SER4SC

SEISMIC AND ENERGY RENOVATION FOR SUSTAINABLE CITIES
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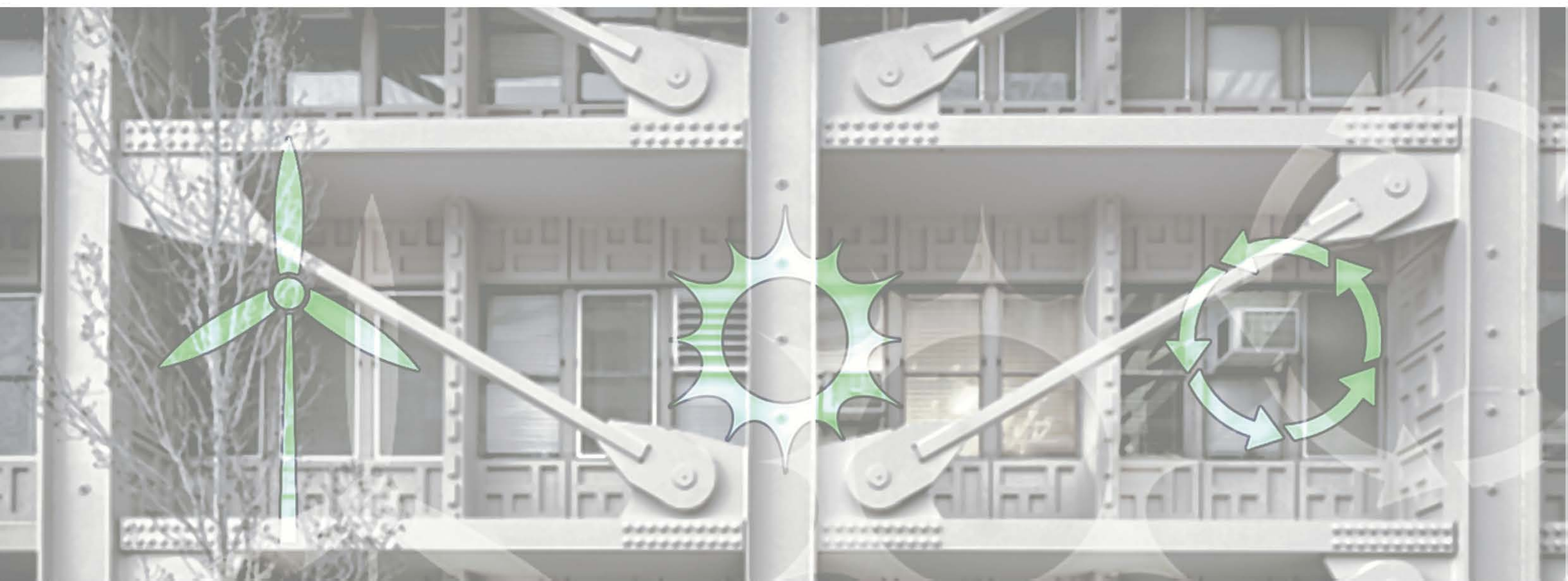

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INTERNATIONAL CONFERENCE
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Critical Issues on Integrated Solutions for Seismic and Energy Retrofitting of High-rise Building in Reinforced Concrete Walls and Panels: The M4 in Tor Bella Monaca - Rome

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Abstract

In Italy, after the destructions of World War II, due the particular development of economy and the political decision in the field of reconstruction, a government option for building construction industrialization comes up only at the beginning of '60s. A wide number of different proposals of building sector industrialization came from technicians, industries and researchers, and the debate interested all the years between the end of the war and the approval of the law number 167 in 1962. First of all the city builders are fascinated by the French Grands Ensembles and the main design tools are based on standard house typologies and infrastructures projecting. This happens before that the national technical laws transpose the seismic and energy design and put them into the professional practice.
Thus, the paper focuses on a heritage referred to industrial production for infrastructures, with a high compromising in respecting requested building performances. The case study is the high-rise building typology in the neighborhood of Tor Bella Monaca in Rome, one the biggest of that period in Italy. Here, comparing to the last INA-Casa experience, the quality of apartment's plan collapses, and new critical issues become usual on the point of view of the envelope (thermal bridges and low insulation). The group of research proposes the analysis of different possible interventions based on an integrated approach between architectural quality of residential units renovation, energy and seismic retrofit. As expected, the cost-effective evaluation of the proposal shows the convenience of the integrated approach in supporting public administration in social housing renovation. The best solutions, according to the parameter of efficiency, resistance, residential units improvement, offer an increasing of residential units (plus 30%), a balanced reduction of energy consumption associated to energy removable production, and a considerable improvement of the seismic behavior of the structure.

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Keywords: Seismic retrofit, energy retrofit, social housing renovation, reinforced concrete walls, high-rise buildings, Rome social housing

Introduction

Since the 1960s, the option for industrialization of the building industry has been able to respond to the great housing needs resulting from the growth of cities due to the economic boom. This was done by

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completely altering the expectations of quality of public housing as well as consolidated during the years of the INA-Casa plan. At the end of the World War II there were many proposals for an industrialization of the building production, both in response to the needs of reconstruction and for a faster, and more sustained, industrialization of the country. The eighth Triennial of Milan, led by Pietro Bottoni, left in architectural culture and, materially, in the QT8 district, an awareness of the great potential and the main features of an Italian way to industrialization of the construction sector.

At that time, it begins that path that will bring the Italian industrial system to evolve towards the lightweight prefabrication of high-quality building components and based on dimensional unification[1]. This is well identifiable in the "Manuale dell'Architetto" coordinated by Mario Ridolfi under the funds of the Marshall plan [2].

The 14 years of the INA-House plan, though with the option for craftsmanship, will still give a certain space to this industrial route based primarily on the evolution of brick and ceramics production, already advanced in the autarchic age, and on the cement [3].

Even if this kind of industrialization permitted a wide range of solution for dwellings, buildings and neighborhood design, the final choice for building industrialization did not follow this much as FrenchGrand Ensembles model. Thus the main design tools were based on standard house typologies and infrastructures building site models, adopting the rigid methodologies of industrial r.c. structures construction.

This happened before that the national technical laws transposed the seismic and energy design and put them into the professional practice. Institutes for the prefabrication and group of research focused on the definition of the tools in building design among the industrialization of the building sector [4].

The main path followed in the industrialization focused on the components and the technology of reinforced concrete, even if among the most relevant researches we find the ones on the use of steel [5,6]. Thus, the present paper focuses on a heritage referred to industrial production for infrastructures, with a high compromising in respecting requested building performances. In the text and in the figures are concisely presented the results of an integrated approach to the seismic and energy retrofitting linked to a functional renovation of a specific typology: the high-rise buildings.

A specific attention in this field has been paid by different scholars. For example an interesting comparison between alternative retrofitting scenarios for buildings in L'Aquila, based on modelling either of seismic or of seismic-energy integrated retrofitting, shows the economical convenience in supporting a seismic retrofit integrated with a 25% or 50% improvement of energy behaviour (table 1) [7].

The paper deals with the features of a specific case of high-rise buildings in r.c. panels, a very common typology in social housing during late 70s and 80s, which have specific problems in the two aspects of retrofitting. The research of a structural typology of seismic retrofit is related to functional renovation of the buildings, looking for an improvement of economic resources for supporting public intervention.

Table 1. Comparison of alternative retrofitting scenarios, highlighting the benefit in terms of return of investments when integrating energy efficiency measures. Data limited to Municipality of L'Aquila. Source PLINIVS-LUPT Study Centre [7].

Output	Scenario 1		Scenario 2		Scenario 3	
	Seismic		Seismic+ energy 25%		Seismic + energy 50%	
	Government	Citizens	Government	Citizens	Government	Citizens
Net Present Value (€)	-1,189,97,599	-390,360,972	-1,216,260,730	184,529,861	-1,255,745,425	753,473,357
Years to Payback		n.a.		13		8

1.1. General context

The seismic rehabilitation of buildings constructed in reinforced concrete panels is as current as the problem of their energy retrofit. The research is part of a process of verifying the performance of social housing in Rome built during the 1st and 2nd PEEP and follows the analysis of some manifest inconsistencies between the typology of accommodation and the social and family distribution of the user. Thus, the program includes the possibility of functional and dimensional adjustment of the intervention. This last one has just been considered by the municipality of Rome, due to the presence, in several neighbourhoods, of surfaces of “extra standard”, and the municipal council has deliberated cases of possibility of improvement of built volumes[1]. The deliberation n. 65/2006 of the municipal council of Rome considers the individuation of new areas for social housing programs and the 16 of June 2011 started the participative process for 20 plans.

After several years, a big part of these program have not been completed and we think that, due the new economic context, it is possible to use the resource of the “extra standard surfaces” not only for the edification of new buildings but better for the solution of some constitutive problem of the existing buildings. In table 2 are listed different parameters of Tor Bella Monaca. As you can read the size of green surfaces is more than double than the one requested by the standard stated in D.M. 1444/1968 (18,2 m^2/ab Vs 9 m^2/ab) and public services surfaces (10 m^2) are quite 2 times the standard for schools (4,5 m^2) plus community facilities (2 m^2). So the paper investigate the possibility of intervention on the problems of main structure and energy behaviour, through the revision of the size and the typology of the dwellings [8].

Table 2. Parameters of the PEEP zone “Tor Bella Monaca”. The size of the surfaces for public services, green areas and viability is very superior than the standard stated in the D.M. 1444/1968 [9]

	Size	Standard
Inhabitants	28,000	
Total Area	188 ha	
Land area	83.5 ha	
Surfaces for craft areas	2 ha	
Housing volume	2,000,000 m^3	
Other volume	444,000 m^3	
Green	51 ha	18.2 m^2/ab
Community facilities	28 ha	10 m^2/ab
Viability	24 ha	8.6 m^2/ab

Building quality: the reasons for an integrated approach

In the dwellings of the second PEEP, comparing to the previous national plan INA-Casa experience, the quality of apartment plan collapses according to different parameters, and new critical issues become more usual on the point of view of the envelope (diffusion of thermal bridges, low insulation, lacking protection of reinforced concrete structures, etc.)[10–12]. The housing plans before PEEP introduced a control on the functional and typological characteristic of the dwellings but the needs of improving building industrialization generated a series of plan constrains in design. Furthermore dwellings typologies have been designed according to average number of family members during the ‘70s.

According to ISTAT [13] the average number of components of a family in Rome changed from 70s to current days. The families with one-member passed from 12,90% to 31,15% of the total number of families, and the families with more than 5 members reached the 5,72% in 2011, starting from the 21,51% in 1971 (Fig. 1).

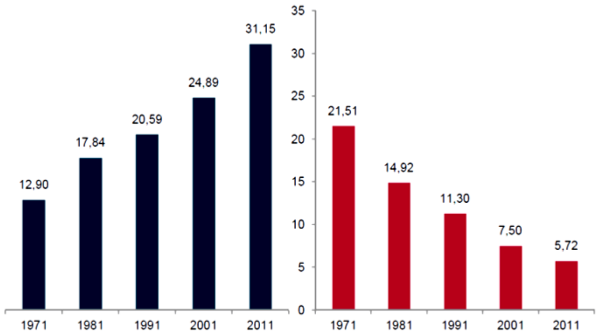

Fig. 1. Families with one member, on left, and families with more than 5 members, on right. Percentage on total number of families. Census 1971, 1981, 1991, 2001, 2011. [13]

The group of research proposes a possible intervention based on an integrated approach between quality of residential units improvement, energy and seismic retrofit. The integrated approach usually focused on the exploration of innovative materials. In this case the specific issue stays in the verify of integrated approach on a high-rise typology [14,15]. In fact in the residential towers built in r.c. panels the reason of the seismic retrofitting can requesttechnological solutions through the revision of constructive principles.

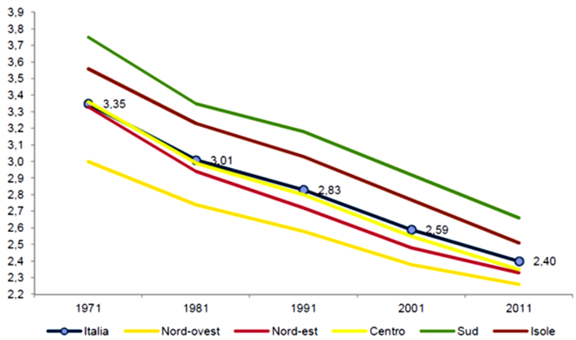

Fig. 2. Average number of components of families during the last 50 year in different areas of Italy. Census 1971, 1981, 1991, 2001, 2011. [13]

1.2. Strategies in the renovation of the high-rise buildings in r.c. panels.

The neighborhoods of the 1st PEEP do not belong either morphologically to the compact city or, quantitatively, to the city of high density. In fact, the neighborhoods of the compact city have higher FAR value[8]. Through the provisions of the “Legge sulla casa” n° 513/1977 [16]and of the “Direttive regionali” (Regione Lazio 1977), was imposed the adoption of housing models and reference modules.The types proposed for the dwellings and the rigid matrix generated by the adoption of r.c. panels brought to a recurrent repetition of design solution, leaving space for the research mainly in the characters of the monument of the mega-structural architecture. According to Banham [17] in Rome we can identify four main megastructures: Vigne Nuove, Corviale, Pineto and Laurentino [8].But there are several cases of neighborhoods, blocks, comparts, buildings, where we identify the tools of heavy prefabrication, even if we don't find the size of the megastructures. This is the case of the buildings of Tor Bella Monaca (TBM). There the obtainment of the three goals of functional renovation, seismic mitigation and energy retrofitting could be very expensive and quite impossible if not conducted together.

As you can read below the seismic mitigation is not reachable without a great intervention on the building and the energy retrofitting comes from a general review of all the envelope. The analysis on TBM offered the opportunity to verify the role of the different parameters of the study. On one side we proposed three different scenarios for the several high-rise buildings present in the district. On the other side we categorized different kind of integrated interventions, according to the two typologies of prefabrication described and present in the neighborhood. Nowadays the ATER has difficulties in raising funds for the realization of new dwellings or for the adaptations of the existing and the renovation can be supported by the investment for retrofitting. In this kind of buildings the intervention that are needed for the envelope and of the structure cover a great part of the intervention of a strong renovation. In this way, the strategy adopted in increasing residential surfaces, according to the urbanistic extra-standard, permit to valorize the resource obtained with the energy retrofitting, and tax incentive (65%) available for the mitigation. The comparison among the scenarios and between the three typologies confirms this opportunity. For the short text of this contribution we describe in detail the case of a single typology of high-rise building in the compart M4.

1.3. Case study compart M4

The M4 compart consists of five contiguous buildings, three towers of 15 levels alternating with two low-rise buildings of 4 levels. Overall, today it includes 241 dwellings for a maximum of 792 tenants and

Fig. 3. Partial view of the façade east of a high rise building in the M4 compart, before (left) and afte the intervention "C" (right).

is characterized by a covered area of 3,230 m^2, a useful volume of 106,324 m^3. From the construction point of view, all the buildings of the compartment are built using the *Banches et Predalles*.

The technique is base both on the rationalization of the cast and on the prefabrication of specific components [18]. The vertical bearing structures are walls in reinforced concrete casted in prefabricated mould. The slabs are built using *latticed predalles*, thick 4 to 6 cm, lightened (using hollow bricks or polystyrene) and completed with cast in site [19]. Thanks to the *predalles* "the flexibility of the intervention on the floors is major than the case of flat slab used in the method called *coffrage tunnel*" [8].

The concrete walls are disposed in two group of 4 parallel walls oriented north-south. They are connected to transversal walls, thick mm 150, in the centre of the tower and inversely they are not braced with other walls in the facades, as shown in fig. 04. This generates, considering the earthquake, a seismic vulnerability. A high fundamental period characterizes the dynamic behavior of the structure in the soft direction. This data, in general, could drive the behavior in the direction of a safer seismic protection, but this is also causes of the damaging of not structural elements (components, internal walls). Furthermore, the movements are so high to causing the collapse of the whole structures. The facades are realized using sandwich panels concrete-insulation-concrete. In fact the buildings have been built after the adoption of the Law 373/1976 which prescripts insulation of façade walls. Anyway, we found other high-rise buildings, in Tor Bella Monaca, where the envelope has not any kind of insulation and the non-bearing walls consist in hollow walls.

The study of energy performance of the envelope of this building has shown poor performance due mainly to thermal bridges. Although the walls and the roof have thermal transmittance values that are higher than nowadays best practice values, they are not that far, as some insulation is provided in all of them.

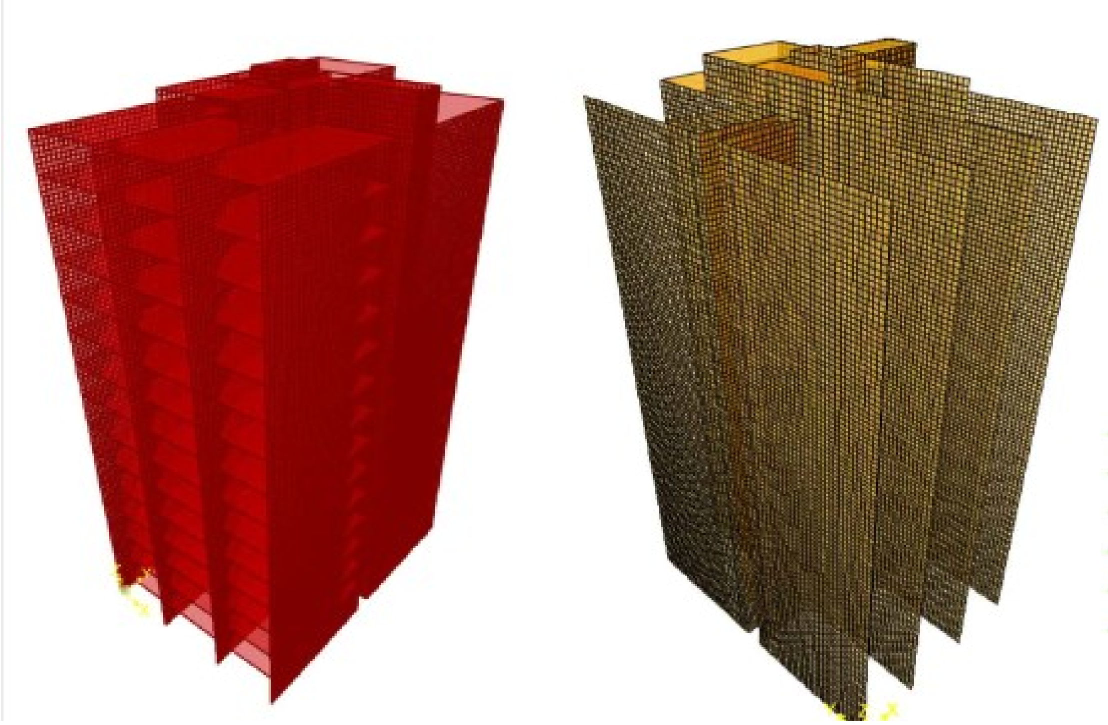

Fig. 4. A model of the whole structure, left, and a model of the vertical r.c. bearing panels, right. It is evident a prevalent disposition of the walls in the direction north-south.

Yet, insulation is not continuous, leading to very large thermal bridges, as shown in fig. 05, where the heat flux concentration between the insulating layers in the infill walls above and below an intermediate floor is depicted by isotherm lines.

The analysis of the relevance of each envelope component on overall heat transfer has shown that thermal bridges account for more than half of the heat transfer, as shown in fig. 06. Notice that the value account for all thermal bridges: those at the junction of walls to floors, balcony, or other walls, and those between windows and walls. Results are comparable to those from [20] for buildings of the same period in northern Italy. Besides its effect on energy performance, the relevance of thermal bridges enhances condensation risk. Thus, any refurbishment of the façade should address these at first.

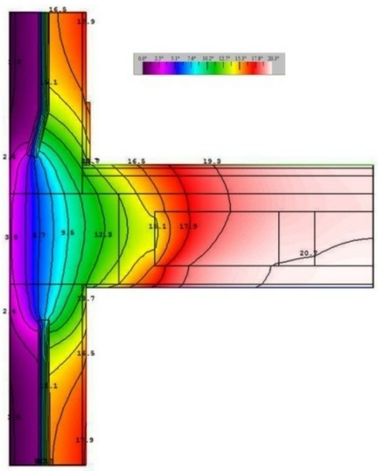

Fig. 5. Sketch of isotherm lines in a thermal bridge in the outer wall

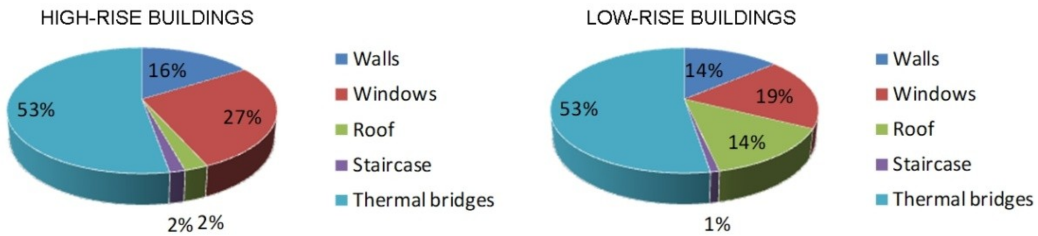

Fig. 6. Relevance of each component of the building envelope and of thermal bridges on heat transfer

1.4. Interventions

The main goal of the regeneration intervention in M4 of TBM is to balance out supply and demand in terms of dimension of dwellings. The original project was born in a period when the average number of family members was much higher than nowadays. The direct consequence was in the dimension of dwellings. Nearby 60% of existing stock of M4 building is larger than 70-meter square and the half of these dwellings are larger than 85-meter square. Only 20% are dwellings smaller than 60-meter square. Dwellings for small families, young couples with few children, students and seniors are missing.

Not only dimensional problems are evident. Internal layout is also an issue. Existing internal dwelling layout is based on passed models, with a clear separation of functions. Open spaces are missing as well as the joining of living and dining room. The distribution of daylight to dwelling interiors is missing.

The intervention addresses all these deficiencies. The main goal is to reduce the number of great size dwellings no more functional to shelter large families and to create a huge number of small-size dwellings following the international trend of short-term rent social housing. The increment in term of number of dwellings is reached by splitting large-size dwellings and adding residential area gained by changing the use of abandoned spaces.

In addition, existing dwellings are renovated with the goal of spanning wide spaces and providing higher level of internal comfort. Energy performance of the buildings have been calculated through standard energy demand assessment as provided by EN 13790 and Italian standards UNI 11300 and related standards, through MC11300 software.As thermal bridges are very relevant on heat transfer, outer wall insulation is almost mandatoryas it reduces their relevance.

The interventions on the building envelope are:

- External insulation of the opaque envelope by application of 80 mm thick mineral wool panels (thermal conductivity 0.032 W/m·K). This reduces heat transfer through concrete walls by 67% and of infill walls by 52%. Moreover it reduces thermal bridges by 80% on average, being very effective on the junction between intermediate floor and infill walls where they are reduced by 88%. Mineral wool is chosen for its best fire resistance that is a major concern in such high rise buildings. To ensure durability, which is the second major concern in interventions on such buildings, cladding with composite aluminum panels is considered.
- External insulation of roof by application of 80 mm thick expanded polyurethane panels (thermal conductivity 0.028 W/m·K). This reduces heat transfer by 65%. As fire resistance is of lesser concern on the roof, the better performing polyurethane may be used.
- Replacement of existing windows (4.33 $W/m^2 \cdot K$ thermal transmittance on average)with double glazed low-emissivity windows with frame with thermal break (1.20 $W/m^2 \cdot K$ thermal transmittance on average).

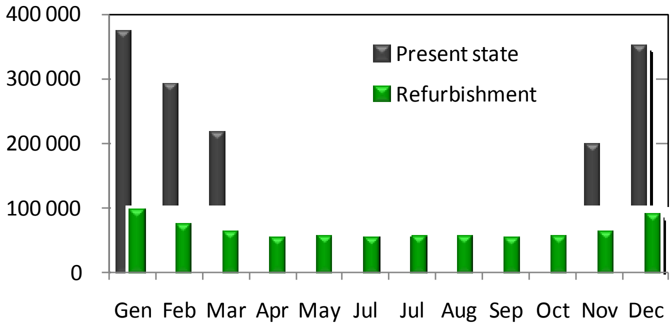

Fig. 7. Primary energy demand before and after refurbishment

These reduce heat transfer rate through the envelope by 73% in line buildings and by 63% in tower buildings. Yet, overall energy demand reduction is 92% for line buildings and 90% for tower buildings as direct solar heating and internal gains become more effective after refurbishment. Besides, as the overall primary energy demand is related to domestic hot water demand, too, overall demand of heat is reduced by 71 %: at present, heating accounts for 80% of heat demand, after refurbishment it will account only for 26% of heat demand.

Energy renewal provides also a lower ratio between winter and summer demand that becomes 2.5 from the former value of 13.7, as depicted in fig. 07. This allows exploiting solar energy. This may be achieved with systems refurbishment:

- Heat pump heating system combined with Photovoltaic system (PV) for heat generation.
- Radiant floors for room heating, so to allow for low temperature heating distribution. This requires the makeover of all floors inside dwellings that is anyway mandatory due to the proposed reshaping of internal spaces and splitting of residential units.
- Centralized domestic hot water (DHW) system. This allows to use heat pumps for water heating with higher efficiency.

Actually, there are many shafts in the buildings, so complete renewal of systems is quite simple.PV panels may be put on top of the three towers. Indeed, the large roofs of line buildings are shadowed for more than 4 hours each day, including midday. Considering that almost 30% of the roof area would be needed for operation, using common PV panels with pick power of 125 W/m^2 referred to gross area, roof surface is sufficient for a system with 131 kW overall peak power,with 30° inclination, facing South (10° deviation towards East, according to building orientation). This will be able to provide 63% of energy demand for heating and DHW. The whole heat demand may be produced by the heat pumps exploiting PV power generation from March to October, while in winter months energy production from lowers down to 12%, as shown in fig. 08.

Installing PV systems on south facades of the towers is viable but of low energy and economic value as its energy production in winter is not high enough to fulfill building demand while in summer its power generation is very low. Proper design, as well as heat storage systems and advanced power control through demand side management may provide higher performance of the system, as illustrated in [21], but it is out of the scope of the present paper. Retrofitting of building envelope leads to a reduction of cost for Heating and DHW by 60%. Retrofitting of these systems together with PV system, too, leads to a reduction of energy cost by 98% as surplus power production may be used for lighting or sold to Electric Grid.

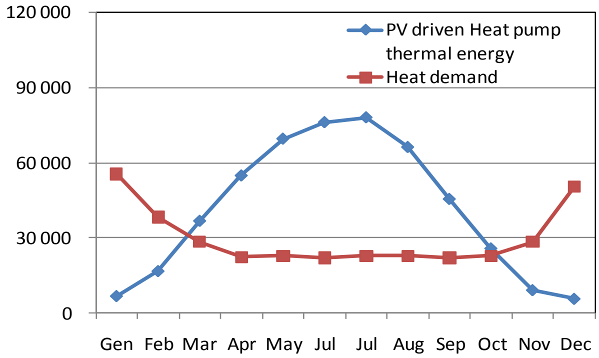

Fig. 8. Thermal energy demands and thermal energy production from PV.

The strengthening of the building addresses explicitly to the seismic retrofitting. The main goal is to increase the strength and the stiffness in the weak direction of the structure. To achieve this goal, an external steel strengthening is proposed.

The external reinforcement has important outcomes in:

- the reduction of economic losses for secondary construction works;
- the opportunity to maintain the occupancy of the building while the works are in progress;
- the ease and the economy in building the foundation of the strengthening structure itself.

The strengthening structure consists of steel truss elements (two on each façade) joined to each other by two transversal truss pieces, made on the outside line of the new loggias. Their alignment is functional to the position of windows. From a structural point of view, existing walls are not sufficiently resistant. In any case, they have an important stiffness in the weak direction. According to the current technical rules they are not enough ductile in order to contribute to general seismic protection. Due to economic sustainability of structural retrofitting, reinforcement of existing walls and seismic protection by base isolation systems were not considered. Concerning foundations, for each of the two side, a beam connected (but external) to the existing system is proposed.

Comparison of different scenarios

The need of seismic retrofit and the task of energy behavior improvement set themselves as the main field for the definition of traditional scenarios of renovation. A scenario "A" can be identified in the energy retrofit and a scenario "B" in the seismic retrofit. The integration with the dwelling renovation in the adjustment of a high rise building to the current need of social housing policies is a relevant characteristic that permit the definition of the third scenario ("C") with all its characteristic.

Table 3. Cost benefit results: comparison among different scenarios of M4 case of study. In order to simplify the calculations the discount rate is supposed corresponding to inflation one.

	Scenario A energy retrofitting	Scenario B seismic energy retrofitting	Scenario C seismic + energy retrofitting + dwellings renovation
Energy Retrofitting: Envelope	€ 2,148,120	€ 2,148,120	€ 1,298,923
Seismic Retrofitting		€ 1,285,000	€ 1,524,265
Ancillary costs	€ 537,030	€ 537,030	€ 805,545
Dwellings Renovation			€ 4,464,346
New envelope front S and E			€ 1,152,270
HVAC Retrofitting	€ 563,100	€ 563,100	€ 956,100
Energy Saving	€ 873,221	€ 873,221	€ 1,387,665
Tax incentives (Energy Retr. 10 years)	€ 1,624,125	€ 1,624,125	€ 1,624,125
Tax incentives (Seismic Retr. 10 years)		-€ 835,250	€ 1,085,337
Renting New surfaces (10 years)			€ 1,479,789
Value New Dwelling Surface (10 years)			€ 3,374,892
Net cost of intervention	€ 750,904	€ 1,200,654	€ 1,249,641
SUA (m^2)	16,596	16,596	18,473
Number of dwellings	241	241	310
Inhabitants	792	792	917

In scenario A, only energy retrofitting is considered: complete renewal of building envelope (four facades each), as described above, as well as radiant floor heating and centralized DHW and PV system.

In scenario B, energy retrofitting and seismic retrofitting are considered. In the scenario C a total number of 69 dwellings (+29%) is added to the original number of 215, equal to 125 new inhabitants (+16%). New dwellings are mainly created in the small-size range: ninety-nine 38.75-meter square and ninety 64.91-meter square dwellings are added. The total number of dwellings smaller than 60-meter square passes from 20% to 40% of the total amount as well as dwellings between 60 and 70-meter square from 20% to 45%. The number of dwellings greater than 85-meter square is reduced from the 30% to the 15% of the total amount. A total number of 67 existing dwellings is renovated with slight additions of useful floor area. The 10 accommodations for disabled people are renovated and made more comfortable and spacious. HVAC retrofitting costs are higher in this scenario as the new dwellings implicate new systems. Besides, the increase in surface of dwellings implies new facades that will have appropriate heat transfer characteristics. Thus, renewal of building envelope is limited to two facades for each building. Seismic retrofitting accounts for additional floor slabs, too.

Conclusion

In the present text length limits, the contribution expounds just the case of the compart M4. The design strategy, which is included in the financial and regulatory contest, shows how the seismic and energy integrated retrofit can be a useful tool to proceed, virtually no cost to the renewal, the increasing and the adapting of the social housing estate (only 3.9% increase in total net cost with 28.6% increase of dwellings, in comparison to a simple seismic and energy retrofit of the building). The experimentation carried out on several buildings has confirmed how the original construction typologies have a considerable influence on the flexibility of the modification and the success of these approaches.

Thus the decision of presenting the case of M4 compartment, for its planimetric rigidity linked to the industrialized construction process, since, despite these constitutive limits, it has shown the validity of the approach. In particular, among the main limits we can certainly place the difficulty in the buildings so constructed, in obtaining, the functional and architectural qualities desired for the dwellings without departing too much from the minimum areas required by the law.

For this reason, it is important to highlight that the result of the implementation of housing has in any case involved a waste of surfaces, dictated by the impossibility of organizing the accommodation in an optimal manner, in the rhythm of the reinforced concrete bearing partitions.

But as expected, the cost-effective evaluation of the proposal shows the convenience of the integrated approach in supporting public administration in social housing renovation. Actually the value predictable for the new dwelling surfaces is lower than the real estate audit, considering the incentives established for tenants who buy their houses. This underestimation reduces the risk of the intervention plan. The best solutions, according to the parameter of efficiency, resistance, residential units improvement, offer an increasing of residential units (plus 40%), a balanced reduction of energy consumption associated to energy removable production, and a considerable improvement of the seismic behavior of the structure.

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1 The Inter Ministerial Decree of the 2nd April 1968, no. 1444 introduced indefinable limits of building density, height, distance between buildings and maximum ratio between spaces intended for residential and manufacturing sites and spaces public or reserved to community facilities, public greenery or parking lots to observe for the purpose of the formation of new urban planning instruments or the revision of existing ones. The minimum requests for each public services has been defined as a "standard".