Chapter 9
Energy Retrofit Strategies in the Building Sector

Giuliano Dall'O'

Abstract In the energy-environmental balance of a city, the building sector uses on average 40% of the energy taken from fossil fuel sources, thereby significantly contributing to air pollution and the emission of greenhouse gases. Green planning strategies must therefore carefully consider this sector, promoting energy retrofit actions that can contain environmental impacts. The energy and environmental redevelopment of buildings must not only be considered an emergency but also an interesting opportunity for growth in the construction market; however, some critical issues, not only of a technical but also economic and social nature, must be assessed. This chapter, focusing on the issue of energy and environmental redevelopment of buildings in cities and communities, on the territorial scale, aims to provide green planners with useful tools to approach their strategies in a pragmatic manner.

9.1 Buildings in the Cities, a Complex Framework

Cities and communities are the social, economic and cultural points of aggregation of human activities and buildings, with urban infrastructures, are pieces of a mosaic that have grown over time. Buildings are the elements that most characterize a city: their shape, their aesthetic appearance, their composition within the urban fabric contribute to making a city attractive or neutral, inclusive or inhospitable.

The energy consumption of buildings depends above all on the function they perform in creating a protected environment for humans, from the climatic point of view in winter, through the heating system, but often also in summer through the air conditioning system. Summer and winter air conditioning is not the only cause of energy consumption.

Energy is also consumed for artificial lighting, for installations and for all the equipment needed to make what Le Corbusier defined "the living machine".

G. Dall'O' (✉)
Architecture, Built Environment and Construction Engineering, ABC Department, Politecnico di Milano, Via G. Ponzio, 31, 20133 Milan, Italy
e-mail: giuliano.dallo@polimi.it

G. Dall'O' (ed.), *Green Planning for Cities and Communities*,
Research for Development, https://doi.org/10.1007/978-3-030-41072-8_9

The environmental impact of buildings is considerable. According to European Union statistics,[1] buildings are responsible for approximately 40% of energy consumption and 36% of CO_2 emissions in the EU, making them the single largest energy consumer in Europe. At present, about 35% of the EU's buildings are over 50 years old, and almost 75% of the building stock is energy inefficient. At the same time, only 0.4–1.2% (depending on the country) of the building stock is renovated each year.

Renovation of existing buildings could therefore lead to significant energy savings and play a key role in the clean energy transition since it has the potential to reduce the EU's total energy consumption by 5–6% and lower CO_2 emissions by about 5%.

The awareness of how necessary it is to intervene in the building sector to reduce energy consumption from fossil fuels is well established at a political level. SDG 7 (affordable and clean energy) and SDG 11 (sustainable cities and communities) confirm governance strategies that had already been adopted in many countries.

A significant commitment in the direction of promoting energy efficiency in the building sector has been made by the EU. The EU's legislative framework for energy-efficient buildings was strengthened in 2002 with the adoption of the Energy Performance of Buildings Directive or EPBD (EC 2002) which included four main aspects:

- Establishment of a calculation methodology: Member States were to implement a methodology for the calculation of the energy performance of buildings, taking account of all factors that influence energy use.
- Minimum energy performance requirements: regulations would need to set minimum energy performance requirements for new buildings and for large (>1000 m^2) existing buildings when they were refurbished.
- Energy performance certificates: an energy performance certificate would need to be made available whenever buildings were constructed, sold or rented out.
- Inspections of boilers and air conditioning: regulations would be needed, requiring inspections of boilers and heating systems (with the possibility of alternative approaches such as providing advice), as well as inspection of air conditioning systems.

Over the years, the evolving regulatory framework has mobilized significant resources and shown itself to have a positive impact on Europe's energy efficiency. The above-mentioned EPBD, transposed by the Member States, was updated by Directive 2010/31/EU (EU 2010) on energy performance of buildings (EPBD recast) which widened the scope of the EPBD and raised the bar. It introduced the concept of Nearly Zero-Energy Buildings (NZEB) and a target of 2018/2020 for their introduction.

The European Commission has not simply restricted itself to enacting laws but has also carried out an effective monitoring action to measure its effectiveness.

[1] https://rezbuildproject.eu/2018/12/03/sustainable-buildings-fight-climate-change/ (Accessed 20 September 2019).

The “EPBD evaluation report” (EC 2016), presented by the European Commission in November 2016, addresses the effectiveness, efficiency, relevance, coherence and EU added value of the Directive. The evaluation report identified many positive effects and only limited regulatory failures; at the same time, it identified the need for simplification and streamlining of measures, enhancement of compliance, better linking with financial support, adaptation to technological developments and a strong need to increase building renovation.

The 2018/844 Directive (EU 2018) marks a further change with respect to the previous legislative framework and does so by starting to assign to buildings the role that is theirs within the transformation of modern society in a sustainable sense. The Directive does not enter into the merits of how this should be achieved, leaving this decision to the Member States. Each of these, in fact, must identify its own long-term redevelopment strategy in order to have a decarbonized and highly energy-efficient building stock by 2050, facilitating, in terms of costs, the effective transformation of existing buildings in NZEB. This strategy can be used to address the issue of safety in the event of fires, as well as to deal with the risks associated with intense seismic activity.

The redevelopment strategy must also include measurable progress indicators in order to verify the trend at 2030, 2040 and 2050 and include the details relating to the implementation of the policies and actions envisaged.

The Directive suggests, as a measure to achieve targeted and cost-effective restructuring, the introduction of an optional “Building Renovation Passport” system, a personalized document for each building that details how and when to implement a deep (in-depth) redevelopment in stages, or transform an existing building in a NZEB thanks to partial intervention works distributed over a period of 15–20 years.

The energy renovation of buildings is a process that has started, and the first results, as highlighted by the EPBD evaluation report, are tangible. The guidelines defined by the European directives, and substantially accepted by the market, show that the energy performance improvement targets can be obtained through a mix of strategies:

- defining high performance energy standards for new buildings (ideally tending to zero-energy buildings);
- improving the energy performance of the existing building stock both through regulatory legislative instruments and through financing policies (Fig. 9.1);
- taking advantage of renewable energy sources to speed up the decarbonization; strengthening the role of energy certification of buildings which, by informing citizens about the energy quality of the building, can guide market choices (energy efficiency as an added value in real estate).

The energy retrofit of buildings is a complex issue: intervening in an urban context that has developed over the years, or in some cases over centuries, through a stratification of building interventions made of ever-changing forms and technologies is by no means easy. The problem is not the single building in itself but the context in which the building is inserted, which often places constraints on redevelopment (e.g the impossibility of exploiting solar energy or the difficulty in modifying shapes).

Fig. 9.1 New façade sampling for an energy retrofit project in Dresden (D). *Credits* The Author 2012

For buildings designed in periods in which energy was cheap and environmental sustainability was not an issue, it is sometimes difficult to increase energy performance to high levels (e.g. NZEB or ZEB).

Energy inefficiency is sometimes not the only critical aspect of the building: the inadequacy of protection against seismic activity of the location, for example, can make structural interventions the priority. The overall costs of restructuring, in many cases, can be higher than those of demolition and rebuilding.

There is a question that a green planner must always ask him/herself: is it necessary to redevelop all existing buildings or is it appropriate to make a selection and only redevelop those buildings that have intrinsic value within the city?

The energy retrofit of buildings with an "urbanistic" approach, i.e. an approach on a larger scale that considers the surrounding neighbourhood and the city, allows for more effective environmental, economic and social choices: the energy and environmental improvement of buildings should, above all, become an energy and environmental enhancement of the city, also considering the social aspects.

Urban regeneration must be used as an essential opportunity to make urban spaces more liveable and stimulating for citizens. The exterior aspect of the renovated building is therefore important because it assists in making the city more attractive (Fig. 9.2).

Fig. 9.2 Energetically renovated facade of an old social housing building in Dresden (D). *Credits* The Author 2012

The energy crisis first and the environmental crisis subsequently have catalysed the energy issue by making the energy performance of buildings apparently the unique objective.

Energy efficiency is certainly important; however, the environmental sustainability of the building must not be neglected, considering aspects that cannot be "measured" with the metre of energy performance, for example, the quality of building materials, the impacts of the building on the environment and the relationship of the building with the context. A zero-energy building can be sustainable from the energy point of view but unsustainable for the community if it is located outside the urban context, in an area badly served by public transport, which means the necessity of using private vehicles to reach it. The sustainability of living is more important than the sustainability of the building.

Environmental certification protocols such as Leadership in Energy and Environmental Design (LEED®) promoted by USGBC (US) or Building Research Establishment Environmental Assessment Method (BREEAM®) promoted by BRE (UK) enhance these aspects and therefore should be more widely employed.

9.2 Energy Balance of Buildings

Retrofit measures on the building envelope (or shell for US technicians) have the purpose of making more sustainable the relationship between the indoor space (or confined environment) in which it is necessary to ensure optimal comfort conditions and the external environment.

Heat fluxes through the opaque and/or transparent walls of the envelope must be controlled considering that the strategies in summer and in winter may change according to the different external climatic conditions. The general concepts of the strategies to be adopted can be summarized as follows:

- improvement of the thermal quality of the opaque and transparent envelope by mean of the increasing of the thermal resistance (reduction of the U value);
- control of solar radiation with the aim to making the most of the free heat contributions in winter while ensuring protection from the sun in summer;
- control of the lighting component of the solar radiation, favouring the technical solutions that use natural lighting but at the same time, protecting the interior spaces from the effects of glare;
- reduction of uncontrolled air infiltration.

To better understand how the retrofit strategies may be defined, it is important to refer to the energy balance on the building as illustrated in a simple schematic way, Fig. 9.3 fulfils that purpose for a winter energy balance (Dall'O' 2013).

The objective of an HVAC[2] system is to maintain within the indoor spaces the design operating conditions, such as a constant the air temperature of 20 °C in the winter season. The building interacts with the external environment, where the climatic conditions may vary: when the outside temperatures are lower, a heat flux to the outside is generated through the walls that define the envelope.

The thermal losses from the envelope increase as the outside temperature decreases, with a dependency upon the values of the thermal resistance of the individual components (opaque vertical walls, windows, roofs, basements, etc.). Better insulation, increasing the thermal resistance to the passage of heat, therefore helps to reduce heat losses.

To ensure the healthy environment of the internal spaces, it is necessary to maintain suitable internal air quality (IAQ). A correct air ventilation of internal spaces is therefore necessary, but on the other hand, it does contribute significantly to increasing heat losses since a part of the inside air must be continuously replaced with external fresh air which must be heated. The global energy losses for heating are the sum of the losses due to thermal dispersions through the envelope and the losses due to ventilation of spaces.

In the energy balance of a building, however, not only the heat losses but also the heat gains should be considered. Internal free gains are provided not only by people and equipment within the building (e.g. lighting systems, appliances, etc.) but also as

---

[2]HVAC is short for heating, ventilation and air conditioning. The system is used to provide heating and cooling services to buildings.

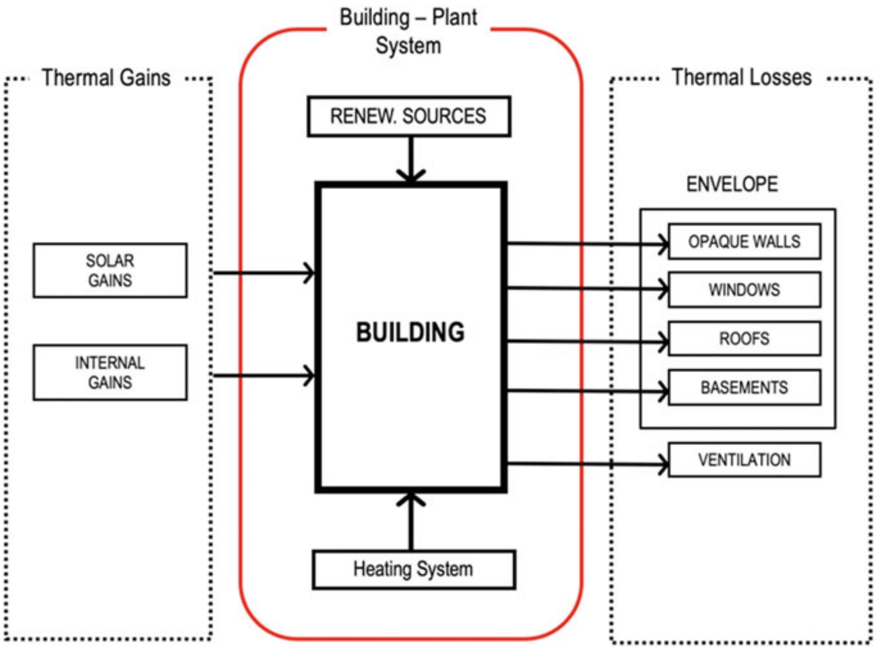

Fig. 9.3 Simplified energy balance for a building during heating season (Dall'O' 2013)

natural heat coming from the contributions of solar radiation through the transparent and opaque components of the building envelope.

If the objective is to maintain a constant internal comfort temperature, the difference between energy losses and energy gains must be compensated by the installation of an HVAC system: its contribution to the energy balance could be dramatically reduced by employing renewable energy sources (e.g. solar thermal, solar PV, biomass, etc.) to power it.

The energy balance shown in Fig. 9.3 considers only winter heating. In the overall energy assessment for the winter season, one should consider also other types of energy uses, such as those related to the production of domestic hot water, just as for the summer energy uses related to air conditioning must be taken into consideration (Dall'O' 2013).

The energy balance for summer cooling is more complex, as shown in the simplified diagram of Fig. 9.4.

The summer cooling load is greatly influenced by the construction components and materials of the building envelope and in particular by the transparent surfaces that interface with the solar radiation: the shielding and shading devices and the optical characteristics of glazing (in particular the characteristics of reflection) are very important to minimize the heat intake due to solar radiation.

During the winter heating, all free heat contributions, whether internal or external gains, are useful in the energy balance; during summer cooling, the opposite applies

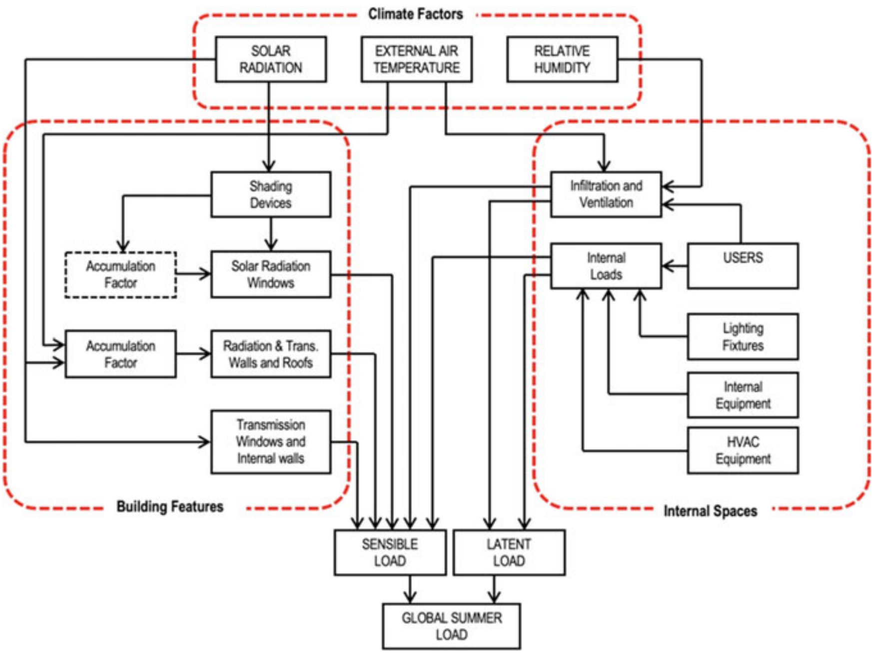

Fig. 9.4 Simplified calculation diagram for the summer cooling energy balance on a building (Dall'O' 2013)

since all the incoming heat (solar radiation) and generated heat (people, lighting, equipment, etc.) must be removed by the HVAC system. For this reason, the retrofit measures that aim to reduce these loads are very useful in saving energy besides their effects in increasing thermal comfort.

9.3 Green Energy Audit of Buildings

Reducing the energy consumption of an existing building and the environmental impact is often possible and convenient. However, initiating the process of implementing the changes is not simple if the customer–owner has little expertize and little or no awareness of the energy status of his/her building.

The technical instrument to effect this reduction is the energy audit, defined by the ISO 50002:214 Standard[3] as "a systematic analysis of energy use and energy consumption within a defined energy audit scope, in order to identify, quantify and report on the opportunities for improved energy". The main elements of an audit process are

[3]ISO 50002:2014 "Energy audits—Requirements with guidance for use".

- An analysis of building and utility data, including study of the installed equipment and analysis of energy bills;
- A survey of the real operating conditions;
- An understanding of the building behaviour and of the interactions with weather, occupancy and operating schedules;
- The selection and the evaluation of energy conservation measures;
- An estimation of energy-saving potential;
- The identification of customer concerns and needs.

A complete audit procedure has been proposed in the frame of the AUDITAC Project[4] and HARMONAC projects[5] to help in the implementation of the energy performance of buildings (EPB) directive in Europe and to fit to the current European market.

- *Benchmarking stage*: While normalization is required to allow comparison between data recorded on the studied installation and reference values deduced from case studies or statistics, the use of simulation models, to perform a code-compliant simulation of the installation under study, allows one to assess directly the installation, without any normalization being necessary. Indeed, applying a simulation-based benchmarking tool allows an individual normalization and allows avoiding size and climate normalization (Bertagnolio and Lebrun 2008).
- *Preliminary audit stage*: Global monthly consumptions are generally insufficient to allow an accurate understanding of the building's behaviour. Even if the analysis of the energy bills does not allow accurate identification of the different energy consumers present in the facility, the consumption records can be used to calibrate building and system simulation models. To assess the existing system and to simulate correctly the building's thermal behaviour, the simulation model has to be calibrated on the installation under study. The iterations needed to perform the calibration of the model can also be fully integrated in the audit process and help in identifying required measurements and critical issues (Andre and Bertagnolio 2010).
- *Detailed audit stage*: At this stage, on-site measurements, sub-metering and monitoring data are used to refine the calibration of the building energy simulation (BES) tool. Extensive attention is given to understanding not only the operating characteristics of all energy-consuming systems but also situations which cause variations in load profile on short- and longer-term bases (e.g. daily, weekly, monthly, annual). When the calibration criteria have been satisfied, the savings related to the selected energy conservation measures (ECOs) can be quantified (Bertagnolio et al. 2010).
- Investment-grade audit stage: At this stage, the results provided by the calibrated BES tool can be used to assess the selected ECOs and orientate the detailed engineering study.

---

[4] AUDITAC—Field Benchmarking and Market development for Audit methods in Air Conditioning.

[5] HARMONAC—Harmonizing air conditioning inspection and audit procedures in the tertiary building sector.

The problem is not only to evaluate strategies for improving performance but also to define a correct path regarding how to implement them in a rational way, considering not only the technical constraints but also the economic and legal aspects.

The decision to start any project stems from motivation; the stronger the motivation, the easier it will be to put it into effect.

The Green Energy Audit procedure developed by Dall'O' (2013) is not limited to reduce energy consumption; rather, it is aimed at a far more important goal: improving the overall sustainability of the building.

At the methodological level, the word "green" implies a series of choices:

- the definition of measures that lead to a reduction in the consumption of resources; conservation of energy then becomes conservation of resources;
- criteria of choice for interventions can be addressed from the outset with these indicators; the auditor then must have two objectives (or a proportioned mix of the two): to maximize energy performance and to maximize environmental quality;
- measures that use renewable energy are preferred (e.g. solar thermal, solar photovoltaic and biomass);
- when defining measures, the auditor should consider all natural solutions that can help control the climate and light in the building, such as green roofs, green facades, natural shading systems, passive solar and daylighting systems;
- evaluation of sustainability targets according to the recognized protocols (e.g. LEED®, BREEAM®, etc.).

The aim of a Green Energy Audit is to identify measures that can improve the energy performance and sustainability of the building in question.

The cost/effectiveness analysis allows the identification of the most advantageous scenario, while the intersection with the LEED® credits suggests the most sustainable measures and in general terms, the solutions and technologies with environmental benefits. For example, the assessment of measures aimed at improving thermal insulation of the building should consider the benefits of reducing demand for virgin materials and reducing waste: it may be possible to use salvaged, refurbished or reused materials or use materials with a recycled content.

In the construction phase, a construction waste management plan should be developed and implemented with the aim of recycling and salvaging non-hazardous construction materials and demolition debris.

Numerous other environmental aspects could be considered in the assessment of measures and their application: restoring vegetation on the site after construction, reducing the heat island effect using vegetation or materials with a high reflectance, employment of alternative surfaces and techniques to increase on-site infiltration and to reduce pollutants from stormwater runoff.

The main difference between the energy audit and Green Energy Audit approach lies in the way in which the retrofit strategies are defined. In a conventional energy audit, retrofit actions are normally defined on the basis of cost/effectiveness parameters. Some measures considered in the Green Energy Audit are not cost-effective at all because they have no affect on energy saving (e.g measures which optimize the air quality).

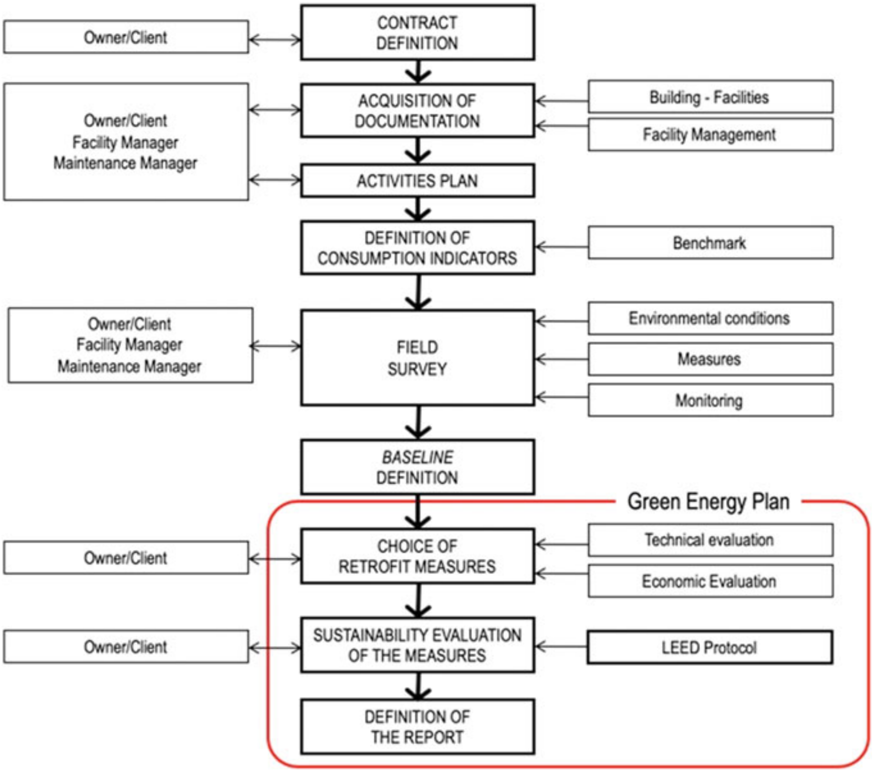

Fig. 9.5 Flux diagram of the Green Energy Audit process (Dall'O' 2013)

A Green Energy Audit is aimed at improving the overall sustainability of the building, so it is necessary to consider environmental aspects which compensate the reduction of cost effectiveness.

For this very reason, in the procedure presented, a prior evaluation is made of the LEED® classification that can be potentially achieved. The procedure of Green Energy Audit is shown in Fig. 9.5 (Dall'O' et al. 2012a; Dall'O' 2013).

9.4 Planning of Energy Retrofit Actions

9.4.1 Towards an Integrated Strategy

Energy retrofit actions, or ECOs, can significantly reduce the energy consumption of existing buildings. With reference to the diagrams in Figs. 9.3 and 9.4, it is possible to optimize the energy performance of the building envelope (external walls, roofs, basements) by reducing the energy flows that pass through it.

Some energy retrofit actions may concern HVAC systems: by increasing the energy performance of plant components, even by replacing a part of them, it is possible to reduce inefficiencies by better exploiting the potential of given fuels or energy vectors.

Renewable energy sources (e.g. solar thermal, photovoltaic solar, biomass) can make an effective contribution to the energy and environmental balance of the building. Their "weight" in the energy balance is greater if the building as a whole is more efficient: their use is therefore recommended as long as all the energy retrofit actions on the building envelope and on the HVAC systems have already been planned.

Energy retrofit actions should cover all energy uses: winter heating, summer cooling, domestic hot water production, lighting and other electrical uses.

In an environmentally sustainable project, actions should also be envisaged to reduce the use of resources, such as the reduction in wastage of drinking water, as well as in the choice of construction materials, the preference necessarily being for those with lower environmental impact.

Consistent with the diagram in Fig. 9.5, the choice of energy retrofit strategies must be verified not only from the technical point of view (i.e. the feasibility of the action) but also from the economic point of view. The actions that concern the building envelope, more expensive and with longer payback times, should be applied in cases where the building requires significant maintenance.

9.4.2 Thermal Insulation of the Roofs

The energy retrofit actions on roofs depend on their morphology. In the case of pitched roofs, thermal insulation could be applied from the inside or from the outside. External thermal insulation is convenient when the roof requires rebuilding. Thermal insulation of the building's roof allows one to obtain energy benefits not only in winter but also in summer since the roof is a part more subject to solar radiation.

The application of these measures is convenient if the space below the pitched roof is normally used/occupied, otherwise it is more convenient to thermally insulate the floor slab which borders with the space below.

An interesting technique also from the environmental point of view is that of the "green roofs system". A green roof is a roof partially or completely covered with vegetation and a growth medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier and drainage and irrigation systems. This technique can be applied both on pitched roofs and on flat roofs, but the latter is decidedly more common thanks to the significant associated advantages that can be obtained.

The green roof can be applied, without distinction to any building regardless of the intended use: there are many examples of application of green roofs on residential constructions or office buildings, industrial warehouses, shopping malls, schools and recreational buildings (Dall'O' 2013).

Green roofs permit many advantages to be obtained for a building, such as absorbing rainwater (water is stored by the substrate and then taken up by the plants, from where it is returned to the atmosphere through transpiration and evaporation), providing thermal insulation (depending on the used material and the thickness of the layer), reducing summer cooling needs (by evaporative cooling), helping to lower urban air temperatures and mitigate the heat island effect (green roofs can contribute to obtain credits on LEED® protocol), creating a habitat for wildlife.

9.4.3 Thermal Insulation of the Façades

So far as the facades of existing buildings are concerned, the most efficient retrofit technique is that of insulation from the outside. The External Thermal Insulation Composite System (ETICS) is an optimal solution for the energy retrofit of the external walls of existing buildings (this technology is also commonplace as solution for new buildings).

ETICS is a system applied from the outside of the wall, usually including an adhesive, a levelling mortar, an insulation panel, an alkali-resistant reinforcement grid, a primer and a finishing coat, as well as sealants and accessory materials for the installation.

The main advantage of this measure derives from the continuity of the insulation, which eliminates thermal bridges and the risk of surface and interstitial condensation. The measure increases the thermal inertia and the sound insulation of walls, thus improving both the thermal and the acoustic comfort for users. The operation is carried out relatively quickly and completely from the outside, with very limited discomfort for users from the works.

If the thermal insulation of the walls from outside is not possible (e.g. for architectonic constraints), the thermal resistance of the walls can be increased through internal insulation using a counter-wall.

Amongst the green technologies for the built environment, green façades or green walls are interesting solutions which can be used for energy and/or environmental improvement retrofit of existing buildings.

The greening systems for vertical walls can be divided into two categories: green façades and living walls (vertical gardens). Green façades are made of green climbing plants that grow directly on the façade or in front of the façade if supported by structures such as grids and cables. Living wall systems (LWS) are constituted by pre-vegetated panels or integrated systems fixed to a structural wall or to a frame, with hydroponics for the growth of vegetation.

The installation of a green wall provides several advantages:

- *in summer,* there is a reduction of the solar load on the protected wall surface, estimated at around 30–40%. Shading generated by the vegetation reduces the maximum surface temperature by about 10 °C on days with higher radiation (the phase shift of the peak of heat is around 8 h);

- *in winter*, the presence of the vegetation on the façade reduces convective phenomena, increasing the overall thermal resistance of the wall.

One of the additional benefits of the vegetation regards the capture and retention of fine dust particles on the surface of the leaves. Particles smaller than 10 μm, present in particular in the urban areas, may cause damage to health because they can be inhaled into the human respiratory system.

Green façades may have a positive impact on both physical and mental health and well-being. Green views and access to green spaces in cities help to relieve the everyday pressures of crowds and noise (Dall'O' 2013).

In the energy balance of a building, windows are critical elements. In fact, within this single component, many needs must be satisfied: thermal insulation, solar control, environmental comfort, visual comfort, acoustic comfort and ventilation.

Where energy performance or structural performance cannot be guaranteed, one should verify the state of the windows and possibly plan a global replacement. In order to reduce the *U* value of the glazing, two strategies can be adopted: a surface coating treatment of the glass panes (e.g. low-emissivity, selective coatings, etc.) and the filling of the interspaces between the panes with gases with low thermal conductibility (e.g. Argon, Xenon, Krypton) instead of air.

A window must guarantee the energy performances not only in winter but also in summer, whereas in the winter, the effects of solar radiation are positive (solar gains), and in the summer, solar radiation is the main source responsible for the thermal loads. On designing the new windows, the control of solar radiation (e.g through the installation of external or internal solar shading systems) must be considered in order to reduce the cooling demand of HVAC systems and increase the thermal comfort of the users.

The use of vegetation for sun protection of façades or windows is a natural solution that can contribute to an increase in the sustainability of the building. The objective is to provide an independent green structure that could be installed adjacent to the walls to be protected or positioned at a certain distance from it.

The possibility of using vegetation with deciduous leaves allows the use of the energy benefits of solar radiation in winter (solar gains) but at the same time protects the walls or the windows in summer.

9.4.4 Improvement in the Efficiency of HVAC Systems

For HVAC systems, retrofit actions must be aimed at achieving the following objectives:

- guaranteeing thermal comfort and IAQ both in summer and in winter;
- generate heat, or cooling, with maximum energy efficiency;
- allow local control of environmental conditions.

As regards heat generation, short-term interventions could consist in replacing the existing boiler. The replacement of an existing boiler with a new one of higher performance (e.g. condensing boiler) helps to increase the heat generation efficiency of the system, hence reducing operating costs for winter heating and DHW.

Amongst the combustion heating technologies, the one that offers the best energy performance is condensing technology. In condensing boilers, high efficiency is obtained (typically up to 108% if referred to lower heating value) by recovering the latent condensing heat of the water vaporcontained in the fumes.

Before replacing the existing boiler, it is advisable to perform a global calculation of the energy needs of the building so that the new boiler is chosen with a corrected heating capacity. Indeed many existing buildings were erected and equipped before laws or rules on energy efficiency were introduced. Since the size of the boiler was not well-defined, boilers were normally oversized with a heat capacity in most cases double that of the required capacity.

Condensing boilers, even if efficient, use fossil fuels (methane). For environmental problems, the current tendency is to not use more traditional fuels but to refer to electricity. In a "green" vision of cities, the generation of heat and cooling will be increasingly orientated towards the use of heat pumps.

In reversible models with a single appliance, it is possible to produce heat for winter heating and cold for summer air conditioning. Heat pumps, by consuming electricity, integrate well with photovoltaic solar systems. NZEB buildings have long used this configuration (solar PV and reversible heat pump).

In existing buildings, much of the energy wastage, which can be estimated at up to 30%, are due to the inefficiencies of the control system. Therefore, great attention must be paid to this aspect. The efficient regulation systems, using a local control, allow the comfort conditions to be managed in a timely manner and allow the use of free external energy supplies (e.g solar radiation and for lighting systems, natural light) or internal (heat developed by people and equipment in winter).

In this sector, technological innovation has evolved considerably, and the market, even via Internet resources, is marketing efficient, simple to use and low-cost home and building automation control systems.

9.4.5 Renewable Energy Sources

Renewable energy sources, in particular solar thermal, solar photovoltaic and biomass, will play a fundamental role in the development of green cities, and in part, they are already doing so.

The theme is obviously complex and for the use of renewable energy sources in green planning, a chapter of this book (Chap. 10, the role of renewable energy sources in green planning of cities and communities) has been dedicated to the topic. This sub-section is limited to an expression of some general considerations.

The drastic reduction of solar PV costs makes it convenient for its installation in existing buildings in "green connected" plant configurations. Solar PV directly produces electrical energy, and this is a great advantage because this energy can be used for electrical uses but also for thermal uses (e.g winter heating and hot water production) and in an efficient manner by employing a heat pump.

A feature of this technology is its application flexibility: the solar modules can be installed as an integral part of the building's roof but can also be integrated into the façade. The technology also lends itself to insertion and integration on an urban scale, for example, in vehicle parking shelters.

Solar thermal technology only produces heat that can be used for uses such as environmental heating, hot water production or processes. The strong competition of solar PV makes this technology applicable to situations in which the only objective is to produce hot water without special needs. It should be recalled that solar PV, thanks to the connection with the public electricity grid, can exploit all the energy captured, while the solar thermal can only operate in combination with thermal storage and is therefore configured as a stand-alone plant. Architectural integration of solar thermal is more difficult, and maintenance costs are greater.

9.5 Deep Renovation of Buildings

The activity of retrofitting is now growing, thanks to the financial incentive policies (in Italy, for example, with tax deductions, it is possible to cover up to 75%, of the costs related to an energy retrofit). Other elements that play in favour are the greater awareness on the part of citizens/users on environmental issues and the real estate marked which is beginning to recognize the value of efficient and sustainable buildings.

However, the CO_2 reduction targets for 2030 and 2050 are very ambitious and require greater efforts.

All new buildings, which are built respecting the high-energy-efficiency standards imposed by national legislation (in the EU at least NZEB), contribute to reducing CO_2 emissions in the building sector; however, it is unthinkable to envisage a complete replacement of the existing building stock in so few years. The sector of existing buildings, built in periods in which energy efficiency was not a problem and hence very inefficient, is the area on which to act decisively.

An energy requalification that acts on buildings in a partial way, for example, through the replacement of the boiler or the replacement of doors and windows, is simply not enough and more needs to be done.

The Energy-Efficiency Directive (EED) (Directive 2012/27/EU) (UE 2012) and the revised Energy Performance Building Directive (EPBD) (Directive 2018/844) (EU 2018) both contain provisions for increasing Europe's renovation rate. The greatest challenge to reducing energy use in buildings lies in increasing the rate, quality and effectiveness of building renovation since the current rate is merely 1.2% per year. Effective renovation approaches need to be widely demonstrated and then replicated to ensure that the renovation rate rises to between 2 and 3% each year.

The US Department Of Energy (DOE) promotes energy technology and innovation in the USA. The DOE has set a "Better Buildings Initiative" challenge that pushes for a 20% reduction of energy across a portfolio of commercial and industrial buildings by 2020.

The DOE has designed "Advanced Energy Retrofit Guides"[6] for existing buildings in order to assist building stakeholders in the selection of energy-efficiency improvements. Within these guides, they claim "deep retrofits can reduce a building's energy use by over 50%. Deep retrofit projects combine many O&M and standard retrofit measures in an integrated whole-building design approach" (Shnapp et al. 2013).

The winning strategy to accelerate the process of renewing existing building stock is "deep renovation". But what is exactly its meaning? An answer to this question is given by Shnapp et al. (2013) that in their research work identify some definitions.

- *Deep Renovation* or *Deep Energy Renovation* is a term for a renovation that captures the full economic energy-efficiency potential of improvement works, with a main focus on the building shell, of existing buildings that leads to a very high-energy performance. The renovated buildings energy reductions are 75% or more compared to the status of the existing building/s before the renovation. The primary energy consumption after renovation, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting after the deep renovation of an existing building, is less than 60 kWh/m^2/yr (definition often used in Europe).
- *Deep Retrofit* or *Deep Energy Retrofit* implies replacing existing systems in a building with similar ones that are of higher quality and performance, which leads to a better energy performance of an existing building. The primary energy consumption includes energy used for heating, cooling, ventilation, hot water, lighting, installed equipment and appliances. After the deep retrofit, the buildings energy reduction is 50% or more compared to the status of the existing building/s the retrofit (definition mainly used in the USA).

Deep Reduction or *Deep Energy Reduction* is a term used in the USA for a deep renovation or a deep refurbishment, which aims at more than 75% reduction in energy use in comparison with that prior to the improvement[7]:

- *Zero-Carbon-Renovation*: A deep renovation with large-energy consumption reductions, where the energy needed to supply the resisting need is carbon neutral;
- *Zero-Energy-Renovation*: A deep renovation with large-energy consumption reductions, where the energy needed to supply the resisting need is supplied as renewable energy on site.

An interesting contribution, from an economic point of view, to the topic of deep (in-depth) renovation was commissioned by EURIMA, the European Insulation Manufacturers Association (Hermelink and Müller 2010). Scope of the study provides a notion of economic viability for single and multi-family homes across the EU, taking a case study analysis as basis. The study discussed the economic feasibility of

[6]Available on: https://www.energy.gov/eere/buildings/advanced-energy-retrofit-guides (Accessed 20 September 2019).

[7]This is a definition commonly used by the Thousand Home Challenge, find more information at: http://thousandhomechallenge.com/.

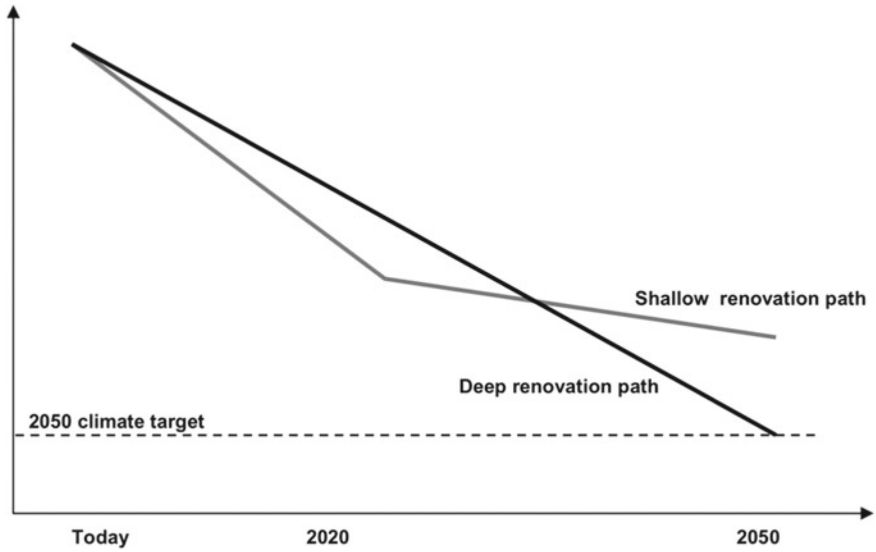

Fig. 9.6 Speed trap of shallow renovation (Hermelink and Müller 2010)

deep renovations for single and multi-family homes using the German "Low Energy Building Stock" programme as a case study.

According to the study, dynamic simulations for future building stock scenarios have clearly shown that "deep renovation at reasonable speed" is a more promising strategy to reach the 2050 climate targets than "shallow renovation at high speed" (shallow meaning that current national requirements for renovation are just met).

It is important to do projections till 2050 as projections till only 2020 may be misleading and suggest an inadequate strategy. As the schematic paths in Fig. 9.6 show, at the interim milestone 2020, a "shallow renovation" strategy might look better than a "deep renovation" strategy while surprisingly failing to achieve the crucial 2050 target.

The usually performed short-term projections contain a severe risk of becoming irreversibly caught in this "speed trap of shallow renovation": usually renovations with the best investment/saving ratio are done at the start of a nation's renovation programme. These are the buildings having the highest absolute saving potential. When these buildings undergo a "shallow" renovation, huge absolute savings remain untapped.

As regards the US market, Cluett and Amann (2015) published a report regarding residential deep energy retrofit. The report explored energy-efficiency programmes that target in-depth energy savings through substantial improvements to existing residential buildings.

The authors have stated that "deep energy retrofit case studies show that existing technology and practices can result in energy savings of 50% or more. However, there are still many barriers to adoption and delivery on a large scale". The barriers highlighted by the study are the following:

- *Workforce*: one of the barriers to implementing in-depth energy retrofit measures was access to a workforce with the right skills.
- *Market interest and acceptance*: encouraging homeowners to undertake in-depth energy retrofits at the time of major home renovations is a promising opportunity.
- *Financial barriers*: it is difficult to complete an in-depth energy retrofit that saves more than 50% of the energy used in a home without significant financial investment. Many homeowners simply cannot afford the upfront capital investment necessary for in-depth energy improvements.
- *Cost effective*: cost effectiveness is a challenge for utility programmes involving in-depth energy retrofits. More data from completed projects are needed in order to assess the cost effectiveness of comprehensive energy retrofits as well as individual measures.

9.6 A Case Study of In-Deep Renovation: Energiesprong

One of the most important in-depth renovation case studies is the Energiesprong project. The idea of Energiesprong originated in the Netherlands, where it began as a government-funded innovation programme to drive an improved energy-efficient standard in the Dutch market.

Today in the Netherlands, over 5000 homes have been retrofitted to desirable, net zero-energy houses at no extra costs for the residents. The mission of the Energiesprong Foundation is to scale this approach to more markets, to create an industry which is able to design, produce and deliver whole house retrofits with excellence across millions of houses.

Currently, Energiesprong teams are active in the Netherlands, France, the UK, Germany and Northern Italy. In New York State (RetrofitNY) and California, initiatives inspired by Energiesprong are working on a solution for the USA.

After an Energiesprong retrofit, a home is net zero energy, meaning it generates the total amount of energy required for its heating, hot water and electrical appliances. It also provides superior indoor comfort.

This can be achieved by using new technologies such as prefabricated facades, insulated rooftops with solar panels, smart heating and ventilation and cooling installations. A refurbishment comes with a long-term performance warranty on both the indoor climate and the energy performance for up to 40 years. A complete home makeover can be completed in less than 10 days, and some have been done in as little as a day.[8]

An energy redevelopment is Energiesprong when it meets the following four conditions:

[8]Source: https://energiesprong.org/about/.

Fig. 9.7 Installation phase of the prefabricated elements of the building envelope in a residential building in UK, within the Energiesprong project. *Credits* The Renewable Energy Hub, https://www.renewableenergyhub.co.uk/blog/what-are-energiesprong-homes/

- *Accessible*: to finance the redevelopment of the building through a drastic reduction in consumption, intervention and maintenance costs.
- *Quality*: the performance of the building is provided and guaranteed in the long-term by the same enterprise who carries out the intervention. This constitutes an intrinsic guarantee of quality.
- *Non-intrusive*: the redevelopment is carried out in two weeks and allows tenants to stay in the building for most of the time. This is made possible thanks to the engineering and optimization of the entire process.

In general, an Energiesprong renovation or new build is financed by future energy cost savings plus the budget for planned maintenance and repairs over the 30 years following the renovation works. Figure 9.7 shows an example of deep renovation process using prefabricated elements.

This allows residents to maintain the same cost of living. In the case of housing associations, tenants pay the housing association an energy service plan which is the equivalent of their previous energy supplier's bill.

9.7 Energy Retrofit Potentials in a Case Study

The topic of energy renovation of buildings is the subject of numerous studies and much research by professors and researchers of the Department of Architecture, Built environment and Construction engineering (ABC) of the Politecnico di Milano.

This case study describes an innovative approach for the analysis of the potential energy savings of retrofitting existing building stocks: it considers in particular the actual technological and economic constraints of the implementation of feasible energy-efficiency measures (Dall'O' et al. 2012b).

The analysis was applied to five municipalities in the province of Milan that have signed the Covenant of Mayors, committing to meet and exceed the 20% CO_2 reduction objective of the EU by 2020. Because the scale of the analysis is municipal, the resolution of the requested data is high. In order to achieve realistic and achievable energy savings, the authors created an energy cadastre and conducted a large in-field survey for each municipality.

By determining the characteristics of the building stock, one then knows which energy retrofit actions are feasible from a technical, legal and economic point of view. The result is a tool that does not overestimate the potential energy savings, helping the public administration/local authorities to define their energy-saving policies.

The methodology for the analysis of the potential energy savings of energy retrofits of existing building assets is outlined in the flow chart in Fig. 9.8.

The different phases of the process are shown in the central portion of the flow chart; the actors (operators and technicians) involved are listed on the left, and the activities and tools are described on the right.

In this study, the authors wanted to emphasize the methodology and the analysis of the potential surfaces. Thus, only improvements to the building envelope, such as the thermal insulation of external walls and roofs and window replacement, were considered.

A comprehensive methodology also includes the analysis of the potential energy savings to be derived from increasing the efficiency of the heating system and household appliances and of installing photovoltaic and thermal panels on the roof.

As identified by Nemry et al. (2008) in order to improve energy efficiency of existing buildings, the most significant options are

- replacement of windows;
- additional facade insulation;
- additional roof insulation.

The first phase consists of collecting all the information that may be useful for analysis on an urban scale, for example, site maps, aerial photogrammetric surveys and orthophotos of the area. Maps available in digital formats are helpful, especially on the Internet, for example, in the digital archives of Provinces and Regions (thematic maps). Google Earth® is also very useful if the maps are sufficiently updated, particularly to detect building roofs.

A cadastre was created in order to classify each building by typology and age of construction.

On-site surveys were useful to determine the state of conservation of the buildings upon which the possible retrofitting depends.

Each building is identified by the block typology and a unique number (Fig. 9.9). This classification was implemented in a database to combine several characteristics and form an energy cadastre.

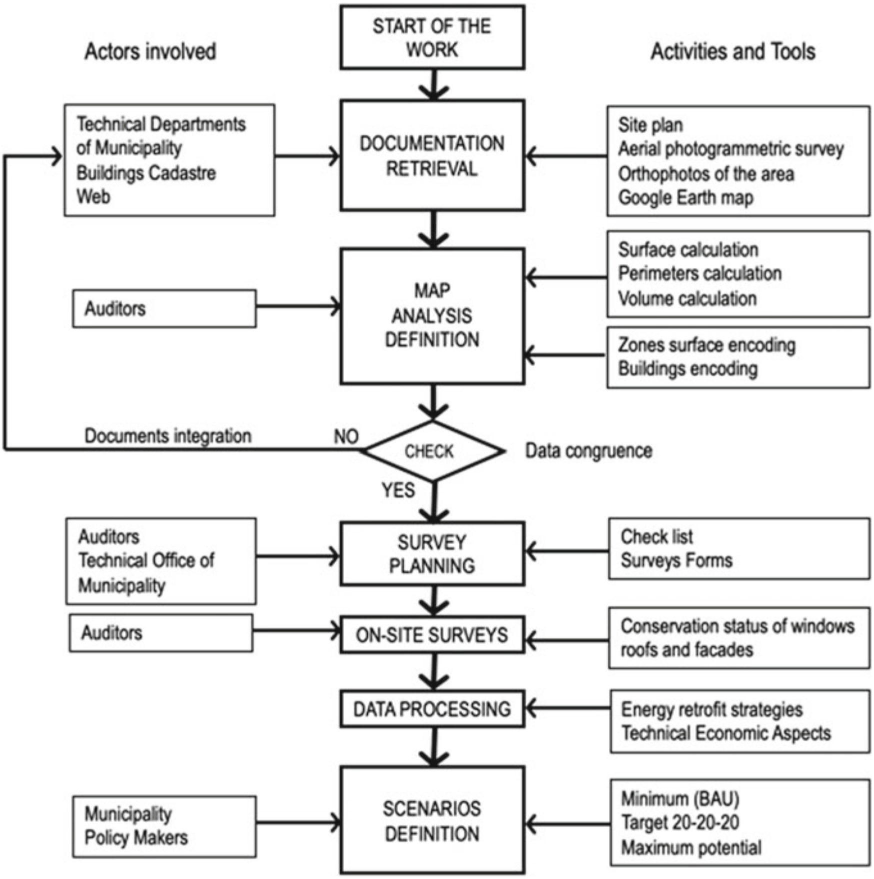

Fig. 9.8 Flow chart of the methodology (Dall'O' et al. 2012b)

Survey results for the state of conservation of the buildings are visible in the graph of Fig. 9.10. The percent of buildings in poor condition is lower for recently constructed buildings.

In the energy cadastre, the net area, transparent surface, opaque surface and roof area for each building were all calculated. Owing to the characteristics surveyed, it was possible to distinguish the potential retrofitting surfaces, i.e. to distinguish between those surfaces where energy retrofitting was possible and those surfaces for which no retrofitting could be envisaged.

Examining the walls of the building envelope, the areas were divided into three categories:

- ETICSable buildings on which it is possible to retrofit using an ETIC; i.e. buildings with plastered walls in poor condition and without constraints;

Fig. 9.9 Extract of the cadastre map with encoding (Dall'O' et al. 2012b)

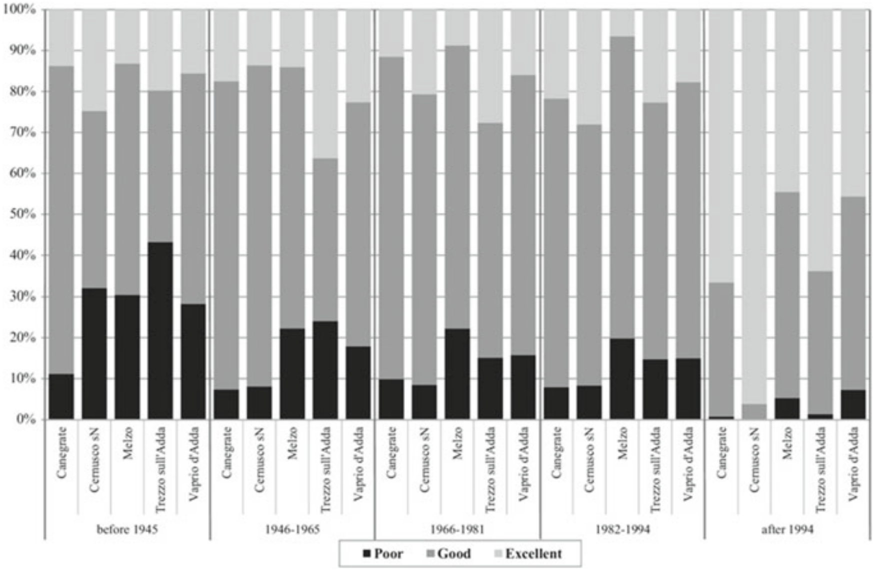

Fig. 9.10 State of conservation of building stock (Dall'O' et al. 2012b)

- Partially ETICSable buildings on which it is partially possible to retrofit using ETICS; i.e. buildings with plastered walls in good condition and without constraints;
- Non-ETICSable buildings on which it is not possible to retrofit using an ETICS; i.e. buildings with non-plaster walls, in excellent conditions or with constraints (e.g historic buildings).

The second scenario assumes that the required efforts, in terms of regulation implementation and related investments, are made to reach the goal of 20% reduction of CO_2 emissions (where 2005 is assumed as baseline).

The third scenario defines the maximum potential of the improvement of the building envelope efficiency considering the real constraints. This last scenario is very important because it provides clear and objective information about the achievable limit if the true goal is to maintain the building stock (Fig. 9.11).

The results of this study, which is based on a real model (five municipalities), provide two elements for reflection: the first is that in intervening in existing buildings sometimes there are objective constraints that do not allow retrofit intervention on the envelope (e.g architectural constraints), the second is that a scenario based on market rules (BAU) is not sufficient to achieve the greenhouse gas reduction targets: a robust action plan is needed, and economic incentives are needed. The Energiesprong model seen in the previous section can be considered to be a winning scheme.

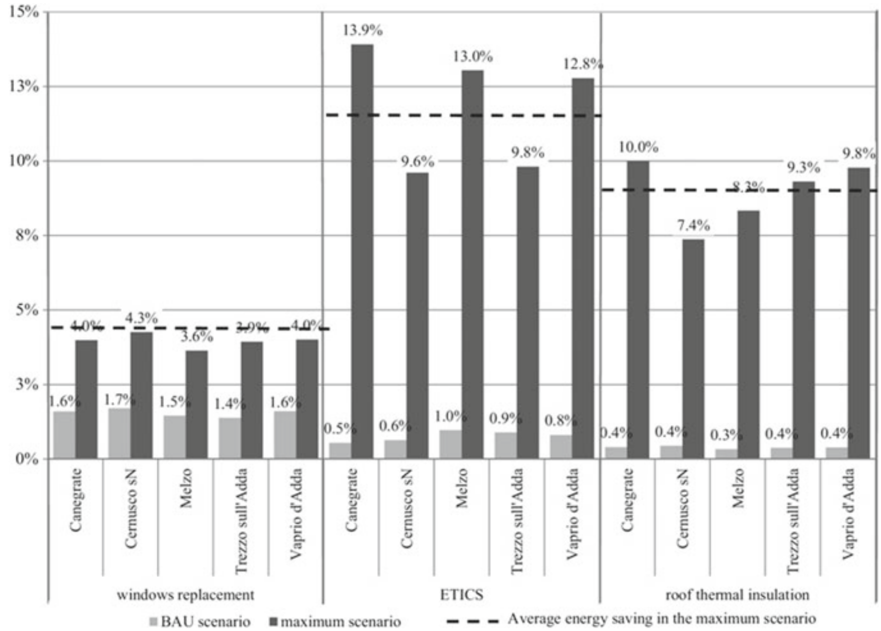

Fig. 9.11 Potential energy savings in the BAU and maximum saving scenario (Dall'O' et al. 2012b)

9.8 Conclusions

The 2015 Paris Agreement on climate change following the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21) boosts the Union's efforts to decarbonize its building stock. Taking into account that almost 50% of Union's final energy consumption is used for heating and cooling, of which 80% is used in buildings, the achievement of the Union's energy and climate goals is linked to the Union's efforts to renovate its building stock by giving priority to energy efficiency, i.e. making use of the "energy efficiency first" principle as well as considering deployment of renewables.

The European Union is committed to developing a sustainable, competitive, secure and decarbonized energy system. The Energy Union and the Energy and Climate Policy Framework for 2030 establish ambitious EU commitments to further reduce greenhouse gas emissions by at least 40% by 2030 as compared with 1990, to increase the proportion of renewable energy consumed, to make energy savings in accordance with Union level ambitions and to improve Europe's energy security, competitiveness and sustainability (EU 2018).

These ambitious goals are faced with an existing building stock which on the one hand constitutes an interesting energy retrofit market but on the other shows a series of critical aspects which must be overcome.

If the approach to the energy redevelopment of buildings considered the city as an object of interest and was not concentrated on the single building, it could promote energy redevelopment policies that also become policies for requalification and renewal of the city as a whole.

An urban strategy, through green planning, should make choices in the interest of the community by promoting an energy requalification that does not a priori exclude the demolition of existing buildings and the replacement of these with new and energy-efficient buildings (NZEB or ZEB).

For the energy recovery of existing buildings that deserve to be maintained due to their peculiarities (architectural, historical, environmental, functional, social and cultural values), rather than waiting for a market development according to a BAU scheme, it is useful to promote strong actions: the Energiesprong model, discussed in this chapter, has proved its effectiveness.

An urban strategy is correct if it concerns itself with energy efficiency, but other aspects must also be considered. The large-scale application of rating systems based on environmental certification protocols for buildings should be facilitated in order to enhance the relationship between buildings and the urban environment in which they are increasingly integrated.

References

Andre P, Bertagnolio S (2010) Development of an evidence-based calibration methodology dedicated to energy audit of office buildings. Methodology and modeling. In: 10th REHVA World Congress—Clima 2010

Bertagnolio S, Lebrun J (2008) Simulation of a building and its HVAC system with an equation solver. Application to benchmarking. Build Simul 1(3):234–250. https://doi.org/10.1007/s12273-008-8219-4

Bertagnolio S, Andre P, Lemort V (2010) Simulation of a building and its HVAC system: application to audit. Build Simul 3(2):139–152. https://doi.org/10.1007/s12273-010-0204-z.hdl:2268/9501?locale=en

Cluett R, Amann J (2015) Multiple benefits of multifamily energy efficiency for cost-effectiveness screening. Report A1502, American Council for an Energy-Efficient Economy. Available at: http://www.ourenergypolicy.org/wp-content/uploads/2015/06/a1502.pdf. Accessed 20 Sept 2019

Dall'O' G (2013) Green Energy Audit of Buildings, a guide for a sustainable energy audit of buildings. Springer, London

Dall'O' G, Speccher A, Bruni E (2012a) The Green Energy Audit, a new procedure for the sustainable auditing of existing buildings integrated with the LEED protocols. Sustain Cities Soc 3:54–65

Dall'O' G, Galante A, Pasetti G (2012b) A methodology for evaluating the potential energy savings of retrofitting residential building stocks. Sustain Cities Soc 4:12–21

EC (2002) Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings

EC (2016) EVALUATION of Directive 2010/31/EU on the energy performance of buildings. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/2_en_autre_document_travail_service_part1_v2_0.pdf. Accessed 13 Sept 2019

EU (2010) Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings

EU (2018) Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (text with EEA relevance)

Hermelink AH, Müller A (2010) Economics of deep renovation: implications of a set of case studies. Report commissioned by EURIMA—European Insulation Manufacturers Association. Available at: https://www.eurima.org/uploads/ModuleXtender/Publications/51/Economics_of_Deep_Renovation_Ecofys_IX_Study_Design_FINAL_01_02_2011_Web_VERSION.pdf. Accessed 13 Sept 2019

Nemry F, Uihlein A, Makishi Colodel C, Wittstock B, Braune A, Wetzel C et al (2008) Environmental improvement potentials of residential buildings (IMPRO-building). Office for Official Publications of the European Communities (JRC Scientific and Technical Research Series), Luxembourg

Shnapp S, Sitjà R, Laustsen J (2013) What is a deep renovation definition? Technical report, Global Buildings Performance Network. Available at: http://www.gbpn.org/sites/default/files/08.DR_TechRep.low_.pdf. Accessed 13 Sept 2019

UE (2012) Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027. Accessed 12 Sept 2019