Chapter 16
Energy Retrofit Cost-Optimal Design Solutions in Social Housing: The Case of Three Tower Buildings of the 1980s

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Introduction

This work aims at characterizing energy retrofit design solutions in social housing by means of cost-optimal analysis. The objective is to compare usual and deep building renovation scenarios with a design method useful to take into account relevant non-energy-related factor concerning architecture and social aspects, i.e. flat adaptations to users' needs, renovation of common spaces for cohousing activities, quality of building elements and life-cycle extension. All these factors improve the living quality of inhabitants and give additional economic value to the social housing districts. This objective is developed in the Italian regulation framework on energy efficiency and building renovation, taking into account EU cost-optimal methodology and Italian public incentives.

In Europe, the existing building stock consists of a large number of buildings, mostly dated back to past centuries. Several statistics estimate that about 65% of this stock has been built without any energy conservation measures [1]. As a result, the residential building stock across EU have extremely low energy performances and require urgent retrofit actions in order to meet the common target of greenhouse

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A. Sayigh (ed.), *Green Buildings and Renewable Energy*, Innovative Renewable Energy, https://doi.org/10.1007/978-3-030-30841-4_16

gas reduction within the next few decades [2, 3]. In fact, to this date, three-quarters of the buildings standing today are expected to remain in use [1, 4]. Therefore, energy renovation is a priority within EU policies and actions, in order to achieve a sustainable built environment and human well-being [5].

Italy, as other Mediterranean countries, is facing a challenging crisis of the real estate and construction market. This crisis affects especially the real estate public companies which manage a large amount of the above-mentioned building stock. Moreover, recent policies on the energy efficiency of buildings are not as effective as we expected: the great part of tax incentives is given to retrofits merely based on technologies existing in the market, without any balanced design approach that may lead to the optimal solution [6, 7].

For these reasons, methods to identify the most cost-effective retrofit measures for particular projects are still a major technical challenge, and cost-optimal solution in social housing is of primary importance: real estate companies may have the need of support in the selection process of the cost-optimal energy retrofit design solution [8, 9].

In this framework, we present three tower building of the 1980s, located in a social housing district of Rome (Italy), as case study. This kind of districts represents—in Italy, as well as in other European countries—most of the urban expansions built during the second half of the twentieth century, thanks to public investments. In recent years, public social housing has been widely investigated by researchers, architects and practitioners because it represents one of the most relevant parts of the existing stock where urban renovation with a holistic approach can take place, aiming at promoting multiple benefits for the inhabitants (social, economic, environmental, safety, health, aesthetics, etc.) [10–12]. On one side, these districts were designed according to innovative architectural design concepts and theories. On the other side, public housing districts were built to meet the fast-growing housing demand. For this reason, the construction process focuses on minimizing costs and time, producing low-quality urban environment. Nowadays, this housing stock suffers for users' discomfort, unhealthy conditions, typological obsolescence and structural and technological deficiency. The combination of the above-mentioned features makes even more important the study of the social housing stock because it allows for a holistic approach in district renovations that could support policymakers in the decision process.

Our study attempts at including non-energy and economic factor in this process. We aim at determining the optimal design solution and at establishing to what extent deep renovation is competitive with respect to the usual renovation. This work forms part of an ongoing project that evaluates seismic and energy renovation of social housing district with a holistic design approach, using the Heritage BIM process.

Case Study

In the first half of the 1970s, the Italian Law n. 865/71, on the basis of Law n. 167/62, introduces the "Piani di Edilizia Economica e Popolare" (PEEP), an urban planning tool which selects and defines public areas for new social housing districts.

As mentioned above, the main purpose of the PEEP was to meet the sharp increase of social housing demand, introducing low-cost flat in the market, thanks to an agreement. In this agreement, the public administration grants the building leases to a private contractor. The PEEP has been the most widely used planning tool over the last three decades, to the point that it characterizes numerous suburbs of the major cities. Moreover, nowadays the PEEP districts account for a large part of the urban footprint (from 9% to 15%) [11].

In the city of Rome, the PEEP has been developed in three stages [13]. The first stage took place between the 1970s and the first half of the 1980s, divided into 48 urban areas for a total of 379,547 rooms. The second stage has been approved in 1978 by the municipality of Rome, providing for 186,486 additional rooms in 41 new areas. Finally, in order to meet the growth of housing demand between 1987 and 1997, the "PEEP completing measure" has been approved, providing 144,000 rooms in 28 areas. Nowadays, about 71,000 social housing flats are managed both by the territorial agency for social housing of Latium, namely, ATER (48,000 units), both by the municipality of Rome (23,000 units). These buildings officially accommodate 198,352 inhabitants, which correspond to about the 14% of the inhabitants of the city of Rome [13].

The three tower buildings selected as case studies are located in the Vigne Nuove district (Fig. 16.1). The district was planned since the 1972 and completed in 1982. The towers, built in the last stage of the district development, were designed by architects Chiarini, Aymonino, Mazzacurati and Prantera [14]. The plan should have included five 15-storey tower blocks, built at the beginning of the 1980s, a service building and an urban park. The latter two were never completed. The buildings are a typical example of the industrialized building system widely used in Italy for social housing districts during the 1970s and the 1980s, composed by cast-in-place reinforced concrete walls and slabs and precast reinforced concrete panels for the façades. Each tower building accommodates 268 inhabitants in 82 flats. Eight different flat types contain from two to six inhabitants. Each floor has from four to six flats and two common spaces (Fig. 16.2). The biggest flat types (gross surface, SUL > 85 m^2) are the most common (44% of the total flats), followed by smaller types (SUL < 65 m^2—41%) and by medium-sized types (SUL 65 > m^2 > 85—15%).

Fig. 16.1 Vigne Nuove housing district: plan (left) and aerial view with the three tower buildings object of study

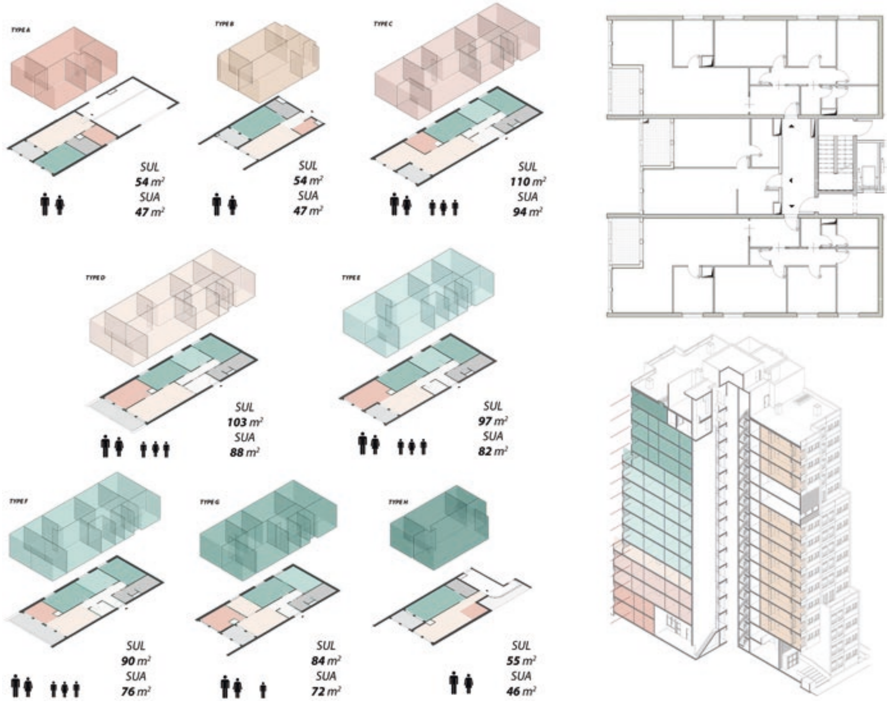


Fig. 16.2 Actual situation: flat types, typical floor plan and axonometric section with flat types

Today the building requires major maintenance works: the building elements and the structure finally reached the end of their life cycle. This is the occasion for proposing an integrated approach to the building renovation that goes beyond usual retrofit actions merely based on the application of technologies existing in the market, without any balanced design approach, leading to the optimal solution. In fact, about 10 years ago, the towers underwent this kind of retrofit action: longitudinal reinforced concrete walls of the façades north-east and south-west where covered with thermal insulation (4 cm of thickness). However, it results in a one-off action that has very limited effect on the thermal performance of the building and leaves unanswered several problems concerning the characteristics of the envelope (thermal bridges, water infiltrations, materials degradation, structural performance reduction).

As a result, the economic investment is revealed all too often ineffective in terms of cost. Moreover, the south-east and north-west façades, based on precast concrete panels represent a crucial problem for the building's energy performance, due to the continuity between façade system and interior floors, generating linear thermal bridges, largely diffused on the whole building. In addition, the lack of a waterproofing layer on roofs and the worn-out sealing joints of precast panels cause several water infiltrations (Fig. 16.3).

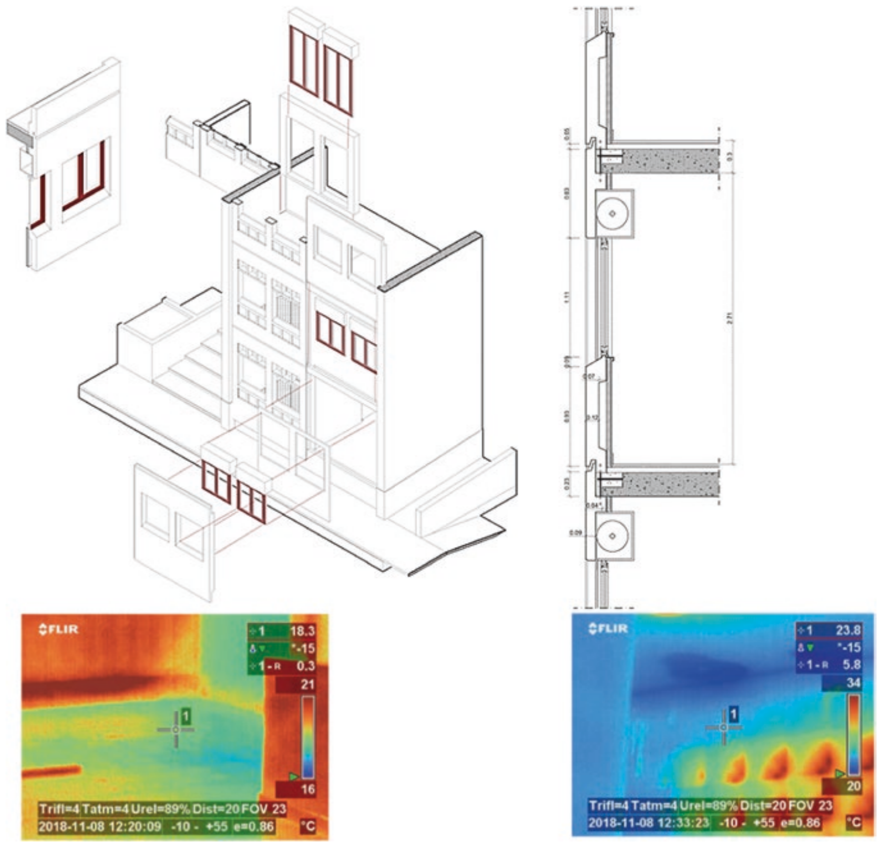


Fig. 16.3 Actual situation: axonometric section and vertical section of the precast concrete panel façade (top); on-site thermography of water infiltrations (below)

Method

The aim of this work is characterizing energy retrofit design solutions in social housing by means of cost-optimal analysis. The method has been conceived in order to develop an integrated design approach, useful to control and assess architectural, seismic, energy and economic aspects in one single platform. For this reason, the building has been modelled with Revit software, applying the well-known H-BIM method (Fig. 16.4). The seismic analysis lies outside the scope of this study, but it is worth to underline that the building renovation design scenarios include structural renovation solutions, as well as the method permits to assess this aspect.

Possible retrofit actions have been proposed and considered in a balanced combination both in the usual building renovation scenario and in the deep renovation scenario. Three different conditions were compared: *actual situation* (the reference case), *scenario A* that includes usual renovation solutions and *scenario B*, which

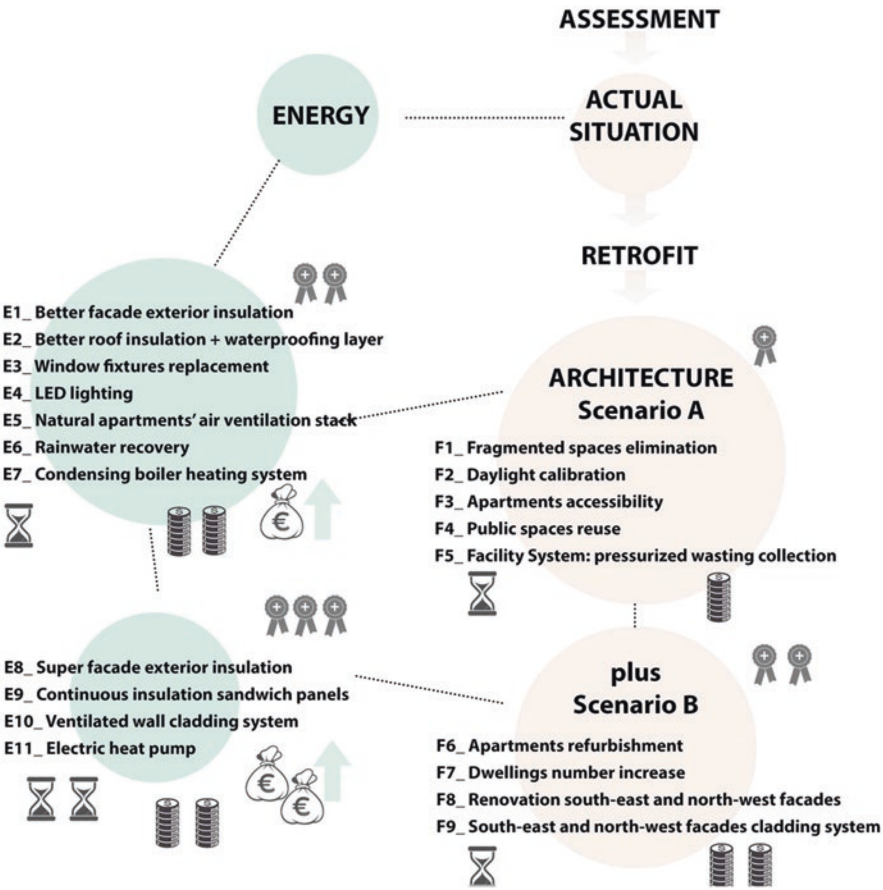


Fig. 16.4 Design solutions diagrams and energy retrofit actions

includes advanced renovation solutions (Figs. 16.5, 16.6, and 16.7). More in detail, scenario A deals with more usual design solutions for retrofit with the aim to comply with minimum requirements of Italian energy efficiency regulation. In this scenario, the following solutions have been applied: new thermal insulation of the envelope—replacement of the existing thermal insulation layer with new expanded polyurethane panels (7 cm) and an interior intervention adding to the existing insulation (5 cm) polyurethane panels (7 cm) on the precast façades; replacement of the heating system with a high-efficiency condensing boiler; high-performing window; and LED lights.

Scenario B, based on deep renovation solutions, is characterized by thermal superinsulation of the envelope; naturally ventilated façade for south-east and north-west reinforced concrete walls; insulation sandwich wall in replacement of the existing precast panels; high-performing window (as in the scenario A); and LED lights (as in the scenario A). These solutions provide the higher thermal

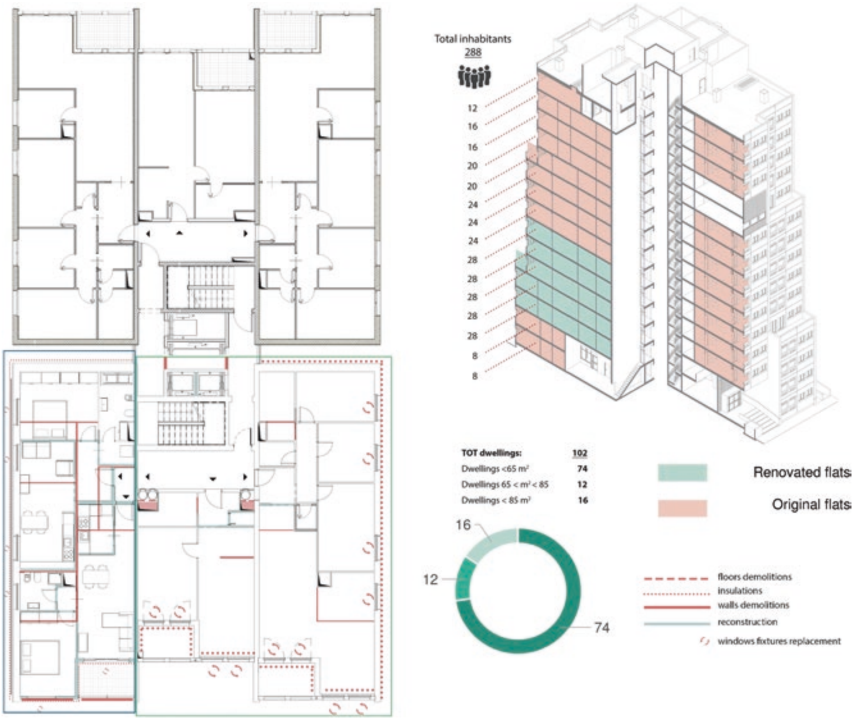


Fig. 16.5 Typical plan comparison: the actual situation with the retrofit scenario A (green) and scenario B (blue). Typological refurbishment: renovated and original flats

Geography position and weather station data				Set Points	Thermal conductivity of building materials [W/m K]
Rome: Lat. 41.953459, Long. 12.531514		topography (GIS)		heating: 20 °C	concrete cast in-place: 1.046
	monthly average temperature	monthly daily hours	temperature mean daily range	cooling: 26 °C	windows fixture aluminium: 230
March June September December	13°C 27 °C 24 °C 10°C	170 320 280 130	9°C 11°C 10°C 8°C		wall gypsum: 0.42 bricks walls: 0.54 insulation panels: 0.35 ceramic tile floor: 0.80
Building Space Type		Space		Space Type settings	Lighting and Power Load Schedule settings
user type: multy-family, multi-storey building		thermal zones: living room, restroom, bedroom, kitchen, stairs		lighting/power load density [W/sm]: living room 10/6 kitchen 10/12 restroom 8/11 bedroom 8/6 stairs 6/2	lighting: home occupancy power: home occupancy
occupancy schedule: home occupancy - 24 hours		service type: conditioned / unconditioned		sensible heat gain per person: 60 W	
system type: centralized heating, residential heating boiler		occupancy factor: 24 hours		latent heat gain per person: 40 W	

Fig. 16.6 Main settings of the energy simulation (left) and building occupancy profile (right)

performance of the building envelope. Furthermore, in order to maximize system performance, a high-efficiency heating pump was introduced.

The economic sustainability of each retrofit action within the scenarios has been analyzed, in order to select the cost-optimal design solution. The costs of building

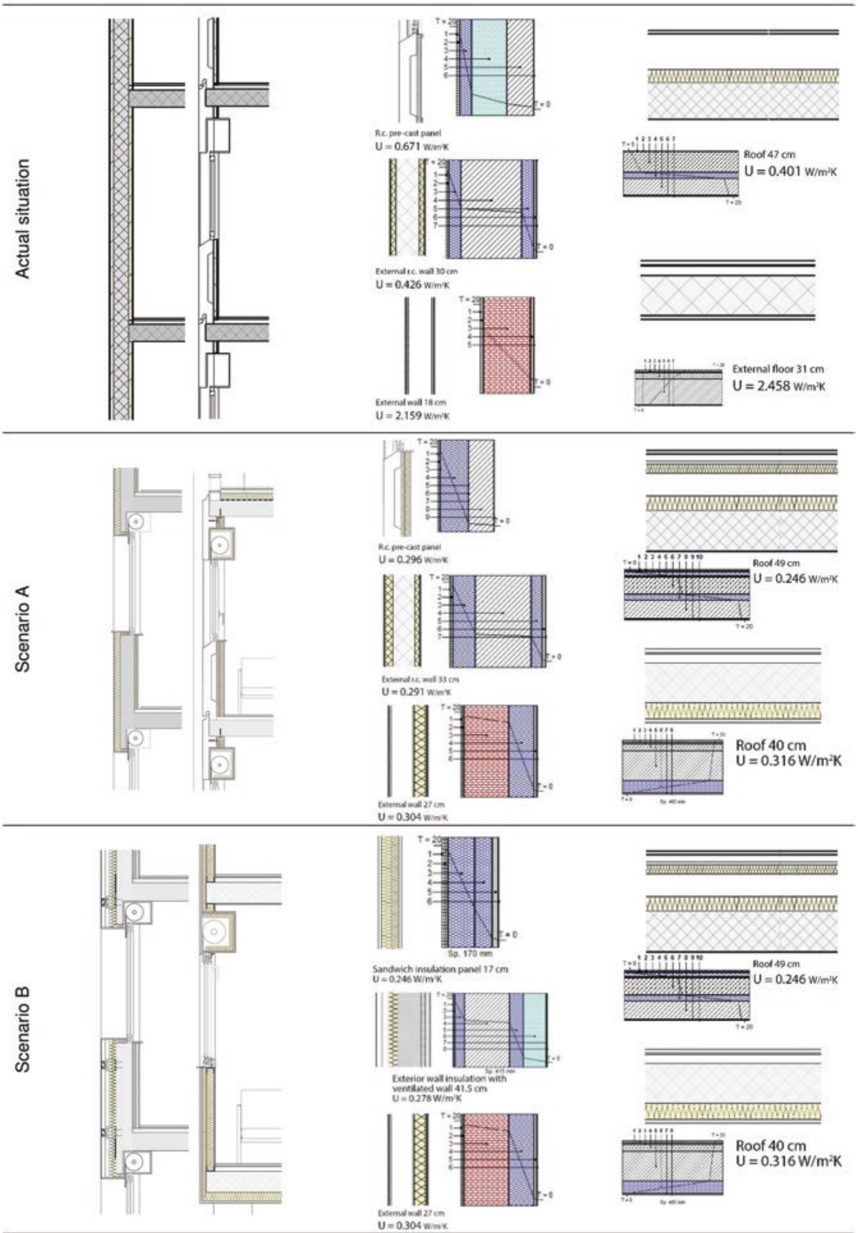


Fig. 16.7 Scenario comparison: façade sections (left) and details (centre); roofs and external floors (right)

retrofit were calculated in an analytical way—regarding the façades and structural works—and parametrically, for the internal refurbishment works. In the latter case, two values have been estimated: 600 euros/m^2 for scenario A and 750 euros/m^2 for scenario B. The costs related to the structural works are excluded by the cost-optimal analysis, as this aspect lies outside the purpose of this paper.

The estimation of global and residual cost, considering the Italian public incentives *ECO-bonus*, is proposed and discussed. The energy analyses have been performed by generating an energy model in Revit. Urban obstructions and topography have been imported from GIS to the model. The most relevant data settings concerning the energy simulation (climate, user type, occupancy profile and system specifications, natural ventilation, internal loads, etc.) as well as thermal properties of the building envelope are presented in Fig. 16.6. Heating design data related to each building elements (walls, windows, floors, infiltrations, lights and equipment) have been calculated with *EnergyPlus* using *Insight plug-in*. This plugin permits to control the economic aspect during the design phase and to compare energy retrofit interventions. Annual dynamic energy simulations have been performed with *Green Building Studio*, using the *DOE-2* simulation engine. As the building does not have a cooling system, in order to compare the actual situation with the proposed scenarios, the energy consumption for cooling has been excluded from the analysis.

Results and Discussion

In this section we present and discuss the results in terms of annual energy consumption (kWh/m^2 year), energy costs (euros/year), payback period (years) and cost (euros) of building renovation for both the actual situation and the scenarios. The section is divided into two parts: the energy performance and the cost analysis.

Energy Performance

Through the dynamic energy analysis of the actual situation, carried out with Green Building Studio, a total energy consumption of 100 kWh/m^2 year emerged (D energy rating) as shown in Fig. 16.8. The results demonstrate a significant utilization of natural gas (52.5% for space heating and 47.5% for domestic hot water). Electric consumptions are the largest proportion in the global consumptions: 63% for lighting and 35% for electronic devices.

The heating load component analysis highlights that exterior walls and windows are responsible for most of the thermal losses through the building envelope: 45% for walls and 24% for windows (Fig. 16.11). This is due to the combined effect of the building typology with the low-quality construction materials and to the little

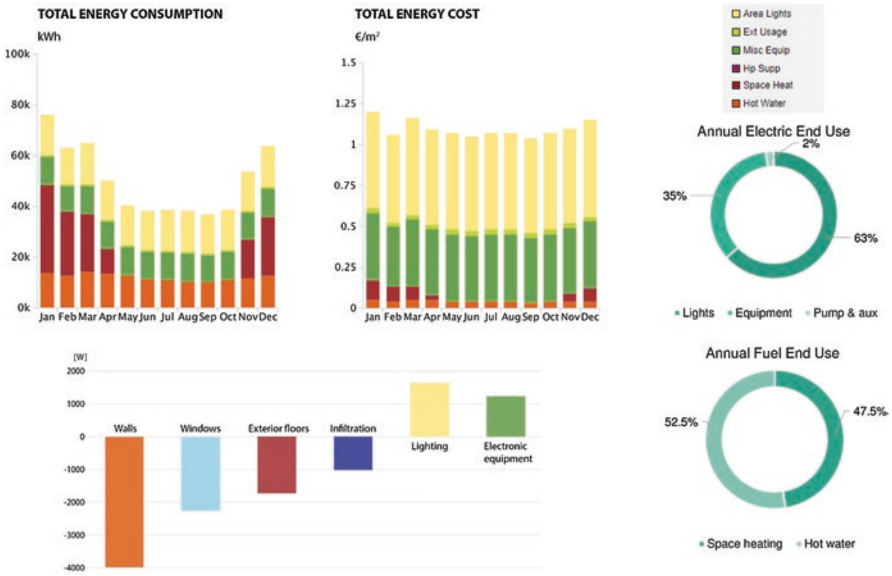


Fig. 16.8 Results of the dynamic analysis for the actual situation: total energy consumption and total energy cost (top-left), energy consumption in terms of electric energy and natural gas fuel (right) and heating load analysis of building components (bottom-left)

attention to the thermal performance of the envelope. Form and typology of the building (in particular, plan depth and width) reduce direct heat gains in winter and natural lighting. Even though each façade has minimum thermal insulation panels (5 cm of thickness), the low thermal properties of reinforced concrete and windows, as well as the presence of thermal bridges in most of the nodes between floors and façades, produce very low thermal performance.

The energy retrofit solutions of scenario A have been analyzed in terms of global consumption reduction separated into building elements and systems: façades, roofs and external floors, heating system and lighting (Fig. 16.9). In the first case, by introducing thermal insulation on walls and replacing the existing windows, it is possible to obtain an energy consumption reduction of 10% (90 kWh/m^2 year). In the second case, the thermal insulation of floors and roofs decreases consumption of 6% (94 kWh/m^2 year). The replacement of the heating system with an efficient condensing boiler (90% AFUE) contributes to breaking down the total energy consumption by 17%, reducing the great part of natural gas demand. Finally, the introduction of LED lighting to replace the existing lighting system reduces energy consumption by 15% and electrical loads by 80% (85 kWh/m^2 year).

Through a balanced combination of the above-mentioned retrofit solutions, it is possible to achieve a global energy savings of 52% (763,256 kWh) compared to the actual situation (1,393,094 kWh) and to achieve the B energy rating (48 kWh/m^2 year).

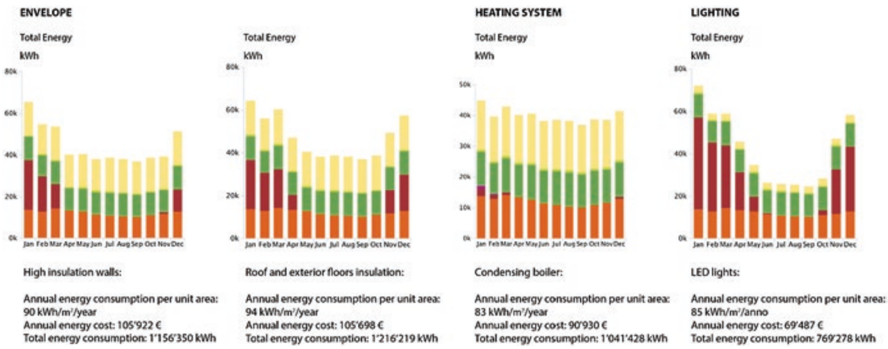


Fig. 16.9 Selected energy retrofit actions of scenario A: monthly and annual energy consumptions and costs

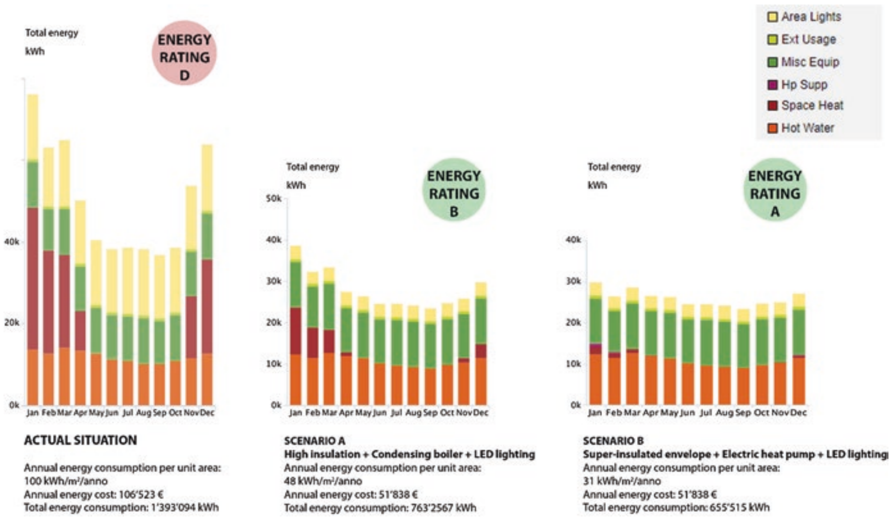


Fig. 16.10 Energy ratings and energy consumptions for actual situation (left), scenario A (centre) and scenario B (right)

The combination of energy retrofit solutions in the scenario B determines an annual energy demand of 31 kWh/m^2 year (A energy rating). Thus, it is possible to save up to 69% of the energy consumption and to obtain an additional 17% of energy savings compared to scenario A. Also in this case, the final consumptions are due to the combined effect of the single energy retrofit measures and in particular to the super-insulation of the envelop and to the heating systems, as highlighted in Fig. 16.10. In the same figure, it is possible to notice that the great part of the energy consumption in the renovation scenarios is due to DHW and electronic devices: two factors independent from architecture characteristics and construction features of the building.

Cost Analysis

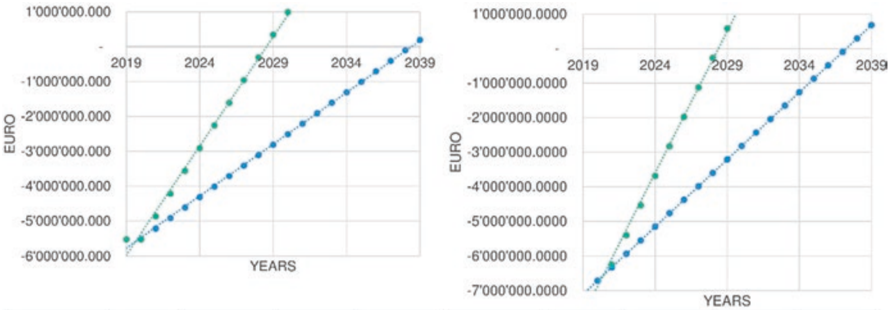
The main results of this section are presented in Fig. 16.11 and Fig. 16.12. The annual energy cost of each tower building in the actual situation is about 106,000 euros/year, of which the 94% is due to electric energy (100,000 euros/year). It is significant to notice how effective is replacing of the lighting system with LEDs that consents a 65% cost reduction. In addition, the selection of the heating system should be driven by a combination of the energy and the economic benefits and balanced in relation to the whole design solutions of each scenario. In fact, the high-performance condensing boiler reduces the annual cost by 15%, while the electric heating pump increases the annual energy cost by 21%, up to 134,811 euros/year. In both cases of usual and deep renovation, results show similar values of annual energy cost: about 52,000 euros, with a reduction of 51.3% for scenario A and 50.6% for scenario B. The main difference between the scenarios is the annual cost for natural gas—with 42% of saving in scenario A and 53% saving in scenario B. The annual cost for electric energy is reduced by 51% in both scenarios. Therefore, in economic terms, the application of an electric heat pump combined with other energy retrofit interventions would not be as effective as in the case of one single retrofit action. This highlights the importance of a holistic approach in the selection of the optimal design strategies in the renovation of social housing.

The global costs of building renovation are:

- Scenario A—5,517,311 euros, of which 1,655,711 euros for energy retrofit actions (30% of the global cost)

Total Energy annual cost [euro]	**Actual Situation**	**Retrofit scenario A**	**Retrofit scenario B**
Energy cost	106'523.00	51'838.00	52'653.00
Fuel cost	6'304.00	3'629.00	2'943.00
Electric cost	100'219.00	48'209.00	49'710.00
Total Energy annual cost by intervention [euro]			
High insulation wall and windows		105'922.00	
Roof and floors insulation		105'635.00	
Super-insulated envelope			105'549.00
90% AFUE condensing boiler		90'930.00	
Electric Heat Pump			134'811.00
LED lighting		69'487.00	69'487.00

Fig. 16.11 Annual energy cost and costs of retrofit actions: comparison between actual situation and scenarios



SCENARIO A	Grand Total Cost [Euro]	Grand Total Cost Energy Retrofit [Euro]	Grand Total Cost Internal Refurbishment [Euro]	Cost recovered by means of incentives [Euro]
ECO - BONUS 65% Incentives (10 years)		1'655'711		1'076'212
Tax deduction 50% (10 years)			3'861'600	1'930'800
TOT	5'517'311			3'007'012
		Cost recovered by means of energy savings [Euro/year]	Energy savings gain at 10th year [Euro]	Cost with incentives + energy savings gain [Euro]
		350'480	3'504'800	- 994'501
	TOT [Euro]	Residual Cost	[Euro/m2]	
TOT SCENARIO A without incentives	5'517'311		819	
TOT SCENARIO A with incentives	2'510'299		372	

SCENARIO B	Grand Total Cost [Euro]	Grand Total Cost Energy Retrofit [Euro]	Grand Total Cost Internal Refurbishment [Euro]	Cost recovered by means of incentives [Euro]
ECO - BONUS 65% Incentives (10 years)		2'278'125		1'480'781
Tax deduction 50% (10 years)			4'827'000	2'413'500
TOT	7'105'125			3'894'281
		Cost recovered by means of energy savings [Euro/year]	Energy savings gain at 10th year [Euro]	Cost with incentives + energy savings gain [Euro]
		465'060	4'650'600	- 1'439'756
	TOT [Euro]	Residual Cost	[Euro/m2]	
TOT SCENARIO B without incentives	7'105'125		1054	
TOT SCENARIO B with incentives	3'210'844		476	

Fig. 16.12 Cost analysis: scenario A (left) and scenario B (right)

- Scenario B—7,105,124 euros, of which 2,278,124 euros for energy retrofit actions (32% of the global cost), in particular, 190,412 euros for the naturally ventilated walls and 432,000 for the new sandwich insulated walls

For both cases, the payback period in 10 years was calculated, considering the Italian public incentives *ECO-bonus* (Figs. 16.11 and 16.12). These incentives permit to recover 65% of the costs for energy retrofit actions and 50% of the costs for the renovation works.

The paybacks are:

- Scenario A: 3,007,012 euros, of which 1,076,212 euros for retrofit actions and 1,930,800 for renovation works
- Scenario B: 3,894,281 euros, of which 1,460,781 euros for energy retrofit actions and 2,413,500 euros for renovation works

In addition, energy savings in scenario A and B compared to the actual situation must be taken into account in the cost balance:

- Scenario A: 350,480 euros/year, which corresponds to 6.25% of the global renovation cost
- Scenario B: 465,060 euros/year, which corresponds to 6.55% of the global renovation cost

Considering the 10-year period of the *ECO-bonus*, about 62.5% and 65.5% of the initial investment will be recovered, respectively. The former provides for incentives' payback of 3,007,012 euros and a positive income of 994,501 euros; the payback period is 9 years. Therefore, the cost of the building renovation per unit area drops from 819 euros/m^2 (without public incentives) to 372 euros/m^2. The latter provides incentives for 3,894,281 euros and a positive income of 1,439,756 (about 50% more than scenario A); the payback period is 8 years. In this case, the cost of the building renovation per unit area drops from 1054 euros/m^2 (without public incentives) to 476 euros/m^2. Finally, results demonstrate that the deep building renovation scenario (B) is the cost-optimal investment compared to the usual renovation scenario (A). On one side, with an additional investment of 22%, it is possible to obtain a shorter payback period and a most effective design solution. On the other side, the deep renovation improves the life quality and the well-being of the inhabitants, reduces the energy consumption and adapts the existing flats to the actual social housing demand, taking advantages of the Italian public incentives on energy efficiency and building renovation.

Conclusions

In this paper, we present and discuss selected energy retrofit design solution in three social housing tower buildings representative of the PEEP district of the 1980s. Differences between usual and deep building renovation have been highlighted. A holistic approach, based on the H-BIM process, has been proposed and tested. The renovation of this kind of districts is one of the major opportunities to include non-energy-related aspects in the process and to improve the life quality of inhabitants, as well as reduce energy consumption and give additional economic value to the social housing stock.

The purpose of the method is twofold: on one side, it supports public and private real estate companies in the selection of the cost-optimal design solution for energy retrofit of buildings; on the other side—demonstrating the economic feasibility of such kind of renovation process—it aims at promoting the discussion about the importance of non-energy-related factors, in order to properly evaluate the economic competitiveness of the energy retrofit in the renovation process with a holistic approach.

With respect to the main results, the study demonstrates that deep renovation could be competitive with respect to cost-optimal renovation in the cases of social housing buildings of the 1980s due to a slight increase of the initial investment counterbalanced by faster payback period and a significant reduction in the annual energy costs. In addition, the proposed approach permits to integrate other important aspects that lie outside the scope of this paper, such as the fire safety and seismic retrofit, taking advantage of other incentives, i.e. *SISMA-bonus*.

Acknowledgements This research was funded by the Department of Architecture and Urban Studies—DAStU, Politecnico di Milano, and fund number DDO8ECLZ01.

Authorship: Conceptualization E.C. and M.M.; methodology E.C. and M.M.; investigation V.V.; data curation V.V.; writing, original draft preparation M.M. and V.V.; writing, review and editing M.M.; supervision E.C. and A.R.; funding acquisition A.R.

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