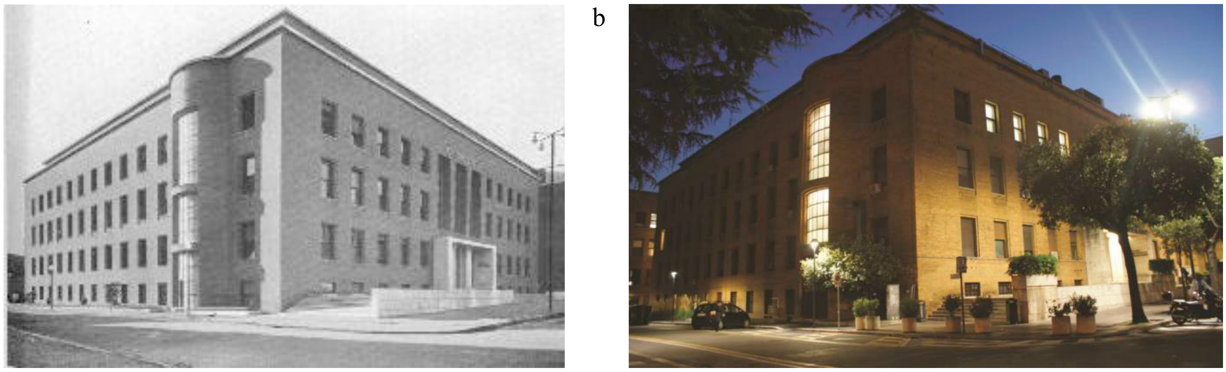

Fig. 2. (a) View when it was built; (b) Current status of the building.

3. Building features and energy status quo

The data required for the building energy analysis was obtained by on-site surveys, thermographic pictures and bibliographic research at the Historical Archives of the Real Estate and Building Management Department of Sapienza University of Rome. Building envelope and its wall construction typologies were reported in Figure 3 so as to provide an abacus of building technology solutions for determining its energy performance in the modelling process. It is noteworthy that the insulation layer was not taken into account in the design and in the construction phase. Indeed, it became mandatory to account for only few years later than the end of the case study.

Masonry is the main solution connected by layers of lime mortar and pozzolana. When the construction system is made by more than one layer, it is composed by brick walls with interposed tuff stone and processing residues, linked by mortar of lime and pozzolana as well. Only teaching rooms and stairs are built by reinforced concrete structures. Then, floor structure is also made by concrete with air chamber to make it lighter. Its thickness is 40 cm and has a widening of the beams at the joints. Acoustic insulation is obtained by pumice substrates.

The roof solution is flat and walkable but weakly isolated since it is covered by cellulite, i.e. a material made of treated and kneaded concrete to obtain a foamy structure with watertight cells.

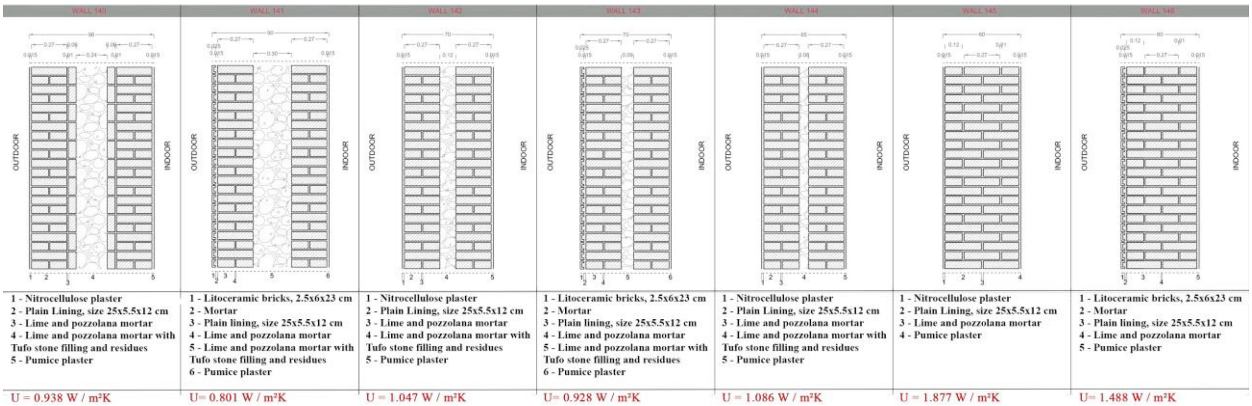

Fig. 3- Abacus of building envelope typologies and their wall construction.

Referring to windows, original solutions are still there. They are made by pitch-pine, a kind of laricus coming from United States very resinous and compact. While, the largest openings are characterized by iron structure. Those ones are located in the assembly hall and in the ground floor. Furthermore, the smallest windows were replaced by modern PVC or aluminium-based ones. All those kinds are summarized in Figure 4.

a b c d

Fig. 4. (a) Original wooden window; (b) original iron window; (c) modern PVC window; (d) modern aluminium window.

As aforementioned, a thermographic campaign was carried out to identify linkage or interruptions in the facade solutions. This was also useful to check the heat transfer where the radiators are usually located, i.e. under the windows, as shown in Figure 5.

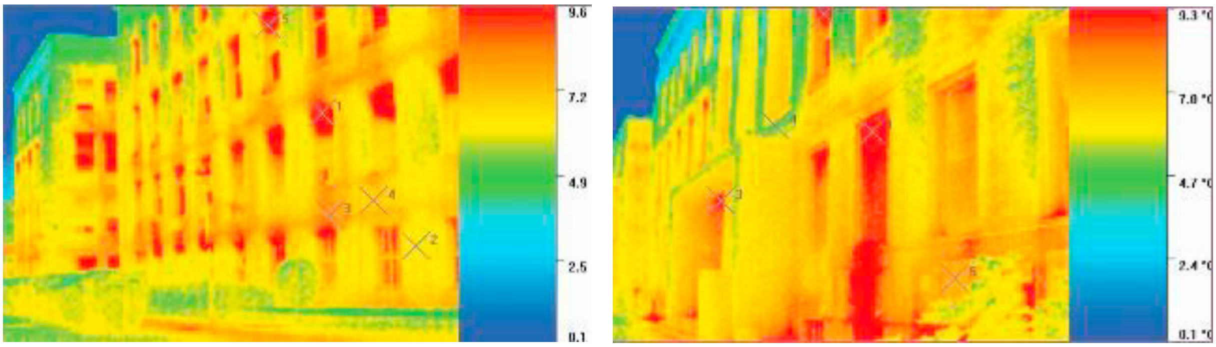

Fig. 5. Thermographic pictures.

It is relevant to observe that for summer behaviour, low protection is applied for solar radiation. Indeed, high solar gain factor of glasses (g = 0.82) is mitigated by the presence of external ledges.

Table 1. U-value of building components.

Description	U [W/m^{2}K]
Vertical building envelope	0.67 ÷ 1.48
Ground floor	1.50
Roof	0.77
Original windows	5.3 ÷ 5.6
Substituted windows	3.1 ÷ 3.4

Centralized heating system is installed to provide heat and hot water. It is equipped with two heat exchanger with a total power of 820 kW, fed by district heating network with steam from a main station of 15 MW power, located in Medical Center Policlinico Umberto I. Pictures of it is shown in Figure 6. Heating substation produces hot water at 80°C supplied by pumps at constant flow to the hydraulic loop. The heating terminals are radiators and the regulation system is set by external temperature. No thermostat and its effect is installed at room level. As a consequence, indoor overheating during winter season is a common issue entailing high energy expenditure and low system efficiency. Referring to cooling supply, later on split-system based on air to air heat pump were installed in each room, often conflicting with architectural values. While, assembly hall is supplied by an Air Handling Unit.

a  b 

Fig. 6. (a) Centralized heating chimney. (b) Steam generator of district heating system.

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 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. The building model was validated by comparison with the data from energy bills.

According to energy labelling, the building belongs to category E since its fossil primary energy consumption is 132.2 kWh/m^{2}y. The renewable fraction is limited to 8.4%, coming from the connection to the National Grid. Those quantities are depicted in Table 2. The primary energy needed for heating purposes is 44.7 kWh/m^{2}y while, the one for cooling purposes is 39.1 kWh/m^{2}y. Furthermore, the average seasonal efficiency of heating system is 51.2%.

Table 2. Primary energy consumptions.

		Heating	Cooling	Hot water	Lighting	Elevators	Total
Renewable	[kWh/y]	0	32,279	422	113,040	3,319	149,060
Fossil	[kWh/y]	997,485	134,014	1,752	469,310	13,779	1,616,340
Total	[kWh/y]	997,485	166,293	2,174	582,350	17,097	1,765,399
Renewable fraction	%	0.0%	19.4%	19.4%	19.4%	19.4%	8.4%

Heating (56.5%) and lighting (33%) result the great part of energy consumption. By comparing this outcome with the data in literature [24-27], it is possible to state:

- as regards heating consumption, considering the data in Rome for residential buildings, i.e. 87 kWh/m^{2}y and the educational one, i.e. 54 kWh/m^{2}y, the case study consumption which is equal to 81.8 kWh/m^{2}anno is more aligned with dwellings rather than school due to its continuous operation during the day;
- as regards electricity consumption, considering a school building consumption value equal to 36 kWh/m^{2}y, the case study with 62.9 kWh/m^{2}y is much higher of it, since appliances used by many people.

4. Intervention strategies

A series of energy retrofitting measures have been designed starting from the analysis of the current energy performance, by observing the constraint of compatibility with respect of the architectural features of the building.

First of all, to improve the thermo-physical properties of the building envelope an insulation layer was designed to be installed indoor to avoid modifications on the elevations' appearance. The same idea was applied to roof and ground floor. Referring to the windows, the original frames were preserved but, the changes were made in the choice of glasses and its connection to the fixtures. So doing, the transparent surface could have better performance to solar radiation without changing its original design.

Aerogel panel was chosen as technological solution for indoor insulation layer. Its thickness was sized in 5 cm. While, for ground floor insulation, expanded glass wool panels were chosen with a thickness of 9 cm.

Referring to the non-original windows, the materials were kept but improving their performance by introducing frames with thermal-break. Whereas, for glasses choice, triple glazing solutions with a total thickness of 36 mm and low-emissivity film were planned. Finally, PVC frames will remain as they are. Table 3 summarizes the improved U-values corresponding to each measure.

Table 3. U-value of building components after interventions.

Description	U [W/m^{2}K]
Vertical building envelope	0.26 ÷ 0.33
Ground floor	0.21
Roof	0.20
Original windows (improved maintaining the appearance)	1.8 ÷ 1.9

Passive behaviour of the building improved largely, reducing the heating demand from 44.7 to 17.4 kWh/m^{2}y, and slightly affecting also the cooling one from 39.1 to 33.2 kWh/m^{2}y.

As regards the control systems, the regulatory system was hypothesized to be installed in each room to control and make more effectively the energy consumption. Moreover, thermostatic valves were provided to each terminal along with the opportunity to adopt the distribution systems to their control and monitoring by variable flow systems. In this way, the average seasonal system efficiency will overcome the value of 60%.

a

Fig. 7. (a) Current facade with external cooling unit. (b) Facade once those units will be removed.

Figure 7 shows that, if the individual cooling systems will be replaced by a centralized one, the facade will be cleaned by the external unit so as to recover its original appearance.

In order to increase the renewable share, an integrated PV array was designed with a rated power of 111.5 kWp to be located on the roof and terraces, (see Figure 8). Accounting for a slope of 30°, the annual production is about 130,000 kWh.

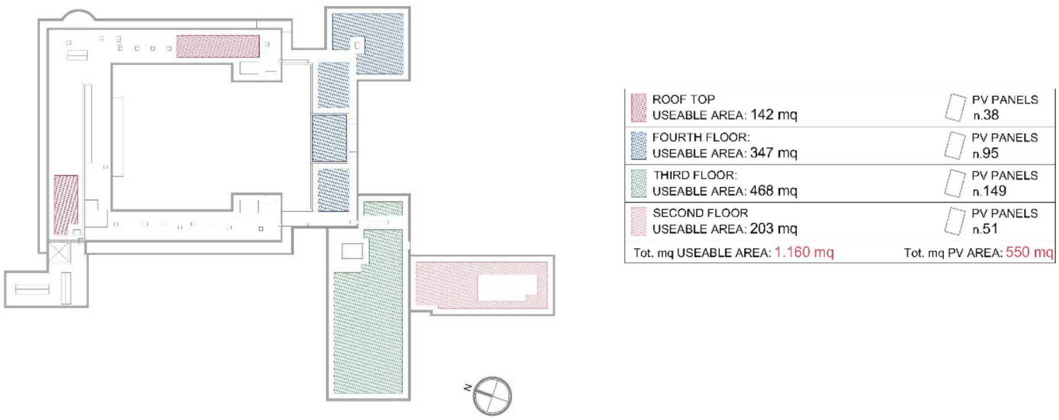

Fig. 8. PV array allocation.

Considering all the proposed interventions, the building energy label can achieve letter B, with a fossil primary energy equal to 66.1 kWh/m^{2}y, i.e. -50%, and with a renewable fraction of 23.4% deriving from the PV array and the National Grid contribution, as shown in Table 4.

Table 4. Primary energy consumptions after interventions.

		Heating	Cooling	Hot water	Lighting	Elevators	Total
Renewable	[kWh/y]	0	50,844	422	191,106	4,687	247,059
Fossil	[kWh/y]	353,459	86,750	1,752	457,750	8,742	808,452
Total	[kWh/y]	353,459	137,594	2,174	548,855	13,429	1,055,511
Renewable fraction	%	0.0%	37.0%	19.4%	34.8%	34.9%	23.4%

5. Conclusions

The aim of this study was to improve the energy performance class of a listed building that hosts the faculty of Orthopaedic and Traumatology Clinic of Sapienza University of Rome, respecting its historical value. How the building is currently used is in contrast with the original design and how it was adopted to the new functions entailed higher energy demand without effectively meeting standards of indoor comfort and energy saving.

The study showed the possibility of functional improvements that can be combined with the recovery of some of the original features of the building. It is evident that large improvements are possible along with the introduction of a higher renewable energy share by the installation of a PV array on the roof so as to not disrupt the architectural values of the building.

The achieved result is the compromise between the architectural value to be protected, preserved, recovered and the energy efficiency that, in the case of listed buildings, could play as a protection tool, allowing the building to be maintained in use more efficiently and effectively. A dedicated call for economic incentives is needed since the expenditures for refurbishment interventions on those buildings are generally higher and the design much more complex and expensive.

References

[1] Astiaso Garcia D, Cinquepalmi F, Cumo F. Air quality in Italian small harbours: A proposed assessment methodology. Rendiconti Lincei, 2013;24:309.

[2] de Santoli L, Lo Basso G, Nastasi B. The Potential of Hydrogen Enriched Natural Gas deriving from Power-to-Gas option in Building Energy Retrofitting. Energy Build 2017;149:424-436.
[3] Lo Basso G, Nastasi B, Salata F, Golasi I. Energy retrofitting of residential buildings - how to couple CHP and HP for thermal management and off-design operation. Energy Build 2017, in press.
[4] Mancini F, Salvo S, Piacentini V. Issues of Energy Retrofitting of a Modern Public Housing Estates: The 'Giorgio Morandi' Complex at Tor Sapienza, Rome. Energy Procedia, 2016;101:1111-1118.
[5] Mancini F, Salvo S, Toscano R., Upgrading 20th century historic buildings in accordance to principles of energy efficiency. AICARR, Historical and existing buildings: designing the retrofit. February 26-28 2014, Rome.
[6] Rossi F, Morini E, Castellani B, Nicolini A, Bonamente E, Anderini E, Cotana F. Beneficial effects of retroreflective materials in urban canyons: Results from seasonal monitoring campaign. J Physics: Conf Series, 2015;655(1):012012.
[7] Astiaso Garcia D. Can radiant floor heating systems be used in removable glazed enclosed patios meeting thermal comfort standards?. Building and Environment, 2016; 106, 378-388.
[8] Morini E, Castellani B, Presciutti A, Filipponi M, Nicolini A, Rossi F. Optic-energy performance improvement of exterior paints for buildings. Energy Build 2017;139:690-701.
[9] Vialetto G, Noro M, Rokni M. Combined micro-cogeneration and electric vehicle system for household application: An energy and economic analysis in a Northern European climate. Int J Hydrogen Energy 2017;42(15):10285-10297.
[10] de Santoli L, Lo Basso G, Nastasi B. Innovative Hybrid CHP systems for high temperature heating plant in existing buildings. Energy Procedia 2017, in press.
[11] de Santoli L, Mancini F, Rossetti S. The energy sustainability of Palazzo Italia at EXPO 2015: analysis of an nZEB building. Energy and Buildings 2014; 82:534–539.
[12] Di Matteo U, Nastasi B, Albo A, Astiaso Garcia D. Energy Contribution of OFMSW (Organic Fraction of Municipal Solid Waste) to Energy-Environmental Sustainability in Urban Areas at Small Scale. Energies 2017;10:229.
[13] Astiaso Garcia D, Sangiorgio S, Rosa F. Estimating the Potential Biomasses Energy Source of Forest and Agricultural Residues in the Cinque Terre Italian National Park. Energy Procedia, 2015; 82:674-680.
[14] Mancini F, Cecconi M, De Sanctis F, Beltotto A. Energy Retrofit of a Historic Building Using Simplified Dynamic Energy Modeling. Energy Procedia, 2016; 101:1119-1126.
[15] de Santoli L, Mancini F, Nastasi B, Ridolfi S. Energy retrofitting of dwellings from the 40's in Borgata Trullo – Rome. Energy Procedia 2017, in press.
[16] De Santoli L, Mancini F, Rossetti S, Nastasi B. Energy and system renovation plan for Galleria Borghese, Rome. Energy and Buildings, 2016; 129: 549-562.
[17] Clemente C. Riqualificazione integrata e valorizzazione dell'edilizia universitaria. L'esperienza delle ricerche operative in corso sul patrimonio edilizio della Sapienza - Retrofit and valorisation of university building. The experience of operational research in progress on the Sapienza building stock and heritage. Techne 2014;8: 290-291.
[18] Castellani B, Gambelli AM, Morini E, Nastasi B, Presciutti A, Filipponi M, et al. Experimental investigation on CO_2 methanation process for solar energy storage compared to CO_2-based methanol synthesis. Energies 2017;10(7):855.
[19] Lo Basso G, Nastasi B, Astiaso Garcia D, Cumo F. How to handle the Hydrogen enriched Natural Gas blends in combustion efficiency measurement procedure of conventional and condensing boilers. Energy 2017;123:615-636.
[20] Carbonara G. Energy efficiency as a protection tool, Energy Build, 2015;95:9-12.
[21] Nastasi B. 2013. Planning of Rural-Urban Continuum Towards a Sustainable Relationship between Agricultural and Energy Production. In: Agricultural development within the rural-urban continuum. Hamburg: Print & Mail (PRIMA), p. 118-118.
[22] Astiaso Garcia D. Green areas management and bioengineering techniques for improving urban ecological sustainability. Sustainable Cities and Society 2017; 30:108-117.
[23] Nastasi B, Di Matteo U. Solar energy technologies in Sustainable Energy Action Plans of Italian big cities. Energy Procedia, 2016;101:1064-1071.
[24] Salata F, Golasi I, Domestico U, Banditelli M, Lo Basso G, Nastasi B, et al. Heading towards the nZEB through CHP+HP systems. A comparison between retrofit solutions able to increase the energy performance for the heating and domestic hot water production in residential buildings. Energy Convers Manage 2017;138:61-76.
[25] De Santoli L, Mancini F, Cecconi M. Riqualificazione dell'edilizia residenziale di una città. Il caso di Roma. AiCARR Journal, April 2010, pag. 2-6.
[26] De Santoli L, Mancini F, Cecconi M. Energy analysis for retrofitting proposals in Rome residential sector. 47° Congresso Internazionale Aicarr, 8-9 Octber 2009, Tivoli (RM), pag. 587-598.
[27] Corgnati SP, Fabrizio E, Ariaudo F, Rollino L. RSE, Ricerca di Sistema su edifici tipo, indici di benchmark di consumo per tipologie di edificio, ad uso scolastico (medie superiori e istituti tecnici) applicabilità di tecnologie innovative nei diversi climi italiani, 2010.