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Issues of energy retrofitting of a modern public housing estates: the ‘Giorgio Morandi’ complex at Tor Sapienza, Rome, 1975-1979

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Abstract

Energy retrofitting of historical residential buildings represents today an interesting challenge of the building sector. This is true especially in Italy where great part of the national building stock dates back to pre-modern and modern times and, especially, to the decades between the 1960s and the 1980s. Most of these buildings, in fact, offer thermal performances that are inadequate to current requirements in terms of energy efficiency, human comfort as well as to seismic safety.
This study focuses on the energy retrofitting of public housing estates such as the “Giorgio Morandi” complex at Tor Sapienza in Rome. The upgrading of this complex is outlined, taking into account issues of energy saving but, also, constraints related to the historical values of the buildings. Intervention options able to improve energy efficiency are therefore foreseeable only in strict observance of cultural heritage values, which entails a deep analysis and survey of the existence in order to identify respectful, correct and feasible solutions.

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Keywords: energy retrofit, energy saving, public housing, historical buildings.

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1. Introduction

The second half of the 20TH century in most of Europe was a period of social, political and economic reconstruction after the devastations caused by the Second Word War. Starting from the end of the 40's many public actions took place to give impulse to the achievement of public housing and solve the housing problem, a serious issue for a high percentage of the European citizens. A new way of designing and building public residential complexes was therefore developed. Many projects aimed at creating large but self-sufficient neighborhoods, structured on intensive models, which were based on a mix of buildings, green areas and services. The very first examples of this kind of interventions were built in North European countries such as Britain - such as Brunswick Centre (Figure 1a), and Alexandra Road in London - France and The Netherlands. But also Mediterranean countries such as Spain and Italy achieved very interesting experiences in this field. New concepts of social housing started to influence also Italian architects, for example in the case of Rozzol Melara in Trieste (Figure 1b), 'Scampia' in Naples, 'Corviale', 'Laurentino 38' and 'Tor Sapienza' in Rome.

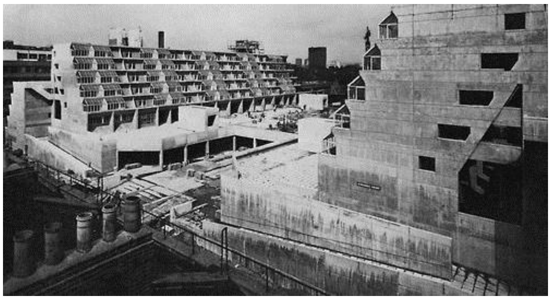
a  b 

Fig. 1. (a) Brunswick Centre, London, Patrick Hodgkinson 1967-1972. (b) Rozzol Melara, Trieste, Carlo Celli 1968-1984.

Unfortunately, most of these settlements are today rundown and affected by deep decay due to neglect, lack of maintenance, loss of facilities and of urban connections. It is therefore necessary to provide for a general requalification of the buildings, including their energy efficiency. The European Union itself, through the Directive 27/EC/2012, invites the Member States to requalify at least 3% of the housing stock, thereby defining the central role of public housing in the development – and solution - of issues related to energy efficiency.

However, the problem has been solved in several different ways. Some redevelopment projects have transformed the buildings radically by replacing original materials, colors and finishes with new ones, by increasing the surfaces considerably by including open spaces (balconies, terraces, loggias), by adding solar panels to the facades, by creating double skin systems etc. The result is often a deep change in the image and a loss of original physical substance of these buildings, which may or may not be an advantage according to their historical value (Figure 2).

Fig. 2. Bois le Prêtre Tower in Paris, after refurbishment, Lacaton & Vassal, 2010.

2. The ATER district "Giorgio Morandi" at Tor Sapienza, Rome

The settlement we are analyzing is located at Tor Sapienza, in the Eastern outskirts of Rome, a neighborhood developed in the first half of the 1900s and further enlarged between the 1970's and the 1980's as a public housing pole. The "Giorgio Morandi" public residential complex was built between 1975 and 1979 (Figures 3a and 3b) as part of the "Piano di Zona n.19" by the IACP (Autonomous Institute for Social Housing), today called ATER (Territorial Agency for Residential Buildings).

A

b

Fig. 3. The "Giorgio Morandi" housing complex under construction, 1975-1979.

Alberto Gatti's project consisted in six residential multi-storey buildings defining the perimeter of a large rectangular courtyard with green paths and a thorn-like building in the middle, originally destined to public facilities but then unfortunately left abandoned ore illegally used. The ground floor of the residential buildings is mostly permeable, while the dwellings are located from first to seventh floor; garages are placed at the underground level.

The main design principle is based on the use of load-bearing walls, built simultaneously with the floors, which rely on the 'tunnel' construction method. The structural bay is 5.10 meters, but reduces to 2.55 meters in correspondence to the staircase. There are six types of residences - from 65 to 115 square meters wide - which are evident on the facades due to changes of width of the load-bearing walls on the short side of the buildings (Figures 4, 5).

The buildings' outer casing is strongly characterized by the use of exposed concrete facing (in contrast with the red and blue metal frames of windows) and by the concrete load-bearing walls, which establish the rhythm of the front, define the jagged sections and determine the internal distribution [1, 2, 3] (Figure 6).

Fig.4. General plan of the settlement.

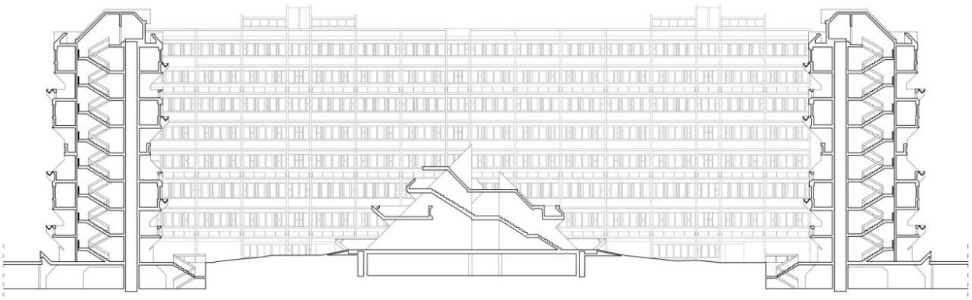


Fig.5. Section.

Fig.6. Facades in their current conditions.

These buildings, built as a structuring element of the outskirts of Rome, today are becoming an important cornerstone of the neighbourhood. Their redevelopment therefore imposes choices that are appropriate to solving both issues of energy saving and the conservation of historical and architectural values. For example it is very important to preserve the original features of the outer casing, the visual effect of the concrete panels coupled with coloured metal elements, the jagged outline of the walls, the permeability of spaces.

3. Current situation

The analysis of the physical and technical characteristics of the buildings was carried out before and in view of the transformation project, and was mainly achieved through direct observation, graphic survey, bibliographical and archival documentation, thermographic analysis and also by gathering the opinion of the occupants. The thermographic survey revealed thermal dispersion through the buildings' casing, and highlighted detected the presence of independent heating systems and the incidence of changes and transformations - such as the replacement of window cases – that had occurred in the latest years.

In fact, the chosen temperature values represent the most remarkable points on the building surfaces in order to make a comparison between the original windows, the new windows and the concrete façade panels: these are characterized by a great thermal variation because of their different materials, structures and also of their different construction period (Figure 7). Furthermore, this kind of analysis allowed to detect the plant passages and the position of the heating systems, showing the highest dispersions during the evening (Figure 8).

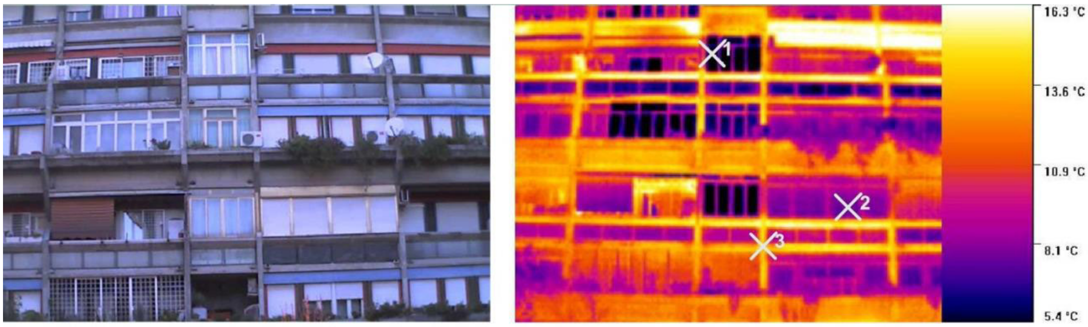


Fig. 7. Thermographic survey. (T1= 8°C; T2= 4.4 °C; T3= 13.4 °C).

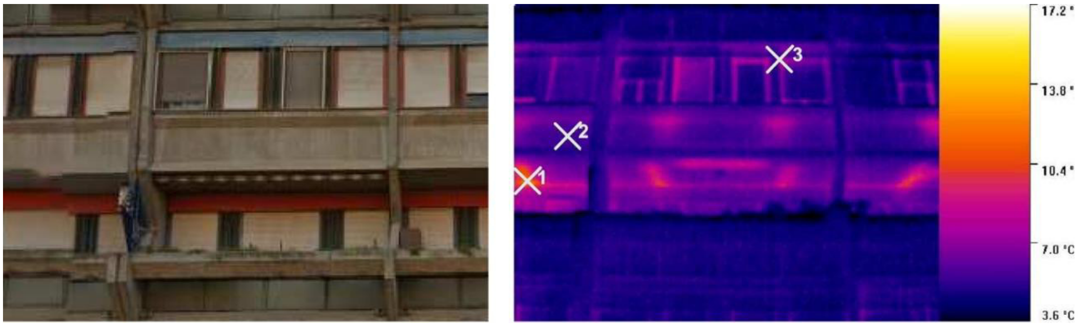


Fig. 8. Thermographic extract. (T1= 13.8°C; T2= 5.8 °C; T3= 8.2 °C).

As usual in the construction techniques of the time, both the opaque and the transparent components of the building casings are weakly isolated (Table 1); the layer of thermal insulation is generally very thin - 5 cm for the opaque vertical walls and the roof floor - or totally absent, as in the case of the first floor, of the walls enclosing unheated space, and of the stairwells. Some casing components may be subject to winter interstitial condensation, that are otherwise acceptable thanks to summer evaporation.

In reference to the summer season, one may notice a low protection from solar radiation, with a high solar gain factor of glasses (g = 0.80), although mitigated by the presence of external ledges.

Table 1. Thermal transmission values of the casing components.

Description	U [W/m^{2}K]
Load-bearing concrete external walls	0.82
Prefabricated concrete panel for facades, adjoining with the external spaces	0.80
Load-bearing concrete external walls, adjoining with the stairwell	0.87
Horizontal structure in the first level, adjoining with the external spaces	0.79
Roof	0.55
Window with metal frame and single glass	5.53

The heating system is autonomous, with boilers for heating and domestic hot water production, with radiators as plant system terminals, which may be adjusted in each apartment through programmable thermostats.

The modeling of the building was carried out through the 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 application) for the calculation of energy needs. The building model was validated by comparison with the data of energy bills.

The energy certification of the apartments in the current situation and on behalf of the data gathered during the investigation work, revealed that the energy classes of the buildings vary from E to G, depending on the location of the residential units. On behalf of this information, an energy analysis of the apartments in the current situation was outlined, with reference to the specific thermal loads and energy needs. The results referred to sample apartments, located on the lower floor, on the mezzanine floor and above, are shown in Table 2. The high specific loads, both in the winter and in the summer season, show a weak passive protection of the building casing, scoring 85.5 W/m^2 in the winter and 76.9 W/m^2 in summer.

Consequently, the energy needs are rather high, with values of 70.3 kWh/m^{2}y in winter and 50.3 kWh/m^{2}y in summer. The low value of the average seasonal efficiency (average 53.4%) leads to primary energy requirements for heating in the amount of 131.6 kWh/m^{2}y.

Table 2. Energy analysis.

	Thermal loads		Energy requirement		Average seasonal performance	Primary energy requirement
	[W/m^2]		[kWh/m^{2}y]		[%]	[kWh/m^{2}y]
	Winter	Summer	Winter	Summer		
Apartment 1- p. 1	91.8	69.1	88.0	38.5	54.4%	161.8
Apartment 2 - p. 1	86.1	84.9	53.0	82.1	49.4%	107.4
Apartment 1 - p. 3	75.9	70.6	54.3	46.2	50.8%	107.0
Apartment 2 - p. 3	78.6	91.1	52.5	45.4	50.6%	103.8
Apartment 1 - p. 7	80.8	60.5	82.0	32.3	58.5%	140.2
Apartment 2 - p. 7	103.9	98.3	92.0	62.1	53.1%	173.1
Average	85.5	76.9	70.3	50.3	53.4%	131.6

4. Intervention strategies

A series of redevelopment hypothesis have been designed starting from the analysis of the current energy performance, by observing the constraint of compatibility and in respect of the architectural features of the buildings [4, 5, 6, 7]:

- on the building casing to improve passive protection and considerably reduce the thermal loads of project;
- on plant systems to increase the efficiency of thermal energy production and introduce a substantial share of renewable energy in the overall balance of the building.

Recently, emerging research lines deal with the decarbonization targets for existing buildings by means of partial fuel substitution [8,9], by integrating other renewable energy sources such as biomass at building and district scale [10]. The main constraints posed by historical buildings, which are often listed, promote the preservation of MEP (Mechanical Electrical Plumbing) facilities built in the 1900s, and drive research towards the improvement of energy supply. This latter direction moves towards hybrid fuels [11,12].

In order to maintain the original appearance of the facades characterized by facing concrete and the design of the walls' profiles, the addition of an insulating layer to the vertical and horizontal structures was considered, but placed on the inner side of the walls, consisting in polyurethane foam panels (polyISO type) with varied thickness according to the need (7 cm in the vertical external walls, 6 cm in vertical walls adjacent to the stairwells, 5 cm in the first floor and roof structures). The replacement of windows - but using components that are similar to the existing in terms of size and colour but with hot-cutting aluminium window frames and triple solar control glasses - was also considered in order to improve both the winter and summer performances.

Table 3 shows thermal transmission values after the intervention.

Table 3. Thermic transmission values after the intervention.

Description	U [W/m^{2}K]
Load-bearing concrete external walls, with internal isolation	0.307
Prefabricated concrete panel for facades, adjoining with the external spaces, with internal isolation	0.258
Load-bearing concrete external walls, adjoining with the stairwell, with internal isolation	0.263
Horizontal structure in the first level, adjoining with the external spaces, with external isolation	0.260
Insulated roof	0.282
Window with metal frame and triple glass	1.100

The described interventions allow a significant reduction of the thermal loads; consequently it is possible to continue using radiators as emission terminals, even with low operating temperatures that are compatible with a heat pump system for the production of thermal energy. More specifically, the improvement of the buildings' passive performance allows to bring the winter heat load from an average value of 85.5 W/m^2 to 25.9 W/m^2 (with a reduction of 69.7%) and the summer heat load from an average value of 76.9 W/m^2 to 41.0 W/m^2 (with a reduction of 46.6%). In terms of energy, the improvement of the buildings' passive performance brings the energy requirement in winter from a mean value of 70.3 kWh/m^{2}y to 37.4 kWh/m^{2}y, with a reduction of 46.8%, and the summer energy needs of an average value of 50.3 kWh/m^{2}y to 7.6 kWh/m^{2}y, with a reduction of 84.9%. Therefore it was suggested to provide an air-cooled heat pump for thermal energy production, to be placed in the technical rooms on the roof together with other main equipment [13]. However, to improve the regulation efficiency, thermostatic valves should be installed on each radiator.

The electrical energy required for the operation of the heat pump will be produced by a photovoltaic system placed on the roof, arranged so to be perfectly integrated and not visible from the ground view. A thermal accumulation system has also been designed in order to contain the sizing of the heat pump. The accumulation system also has the role to separate the thermal energy production from its use, according to the need of the national energy system and in order to use renewable sources that can produce energy at a discontinuous rate [14].

Table 4 shows the energy needed by the distribution system during winter, with monthly and daily details; it also lists the amount of water required to accumulate daily energy requirements; for example, in January, which is the coldest month in Rome, about 30 kg of heating mass for each square meter of heated area are necessary to accumulate daily energy requirements.

Table 4. Energy requirement for winter (monthly and daily details).

		JAN	FEB	MAR	APR	NOV	DEC
Monthly energy requirement	[kWh/(m^{2}month)]	10.48	7.82	1.36	1.30	4.43	9.90
Days		31	28	31	15	30	31
Medium energy daily requirement	[kWh/(m^{2}day)]	0.34	0.28	0.04	0.09	0.15	0.32
Accumulation amounts (daily requirement)	[kg/m^2]	29.1	24.0	3.8	7.4	12.7	27.5

5. Energy efficiency and economic analysis

The sizing of the thermal plant, the accumulation system and the photovoltaic system were carried out for one of the buildings of the settlement (Building 4), with a surface of about 1,680 m^2. The following data was obtained after calculations and in occurrence of the architectural constraints:

- heat pump of 45 kW power, dimensioned on the basis of the winter heat load and considering the presence of the accumulation;
- thermal storage of 12,000 liters; on the basis of the calculations, the volume of water needed to accumulate the average daily requirement of January amounted to 49,000 liters; in absence of adequate technical spaces, the accumulation will have a size of only 12,000 liters (6 to 2,000 liters tanks) providing about 1/4 of the daily requirement of the coldest months;
- photovoltaic system having a total output of 47 kWp, capable of producing about 55,000 kWh/y (approximately 20,000 kWh of which in the heating period); the photovoltaic system is located on the roof, in part horizontally (150 m^2, capacity of 19 kWp) and in part with 30° inclination in order to maximize its efficiency (225 m^2, capacity of 28 kWp).

To heat the building 66,815 kWh of useful energy produced by the heat pump are necessary, by using 21,422 kWh of air source and 20,880 kWh of electricity energy. Since the photovoltaic system can produce about 20,000 kWh in winter, we can say that the heating system energy demand is almost entirely covered by renewable sources. The remaining 35,000 kWh of electricity produced by the PV system can be compensated to cover a large proportion of consumption connected to the hot water preparation (~13,000 kWh), to cooking (~20,000 kWh), for general electrical purposes (~76,000 kWh) and any needed summer cooling systems.

An economic evaluation of the investments and the savings achieved was also calculated [15]. More specifically, the estimated cost to achieve such interventions mount to about 670,000 euros and the estimated achievable savings on energy bills is of about 45,000 euros; the estimated payback time is about 15 years.

6. Conclusions

The two levels of this research – one referred to the technical, functional and practical matter, the other to the evaluation of historical and architectural values - are closely connected with each other. In the first analytical step, we determine which are the strengths, the weaknesses and the significant elements of the project; in the second phase, which considers possible interventions for energy retrofitting, the aim was to consider the results of the previous phase as a basis to assess how to preserve the historic and architectural features of the building (for example the shape of the walls or the facing concrete used for the fronts). Today the "Giorgio Morandi" complex is in a state of decay and requires a complete redevelopment in order to reorganize the structural, social, organizational problems, but also issues concerning energy improvement, which can be understood as part of a wider process or as the prime mover of a complete recovery of the whole neighborhood.

The design choices aim to improve the energy performances of the buildings and to increase the inhabitants' quality of life, but also aim to respect the historical aspects of the buildings, which are parts of the Alberto Gatti's project, recently considered "of great historical interest" by the Italian Ministry of Culture. These buildings should be recognized as retaining specific historical value, as a fundamental memory of a recent but important phase of Italian and European history, and as an architectural and urban signs in the fragmented outskirts of Rome.

The result of this research work consist in the proposal of an energy upgrading project that develops very up-to-date issues of sustainability and energy saving applied to historical buildings, by operating on the basis of a deep awareness of the importance of preserving and enhancing these testimonies of our recent past.

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