Energy communities and requalification. Towards energy transition and self-sufficiency: a “challenge” for the Olympic Village

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ABSTRACT

Against the current global climate emergency and energy crisis, one of the most effective tool for reforming the current energy system, while at the same time prompting development based upon sharing and savings are the Renewable Energy Communities (REC). This study proposes assessing the energy consumption of residential buildings in the Olympic Village of Rome, in order to suggest energy retrofits and assess the feasibility for the establishment of an energy community. First of all was performed a preliminary biophysical, bioclimatic, and anthropic analysis of the neighborhood, followed by a building system energy analysis; specifically, were analyzed the technical and plant systems, estimating the incidence of the building envelope’s heat losses and the breakdown of consumption. Then were suggested actions aimed at improving those system’s performance, with the elaboration of three energy scenarios of differing intensity. Lastly, was performed an analysis on the feasibility of instituting a REC in the area of the Olympic Village. The preliminary results of the research emphasize how the local sharing of energy through the establishment of RECs can generate significant environmental, social, and economic benefits. The model proposed for the Olympic Village case study demonstrates its replicability in numerous settings.

Keywords: Electrification in the built environment, Energy consumption analysis, Renewable energy communities, Residential users, Retrofitting interventions.

1. INTRODUCTION

The scientific community estimates that the effects of global warming, responsible for extreme weather events, along with the increasing urbanization by the global population, lead to a progressive deterioration of living conditions within cities, from multiple perspectives.

One of the sectors primarily accountable for this situation is the energy sector, whose production and consumption account for more than 75 % of greenhouse gas emissions within the EU. Specifically, the most energy-intensive sector is the building sector, considered in its entirety throughout the lifecycle: from initial construction phases to the production and use of construction materials, to the actual utilization of the building until its demolition. It is estimated that the construction sector is responsible for 40% of CO2 emissions into the atmosphere.

In response to this trend, the European Union has sanctioned the European Green Deal, a political-economic intervention mechanism which, employing various strategies directed at decarbonization through the utilization of renewable energy sources (RES), aims to cutting greenhouse gas emissions in half by 2030 and gradually reach net zero by 2050, achieving climate neutrality. Climate neutrality refers to the idea of balancing between greenhouse gas emissions and the planet's natural absorption carbon dioxide.

A strategy targeting the reduction of energy consumption in densely populated urban areas involves the establishment of Renewable Energy Communities (RECs).

The European Commission defines RECs as communities of public and private entities that aggregate consumers and producers of energy from renewable sources promoting the local production of energy distributed via smart grids, to promote the electrification of consumption and to produce and share sustainably generated energy.

This community configuration gives multiple benefits. From an environmental perspective, local production of renewable energy minimizes waste and promotes sustainable practices, thereby contributing to the reduction of greenhouse gas. This approach optimizes the utilization of available energy resources, diminishes reliance on traditional sources, and aids in lowering energy bill costs. From a social point of view, it aims to a cooperative approach to energy management, involving citizen in a central role in the energy market. In Italy, the Ministry of Ecological Transition (MASE), with the recent promulgation of the REC Decree on 23 January 2024, has allocated financing for the creation of these communities, promoting the local production of energy distributed via smart grids.

This research focuses on this context, analyzing the residential complex of the Olympic Village in Rome. Through a study of energy consumption of this residential complex, an intervention aimed at electrifying energy usage and retrofitting the building is proposed. To achieve this goal, a preliminary assessment of biophysical, bioclimatic, and anthropic factors of the neighborhood was conducted; other steps of this study involve an energy analysis of the building system within a selected representative building of the residential complex. This analysis included a detailed study of the technological and plant systems, estimating the impact of heat loss ratio from the building envelope and the breakdown of energy consumption.

Subsequently, specific actions were formulated to enhance the performance of the technological and plant systems, achieved through the development of three energy scenarios of varying intensity. The proposed strategies encompass interventions such as thermal insulation of the building envelope and the complete electrification of energy consumption, complemented by local energy production through the installation of a photovoltaic system.

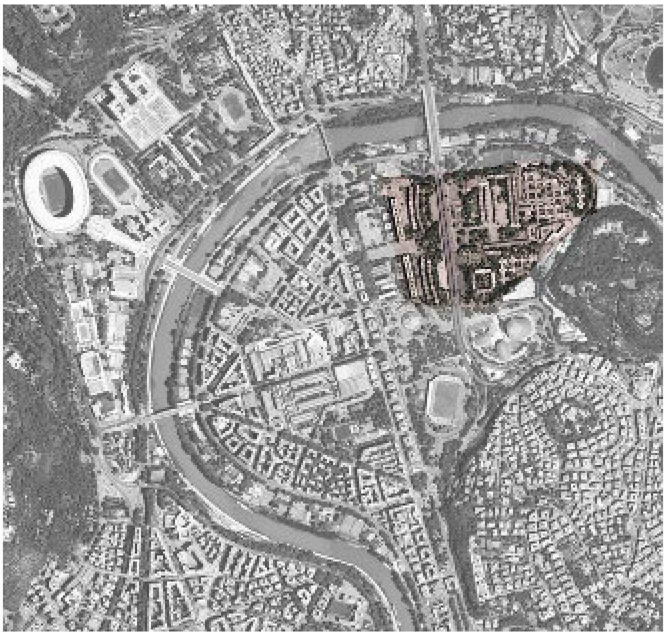

Figure 1. Residential complex of the Olympic Village

2. THE BUILDING COMPLEX OF THE OLYMPIC VILLAGE

The intervention forms an integral component of the urban redevelopment initiative undertaken in Rome in preparation for the 1960 summer Olympics. In order to establish the sports city intended to accommodate athletes, the Italian National Olympic Committee (CONI) selected a publicly owned area situated within the plain between the Villa Glori hill and the bend of the Tevere river to the north of the city.

This area already encompassed sports facilities constructed prior to the Second World War, including the Rondinella Stadium, the National Stadium, the Parioli racecourse, and the Villa Glori hippodrome.

However, in the post-war period, the area became occupied by illegal settlements established by displaced persons, resulting in the formation of a cluster of shanties known as the "Campo Parioli."

The selection of this area for the construction of the Olympic Village proved to be advantageous not only for the territorial redevelopment of the zone, thereby restoring its previous sporting vocation, but also socially, by providing a substantial number of housing units that, after the Olympics, would be allocated to the Roman population.

The project for the Olympic Village was entrusted by the National Institute for State Employees' Housing (INCIS) to a group of architects consisting of Vittorio Cafiero, Adalberto Libera, Amedeo Luccichenti, Vincenzo Monaco, and Luigi Moretti, the latter serving as the group coordinator.

The designated area for the project spans a total of 350,000 m^2, with 70,000 m^2 allocated for buildings and 160,000 m^2 designated for green spaces.

The project involved the creation of 35 buildings, comprising a total of 1,348 apartments of varying sizes, ranging from two to five rooms.

Various types of residential buildings were employed, including single building and double building row houses, closed square courtyard houses, open courtyard houses arranged in a cruciform plan, and building on square plan.

Unlike public residential settlements of the first half of the 20th century, the Olympic Village employed a "canonically" modern architectural language, drawing inspiration from the five points of modern architecture outlined by Le Corbusier [1] [1][2]. However, it integrated materials, construction techniques, and architectural forms rooted in the Italian tradition. Despite being designed by different architects employing various architectural approaches, the overall complex appears homogeneous through the utilization of common typological and construction elements.

3. MATERIALS AND METHODS

The consultation of archival unit "144 - Villaggio Olimpico di Roma" within the archival collection of architect "Luigi W. Moretti [2] " along with site visits, proved fundamental in identifying the technological system of the buildings. Furthermore, a series of interviews were conducted with residents of the residential complex to delineate the occupancy profiles of the housing units and define, through simulation software, the energy demand and environmental impact.

In this research, the row house situated on the southern side of Piazza Jan Palach was selected as the representative building for the energy retrofit proposal.

The structure, measuring 75.6 m in length and 10.75 m in width, consists of a concrete frame construction spanning four above-ground floors, with a total height of 15.7 m.

The ground floor level is elevated on pilotis and houses the four entrances to the building, granting access to four stairwells, each serving two apartments.

The upper three floors collectively accommodate 24 apartments (eight on each floor) with floor areas ranging from 60 m^2 to 90 m^2.

The facades feature a brick curtain wall, alternating with horizontal windows on the Piazza Jan Palach side (west) and loggias on the via Finlandia side (east). Positioned on the

[1] The five points of architecture theorized by Le Corbusier include: the free plan, free facade, raised plan on pilotis, roof garden, ribbon windows.

[2] The archive fund is deposited at the Archivio Centrale dello Stato.

roof, corresponding to each stairwell, are four oval-shaped brick towers serving as clothes-drying areas and technical rooms.

Figure 2. Row house situated on the southern side of Piazza Jan Palach.

The research was structured by conducting a preliminary analysis of the environmental and climatic conditions specific to the area, to evaluating the impact of external factors on the thermal comfort conditions within the housing units. Subsequently, simulations were employed to model user energy consumption patterns, thereby informing the selection of suitable technologies for the revitalization of the complex. Finally, a feasibility study was undertaken to assess the viability of implementing a Renewable Energy Community for the entirety of the Olympic Village.

3.1 Environmental and bioclimatic analysis

In this study, the examined area, including the residential building subject to analysis, was divided into three systems: environmental, anthropic, and bioclimatic. Each system was evaluated to assess its respective energy contribution.

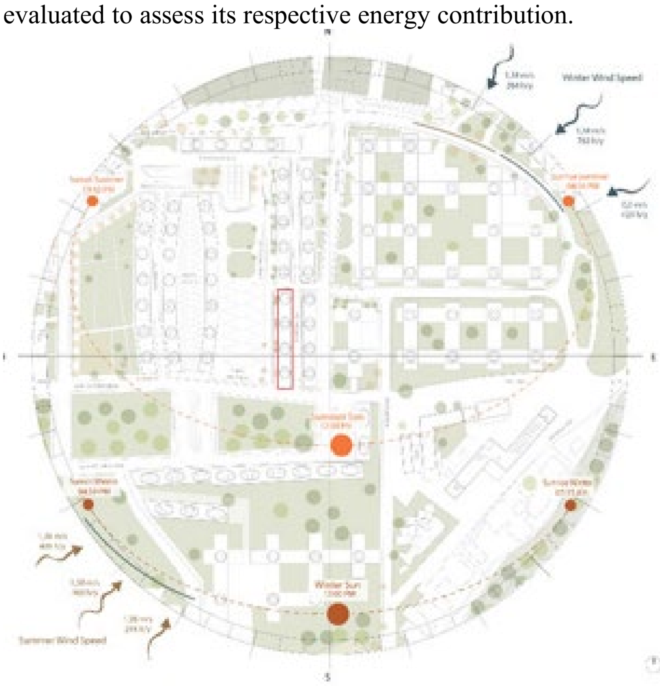

Figure 3. Bioclimatic analysis of the area.

The bioclimatic analysis of the area was conducted using the simulation software Autodesk Forma, with input data including climatic factors and components of the anthropic and biophysical systems.

The simulation, selecting the days of the winter and summer solstices as representative moments of the year, revealed a microclimatic condition[3] strongly influenced by the components of the two systems.

Specifically, the anthropic system encompasses paved open spaces and asphalted neighborhood streets, engendering the "heat island" effect. Moreover, ground-floor commercial activities, through their interruption of the piloted portico space, reduce heat permeability, instigating a "buffering effect."

The combined effects result in a significant temperature increase, which is, however, mitigated by the biophysical system. It is characterized by tall trees and small green areas along the squares, which counteract the “heat island” effect.

Figure 4. Insolation analysis of the area.

During this analysis, a study of insolation was conducted, which is essential for evaluating the impact of solar radiation on the urban tissue. Through qualitative analysis, the absence of shadows cast on any active solar systems plan on the roof was verified. Based on the results obtained, energy retrofit strategies were hypothesized, which included:

- Urban scale, proposing the redefinition of the hierarchy of neighborhood routes, driveways, and pedestrian paths; replacing impermeable pavements (both open and enclosed spaces) with surfaces capable of reducing the heat island effect;
- architectural scale, intervening on the building envelope with improving technologies aimed at reducing the entry of free solar heat gains during the summer period.

3.2 Current state of the building envelope

The typological-constructional aspect unifies the various building types within the residential complex: the load-bearing structure is made of reinforced concrete, with the ground floor characterized by an open portico on piloti. The typological and constructional aspects serve to unify the diverse building types within the residential complex. The load-bearing structure is constructed of reinforced concrete, with the ground floor distinguished by an open portico supported on piloti. Floor slabs are comprised of cast-in-place reinforced concrete, while perimeter walls consist of double-wall masonry brickwork externally coated with yellow-pink bricks. Windows are constructed of painted metal and maintain standardized dimensions across all building units. Lastly, the roofs are flat and accessible, featuring brick towers within which technical rooms are incorporated [3].

The perimeter walls, measuring 33 cm in thickness, are constructed using the "cavity wall" technology, comprising

[3] The microclimatic condition is described by parameters such as average air temperature, wind direction and intensity, humidity, direct and indirect solar radiation.

solid brickwork forming the external curtain and perforated bricks internally. Similarly, the internal walls separating the apartments from the stairwell, measuring 28 cm in thickness, also employ "cavity wall" construction, utilizing perforated bricks and plaster on both sides.

The vertical external windows, larger than the standards of the time, are constructed of metal profiles without seals and feature 2 mm thick glass; the shading systems comprise roller blind with internal boxes lacking insulation.

Accessible flat roof slabs and the slabs on open spaces (ground floor portico), are constructed of cast-in-place reinforced concrete, with respective sections of 29.8 cm and 25.5 cm. The former is externally waterproofed with layers of asphalt emulsion and bitumen cardboard, complemented by prefabricated cement slabs, while the latter is internally lined with terrazzo tiles and externally with plaster and paint.

From the analysis of the existing stratigraphy, it was observed that the thermal transmittance U of the external wall varies between 1.20 - 5.12 W/m^{2}K (considering both opaque and transparent portions), while for the floor slabs, it varies between 1.40 - 1.72 W/m^{2}K. These values exceed the maximum thresholds established by the Ministerial Decree of 26 june 2015, currently in force.

3.3 Analysis of energy consumption

The analysis of thermal and electrical consumption was conducted on the 24 apartments in the examined building. Energy requirements were calculated using the Enea Smart-Sim simulation software and verified during site visits through interviews with occupants regarding the use of appliances. Below is the list of input data used in the spreadsheet for each apartment:

(1) General apartment data (climatic zone, degree-days);
(2) Architectural characteristics (dimensions, orientation, location within the building);
(3) Occupancy profile of each apartment;
(4) Type of plant systems (subsystems for thermal and electrical energy production);
(5) Characteristics of appliances, lighting systems, and general equipment.

The data collected for each apartment were aggregated to define the overall annual picture in terms of energy demand and CO2 emissions for the entire building (Table 1).

Table 1. Energy consumption, CO2 emissions, and energy costs of the standard building (current state).

Electricity Consumption [kWh/year]	73.680
Gas Consumption [m^3/year]	33.144
Primary Energy Consumption [kWh/year]	465.005
CO2 Emissions [kg CO_2/year]	87.189
Electricity Costs [Euro/year]	19.893
Gas Costs [Euro/year]	33.144

The data analysis reveals that 40 % of thermal losses can be attributed to the vertical opaque component of the building envelope, while 50 % of the consumption is attributed to the heating plant system (Table 2, Table 3).

Table 2. Impact of individual structures on the winter thermal load

Thermal loss incidence	
Walls	39 %
Windows	25 %
Floors	24 %
Casings	11 %

Table 3. Distribution of consumption (current state).

Distribution of consuption	
Heating	50 %
Other	15 %
Washing	15 %
Domestic hot water	10 %
Kitchen	8 %
Lighting	2 %

4. ANALYSIS OF RESULTS AND INTERVENTION STRATEGIES

Considering the findings derived from the energy analysis conducted on the urban area and the representative building, hypothetical interventions aimed at enhancing energy performance have been formulated at both urban and architectural scales. At the settlement scale, proposals entail the establishment of a Renewable Energy Community within the Olympic Village residential complex [4]. Meanwhile, interventions at the building scale concentrate on the enhancement of the building envelope and the optimization of building systems, all while adhering strictly to the constraints delineated in the Carta per la Qualità [4] of the Piano Regolatore Generale [5].

4.1 Intervention strategies and technical solutions for the building envelope

The proposed energy retrofit interventions aimed at improving the thermal performance of the building envelope, to meet the requirements imposed by the legislation, include:

(1) Insulation of vertical opaque structures;
(2) Insulation of the roof slab;
(3) Insulation of the portico floor slab on pilotis;
(4) Replacement of windows and insulation of the windowsill.

The technical solution for improving the thermal behavior of the walls involves the insertion of insulating material into the cavity of the walls through the technique of mechanical blowing of glass wool. For the roof slabs, intermediate slabs, and slabs on portico, it has been hypothesized to redo the screed with a thermally insulating material and, additionally, to insert a silica aerogel insulation panel, ensuring that the new stratigraphy does not alter the storey height, already at the limit value of 2.70 m. For the vertical transparent closures, solutions respecting the existing dimensional characteristics have been planned: the replacement of

[4] As observed from the mappings, the area and consequently the building subject to energy retrofitting exhibit significant urban, architectural, and cultural value, qualifying it for inclusion in the elaboration G1a "Quality Charter" article 16 NTA of the current PRG.

secondary aluminum windows with thermal break and the insulation of the shutter box with expanded polystyrene.

Table 4. U-values of the building envelope components [W/m2K]

Description	Current state	Project state	Limit values
External walls	1,21	0,31	0,32
Internal walls	1,18	0,28	0,80
Slabs floor on portico	1,72	0,25	0,32
Intermediate slabs floor	1,40	0,24	0,80
Roof slabs floor	1,67	0,21	0,26
Windows	5,12	1,53	1,80

The selection of insulating materials has been influenced by both their insulating properties and sustainability level. Sustainability is achieved by striking the right balance between reduced energy demand and equivalent sustainability values expressed in energy consumed and CO2 emitted during the life cycle of the materials; It is evident that utilizing a material that simultaneously reduces the building's energy demand while generating a high level of embodied energy, poses a contradiction in the context of energy and environmental revitalization. To address this, the choice of the most suitable materials meeting these criteria has been facilitated by identifying certified products through Criteri Ambientali Minimi [5] (CAMs). These CAMs guarantee a concrete and verify assessment of the environmental performance of products throughout their life cycle.

Table 5. Sustainability level of the materials used in the building envelope intervention.

CAM n. %	% recycled raw material
Silica aerogel	equal to 70%
Glass wool flakes	more than 60%
Bio-cork mortar	more than 14%
Expanded polystyrene	from 10 to 60%
Secondary aluminum	equal to 20%

4.2 Intervention strategies and technical solutions for building systems

The strategy concerning the building systems is based on the replacement of traditional systems with systems consisting of coordinated components powered exclusively by electricity, including:

(1) Installation of the integrated Building Management System (BMS);
(2) Installation of centralized heat pumps for heating and cooling;
(3) Installation of autonomous heat pumps for domestic hot water production;
(4) Installation of a photovoltaic system;
(5) Installation of a point-based controlled mechanical ventilation system;
(6) Replacement of gas cooktops with induction ones;
(7) Replacement of traditional lamps with LED ones.

The sizing of heat pumps for heating and cooling was performed by calculating the winter and summer thermal loads and assuming the implementation of the proposed retrofit interventions for the building envelope.

For type building, eight heat pumps were identified [6], with a total nominal thermal power of 240 kW, positioned inside the rooftop turret. As for the heat pumps for domestic hot water, it is planned to install machines with a nominal thermal power of 1 kW inside each apartment, while ventilation units are planned to be installed inside the shutter boxes of each room to ensure air quality. The electrification of all flats leads to an increase in electricity consumption, for this reason installation of photovoltaic panels on the roof has been evaluated. The receiving surface of 113 m^2 [7] can produce only 28 % of the total power drawn from the electrical grid.

4.3 Development of intervention scenarios

Following the identification of interventions aimed at enhancing the performance of the building envelope and the efficiency of the building system, three scenarios have been developed:

- Scenario 1: Insulation of perimeter walls and roof + efficiency improvements to the entire building system;
- Scenario 2: Interventions from Scenario 1 + replacement of windows;
- Scenario 3: Interventions from Scenario 2 + insulation of the portico floor slab on piloti.

Table 6. Comparison among the three intervention scenarios.

	Scenarios 1	Scenarios 2	Scenarios 3
Electricity Consumption [kWh/year]	148.272	140.400	122.031
Gas Consumption [m^3/year]	0	0	0
Primary Energy Consumption [kWh/year]	284.832	185.760	144.480
CO2 Emissions [kg CO2/year]	64.272	61.296	52.908
Electricity Costs [Euro/year]	40.033	37.908	32.948
Gas Costs [Euro/year]	0	0	0

Comparing the current state of building with Scenario 3, there is a significant decrease in primary energy consumption and CO2 emissions, by 69 % and 40 % respectively. This intervention, resulting in a reduction of 96 %, facilitates a 40 % decrease in the annual expenditure associated with energy carriers.

In the simulation of the Renewable Energy Community (REC), Scenario 3 is selected as the most suitable option since the residences are more efficient and capable of fully optimizing self-produced energy.

[5] The “Criteri Ambientali Minimi” (CAM) are the environmental requirements defined for various phases of the procurement process, aimed at identifying the best product in terms of environmental performance throughout its life cycle, considering market availability. They are defined within the framework established by the Plan for the environmental sustainability of consumption in the public administration sector and are adopted by Ministerial Decree of June 23, 2022, No. 256.

4.4 The renewable energy community of the Olympic Village

To minimize the grid's energy draw and reduce CO2 emissions, a feasibility study for a Renewable Energy Community (REC) has been devised to facilitate the sharing of self-produced electricity from Renewable Energy Sources (RES). The feasibility study encompasses the following phases:

(1) Identifying the member buildings (Prosumers and Consumers[6]) of the REC: Two criteria are considered for selecting member buildings. Firstly, the geographical boundary delineated by the primary substation is considered. Secondly, the type of load is considered, with preference given to buildings exhibiting diverse energy loads compared to typical residential structures. Consequently, school buildings were chosen to utilize self-produced energy during their inactive periods.

(2) Identifying the average annual consumption of member buildings: The total energy consumption values calculated for both residential and school complexes pertain to retrofitted structures. For residential buildings, the calculation was based on a performance index (59.1 kWh/m^{2}y) resulting from the energy efficiency retrofit conducted on the type building. For school buildings, the simulation software S.I.R.E. ENEA was utilized, yielding an index of (12.1 kWh/m^{2}y). Ultimately, the total consumption for the residential complex amounts to 1,382,062 kWh/year, while for the school complex, it is 153,574 kWh/year.

(3) Estimating the Renewable Energy Source (RES) production: The potential annual production from rooftop photovoltaic systems was evaluated by calculating the effective capturing surfaces, accounting for shading areas (during the winter solstice). A dual simulation was conducted with varying panel tilt angles: one set at 32° (considered optimal based on the location's latitude) and the other at 10°. For orientations an azimuth angle of 0° (South direction) was selected. The latter option was chosen as it resulted in a larger capturing surface, specifically 584 m^2 for the residential complex and 753 m^2 for the school[7], with an expected annual production of 173 MWh/year and 250 MWh/year, respectively.

(4) Determination of the Self-Sufficiency Index (SSI) of the RES: The energy flows consumed and produced by the RES were entered into the RECON ENEA simulation software, resulting in a Self-Sufficiency Index (SSI) of 25%.

(5) Quantification of the revenues generated from shared energy[8]: Utilizing the same software as outlined in point 4, the economic flows generated from energy supplied to the grid and distributed among members of the RES, along with the savings accrued from reduced grid energy consumption, are assessed.

The simulation furnishes an estimation of the RES in terms of annual self-produced energy, CO_2 emissions mitigated, investment costs net of tax incentives, and the payback period.

Table 7. Dimensional characteristics of the photovoltaic field, energy, environmental, and economic indicators of the CER

Electricity Consumption [MWh/year]	1.535
Expected Annual Production [MWh/year]	423
Photovoltaic System Nominal Power [kWp]	313
Energy Self-Sufficiency Index	25%
Avoided CO2 Emissions [kg CO2/year]	224.000
Local CO2 Emissions [Euro/year]	0
Annual Primary Energy Savings	847
Initial Investment [Euro/year]	390.300
Annual Revenues [Euro/year]	148.640
Payback Period [years]	2,62

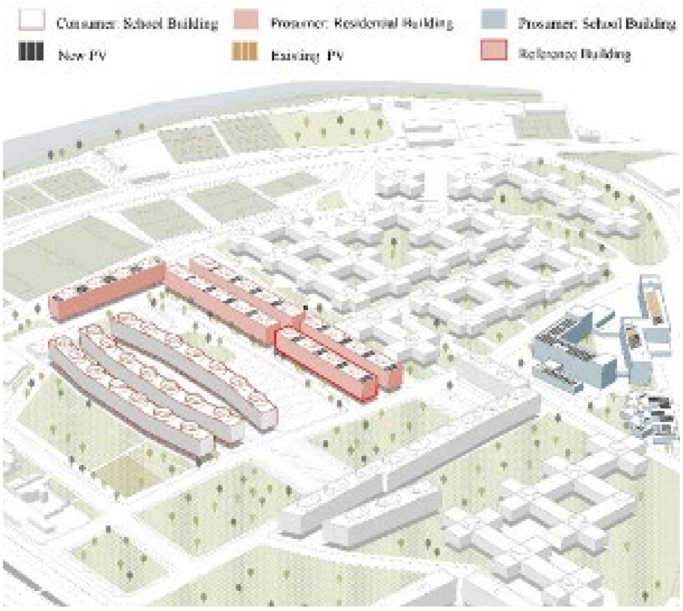

Figure 5. Renewable Energy Community of the Olympic Village

5. CONCLUSIONS

In conclusion, the following research has demonstrated the possibility of significant improvement and efficiency in the energy system of the residential complex under examination through retrofitting interventions on the building envelope and the plant system.

These proposed actions will also allow electrification of the energy supply systems of the residences and installation of energy production and consumption systems from renewable sources. This will result in zero local CO_2

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[6] Decree MASE No. 414 of 7 December 2023 recognizes the key figure of the CER as the prosumer, who is both a producer and consumer. The consumer, on the other hand, is simply the user. In this specific case, the consumer is the residential building that does not have a production system because the height of the roof parapet is not sufficient to make the photovoltaic system "invisible" (Article 16 NTA of the PRG).

[7] The capturing surface of the school complex also takes into account the existing systems. According to Decree MASE No. 414 of 7 December 2023, the CERs can also hold existing systems up to 30% of the total capacity held. The power values of the existing systems were extracted from the SIOP Lazio information system - Photovoltaic systems in school buildings in the province of Rome.

Energy Self-Sufficiency Index (IAS) defined as the ratio between the sum of self-consumed and shared energy and the total energy requirement.

[8] Shared energy: defined as the minimum, for each hour, between the sum of the electric energy produced and fed into the grid and the sum of the energy withdrawn. The MISE (Italian Ministry of Economic Development) recognizes a twenty-year incentive for feed-in equal to € 0.05/kWh and one for sharing equal to € 0.11/kWh.

emissions and a reduction in energy demand on the central grid.

These technological and plant innovations constitute the starting point for the creation of a Renewable Energy Community. Subsequently, through the aggregation of multiple users, it will be possible to produce and manage large quantities of flexible loads accumulated during the hours of the day and inject energy surpluses into the grid, thus becoming self-sufficient and actively participating in the national market.

The REC is certainly a winning model for managing and improving energy systems, advantageous not only in the short term in terms of energy and economic aspects for the individual citizen - thanks to local and autonomous energy production through RES and the simultaneous reduction in the cost of supply on the market - but also on a larger scale and in the longer term. Economically, the Renewable Energy Community allows for economies of scale capable of engaging on equal terms with stakeholders in the energy market, providing a significant opportunity for small and medium-sized local businesses in the sector and thus contributing to the industrial and employment growth of the area. Socially, citizen involvement in the investigations and operational choices of the system and the network promotes community cohesion and improves territorial and environmental life and awareness regarding sustainability issues [8].

Finally, given the scalability, replicability, and adaptability of the interventions, this research can be configured as a basic model for the study and analysis of other urban districts, representing a valid tool for the promotion and transition to a more sustainable and inclusive economy.

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