Energy analysis and refurbishment proposals for public housing in the city of Bari,Italy

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Keywords: Existing building stock, Building energy performance, Thermal analysis, Retrofit, Economic analysis, Strategies of energy planning

Abstract

From the perspectives of the energy and the environment, building stock should be considered a useful resource in the struggle against greenhouse gas emissions and scarcity of energy resources.

The aim of this work is to provide an example of the application of a methodology to evaluate the energy needs of the building stock of a city and to determine the possible strategies for energy planning.

This paper aims to obtain an estimate, on an urban scale, of the energy needs and CO_2 emissions of the public residential buildings of Bari. This estimate is achieved by evaluating the critical issues of the built heritage, the most common architectural typologies and the heating systems in the territory of the city of Bari in southern Italy, as well as the possible strategies for upgrading energy efficiency, through the combined use of energy software and geo-referenced systems. Furthermore, several possible interventions are assumed to improve the energy performance of buildings in not only environmental terms but also economic terms through the instrument of cost–benefit analysis. The ultimate goal is to compare the different intervention strategies to determine which demonstrate greater cost effectiveness and feasibility for future energy planning.

1. Introduction

It is widely recognised that one of the strategies to resolve the problems of greenhouse gas emissions and scarcity of resources is energy conservation. Currently, partly because of the economic crisis, climate change and the continuous increase of the welfare needs of the population, the consumption of non-renewable energy sources has increased substantially, especially in the construction sector.

In Europe, energy-saving policies in the civil sector have been adopted in all of the energy action plans born from the transposition of Directive 2002/91/EC concerning the energy performance of buildings, and especially from Directive 2006/32/EC on energy services. The same European Directive on Energy Efficiency 2012/27/UE aims to increase the rate of building renovation (European Union, 2012). Moreover, since 2007, the European Union has adopted the document “Energy for a changing world”, unilaterally committing to reduce its CO_2 emissions by 20% by 2020 to increase the level of energy efficiency by 20% and for the use of renewable energy sources in the total energy mix to be 20%. The European Union Action Plan for Energy Efficiency included, as a priority, the creation of a Covenant of Mayors to actively engage European cities in the path toward energy and environmental sustainability to combine measures at the local and regional levels and to promote effective actions against climate change (European Union, 2010).

According to the European Union, local authorities must take responsibility for the fight against climate change in an effort to anticipate the sustainability objectives that European Union has set.

In this context, the Sustainable Energy Action Plan (SEAP) is the key document that defines the energy policies that municipalities intend to take to achieve the objectives of 20-20-20.

The SEAP is an important instrument in dealing with the local community because it contains the actions that both the authorities and citizens must undertake. Moreover, the Action Plan would allow the authorities to systematise and harmonise the various activities that are implemented or planned for the future. The regular monitoring of the actions could check the performance of the plan over time, at least from the point of view of energy and of environmental performances.

Starting from the analysis of the information contained in the SEAP, the Municipality is able to identify the priority areas and actions to be implemented to achieve the objectives of reducing CO_2 emissions and, consequently, to plan a set of actual measures in terms of the expected energy savings, scheduling, and assignment of responsibilities, both with respect to the financial aspects for the pursuit of long-term energy policies. The issues considered in the SEAP concern the various sectors of the Municipality, so any future development at the urban level should take into account the provisions of the Plan of Action.

Many studies and international research projects (FP7 SEMANCO project, 2011) have been performed to analyse the refurbishment of the existing residential building stock of several countries in the EU from the energetic, environmental and economic points of view. Singh et al. (2013) consider the city of Liege and take into account different parameters (buildings age, structures, type of heating system, type of fuel used, built-up area, adjacency, insulation of roofs and walls and energy consumption); their study concludes that approximately 69% of the buildings that were constructed before 1945 require serious renovation to improve the roof and external wall insulation level. Theodoridou et al. (2011) provided detailed information on the residential urban building stock, as determined in a field study in typical large and smaller Greek cities. Given the complexity of the Greek building sector, the rather limited interest demonstrated by the owners of the buildings, and a series of legal and administrative hurdles considering energy renovation measures, these researchers concluded that it will not be an easy task to implement the urgently needed energy renovation policies. Sartori et al. (2009) developed a model for studying the effect of three hypothetical approaches in reducing the electricity and energy demand in the Norwegian building stock: wide diffusion of thermal carriers, heat pumps and conservation measures. Adopting conservation measures on a large scale does allow for reduction of both electricity and total energy demand from the present day levels while the building stock continues to grow. Ástmarsson et al. (2013) investigated how regulatory changes and contractual solutions can help solve the landlord/tenant dilemma in relation to sustainable renovation of residential buildings. These researchers indicated that when the interests of landlords and tenants are misaligned, one of the greatest barriers hindering the development of sustainable renovation of residential buildings in Europe is realised.

Currently, it is known that 40% of the energy used in Italy is essentially used to heat, cool, illuminate and ventilate buildings. Furthermore, existing buildings are far from efficient, but are becoming increasingly important in the fight against environmental and climate problems because they represent the vast majority of the Italian building stock in a country with a very small proportion of building area.

For this reason, it is essential to assess the energy needs of the existing buildings. Several models (Sathaye et al., 2004; Theodoridou et al., 2012) used to assess the energy needs can be divided into three categories:

- Bottom-up models: these models start from the study of the energy consumption of individual buildings, assessed in detail in every aspect, and then the results are extended to the entire neighbourhood or city to assess the energy consumption or energy savings in the renovation of the buildings.
- Top-down models: these models start from data concerning energy consumption on an urban scale, compare it with the climate data and data from censuses or statistical surveys, and then obtain the average consumption of the buildings. From a larger scale, top-down models achieve a scale of detail suitable to compare different economic variables, but they are unable to distinguish the variations in consumption and the distributions of emissions in the urban space.

– Hybrid models: these models study the energy needs of standard buildings and adapt them to assess the energy consumption on the urban scale, using detailed spatial representations of the building stock, so that it is possible to associate with each building its own consumption and to obtain an estimate that is sufficiently accurate on a global level.

This paper uses the last methodology, providing a real application example and possible energy-saving strategies.

2. Methods

The aim of this work was to provide an example application of a methodology adopted today for optimal energy planning. In fact, increasing numbers of studies are being devoted to understanding the trends of energy efficiency in cities and European countries (Bosseboeuf, 2009) and to improve the study of methods to obtain estimates of the true energy needs through the classification of buildings according to the periods of construction, air-conditioning systems and construction characteristics (Corgnati et al., 2008; Corrado et al., 2012; Ballarini et al., 2014).

In fact, this classification of building types can be used for a first assessment of the energy performance of the built heritage. To determine a descriptive model of the building stock, it is necessary to understand the diffusion of the types, the level of obsolescence of the buildings, the levels of insulation, and the air-conditioning systems commonly used (Dascalaki et al., 2011). One example of this is the European project Typology Approach for Building Stock Energy Assessment (Loga et al., 2010), which was developed to classify building types according to the period of construction, diffusion of buildings and consequent possible saving solutions.

The present work aims not to provide both an analysis of the existing buildings and a methodological analysis of possible retrofits through real strategies of energy planning (Fig. 1).

The first step of the proposed methodology starts from a study of the area and the historical evolution of the city, analysing in particular the periods of construction and the relationship between urban form and the building types. When the most significant types have been identified, it is possible to derive an actual and accurate mapping of the existing buildings using geo-referenced software, thereby assessing their distribution in urban areas. Subsequently, the estimation of the energy requirement is performed through “example buildings” (Ballarini et al., 2009), selected for their spread throughout the territory and the significance of their constructive characteristics and heating systems.

The building envelope should keep separate the inside thermal conditions from the outside, ensuring comfortable conditions for the occupants. The building envelope must minimise the energy consumption in the building, thereby minimising the number of hours of thermal discomfort conditions.

The ‘‘standard energy rating’’ was applied to the analysed buildings through the calculation methodology specified in the European Standard EN ISO 13790 (European Committee for Standardisation, 2008) to determine the net energy needs for heating and through the application of the national standard UNI/TS 11300-2 (Ente Nazionale Italiano di Unificazione, 2008b) to determine the primary energy use for space heating.

The ‘‘standard energy rating’’ requires the user’s input data to refer to a standard use, as derived from the Italian standard UNI/TS 11300-1 (Ente Nazionale Italiano di Unificazione, 2008a).

The energy performance indicator (EP_H) expresses the normalisation by the heated floor area (A_f) of the primary energy demand for space heating ($Q_{H,p}$):

$$EP_H = \frac{Q_{H,p}}{A_f} \quad \left[kWh / m^2 a\right] \tag{1}$$

The average seasonal efficiency of the heating system is expressed by equation (2), and it represents the ratio of the building energy need for heating $Q_{H,nd}$ to the seasonal primary energy demand for heating $Q_{H,p}$:

$$\eta_{H,g} = \frac{Q_{H,nd}}{Q_{H,p}} \tag{2}$$

After the energy demand of the individual buildings have been calculated, the evaluation is extended to the urban scale, and then the overall needs of the entire residential building stock are rated. In fact, the use of GIS platforms allows for the creation of a database of the characteristics necessary to assess the energy performance of built heritage within broad energy planning. Currently, enabled by the historical archives of the cities, aero-photogrammetric surveys and cadastral data, we have all the information needed for the analysis, making it easier to implement strategic actions (Dall’O’ et al., 2012).

The necessary characteristics, called “attributes”, are associated with each building. The attributes of a building’s geometric characteristics, such as area, perimeter and number of the floors, allow for the external envelope surface area to volume ratio, i.e., the compactness factor, and the distribution of building types in the urban area by GIS to be obtained, providing useful mapping to calculate the energy needs at the local or regional level.

Finally, according to the results, strategies for energy savings and an improvement in the energy performance of buildings are proposed, both in environmental and economic terms. As demonstrated in other studies (Tommerup et al., 2006; Ma et al., 2012), in fact, built heritage can be improved in terms of the energy performance with efficient and relatively inexpensive actions.

Therefore, the ultimate goal of the work is to compare different saving strategies to understand which strategies are more cost-effective and feasible for future energy planning.

A cost-benefit analysis was performed using the Net Present Value method (Steiner, 1992). The *NPV* is defined by Eq. (3):

$$NPV_j(i,t) = -I_j + \sum_{t=i}^{N} \frac{R_{jt}}{(1+i)^t} \qquad (3)$$

I_j is the total cost of energy saving intervention, and R_{jt} is the economic value of energy savings due to thermal performance upgrade works in the *t*-th year.

R_{jt} is given by Eq. (4):

$$R_{jt} = c_t \cdot \Delta EP_{H,j} \qquad (4)$$

If the annual variation of energy price and the effect of inflation is included in discount rate *i*, Eq. (3) can be written as:

$$NPV_j(i,t) = -I_j + R_j \sum_{t=i}^{N} \frac{1}{(1+i)^t} = -I_j + R_j \frac{(1+i)^N - 1}{r\,(1+i)^N} \qquad (5)$$

The Discounted Payback Period (DPP) is the solution of the following equation:

$$NPV_j(i, DPP) = 0 \qquad (6)$$

2.1 The case study: the public residential housing of the city of Bari.

The analysed case study concerns the city of Bari in the south of Italy. Bari is located in the Mediterranean climatic zone, which belongs to group C in the Koppen climate classification, with 1185 degree days. According to the Typical Meteorological Year (TMY) generated by Meteonorm (Meteotest, 2008), the maximum Dry Bulb temperature is 36.6 °C on July 21st and the minimum is -0.7°C on January 12th.

In recent years, the city decided to face the problem of energy savings by adopting a Sustainable Energy Action Plan (SEAP) (Municipality of Bari, 2011a) and implementing the European project “Smart Cities” (Municipality of Bari, 2011b).

In fact, sustainability is the key to enhance the competitiveness of the city, to attract talent, companies and capital in the urban area and to improve the quality of life of the citizens.

Since 1995, a program has been ongoing to implement efficient use of energy in the municipality by establishing an energy office. In this context, the Study of Municipal Environmental Energy Plan for renewable sources (PEAC) was designed to encourage the efficient use of energy, the reduction of energy consumption, and the use of renewable energy sources to improve the energy transformation processes, the conditions of environmental compatibility of energy use, and the environmental quality.

Starting from the analysis of the information contained in the BEI (Baseline Emission Inventory), consisting of photography of the municipal energy situation, the municipality of Bari has identified the strategic sectors for achieving European goals for the reduction of CO_2 emissions (35% less than those of 2002 by 2020) and a possible set of practical measures in terms of the expected energy savings, scheduling, allocation of responsibilities, and financial aspects to pursue long-term energy policies.

As SEAP stresses, most of the emissions are generated by the buildings (61%), mainly in the services and household sectors, followed by the transport sector. The SWOT analysis, found in the preliminary SEAP document, indicates that the most significant weakness of the city is represented by construction stock, built largely in the 1960s and 1970s, where buildings are characterised by poor thermal performance and high heat loss. The building stock of Bari currently has approximately 130,000 houses.

The current composition of the building stock is the main cause of the poor energy performance: most of the building was performed during the post-war reconstruction or in the period preceding the legislation on the reduction of energy consumption in the civil sector. This criticality is accentuated by the presence of predominantly autonomous heating and cooling systems and, therefore, inherently has lower efficiency than those of the systems with centralised boilers.

There is, in fact, a high presence of apartments heated by autonomous gas boilers, usually located outside and characterised by low conversion efficiency. Their average efficiency is estimated at approximately 70%.

The lack of data on the existing buildings in the public and private sectors of the city of Bari and the lack of executive and processed analytical descriptions, both in terms of the building envelope and acclimatisation systems and the related energy consumption, does not allow very reliable estimates at city level to be made at present. Analysis performed on the territory makes it clear that a significant part of the building stock is public housing. The public housing was built, in particular, by the Independent Institute of Social Housing (IACP, Istituto Autonomo Case Popolari, i.e., Independent Institute for Public Housing) and the municipality of Bari (ERP, Edilizia Residenziale Pubblica, i.e., Residential Public Housing). To obtain an energy mapping of a part of the building stock of the city, by considering these public housing buildings, we can estimate, although in statistical terms, the CO_2 emissions of the buildings in accordance with the objectives of the SEAP.

To study the thermal losses and energy performances, approximately 1,800 IACP buildings scattered throughout the city were analysed. The structural characteristics, typology and heating systems, which are the common elements in the public residential building stock, were identified to provide support to the study of the residential municipal sector.

Different periods of time, marked by the introduction of laws or innovative materials, have been identified to find common typological characteristics in the studied buildings, which, as noted by historical documents relating to the city of Bari and the evolution of residential public buildings (Fig. 2), were built, for the most part, between the 1950s and the 1970s (Martinelli, 2009).

Public housing has changed the urban fabric and has been a real field of experimentation for decades.

If the first interventions were incorporated within the consolidated city, then the large residential public districts were built on the edge of the existing urban fabric and were generally characterised by a greater presence of open spaces, setting new size ratios and different modes of aggregation of the elements.

As in the rest of Italy, the public housing of Bari has been developed throughout the Twentieth century, the century that saw the development of the cities founded to provide housing and services for the most vulnerable social groups.

In the first thirty years of the twentieth century, the city began programmatically to address the issue of public housing, first, through solidarity operations and, since 1906, through the creation of the IACP, which remains the leader in the construction and management of public housing. IACP began its activities with the participation in small projects, consisting mainly of compact building blocks located at the edge of urban areas.

In the Fifties, public housing radically changed the concept of public city and opened an important period of experimentation, not only at building level but also at urban level.

There was the transition from the form of fragments, buildings, or small interventions within the consolidated urban fabric to the realisation of entire neighbourhoods as places to experiment with new ideas in different cities.

The aim was not to create complex buildings, more or less articulated, but to create self-sufficient residential districts with services that are often cut off from any urban context. These interventions are placed at the edge of the built city.

With the Law 167/1962 (Italian Government, 1962), which provided provisions to facilitate the acquisition of building areas for affordable social housing, the Area Plans of the First Generation were drafted: these plans provided interventions of large size in three areas: the area of St. Paul, the area of Japigia in the East, near the coast, and the area of Poggiofranco in the South.

These three large districts defined many large portions of the modern city of Bari, and through a strong typological-settlement experimentation, offered new models of the city.

In the Seventies and Eighties, with the suspension of public funding for social housing, IACP underwent a sudden slowdown. In those years, the Cooperatives became the great protagonists: their important role in the construction of public housing was further confirmed starting from the Eighties by the construction of the low-cost and popular plan of second generation. For their implementation, IACP, private entrepreneurs and cooperatives realised interventions of smaller size in the neighbourhoods to counteract the negative effects of segregation of the weaker sectors of society.

The last interventions in public housing do not interact with the nearby districts, but offer innovative settlement solutions, even if they often remain totally isolated.

Since the end of the century, the focus has shifted from the creation of new housing to the refurbishment of existing public housing.

This historical evolution and regulation has contributed to the gradual change of these buildings from the point of view of construction and technology.

Until the 1960s, the buildings were mostly made of load-bearing walls, while the floors were a combination of concrete and bricks and were often subjected to restoration.

In contrast, buildings built from 1961 to 1975 had a reinforced concrete framed structure with brick external walls and the floors were a mixed structure of reinforced concrete or pre-stressed concrete and brick.

The introduction of laws and regulations for energy savings in 1976 (Italian Government, 1976) led to a change in construction technology, as it was envisaged that designers would be obliged to use insulating materials to reduce energy consumption. Buildings from this date until approximately 1990, therefore, have a reinforced concrete framed structure with external walls with hollow brick blocks, air cavities and thermal insulating materials.

Buildings from 1991 until 2004 are characterised by the recent regulations on the energy performance of buildings (Italian Government, 1991).

From 2005, more demanding requirements on the energy performance of buildings (Italian Government, 2005) have produced higher levels of insulation and higher plant efficiencies.

According to the periods of construction of the buildings, the most common types of heating system for the IACP and ERP housing of Bari were considered, derived from a combination of the types of heating subsystems (emissions/distribution, storage, production). It was highlighted that the majority of boilers have been installed since the end of the 1980s, which has allowed us to consider efficiency values higher than 80% (De Santoli et al., 2010).

The data analysis indicated that, while originally, during the construction of public housing, the distribution subsystem was centralised, between the 1970s and 1980s, these systems were converted entirely into autonomous subsystems, with one subsystem for each apartment.

In the social housing of Bari, the type of emission subsystem consists of radiators. UNI/TS 11300-2 (Ente Italiano di Unificazione, 2008b) defines the conventional emission efficiency of different types of radiators used to calculate energy demand.

3. Results

3.1 The energy performance of five example buildings before and after the refurbishment.

To estimate and assess the potential for energy savings in municipal public housing, five example buildings were considered, with each belonging to a different selected period of construction. Their levels of energy consumption and environmental impacts were analysed. The studied buildings were chosen according to their characteristics, typical of the building stock of each identified historical period, as truly representative of a larger case series to quantify the impact of the entire public housing stock on the city of Bari. This classification is derived by direct inspections of the territory of Bari and the study of archival documents.

Table 1 summarises the most widespread typical building features in the local area according to various ages.

The levels of energy performance of the five example buildings were evaluated according to standards and, subsequently, the specific need for winter heating was determined for each building and each period of construction (Fig. 3 and Table 2).

The analysis of the five representative buildings revealed that the older ones are the least efficient because they do not have any form of insulation: in fact, the constructions built before the 1960s have energy needs equal to 193.90 kWh/m^2a. Over the years, the performance improves as a consequence of the evolution of regulations on energy efficiency. However, the levels obtained by the newer buildings are also not sufficient to achieve satisfactory energy performance. The building designed in 2008 reaches an energy need of 64 kWh/m^2 a.

In addition, the levels of emissions have reduced from approximately 38.73 $kgCO_2/m^2a$ for the oldest building to 12.81 $kgCO_2/m^2a$ for the latest building; however, the reduction is not adequate from the environmental point of view.

The analysis of the actual state of the buildings is just a starting point to suggest interventions that aim to reduce the primary energy demand and the CO_2 emissions. In this regard, the actions undertaken involved the building envelope or the heating system along with the installation of solar thermal systems for the supply of hot water. It is possible to improve the thermal performance of the envelope of the studied buildings by providing a series of undertakings to increase the level of insulation of the various structures.

In particular, for all of the buildings, two main approaches for improvement have been proposed: the first approach consists of a usual refurbishment, which includes the solutions necessary to obtain an overall improvement in terms of energy performance, providing common and easy types of intervention, which focus on the building envelope and the replacement of heat generators; the second, however, requires deep refurbishment, which makes extensive use of the introduction of solar thermal technologies and requires more invasive and more expensive actions.

Depending on the buildings, for any intervention on the building envelope, the provided thicknesses of the insulation were varied to adapt to the needs of each case (Table 3). Regarding the insulation material, stone wool was preferred to other materials, according to literature studies (Papadopoulos, 2005; Papadopoulos et al. 2007). The actions planned for the building envelope were:

- insulation of the roof slab with stone wool;
- insulation of the floor above a non-heated room with stone wool;
- construction of the insulation of external walls with outer stone wool insulation;
- insulation of the cavity with perlite;
- inner stone wool insulation, in cases of deep refurbishment;
- replacement of windows with double-glazing (DG) or triple-glazing (TG) windows and rolling shutters with casing.

The heating system improvements instead focused on:

- replacement of the traditional boiler with condensing boilers;
- installation of thermostatic valves;
- installation of solar thermal systems for the production of sanitary hot water (50% or 90% of Domestic Hot Water demand, DHW, depending on the needs).

For each building type, the energy performance was calculated, and then the results were compared with the data of the existing building (Table 4).

The result of the comparison was very interesting and confirmed the initial hypothesis: the enhancing solutions adopted for the older buildings are, in fact, the most effective in terms of energy savings. For the newer buildings, the reduction in primary energy demand is less obvious and the refurbishment becomes less effective, in both the usual and the deep types. In fact, for the oldest building, there is a reduction in EP_H of 74% for the usual refurbishment and almost 91% for the deep refurbishment; however, for the more recent buildings, only a reduction in EP_H of approximately 23% and approximately 60% were found for the usual and deep refurbishments, respectively. A special case is the building built between 1961 and 1975: due to its structural and heating system characteristics, the refurbishment interventions were not observed to be as effective as in other cases and result in the achievement of still lower energy performances, either in the usual refurbishment or in the deep refurbishment.

To assess the feasibility of the solutions adopted, individually and in their totality, for each intervention suggested for the usual refurbishment, a detailed analysis of the investment costs and savings, in terms of the amount of fuel and money, was performed through a cost–benefit analysis.

Table 5 presents the analysed actions and economic index obtained for buildings constructed before 1960. The estimated lifetime was 30 years for the interventions on the building envelope and 20 years for heating system improvements. The annual variation of energy price and the effect of inflation are included in a constant discount rate of 4% (Fraunhofer, 2009). The interventions with positive *NPV* are highlighted in the table.

These indicators were derived for each case study to identify the most convenient action.

Table 6 lists only those solutions that are affordable from the investment point of view, i.e., those that provide a positive *NPV* and a shorter Discounted Payback Period. For buildings constructed before 1975, if only those solutions are implemented, the buildings still exhibit a poor energy performance, although a considerable savings is obtained in terms of the primary energy demand. In contrast, the buildings built between 1976 and 1990 show some improvement in energy performance, while for the newer buildings, no measure was found to be cost-effective, although the implemented measures enable a considerable savings in primary energy demand. This lack of effectiveness occurs because these newer buildings already have a certain level of insulation and heating system performance; therefore, even more expensive interventions are required to improve the energy performance further and achieve the same reduction in primary energy demand obtained in the case of older buildings. Therefore, from the economic point of view, it is always beneficial to refurbish the worst buildings, i.e., those dating to before the 1980s, to achieve a significant improvement and the possibility of recovering the money invested.

3.2 The energy demand and economic analysis at the urban level.

The public building stock of Bari is varied and extensive: for this reason, the data collected and presented above have been reprocessed to obtain an estimate of the global energy demand of the public housing sector. These data were interpolated with the data of National Institute of Statistics (ISTAT, 2001), on a regional and national basis, derived from the 14th General Census of Population and Housing, through the use of tools of urban and energy planning, such as the ArcGIS software.

The five example buildings were the starting point for the development of an overall analysis of the public residential energy demands, on a statistical level. Through ArcGIS, it was possible to undertake a mapping of the buildings according to the number of floors above ground and to derive the total area for each one.

As the graph in Figure 4 shows, in the municipality of Bari, there is a high prevalence of four- or five-story buildings, but there is a lack of those with less than two floors. In recent years, in fact, the tendency to construct buildings with a greater number of floors has spread, in agreement with the need to save as much soil as possible.

Through ArcGIS, it was possible to calculate the occupied area, the perimeter, and the volume of the buildings namely the geometrical characteristics essential for the calculation of the compactness factor, on which the limit value of EP_H depends (Behsh, 2002).

Based on the above-described calculations, the primary energy demand for the heating of the entire public residential building stock of Bari was estimated, as reported in Table 7.

The calculations indicate that the specific average energy need for a heating season for the buildings analysed, regardless of the period of construction, is 148.76 kWh/m^{2}a, which is a notably high result by today’s standards. The public housing in the city of Bari is not in an optimal condition. The case of Bari stands out as a fairly pessimistic picture of the current reality, as characterised by an overall energy demand of 61.15 GWh/a (Fig. 5).

The amount of CO_2 emissions versus the construction period is reported in Figure 6, and its total amount is approximately 11,788 tCO_2/a.

Starting from the analysis of energy performance and the costs of the hypothesised action for the usual refurbishment, we established a ranking of economic/energy convenience, in the civilian sector, of the possible interventions on an urban scale to allow us to optimise the performance of any investment for energy savings.

The interventions were compared by considering how much saving 1 MWh would cost in terms of investment. The cost of saving 1 MWh, which depends on the interventions and the periods of construction, was derived by dividing the total amount of each intervention in € (to be invested for all ERP-IACP buildings and for each construction period) by the total savings in MWh (Fig. 7).

The highest peaks are those of the less cost-effective interventions. In general, savings were determined to cost more in terms of economic investment for buildings constructed after 2004 because such interventions and, in particular, the isolation in coverage are the least effective for the reduction in the EP_H. This result is consistent with the data obtained for the five example buildings.

The least advantageous intervention through the various periods of construction is definitely the replacement of fixtures, while the least expensive intervention is the installation of thermostatic valves, although the reduction in primary energy demand in percentage terms due to the latter is very low.

Subsequently, the interventions were considered cumulatively, grouping those for the building envelope and those for the heating systems and subsequently considering both in their entirety. Note that the cumulative effect of the interventions is less effective than the sum of the individual actions because, when they are realised at the same time, part of the reduction in terms of the demand is added to other interventions.

Figure 8 shows how the heating plant changes are certainly less expensive than the actions on the building envelope. Generally, it is preferable to implement a comprehensive refurbishment, as the cost of the saved energy is less for the action taken at the same time on the building envelope and on the heating plant, rather than only on the building envelope.

However, if all interventions were implemented, focusing only on environmental considerations and in terms of energy saving, the results would be obvious: a greater than 66% reduction in the energy needs of public housing could be achieved (Fig. 9).

CO_2 emissions could be reduced by 63.43%: from 11,788 tCO_2/a in the current state to 4,310 tCO_2/a after the refurbishment (Fig. 10).

4. Discussion

The goal of this research was to propose a means of energy efficiency improvement for the existing buildings based on an analysis of the built heritage and a methodological approach to refurbishment. In particular, the existing buildings are one of the most important sectors to reduce greenhouse gas emission for the next years.

As expected, this study demonstrated that the changes in the energy performances of buildings depend on the period of construction.

Moreover, the study demonstrated that it is possible to improve the performances of the buildings with few and simple interventions; these interventions were found to be more efficient and economically convenient for the older buildings. This greater improvement is particularly true for the buildings built before 1970 because they were built without any energy standards.

The strength of the applied methodology clearly is the possibility to obtain reliable estimates of energy demand of buildings at the urban scale through the census of the most common building typologies and their construction and plant characteristics.

The study focused only on the public social housing of Bari, but the analysis can be simply extended to the entire town.

The knowledge of the historical evolution of the town is important to place the buildings in a specific historical period and to understand the building envelope properties, which is made possible by the homogeneity of the built urban fabric.

This method allows us to solve the issue of the lack of detailed data on the existing buildings because no archive or informative office exists that has the specific data related to the residential buildings in Bari.

This lack of data requires the use of simplifications regarding the descriptions of the buildings, which have been grouped into macro-categories with common characteristics.

Moreover, the absence of computerised data on users' behaviour and energy bills does not permit the comparison with the real energy demand, as was demonstrated in several studies.

Nevertheless, it is important to have truthful and realistic estimates to implement efficient strategies of refurbishment.

Another critical problem is that the proposed methodology requires constant updating and monitoring of the real conditions, as the energy performance of the built heritage is constantly evolving, due to the policies of retrofits that cities are adopting. Therefore, it is essential to understand how the needs change over the years and to adapt the adopted strategies to the new requirements. For example, research programs have been launched by the United Kingdom (Hamilton et al., 2013) to measure and track the energy demand and the energy efficiency retrofits results.

Finally, the method is also a useful tool to evaluate the advantages, in both environmental and economic terms, of the different actions. As it can be observed from the results, global building refurbishment is always preferable to partial envelope requalification, while the actions on the heating system are the most convenient, but not always the most effective, as in the case of the replacement of thermostatic valves.

This study has taken into account only the typical retrofit actions in the city of Bari. However, by reiteration of the methodology, it is possible to assess other forms of intervention or the use of different technologies and materials, which may be better and less expensive.

5. Conclusions and Policy Implications

The substantial difference in profitability between the best and worst investments highlights the importance of the careful planning of energy efficiency upgrading to optimise economic investments and to assess the potential for energy-saving retrofits better.

Urban Energy Maps are useful for improving urban energy planning, to quantify, for example, the relationships between energy needs and demographic variables, as well as to optimise the design of district heating and/or cooling plants.

Energy maps may also support the management of the building stock in terms of the possibility to verify the characteristics of buildings regarding the various energy performances (geometric peculiarities, envelope behaviours, efficiency of heating systems); the capability to query the geo-referenced system, facilitating the analysis of critical issues and the design improvement plans; the possibility for the authorities to identify and evaluate energy-saving strategies, while simultaneously informing the citizens about the energy performances of their dwellings (Ascione et al., 2013).

To apply these retrofit measures, a geo-referenced model facilitates the identification of buildings with higher energy needs. Consequently, energy maps can provide useful information for optimising the process of decision-making. By way of illustration, Figures 11 and 12 show maps of energy demands with reference to a unitary floor area. These maps focus on two different district areas, characterised by a high quantity of public housing, and highlight how the energy demand change at local level. Moreover, the maps can be overlapped to a historical one, enabling visualisation of the possible substantial improvement of all the building types, according to the above results.

Finally, the analysis can be performed for the entire city because these maps are useful for understanding the energy quality of existing buildings and evaluating the results of refurbishment at urban scale.

To meet the costs of refurbishment, the city and the IACP could derive funding from the European Union; however, another possible solution could be that the tenants' rents are increased by as much as the family saves on the costs of fuel for a payback period corresponding to that of the various interventions. In this way, tenants would pay the same amount paid currently for the rent and fuel for a few years and, thus, the city would recover the money spent. Once costs have been amortised, the savings would directly benefit the families via lower costs for rent and fuel.

Therefore, this benefit must be an incentive for the municipal Authorities to undertake refurbishment programs and intervention strategies, from the point of view of a practical understanding of sustainability.

In conclusion, urban districts and communities play an important role in the implementation of energy policies for the rational use of energy and to address environmental problems.

The evaluation of the existing building stock from the energy point of view is notably difficult because of the lack of reliable data; because the immense vastness of the building stock does not permit a detailed analysis, the use of appropriate approximations at the urban level is required.

The methodology presented here demonstrates that it is possible to implement a simplified and applicable approach that supports local administrators, energy planners and other stakeholders to determine the most effective energy policies and strategies at the district and city levels. Following the methodology described in this paper, it is possible, to evaluate and represent the effects of the implementation of new standards of building energy performances defined by laws regarding energy efficiency (Caputo et al., 2013).

The analysis of building and heating system types in the area has revealed how, in the context of public housing, it is possible to identify the typological features linked to each period of construction. These typological features are important for the mapping of existing building stock from the energy point of view, an operation that, at present, is otherwise almost unachievable.

To reduce energy consumption in the building sector, the interventions cannot be limited only to the construction of zero energy buildings. Improvement of the existing buildings, which are a resource from the energy and environmental points of view, is essential.

The only way to achieve significant results, both in terms of energy and the economy, is to evaluate the intervention strategy to be followed conscientiously. Therefore, knowledge of the involved orders of magnitude and an awareness of the reliability of the forecasts are essential: in this sense, the methodology produces reliable estimates. In addition, cost–benefit analysis is an extremely effective tool in determining the direction in which to start a refurbishment programme.

Not all interventions that lead to substantial energy savings are convenient from the economic point of view: therefore, the local authorities must carefully evaluate the priority strategies to be adopted, aiming for timely and effective actions that achieve the appropriate balance between the environmental and economic perspectives.

The present work presented only one of the possible methods to achieve the objectives set by the European Directives and to implement the idea of "smart city", i.e., the ability of cities to adapt to new requirements in every field, focusing on their characteristics, to achieve a future sustainable development.

The methodology represents a supporting tool for stakeholders involved in defining a proper approach to energy efficiency at the city and district levels.

Of course, to implement the proposed methodology, the cooperation of all the local authorities and stakeholders is essential, as is the involvement of all citizens: in fact, only through a valid and continuous collaboration can one aim for a real energy mapping of the entire housing stock that is no longer based on statistical methods. Such energy mapping represents the fundamental starting point when implementing any development policy that provides environmental protection.

Future research can extend the results of this investigation to the other residential buildings and to the summer period (evaluating the cooling demand and the contributions of electricity bills to the energy needs of the city). The results of such future studies will enable understanding of the strategies of refurbishment from the point of view of urban and regional scale. Therefore, this research could provide more details to the public Authorities on the actual situation and on future energy planning.

Nomenclature

Symbol	**Quantity**	**Unit**
A_f	Heated floor area	m^2
CO_2	CO_2 emissions	kg/m^2a
c_t	Specific cost of gas at the *t*-th year	€/kWh
DPP	Discounted payback period	year
EP_H	Energy performance index in the heating season	kWh/ m^2a
$\Delta EP_{H,j}$	Energy performance index differential of the *j*-th action between before and after refurbishment	kWh/ m^2a
I_j	Initial investment of the *j*-th action of refurbishment	€
i	Discount rate	%
$Q_{H,nd}$	Building energy need for heating	kWh
$Q_{H,p}$	Primary energy demand for heating	kWh
R_{jt}	Economic benefit at the *t*-th year for the *j*-th action of refurbishment	€
t	Time	year
U	Thermal transmittance	W/ m^2K
U_g	Thermal transmittance of window glass	W/ m^2K
U_w	Thermal transmittance of window	W/ m^2K
N	Life cycle of the investment	year
NPV	Net present value	€
$\eta_{H,g}$	Heating system seasonal efficiency	%

References

Ascione, F., De Masi, R.F., de Rossi, F., Fistola, R., Sasso M., Vanoli, G.P. (2013). Analysis and diagnosis of the energy performance of buildings and districts: Methodology, validation and development of Urban Energy Maps, Cities 35 (2013), 270–283.

Ástmarsson, B., Jensen, P.A., Maslesa, E. (2013). Sustainable renovation of residential buildings and the landlord/tenant dilemma, Energy Policy 63 (2013), 355–362.

Ballarini, I., Corrado, V. (2009). Application of energy rating methods to the existing building stock: Analysis of some residential buildings in Turin, Politecnico di Torino, Energy and Buildings 41 (2009), 790–800.

Ballarini, I., Corgnati, S.P., Corrado, V. (2014). Use of reference buildings to assess the energy saving potentials of the residential building stock: The experience of TABULA project. Energy Policy, http://dx.doi.org/10.1016/j.enpol.2014.01.027i

Behsh, B. (2002). Building form as an option for enhancing the indoor thermal conditions, 6th Nordic Building Physics Symposium, Trondheim, Norway, 759-766.

Bosseboeuf, D. (2009). Energy efficiency trends and policies in the household & tertiary sectors in the EU 27. Lessons from the ODYSSEE/MURE project, Paris. (www.odyssee-indicators.org).

Caputo P., Costa G., Ferrari S. (2013). A supporting method for defining energy strategies in the building sector at urban scale, Energy Policy 55 (2013), 261-270.

Corgnati, S.P., Filippi, M., Corrado, V. (2008). A method for heating consumption assessment in existing buildings: a field survey concerning 120 Italian schools, Energy and Buildings 40 (2008), 801–809.

Corrado, V., Ballarini, I., Corgnati, S.P. (2012). National scientific report on the TABULA activities in Italy, Politecnico di Torino, Torino, Italy.

Dall’O’, G., Galante, A., Torri, M. (2012). A methodology for the energy performance classification of residential building stock on an urban scale, Energy and Buildings 48 (2012), 211–219.

Dascalaki, E.G., Droutsa, K.G., Balaras, C.A., Kontoyiannidis, S. (2011). Building typologies as a tool for assessing the energy performance of residential buildings – A case study for the Hellenic building stock, Energy and Buildings 43 (2011), 3400–3409.

De Santoli, L., Mancini, M., Cecconi, F. (2010). Riqualificazione dell’edilizia residenziale di una città. Il caso Roma (Energy analysis for retrofitting proposals in Rome residential sector), Aicarr Journal, n.1 (2010), 18–22.

Ente Nazionale Italiano di Unificazione (2008a). UNI/TS 11300-1. Energy performance of buildings – Part 1: evaluation of energy need for space heating and cooling (in Italian).

Ente Nazionale Italiano di Unificazione (2008b). UNI/TS 11300-2. Energy performance of buildings – Part 2: evaluation of primary energy and system efficiencies for space heating and domestic hot water production (in Italian).

European Committee for Standardization (2008). EN ISO 13790. Energy performance of buildings - Calculation of energy use for space heating and cooling.

European Union (2010). EUROPE 2020 – A strategy for smart, sustainable and inclusive growth.

European Union (2012). Directive 2012/27/UE of the European Parliament and of the Council of 25th October, 2012 on Energy efficiency, that changes Directives 2009/125/CE and 2010/30/UE and repeals Directive 2004/8/CE and 2006/32/CE.

FP7 SEMANCO project (2011), Semantic Tools for Carbon Reduction in Urban Planning, (Available from: ec.europa.eu)

Fraunhofer Institute for Systems and Innovation Research ISI (2009), Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries: Final Report for the European Commission Directorate-General Energy and Transport.

Hamilton, I. G., Steadman, P. J., Bruhns, H., Summerfield, A. J., Lowe, R. (2013), Energy efficiency in the British housing stock: Energy demand and the Homes Energy Efficiency Database, Energy Policy 60 (2013), 462–480.

ISTAT (2001). 14th General Census of Population and Housing. Statistics by the National Institute of Statistics (in Italian).

Italian Government (1962). Law 18th April 1962, n. 167, Provisions to facilitate the acquisition of building areas for public housing (In Italian).

Italian Government (1976). Law 30th April 1976, n. 373, Standards for the containment of energy consumption for heating purposes in buildings. (In Italian).

Italian Government (1991). Law 9th January 1991, n. 10, Rules for the implementation of the national energy plan in the field of rational use of energy, energy conservation and development of renewable energy. (In Italian).

Italian Government (2005). Legislative Decree 19th August 2005, n. 192, complying with the European Directive 2002/91/CE on the energy performance of buildings. (In Italian).

Loga, T., Diefenbach, N. (2010). Use of building typologies for energy performance assessment of national building stocks, existent experiences in European countries and common approach, First TABULA Synthesis Report. (Available from: www.buildingtypology.eu)

Ma, Z., Cooper, P., Daly, D., Ledo, L. (2012). Existing building retrofits: Methodology and state-of-the-art, Energy and Buildings 55 (2012), 889–902.

Martinelli, N. (2009). Per un atlante della città pubblica di Bari (For an Atlas of the city of Bari), Adda Editore, Bari.

Meteotest (2008). Meteonorm version 6.1.

Municipality of Bari (2011a). Sustainable Energy Action Plan (SEAP). Planning Document: From Pact to the initiatives to reduce emissions. (www.comunedibari.it).

Municipality of Bari (2011b). Membership approval of the Municipality of Bari to the “Covenant of Mayors”, launched by the European Commission with participation of the Ministry of the Environment, Deliberation of City Council of Bari.

Papadopoulos, A.M. (2005). State of the art in thermal insulation materials and aims for future developments, Energy and Buildings 37 (1) (2005), 77–86.

Papadopoulos, A.M., Giama, E. (2007). Environmental performance evaluation of thermal insulation materials and its impact on the building, Building and Environment 42 (2007), 2178–2187.

Sartori, I., Wachenfeldt, B. J., Hestnes, A. G. (2009). Energy demand in the Norwegian building stock: Scenarios on potential reduction, Energy Policy 37 (2009), 1614–1627.

Sathaye, J., Sanstad, A.H. (2004). Bottom-up energy modeling. Encyclopedia of Energy, 251–264.

Singh, M. K., Mahapatra, S., Teller, J. (2013). An analysis on energy efficiency initiatives in the building stock of Liege, Belgium. Energy Policy 62 (2013), 729–741.

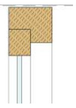
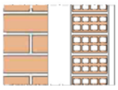
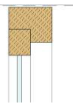
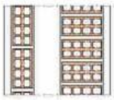
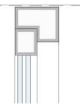
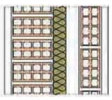
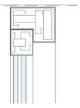
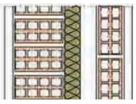
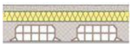
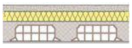
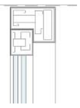
Steiner, H.M. (1992), Engineering Economic Principles, McGraw-Hill, New York, NY

Theodoridou, I., Papadopoulos, A. M., Hegger, M. (2011). Statistical analysis of the Greek residential building stock, Energy and Buildings 43 (2011), 2422–2428.

Theodoridou, I., Papadopoulos, A. M., Hegger, M. (2012). A feasibility evaluation tool for sustainable cities–A case study for Greece, Energy Policy 44 (2012), 207–216.

Tommerup, H., Svendsen, S. (2006). Energy savings in Danish residential building stock, Energy and Buildings 38 (2006), 618–626.

Table(s) with captions

Period of construction	Type of public housing	Common features				
		Opaque external wall	**Roof**	**Inter-mediate floor**	**Window**	**Boiler Efficiency (*)**
Before 1961		 Limestone plastered masonry (< 60 cm) U = 2.40 (W/m^{2}K)	 Reinforced concrete hollow-tile floor with air gap U = 1.27 (W/m^{2}K)	 Reinforced concrete hollow-tile floor U = 1.33 (W/m^{2}K)	 Single-glazed window, wood or galvanized steel frame U_w = 5.90 (W/m^{2}K) U_g = 5.86 (W/m^{2}K)	Standard gas boiler installed outdoors η = 85%
1961 – 1975		 Cavity wall, without insulation (30 cm) U = 1.38 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, low insulation U = 0.91 (W/m^{2}K)	 Reinforced concrete hollow-tile floor U = 1.33 (W/m^{2}K)	 Single-glazed window, wood or galvanized steel frame U_w = 5.10 (W/m^{2}K) U_g = 4.64 (W/m^{2}K)	Standard gas boiler installed outdoors η = 85%
1976 – 1990		 Cavity wall, low insulation (30 cm) U = 0.89 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, low insulation U = 0.89 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, low insulation U = 1.07 (W/m^{2}K)	 Double glazing with air gap U_w = 3.90 (W/m^{2}K) U_g = 3.27 (W/m^{2}K)	Standard gas boiler installed outdoors η = 92%
1991 – 2004		 Cavity wall, average insulation, (30 cm) U = 0.56 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, average insulation U = 0.86 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, average insulation U = 1.29 (W/m^{2}K)	 Double glazing with air gap, thermal – break windows U_w = 3.55 (W/m^{2}K) U_g = 3.26 (W/m^{2}K)	Standard gas boiler installed outdoors η= 92%
After 2004		 Cavity wall, high insulation (> 30 cm) U = 0.40 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, high insulation U = 0.36 (W/m^{2}K)	 Reinforced concrete hollow-tile floor, high insulation U = 0.80 (W/m^{2}K)	 Double glazing with air gap, thermal – break windows U_w = 3.10 (W/m^{2}K) U_g = 3.26 (W/m^{2}K)	Standard gas boiler installed outdoors η = 92%

(*) Net calorific Value

Table 1. Widespread typical building features according to different ages.

Period of construction	***EP_H*** (kWh/m^{2}a)	$\eta_{H,g}$ (%)	**CO_2 Emissions** (kgCO_2/m^{2}a)
Before 1961	193.90	60.7	38.73
1961–1975	155.60	60.4	27.44
1976–1990	97.23	64.0	19.29
1991–2004	96.35	65.4	19.63
After 2004	64.04	74.5	12.81

Table 2. Energy performances of the example buildings.

Period of construction	Building envelope improvements							Heating system improvements		
	Thickness of stone wool in the roof (cm)	Thick-ness of stone wool in the floor (cm)	Thick-ness of external insulation (cm)	Thick-ness of insula-tion of cavity (cm)	Thick-ness of internal insulation (cm)	Windows DG	Windows TG	Condensing boiler	Thermo-static valves	Percentage coverage of DHW demand from solar collectors
					Usual refurbishment					
Before 1961	10	8	12			X		X	X	
1961–1975	8	8	12			X		X	X	
1976–1990	8	8		5		X		X	X	
1991–2004	6	6				X		X	X	
After 2004	4	6						X	X	
					Deep refurbishment					
Before 1961	10	8	12		8	X		X	X	50%
1961–1975	10	10	12				X	X	X	50%
1976–1990	10	8		5			X	X	X	90%
1991–2004	6	6			4		X	X	X	90%
After 2004	4	6				X		X	X	50%

Table 3. Action planned for the refurbishment of the example buildings.

		Existing Building	Usual Refurbishment	Deep Refurbishment
Before 1961	$\boldsymbol{EP_H}$ (kWh/m^{2}a)	193.9	51.06	17.77
	$\boldsymbol{\Delta EP_H}$ (%)	/	-74	-91
1961–1975	$\boldsymbol{EP_H}$ (kWh/m^{2}a)	155.6	53.66	34.6
	$\boldsymbol{\Delta EP_H}$ (%)	/	-66	-78
1976–1990	$\boldsymbol{EP_H}$ (kWh/m^{2}a)	97.23	45.8	22.42
	$\boldsymbol{\Delta EP_H}$ (%)	/	-53	-73
1991–2004	$\boldsymbol{EP_H}$ (kWh/m^{2}a)	96.35	45.68	26.59
	$\boldsymbol{\Delta EP_H}$ (%)	/	-53	-72
After 2004	$\boldsymbol{EP_H}$ (kWh/m^{2}a)	64.04	49.51	25.06
	$\boldsymbol{\Delta EP_H}$ (%)	/	-23	-60

Table 4. Comparison of energy performance of example buildings, before and after the refurbishment.

Actions	ΔEP_H (%)	$R_{j,t}$ (€)	I_J (€)	*NPV* (€)	*DPP* (year)
Insulation of the roof slab	-6.7	710	10,283	5,628	17
Insulation of the floor above non-heated room	-6.4	678	16,624	-1,436	34
Insulation of external walls	-23.34	2,473	60,175	- 4,797	34
Replacing windows	-27.73	2,938	80,130	-14,326	40
Total of Building envelope Actions	-59.52	6,306	167,212	-25,981	38
Replacement of traditional boilers with condensing boilers	-23.07	2,444	32,363	7,603	15
Thermostatic valves	-3.34	354	3,803	1,990	12
Total of heating system improvements	-25.67	2,720	36,166	8,312	15
Total	-69.17	7,329	203,378	-58,096	41

Table 5. Economic indexes for each kind of refurbishment actions, calculated for buildings before 1961.

Period of construction	**Cost-effective actions**	***NPV* (€)**	***DPP* (year)**	**ΔEP_H**
Before 1961	Insulation of the roof slab	5,628	17	-33%
	Replacement of the traditional boiler with condensing boilers	7,603	16	
	Thermostatic valves	1,990	12	
1961–1975	Insulation of the roof slab	507	28	-26%
	Insulation of the floor above non-heated room	1,055	27	
	Replacement of the traditional boiler with condensing boilers	2,897	11	
	Thermostatic valves	195	20	
1976–1990	Insulation of the roof slab	1,718	23	-40%
	Insulation of the floor above non-heated room	1,880	26	
	Insulation of the cavity	3,775	26	
1991–2004	/	/	/	/
After 2004	/	/	/	/

Table 6. Cost-effective actions on each example building and possible improvement of the energy performance.

Period of construction	**Distribution of Buildings** (%)	**Total area** (m^2)	**Specific primary energy demand** EP_H (kWh/m^2a)	**Global primary energy demand** (GWh/a)
Before 1961	36	152,383	193.90	29.55
1961–1975	43	113,764	155.60	17.70
1976–1990	19	127,127	97.23	12.36
1991–2004	1	123,79	96.35	1.19
After 2004	1	5,405	64.04	0.35
Total	100	411,058	148.76	61.15

Table 7. Summary of the distribution of public residential buildings and their specific and global energy needs in a heating season.

Figure captions

Fig. 1. Steps of the applied methodology.

Fig. 2. Distribution of ERP and IACP buildings for historical periods in the municipality of Bari and graphical representation as a percentage.

Fig. 3. Average specific energy demand of the example buildings in Bari, according to the different ages.

Fig. 4. Distribution of ERP and IACP buildings according to ages and number of floors.

Fig. 5. Total heating energy demand of ERP and IACP residential buildings in Bari, according to the different ages.

Fig. 6. CO_2 emissions of the public housing in Bari.

Fig. 7. Cost of 1 MWh saving depending on the interventions and the period of construction.

Fig. 8. Cost of 1 MWh saving depending on the cumulative interventions and the periods of construction.

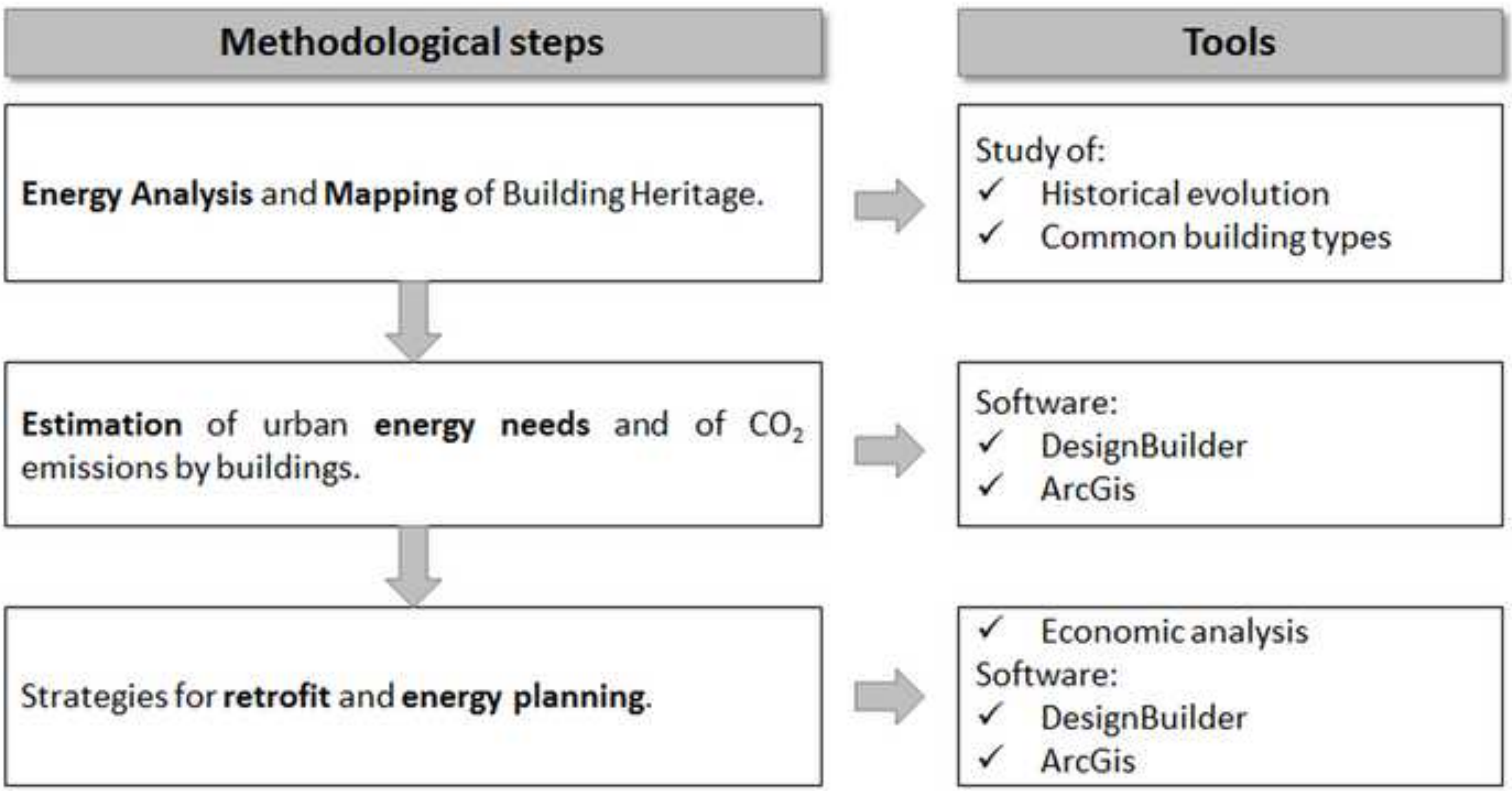
Fig. 9. Comparison of specific primary energy demand of the existing buildings and after the usual refurbishment, according to the period of construction.

Fig. 10. Comparison of total CO_2 emissions of ERP and IACP buildings before and after the usual refurbishment, according to the period of construction.

Fig. 11. Urban energy map of Japigia district, Bari: energy demand of buildings in terms of specific primary energy needs (EP_H, kWh/m^2a) before and after the refurbishment.

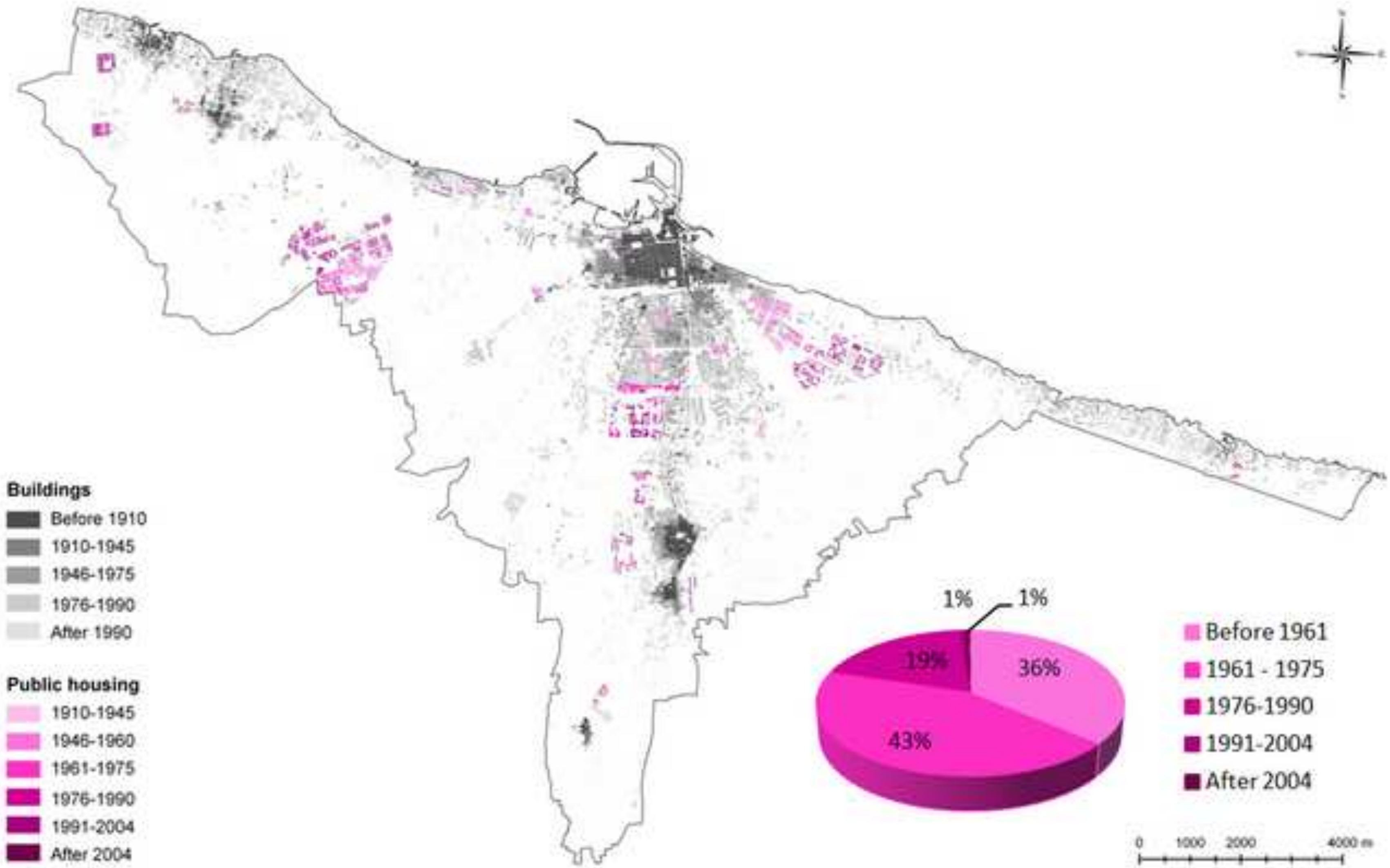
Fig. 12. Urban energy map of San Paolo district, Bari: energy demand of buildings in terms of specific primary energy needs (EP_H, kWh/m^2a) before and after the refurbishment.

Figure 1



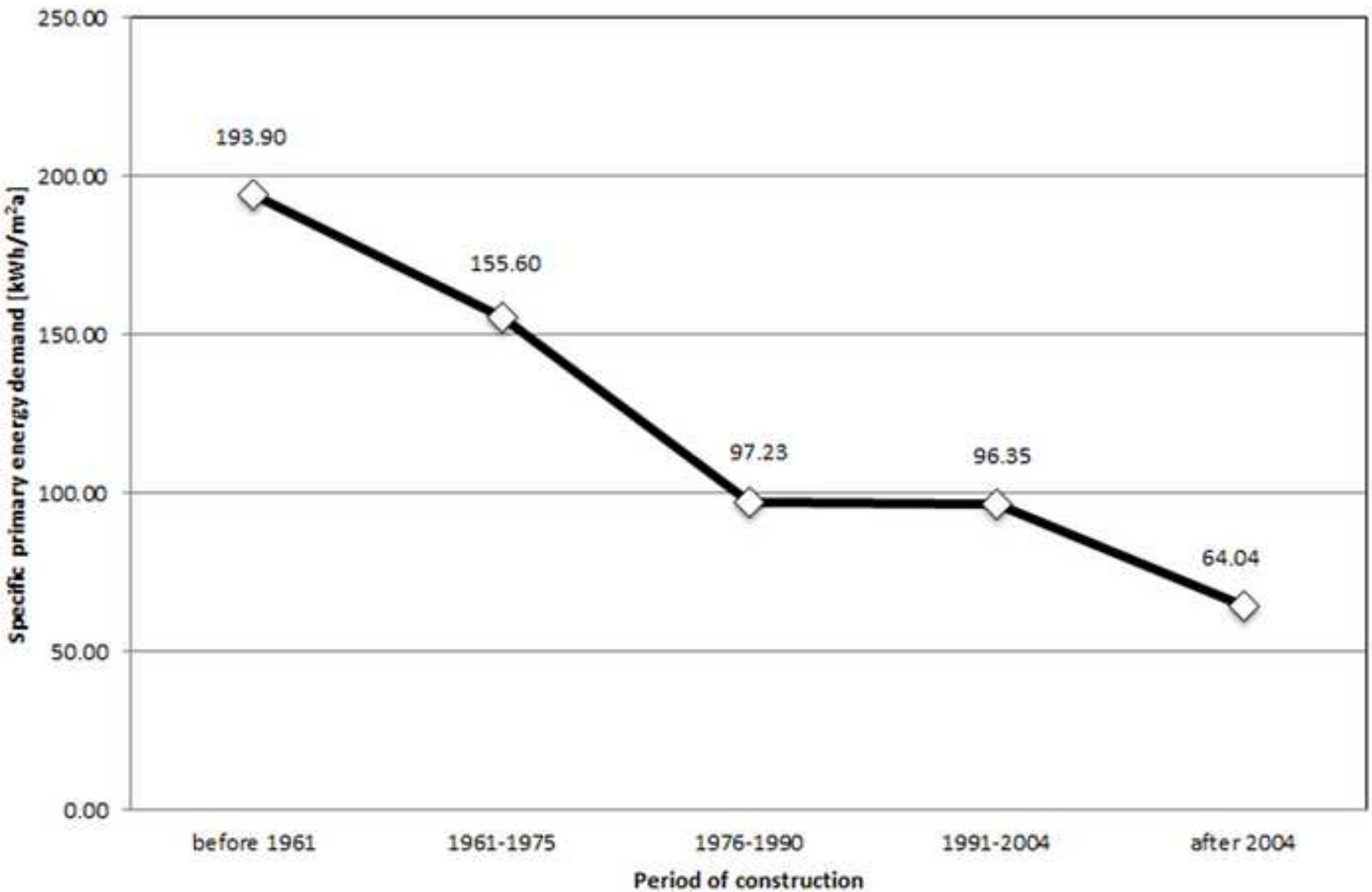
Methodological steps
Tools
Energy Analysis and Mapping of Building Heritage.
Study of:
✓ Historical evolution
✓ Common building types
Estimation of urban energy needs and of CO2 emissions by buildings.
Software:
✓ DesignBuilder
✓ ArcGis
Strategies for retrofit and energy planning.
✓ Economic analysis
Software:
✓ DesignBuilder
✓ ArcGis

Figure 2



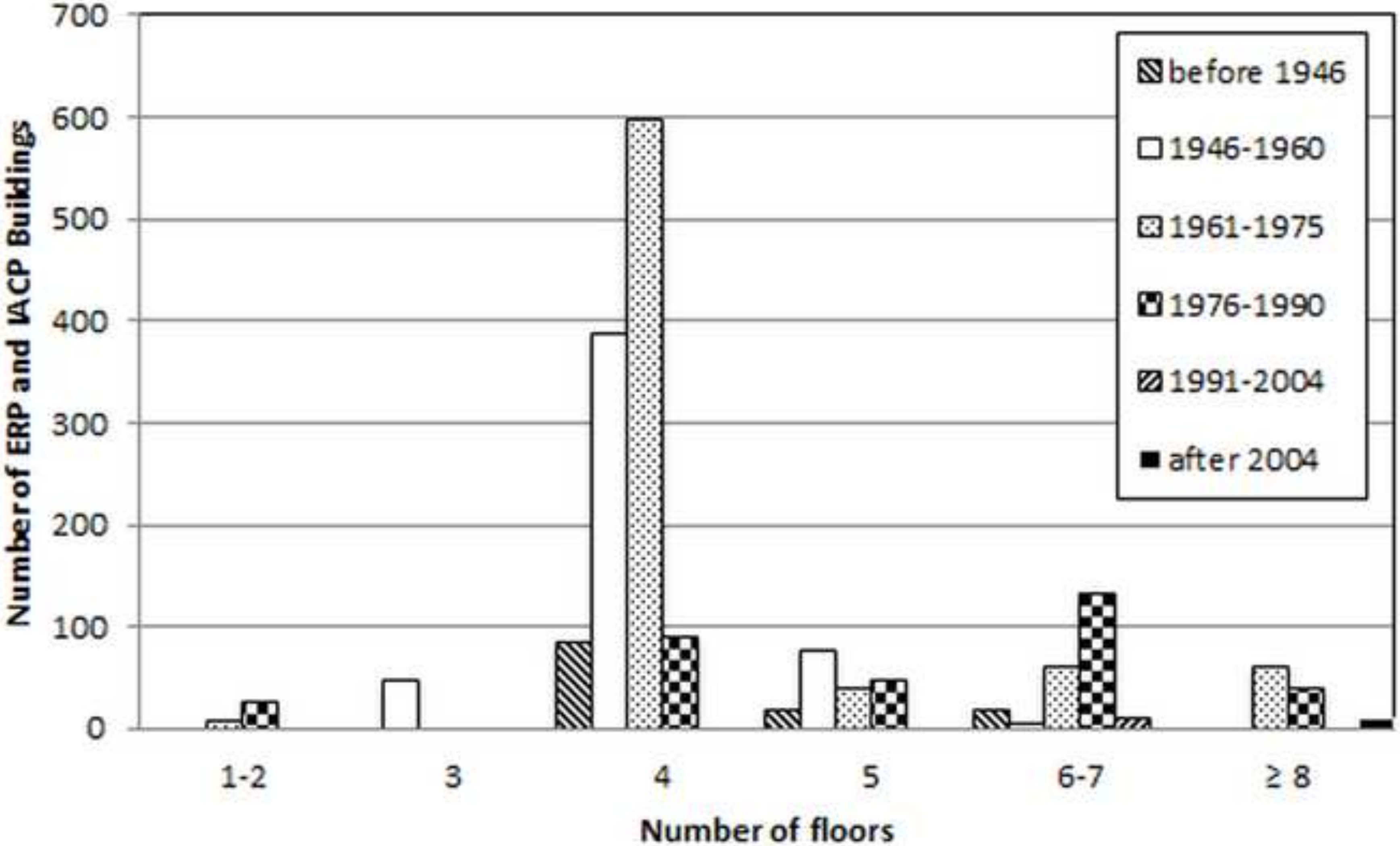
Buildings
Before 1910
1910-1945
1946-1975
1976-1990
After 1990
Public housing
1910-1945
1946-1960
1961-1975
1976-1990
1991-2004
After 2004
1%
1%
19%
36%
43%
Before 1961
1961 - 1975
1976-1990
1991-2004
After 2004
0
1000
2000
4000 m

Figure 3



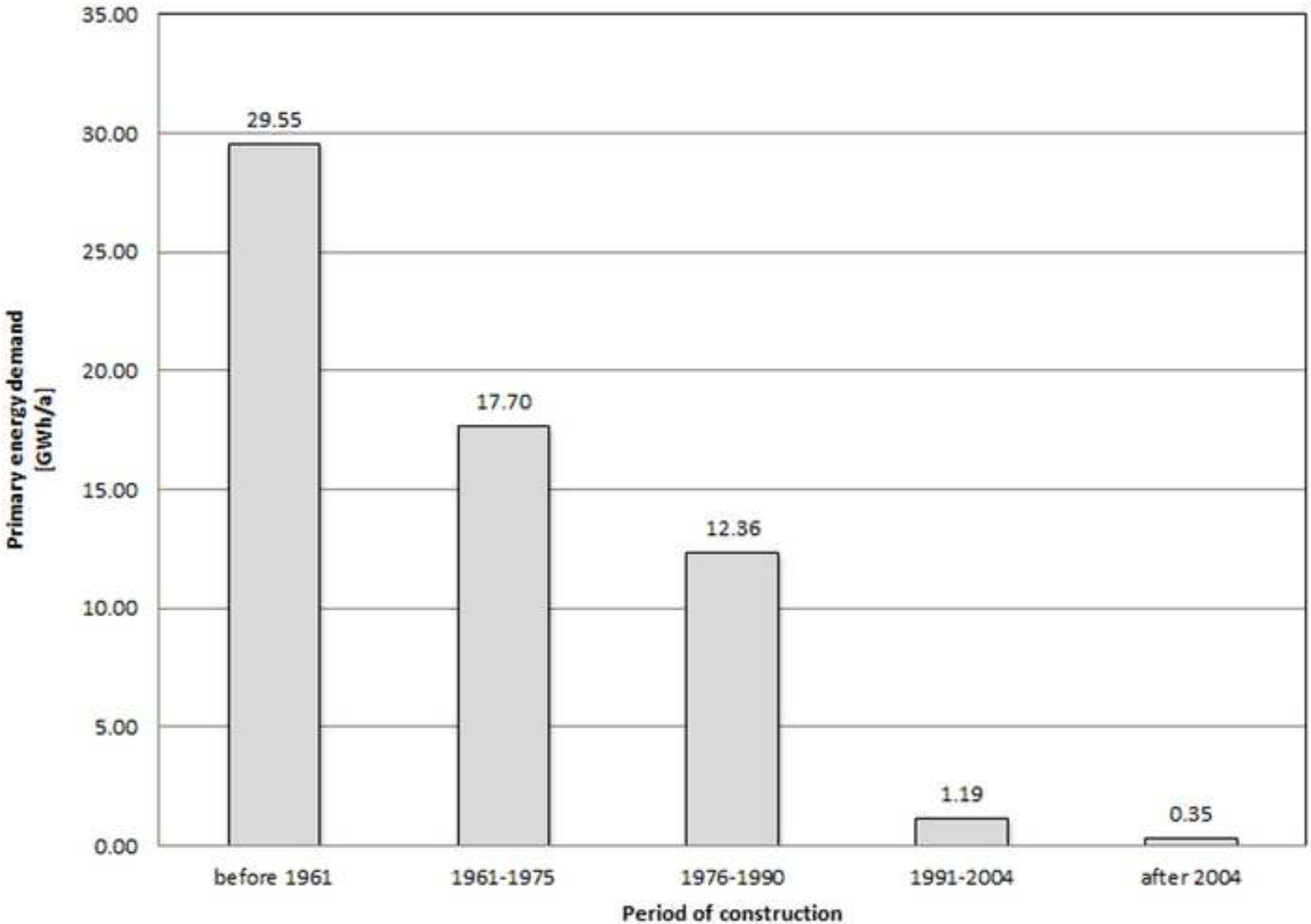
250.00
200.00
150.00
100.00
50.00
0.00
Specific primary energy demand [kWh/m²a]
193.90
155.60
97.23
96.35
64.04
before 1961
1961-1975
1976-1990
1991-2004
after 2004
Period of construction

Figure 4



700
600
500
400
300
200
100
0
Number of ERP and IACP Buildings
before 1946
1946-1960
1961-1975
1976-1990
1991-2004
after 2004
1-2
3
4
5
6-7
≥ 8
Number of floors

Figure 5



35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Primary energy demand [GWh/a]
29.55
17.70
12.36
1.19
0.35
before 1961
1961-1975
1976-1990
1991-2004
after 2004
Period of construction

Figure 6

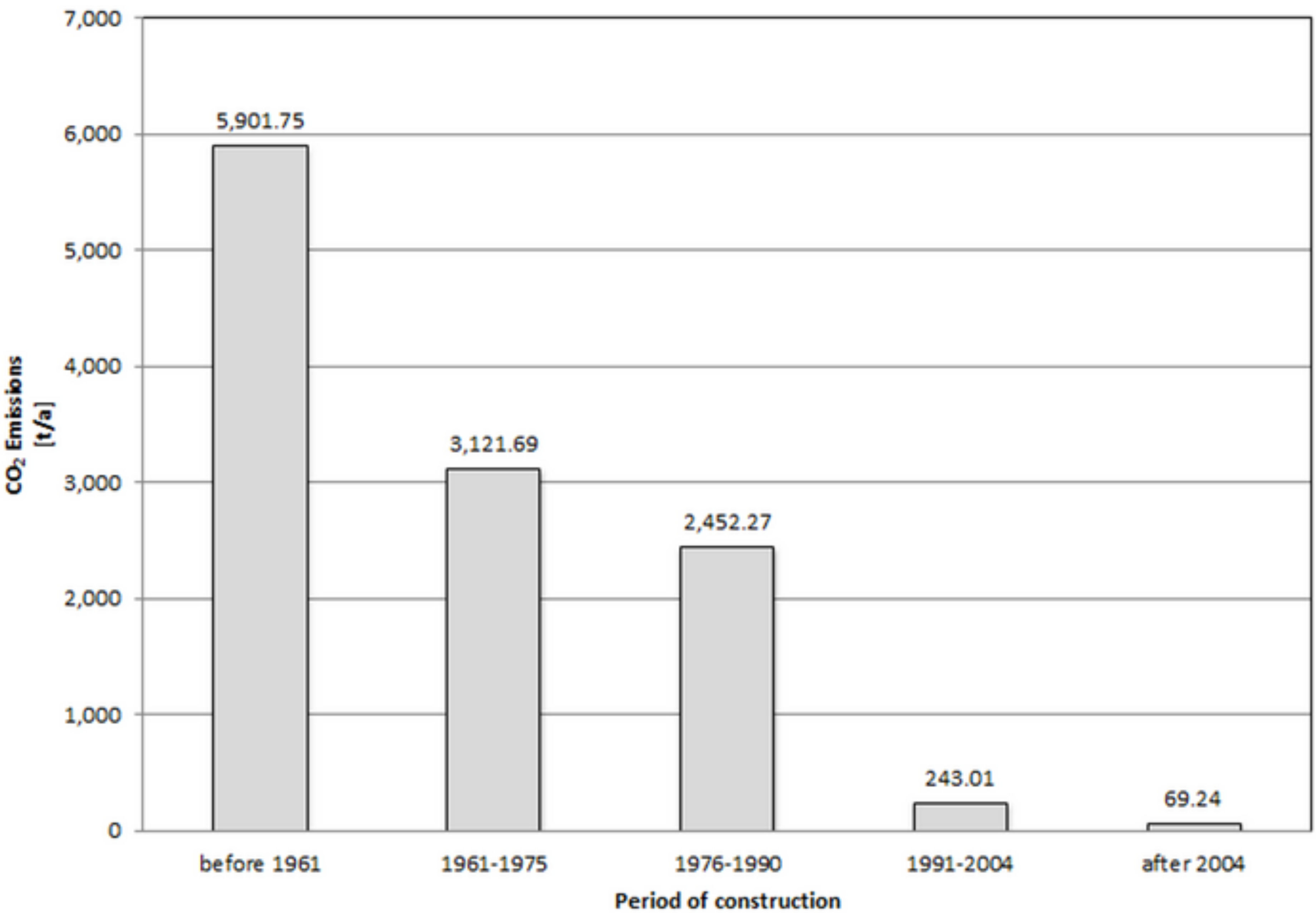
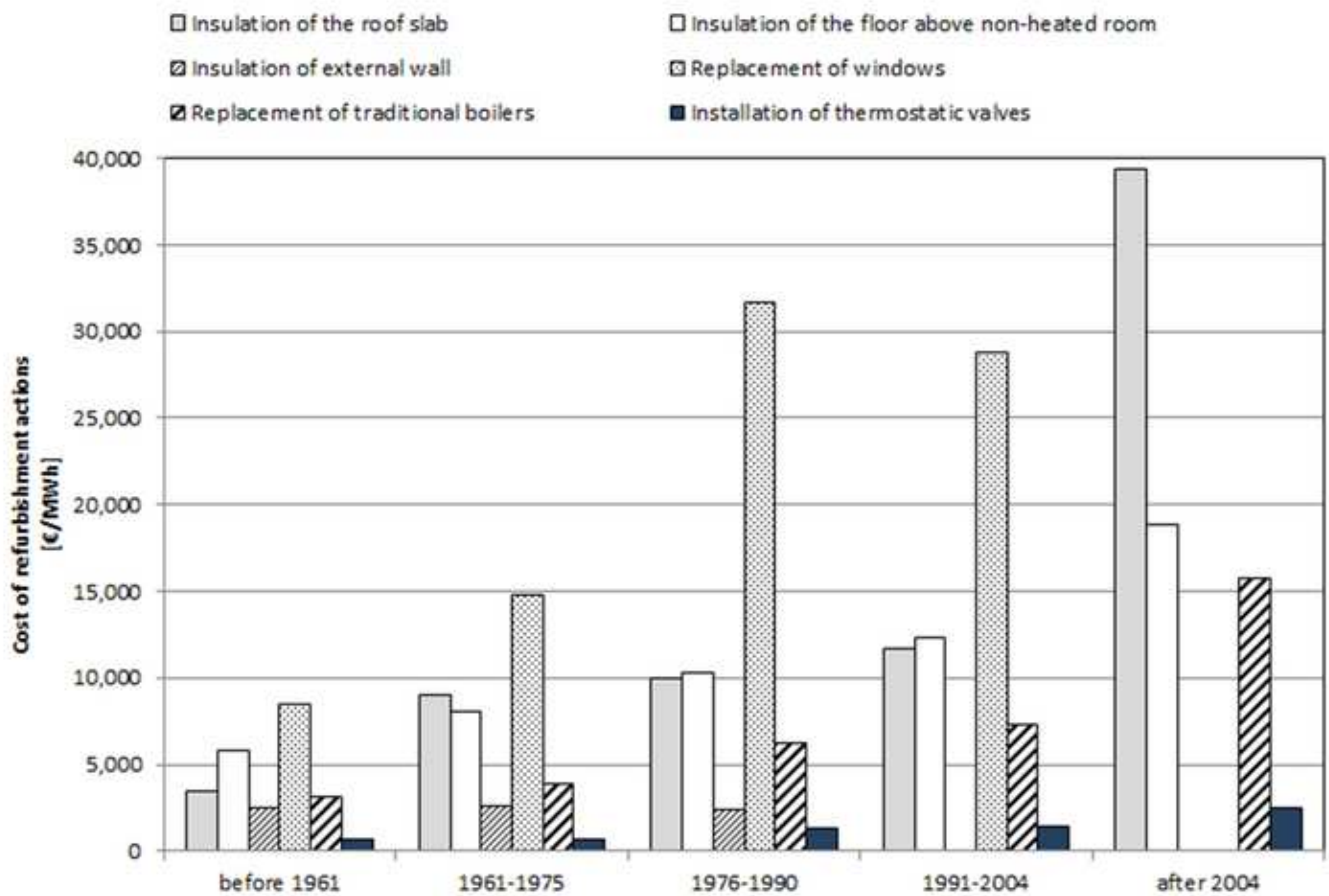
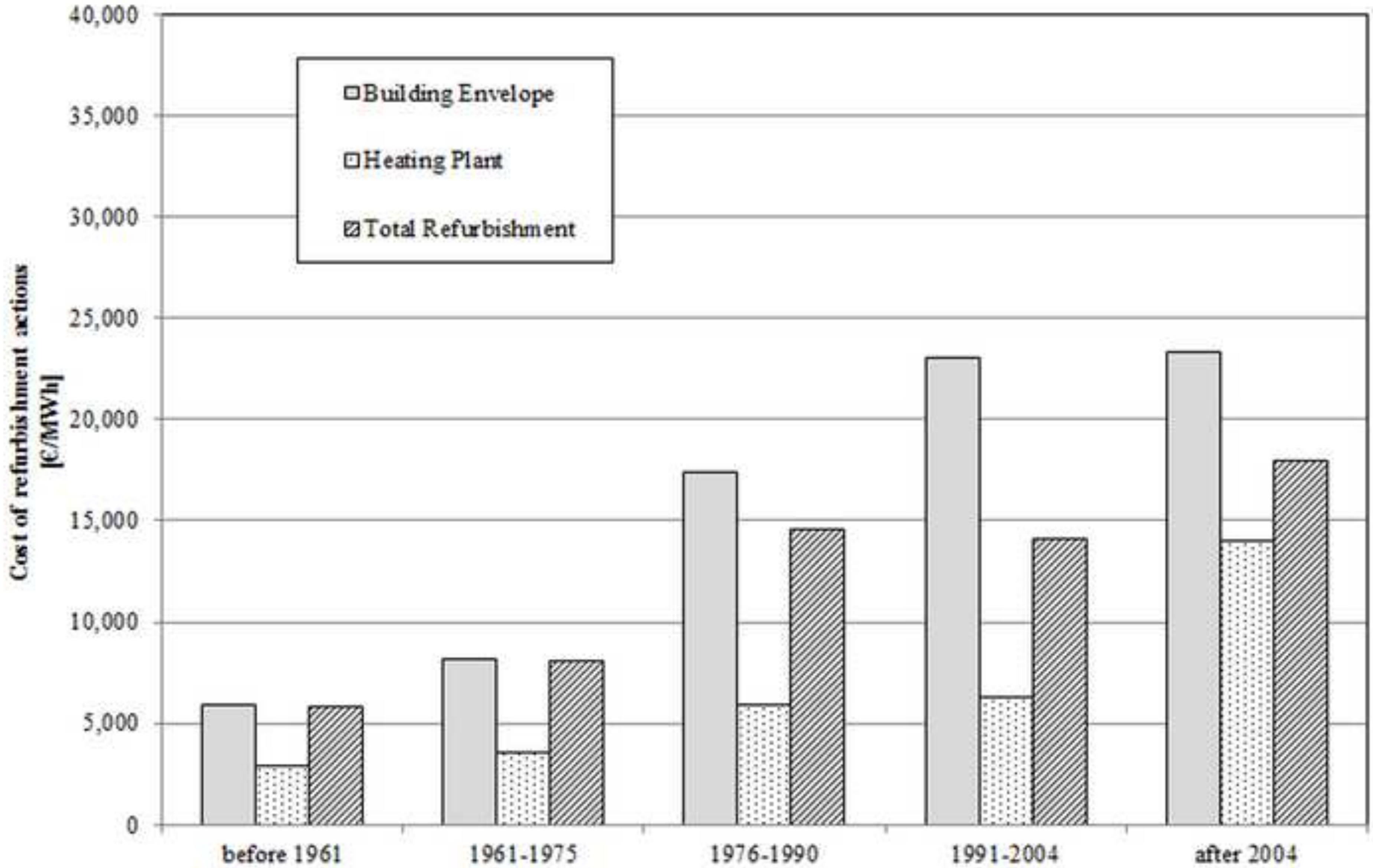

7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
CO_2 Emissions [t/a]
5,901.75
3,121.69
2,452.27
243.01
69.24
before 1961
1961-1975
1976-1990
1991-2004
after 2004
Period of construction

Figure 7



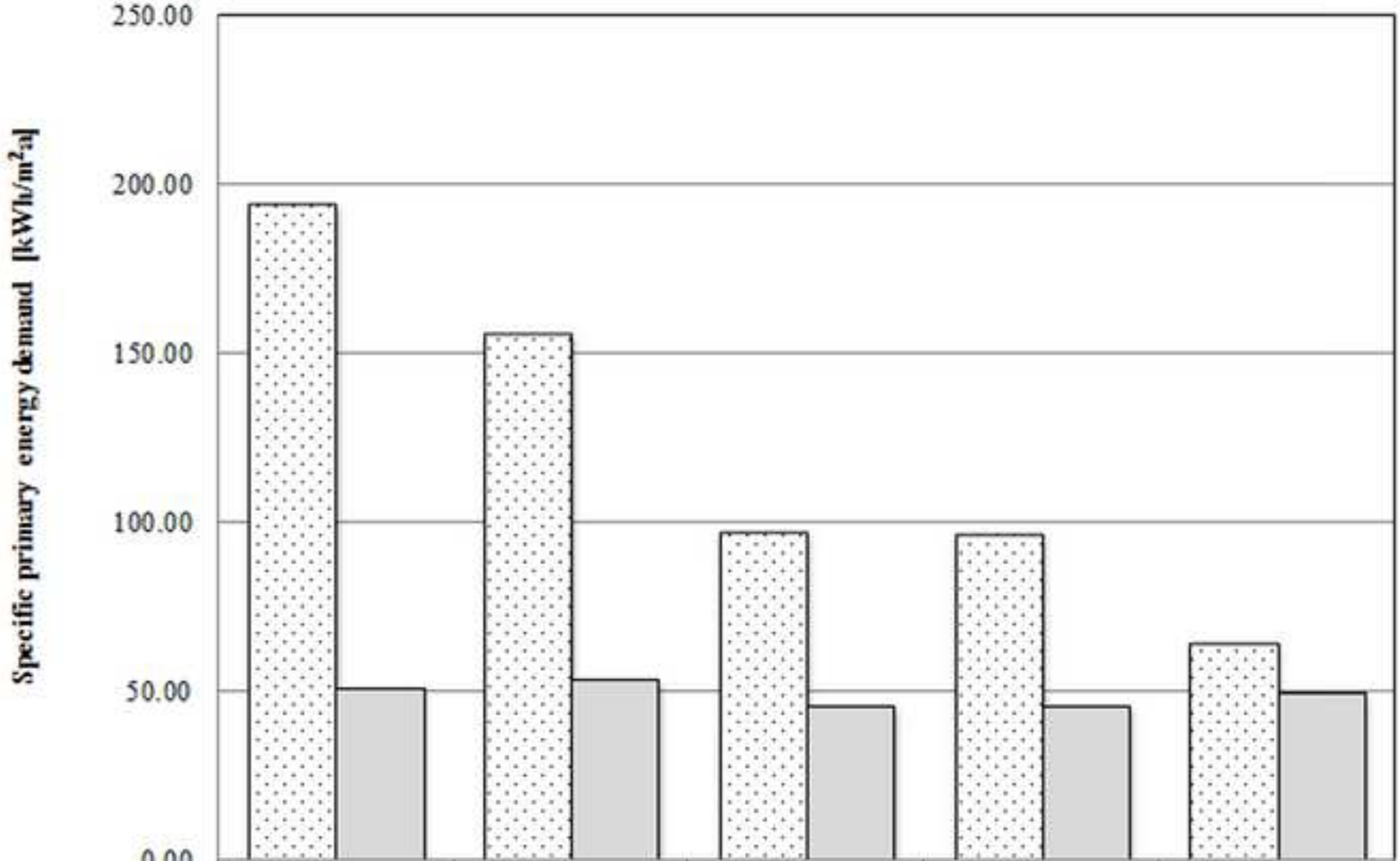
Insulation of the roof slab
Insulation of the floor above non-heated room
Insulation of external wall
Replacement of windows
Replacement of traditional boilers
Installation of thermostatic valves
Cost of refurbishment actions [€/MWh]
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
before 1961
1961-1975
1976-1990
1991-2004
after 2004

Figure 8



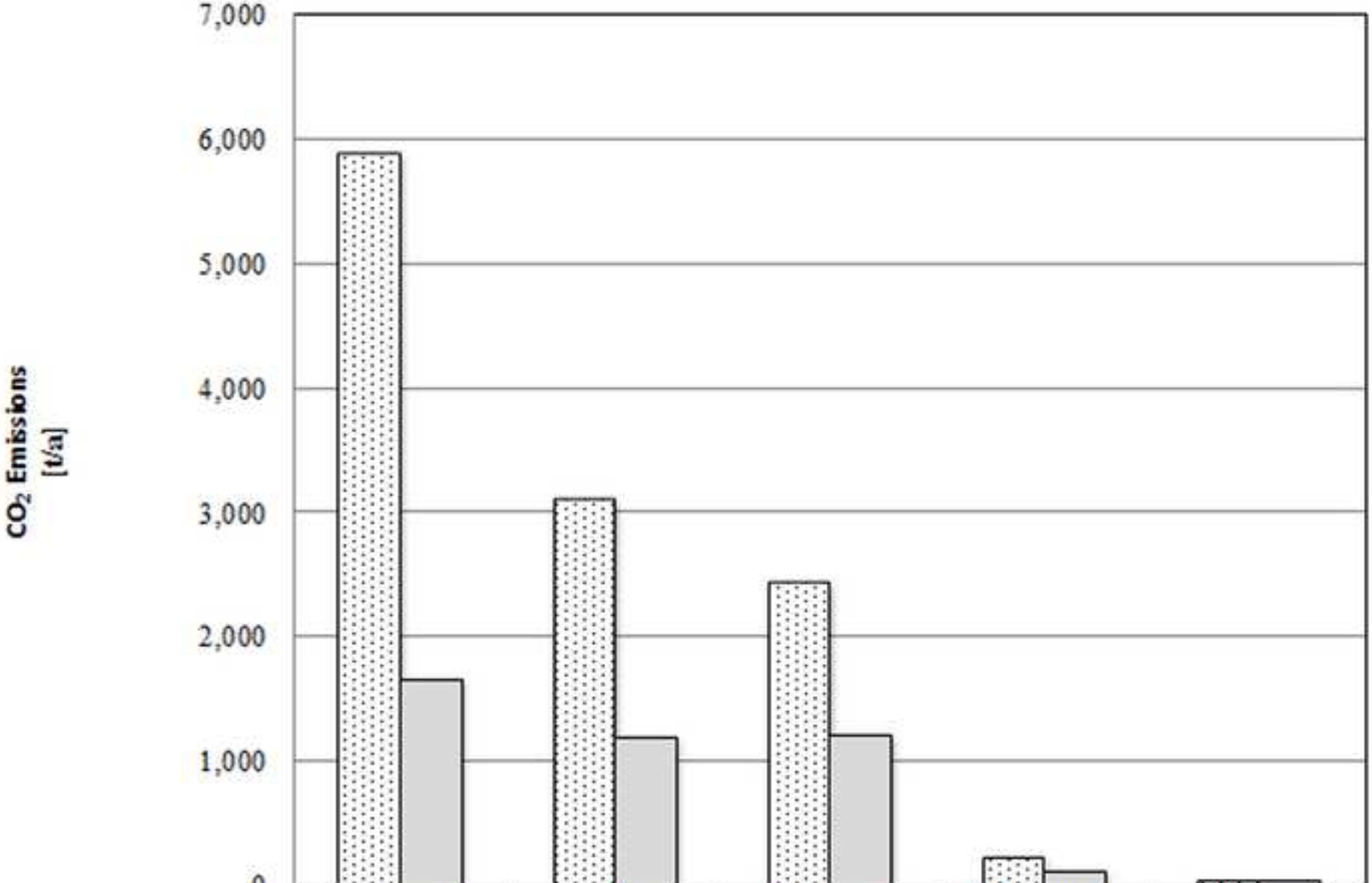
Building Envelope
Heating Plant
Total Refurbishment
Cost of refurbishment actions [€/MWh]
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
before 1961
1961-1975
1976-1990
1991-2004
after 2004

Figure 9



	before 1961	1961-1975	1976-1990	1991-2004	after 2004
Existing buildings	193.90	155.60	97.23	96.35	64.04
After refurbishment	51.05	53.67	45.81	45.68	49.51

Figure 10



	before 1961	1961-1975	1976-1990	1991-2004	after 2004
Existing buildings	5,901.75	3,121.69	2,452.27	243.01	69.24
After refurbishment	1,677.73	1,219.55	1,229.31	130.60	53.46

Figure 11

Figure 12