

Review

Passive Envelope Measures for Improving Energy Efficiency in the Energy Retrofit of Buildings in Italy

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Abstract: The Italian territory is characterized by a big increase in energetic demand, especially for cooling, mainly related to climate change but also to the poor quality of a consistent construction sector, such as the suburban 1960–1980 building stock. At the same time, the cost of fuel and electricity due to the recent war events forces us to find alternative solutions to save energy in buildings. This study proposes building envelope passive design strategies to improve the energy efficiency of residential buildings in the Mediterranean climate, which is typical of the Italian territory. The main purpose is to provide an overview of potential passive measures to improve the energetic quality of construction in response to the above-mentioned issues and consequently to the increasing restrictions of energy regulations (passive buildings and NzeB). A categorization of passive measures is provided by exploring three different passive behaviors: heat reduction, heat gain, and heat protection. Specific energy-efficient measures for building retrofit are investigated according to this classification, including solar greenhouses, natural ventilation techniques, and radiative, convective, and conductive heat transfer through opaque and transparent envelopes. As the building envelope is mainly responsible for heating exchange and accounts for 50% of the overall energy balance, it is concluded that the “ad hoc” design of building envelopes can significantly improve the overall thermal performance of residential buildings.

Keywords: envelope; passive buildings; energy efficiency; retrofit; building energy



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1. Introduction

Due to the NZEB (Nearly Zero Energy Buildings) Directive [1], the need to reduce the energy demand using passive measures and design sustainable buildings that reduce the use of non-renewable energy sources has become a crucial point. Bioclimatic architecture starts with an appropriate building design and material and systems selection, in synergy with environmental elements such as the air and the sun, to improve the thermal and visual comfort of occupants. Bioclimatic architecture has been developed since the 1960s to meld passive strategies for reducing energy use with occupants’ thermal comfort, representing a starting point for new and refurbishment design projects [2]. Several authors have proposed the implementation of energy-saving strategies, organizing them according to environmental parameters [3,4]. The literature review has regarded, at the first stage, the renovation of existing buildings from a sustainable perspective, with the threefold purpose of improving the architectural image, the requirements of their occupants, and the reduction in energy consumption. There are a multitude of studies focusing on sustainable renovation practices in residential buildings, highlighting the decreasing environmental impact and increasing the comfort of life [5–8]. These studies prove how appropriate technology solutions for renovation, in various typologies, can be advantageous in the overall behavior of the building.

The second field covers bioclimatic design and the use of passive measures in sustainable design. In bioclimatic design, there should be two categories of action that can be undertaken to improve the global energy performance of the building: passive and

active measures. Passive measures are design principles of the building envelope that allow for the reduction in energy demand by maximizing or minimizing heat losses and heat gains. A multitude of works can be found in the literature dealing with the improvement of buildings' energy performance using energy retrofit actions [9].

Active measures are systems used to collect energy coming from natural sources (e.g., sun, wind, etc.) to convert and produce an energy vector (electricity, heat, etc.). In the last twenty years, several studies have investigated the benefits of using passive design strategies for energy saving in residential buildings, mainly in retrofit actions. The literature review covers many studies that have investigated optimum thermal insulation [10], window glazing [11], solar shading [12], and cool roof concepts [13]. Most of the cited studies have concluded that applying passive measures is an effective approach to improving energy efficiency. Specifically, several studies evaluated the impact of thermal insulation type and its thickness on reducing energy consumption in residential buildings in Italy [14,15]. In the last two decades, the progressive migration toward transparency in architecture caused intensive efforts to improve the thermal properties of glazed envelopes by using innovative solutions, such as double glazing, low-emissivity coatings, low-conductivity frames, and inert gas fill. This approach could reduce the annual cooling load by 7.2%, with a highly significant reduction in the peak cooling load reaching 36% [16]. In other studies, the contribution of using extensive green roofs to improve thermal mass and consequently reduce cooling energy consumption in residential buildings is assessed [17]. In general, previous studies have focused on a particular envelope component in cold and moderate climates, while others have studied the relative efficiency and impact of passive design strategies. In hot temperate climates, they have not been treated so profoundly. In this sense, this study could represent a design guideline for effective solutions for residential buildings with similar climate areas in Italy.

2. Materials and Methods

This study aims to analyze the building envelope's passive design measures to improve the energy efficiency of residential buildings in the Mediterranean climate, typical of the Italian territory.

The main goal is to provide an overview of passive design strategies applicable to the building envelope's design refurbishment to fulfill new energy-efficient building requirements and improve the thermal behavior of users. These practices can be very helpful in reducing building consumption in the case of existing buildings that, according to the new EU Directive [18], must be upgraded to more efficient standards (at least D Energetic class) by 2050.

To achieve these goals, the study starts by analyzing theories and concepts related to the passive envelope measure topic presented in the literature review. The next step is to identify the typical post-war residential buildings in the Italian territory, summarizing their morphological and technical characteristics. In the next phase (Paragraph 4), general guidelines and possible classification of refurbishment strategies are presented, focusing on a classification model to support technicians and owners in the design process. In Paragraph 5, passive design principles in line with the environmental design concepts are explained. The study concludes with an evaluation of the application of such measures in relation to building characteristics. In Figure 1 the methodology flowchart is explained.

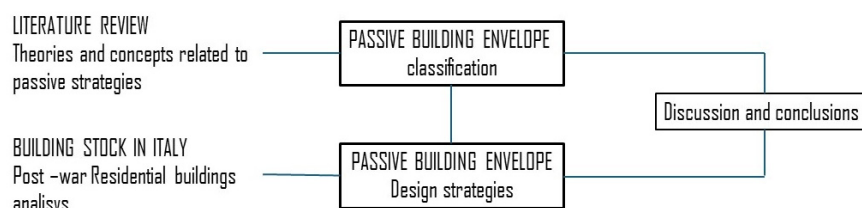


Figure 1. Flowchart of the research methodology.

3. Climatic Analysis and Post-War Residential Building Profile in Italy

In this chapter, a short overview of the current situation of the post-war building stock in Italy is presented to frame which buildings are appropriate for undergoing passive envelope renovation. Assuming that Historical Buildings and, in general, Cultural Heritage are not included in this analysis (the Italian legislation does not include these kinds of buildings in the range of mandatory standards for energy efficiency), the research is focused on the post-war building stock. Understanding the general energy consumption situation in Italy is crucial for developing effective strategies to retrofit buildings and improve energy efficiency. According to the ENEA Report in 2021, about 46% of the existing post-war building stock is very poor from a technological and indoor quality point of view [19]. Most of these buildings, built between the 1950s and 1970s, are low-rise and medium-rise apartment buildings, usually built in line along the street and situated within densely populated surroundings.

Bianco et al. divided Italian single- and multi-family dwellings into six categories according to the year of construction. The year of construction is associated with an archetype since different construction techniques and materials were used [20].

Building blocks generally have two or three apartments per floor, in total between twenty and seventy apartments. Height ranges from four to seven floors (Figure 2).



Figure 2. Typical post-war residential buildings in Italy. (a) Post-war building in Bologna made of prefab concrete panels, (b) building block in Ferrara built in the 1950s, made of a concrete structure and hollow brick blocks.

The bearing structure is made of reinforced concrete beams and pillars. Façades are added to the concrete skeleton, using mostly hollow brick blocks. In other cases, industrialized building technologies are used. These methods, starting from the 1960s, have been imported from beyond the Alps and briefly diffused; they include tunnel formworks, precast large panels, and three-dimensional elements.

A concrete structure frame is generally in good condition, and buildings are expected to function for many years. Thus, an energy retrofit represents the most sustainable means towards a green perspective. Windows are generally single-pane glass. Figure 1 shows an example of post-war residential buildings.

From the climatic point of view, the Italian territory has progressively changed in the last decade, like the rest of the world, due to the global warming.

Environment inputs (sun, wind, water, etc.) are a source of free energy that is available in any climate and represent a very important input in the building design process, [21].

In general, Italy has a temperate climate, and with considerable solar radiation throughout the year, which could play a significant role in reducing energy consumption. The climate can be divided into three main zones: north, center, and south. Between the north and south, there are considerable differences in temperature. The climate in the north of Italy is generally cold during the whole winter; on some winter days, it can be $-2\text{ }^{\circ}\text{C}$

(28 °F) and snowing. The climate of the Po valley geographical region (north–center) is mostly humid subtropical, with cool winters and hot summers. Temperature in winter can be 5–8 °C (46.4 °F). In the south, winter practically does not exist, and the temperature range is about 15–20 °C (68 °F). Temperature differences are less extreme in the summer, which is generally very hot all over the country, as the climatic change has caused, in the last ten years, a progressive temperature increase across the whole country. Due to global warming and climate change, winters are progressively becoming warmer, and the winter season is not as cold as in the past.

4. Passive Approach to Sustainable Design

Tools and methodologies for classifying sustainable technical solutions and refurbishment actions are available at the international and national levels [7,22].

Passive measures are related to the properties and function of the building envelope, without the use of mechanical equipment. The objective in a refurbishment scenario is to improve thermal properties (insulation, thermal mass), reducing heat losses, towards the goal of achieving thermal comfort.

Figure 3 provides a possible classification of the measures and their objective, which are linked to the three main aims of improving energy balance with the use of passive measures: reduce heat losses and improve envelope performance, heat gain, and heat protection. In the next section, the principles will be explained in detail, following the proposed classification. Passive measures for improving the envelope thermal performance usually involve the insulation of walls and roofs against the external environment and glazing replacement. In a deep retrofiting, which aims to achieve very low energy consumption, a key measure is represented by the addition of an insulation layer. Moreover, replacing windows with highly efficient glazing is a retrofit measure that, besides improving the thermal, visual, and acoustic comfort, can decrease air leakages and condensation risk. For a hot summer–cold winter climate, however, methods to reduce overheating are highly recommended. As an example, natural ventilation is very effective in reducing overheating; its efficiency is influenced mainly by the air temperature difference between indoor and outdoor environments, wind velocity and direction, and relative humidity [23,24].

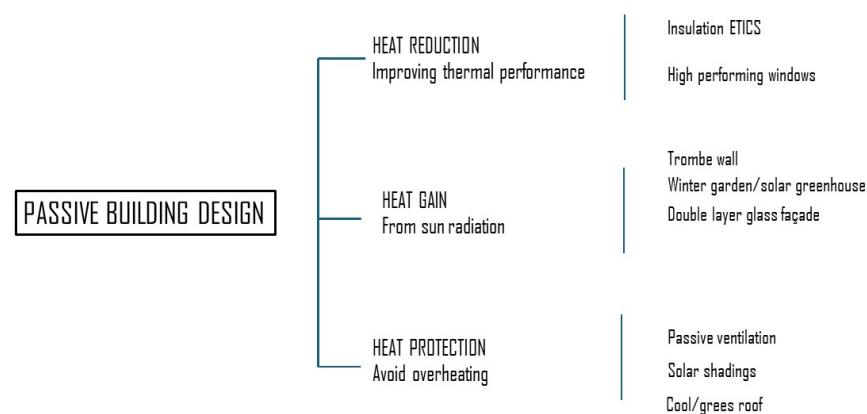


Figure 3. Passive measure classification for building retrofit.

5. Passive Design Strategies

In this section, passive design strategies for building renovation are examined in detail. Renovation of buildings is a key issue to meet the EU's energy efficiency targets [25]. Since 2002, the Energy Performance of Buildings Directive (EPBD) has been the first action requiring all Member States to introduce a general framework for setting building energy code based on a whole energy methodology approach. The implementation of strategies that aim to promote thermal comfort and limit energy consumption is clearly a fundamental aspect of the sustainable renovation of residential buildings today.

5.1. Improving Thermal Performance/Heat Loss Reduction

To reduce the energy demand, the building envelope must prevent, or minimize, heat flow towards walls and roofs. In winter, the flow goes from the inside to the outside, and vice versa during summer, when outside temperatures are higher than the interior temperature. Low thermal transmittance of the components is crucial to ensure good behavior during all seasons. Increasing the airtightness and thermal resistance of the building envelope with the use of insulating materials for opaque elements of the envelope and insulated windows for the openings is the main strategy for heat protection. Insulating the building envelope is one of the most common ways to improve heating efficiency in a cold climate, and it also contributes to the cooling efficiency in hot climates.

5.1.1. Insulation (ETICS)

External Thermal Insulation System, used on the opaque building components, can improve the thermal and sound insulation of the building. Insulation material can reduce transmission heat losses and higher surface temperatures, minimizing the thermal bridge that can cause condensation phenomena. External thermal insulation coating (ETICS) consists of an external covering with insulating panels, fixed to the existing surfaces through wedges and binders, then armed with special nets and completed with a thin layer of plaster [26]. The application of ETICS in the last ten years has become a popular measure to improve the energy performance and the weather resistance of façades in the building stock, also thanks to financial incentives, such as the 110 Energy Decree, that promote this kind of intervention for improving energy efficiency [27]. There is a bewildering range of insulating materials, from the familiar polystyrene and mineral wool to alternative materials that are gradually establishing themselves in the market, such as sheep's wool and hemp.

Typical insulation materials and their performances are briefly summarized in Table 1. Maximum thermal transmittance (U value) for walls according to the energy regulation standard in Italy [28] is $0.26 \text{ W/m}^2 \text{ K}$. In most cases, wall transmittance is about $0.5\text{--}0.8 \text{ W/m}^2 \text{ K}$; this means that at least 12 cm of extruded polystyrene insulation layer has to be considered. In Figure 4, the realization of an energy retrofit adding 12 cm of wood fiber is represented.

Table 1. Most common insulation materials for ETICS and their properties.

Insulation Material	Density ρ kg/m ³	Thermal Conductivity λ (W/mK)	Water Vapor Diffusion Resistance Index μ	Insulation Thickness for U Value $0.2 \text{ W/m}^2 \text{ K}$
Expanded Polystyrene (EPS) *	15–30	0.03–0.04	5–23	15–18
Rockwool	20–40	0.031–0.04	1–2	15–22
Wood fiber	150–250	0.04–0.08	2–5	18–36
Cork	100–120	0.038–0.05	10–18	16–25
Foam glass	10–120	0.04–0.05	-	18–25
Vacuum Insulation Panel	150–180	0.007–0.01	-	3–4

5.1.2. High-Performing Windows

Openings are the weakest part of the envelope, in terms of thermal transmittance, due to their relatively poor thermal properties. Anyway, new technologies provide the opportunity to use insulated windows, consisting of panes and frames with lower thermal conductivity. One of the most relevant interventions in order to improve the energy efficiency of the envelope is replacing existing windows. This kind of solution should be carried out in most cases without confining the occupants in other apartments, and with limited disease for the inhabitants. Over recent decades, multiple panes of glass separated by air spaces have replaced single-glazed window panes, resulting in significant performance improvement. If the cavity between the panes is filled with a less conductive gas, such as argon, the conductance of the cavity is even further reduced, which improves

the thermal performance of glazing units. Low-emissivity coatings, called Low-E glass, are used to reduce the surface emissivity of glass ($U = 1.3 \text{ W/m}^2 \text{ K}$). Also, advanced coatings can reduce, in the summer season, the risk of overheating by reducing solar incidence. In Figure 4, the coating contribution in different climatic conditions is described. Also, the choice of window frame contributes to the overall U value reduction. Window frames can be made of different materials, such as timber, aluminum, steel, or plastic. Advanced solutions have optimized the performance using thermic profiles (e.g., wood or plastic on the inside, with the outside insulation material covered by aluminum; see Figure 5). This can be helpful in improving not only thermal properties but also mechanical resistance to atmospheric agents. The choice of the frame type depends on the properties and cost of the material, as well as the desired architectural expression.

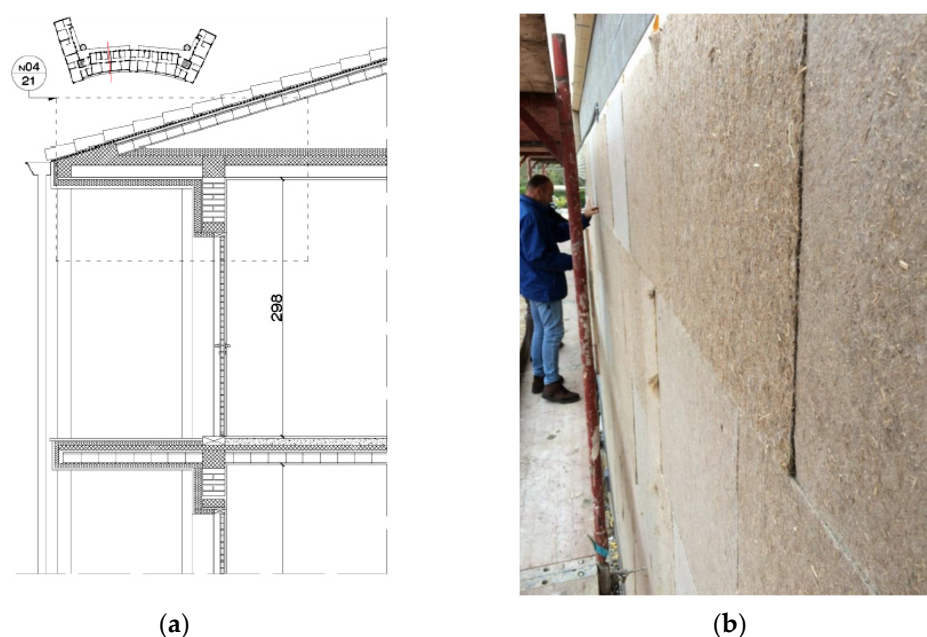


Figure 4. Adding external thermal insulation (12 cm of wood fiber) in a post-war residential building in Italy. (a) Vertical section, (b) insulation panel installation.

An in-depth evaluation shows that the effect of replacing windows on the overall energetic performance can be about 20–25% [15].

5.2. Passive Indirect Heat Gain

Passive solar heating is essential during winter to improve the indoor environment by reducing thermal transmittance of the wall and collecting heat that can be stored using thermal masses. It employs transparent elements of the building envelope to collect, store, and distribute solar energy without the use of mechanical equipment. During summer, when the heating effect is not needed, the glazed parts should be open or protected with adequate shading. A solar buffer space is very helpful to create a warm environment in which natural heating maintains a temperature near that of heated rooms. This space is unconditioned and heated exclusively by solar irradiation. As the temperature in the buffer space is higher than the external temperature, the transmission heat losses of the interior are reduced. In such spaces, the temperature in the buffer space can be within comfort levels for a larger percentage of the year, due to solar heat gains. In this way, the dwelling's usable area increases. Added glazing envelopes create a buffer space, by including an exterior glass layer, which is separated from the inner façade that encloses the living space. The distance between the interior and exterior façade layers can vary. Depending on the depth of the buffer space, double façades can be grouped into several categories.



Figure 5. Replacing existing windows in a post-war building in Ferrara (Italy) with composite high-performing window frame (wood–polystyrene–aluminum) to improve the U value of the window.

Trombe wall, winter garden/solar greenhouse, and double-layer façades are the most used passive solutions for improving the thermal performance of a building [29].

5.2.1. Trombe Wall

A passive solar façade transfers sun rays into thermal energy, using natural convection, without the use of any active mechanical or electrical equipment to ventilate the indoor environment depending on the season and the climatic zone. The main aim of designing a Trombe wall, which generally has a south-facing orientation, is to gain heating energy during winter [30]. This can be very useful in the case of building refurbishment, where thermal losses due to poor walls are very high (high U value) in winter.

A Trombe wall is made of three layers: a thermal mass, usually of a dark color, an air cavity wall with thickness ranging from 2 to 15 cm, and a glass surface. The sunlight is absorbed by the wall, a part of it is transmitted by convection, and the other portion of heat absorbed by the cavity space is conducted to the wall slowly, heating the room space for many hours after sunset. A Trombe wall in the refurbishment of building envelopes is properly used in cold climates or in general where the risk of overheating due to the big amount of sun energy on the façade is not high. Several studies assessed the possible energy conservation, passive heating potential, and CO₂ energy reduction of utilizing a Trombe wall [31]. This technique can reduce heat losses by about 20% and improve the overall energy conservation by 30%.

5.2.2. Winter Garden and Solar Greenhouse

An extended version of a solar cavity space is called a winter garden or solar greenhouse, which is stretched from the ground to the roof of the building. A great number of studies on sunspaces show how to maximize the benefits of heating load in winter and avoid overheating in the summer season. Apart from the advantage in energy efficiency, this solution has the benefit of enlarging the living space [32].

Adding a greenhouse in an existing building can improve both its architectural image and energy efficiency [33]. A greenhouse is a glass structure that heats up because incoming visible solar radiation from the sun is absorbed by floors, walls, and other materials inside of the solar space. The air warmed by the heat from hot interior surfaces is retained in the building by the roof and wall. When orientation is optimum (south, southeast façade), an added greenhouse, which can also be obtained by enclosing existing balconies by means of glass panes, is an intervention that can be considered as a “best practice”, in which the high initial investment cost can be justified by a global renovation of the image of the building (Figure 6) [34].

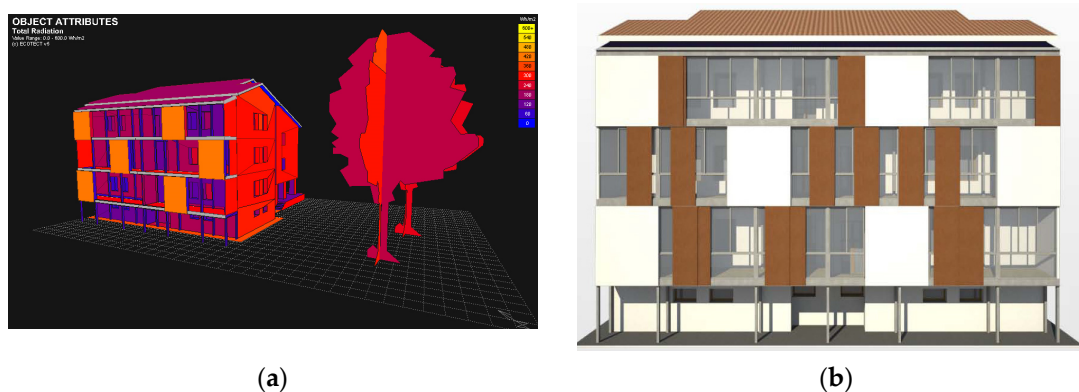


Figure 6. Design for adding a solar greenhouse in a post-war residential building in Italy. (a) Solar radiation measurement with Ecotect software (Autodesk Ecotect Analysis 1.0). (b) The solar greenhouse design with mobile shadings, rendered image.

5.2.3. Double-Layer Glass Façades

A double-layer façade has two layers with different glazing materials—one internal façade and one external façade—which are divided by a ventilated air cavity called a chimney [35,36]. The application of this solution is especially useful in the tertiary sector (mainly offices and productive buildings), and recent investigations indicate this technology could even be suitable for residential buildings, even if there are some issues to resolve, such as whether the air cavity can be considered for natural ventilation.

Double-layer glass façades in refurbishment are generally hybrid systems, formed by the existing wall and a new glass envelope (Figure 7). The external envelope is a glass façade that, during the winter season, collects the solar rays that, by heating the air cavity, consequently improve the thermal capacity of the whole system. The use of high-performing glass is fundamental for obtaining solar reflection and to prevent overheating. If the refurbishment is oriented to the complete substitution of the existing envelope, then the internal wall is also a glass façade, forming the conventional double-layer skin. In most cases, it is more convenient to conserve the existing wall and, after the changeover of the windows, add insulating panels onto the structure and onto the parapets.

The inner and external envelopes can be opened or totally closed. Also, the ventilation in the air cavity can be natural or forced. Italian regulations require natural ventilation of the rooms in residential buildings; for this reason, windows cannot be directly opened in the air cavity, such as happens in tertiary buildings. By the way, just two main solutions can be evaluated. The first one is the realization of a partial glass façade, formed by cells or pipes, only corresponding with the opaque walls; this is a Trombe wall solution. The second one is the realization of a moveable external glass envelope.

Fields of application of a double-layer glass façade are, nowadays, mainly pertinent to office buildings. Many examples of refurbishment show that, with this very efficient technical solution, high levels of thermal comfort and energy saving are obtained (ranging from 20 to 40% reduction in the overall building consumption) [37]. The realization of this intervention has to be carefully planned and designed to evaluate the most coherent and

resolute solution. This could be accomplished with the support of the producers, which put at the designer's disposal their technical competence for the realization of the façades, by supporting more than the diffusion of a specific program, the executive design, and the performance qualifications. In the long term, the high investment costs for refurbishment should be compensated for by the reduction in HVAC use. The challenge is represented by the application in residential buildings.



Figure 7. Double-layer glass façade in the refurbishment of a 1960s building in Milan.

5.3. Heat Protection—Avoid Overheating

Solar radiation is desired during winter, as explained in the previous paragraph, but should be excluded during summer to avoid overheating. Reducing heat gain in buildings located in temperate and hot climates is one of the most important approaches for energy saving. This approach is particularly useful for lowering the use of air conditioning in the summer months. Three passive design strategies in which heat gain affects building envelopes are considered: passive ventilation, external shading device, and cool/green roof.

5.3.1. Passive Ventilation and Stack Effect

If compared to passive heating, passive cooling is more difficult to describe and to quantify, as the ventilation direction and intensity vary daily and hourly. Passive natural ventilation is generated by natural air movement by pressure and/or temperature difference, without requiring mechanically or electrically driven components [38].

These solutions have ancient cultural origins (as an example, Roman massive double walls with air gaps, or the ancient ventilation chimney—or wind towers—in Persia); moreover, there are several recent studies which demonstrate how this dynamic double-skin envelope solution represents a very simple but effective tool to passively manage the climate control of the envelope [39,40].

Natural ventilation is an effective cooling strategy that can highly contribute to energy savings. Wind speed, direction, and temperature difference affect the natural ventilation phenomenon. The speed and direction of the wind over a structure generate a pressure field around the building [16]. This strategy can be realized in two ways (Figure 8):

- Passive ventilation across the building/apartment.
- Passive ventilation in an air cavity, for example, in ventilated façades or ventilated roofs.

In the first case, historical cooling techniques and principles born in the Middle East and in some European countries have been used for centuries, such as wind towers. The most common characteristic elements in the building to enhance natural ventilation are windows, wind towers, courtyards, and atriums. The location of ventilation openings is crucial for the cross or stack ventilation phenomena. As hot air tends to rise to the top, cool air entering from the bottom window will flow out of the upper opening.

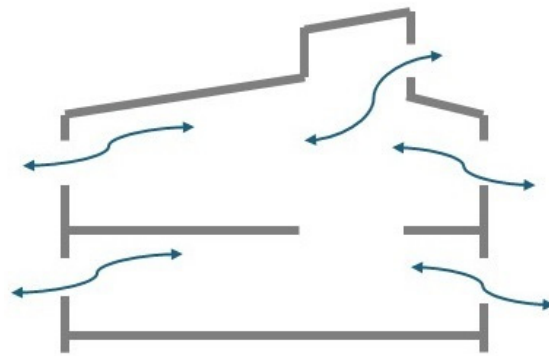


Figure 8. Passive ventilation in a building. Cross and stack ventilation principles.

In the second case, the air cavity represents an additional layer that helps the envelope in reducing thermal gains during the summer season. This is particularly helpful when the envelope does not have sufficient thermal mass (e.g., light walls made by fiberboard slabs and inner insulation). In Figure 9, an example of the energy retrofit of a building from the 1960s is shown, in which a new ventilated skin was added (insulation, air cavity, and brick mounted on stainless steel structure).

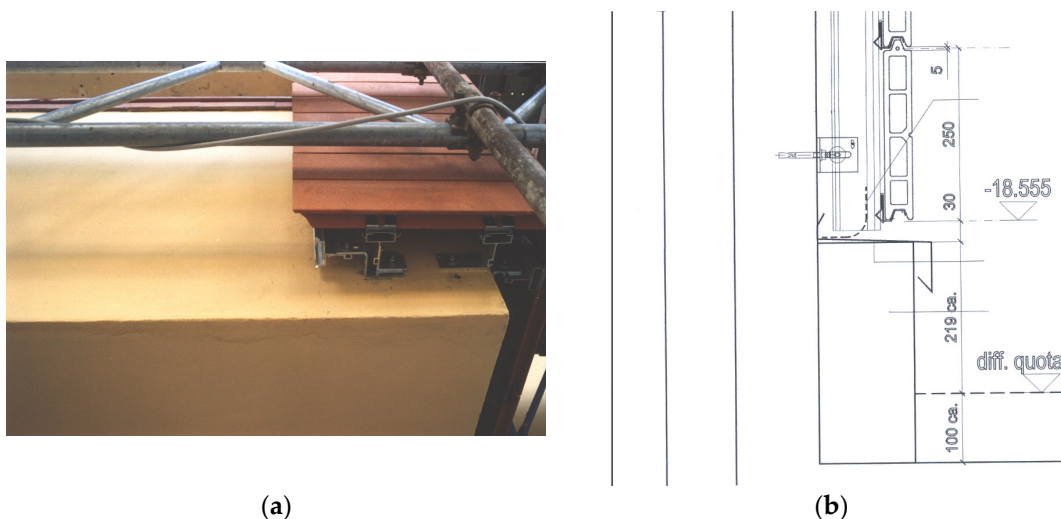


Figure 9. Adding a ventilated façade in the refurbishment of an apartment building in Italy. A new layer with air movement contributes to a reduction in overheating inside the building, especially for south- and west-oriented walls. (a) Image of the façade construction, (b) façade detail.

Typically, the energy cost of a naturally ventilated building can reduce the use of air conditioning by 40% in hot and dry climates, where ventilation is helpful in the summer season [41]. Also, natural ventilation is very important not only for reducing energy usage and cost but also for users' psychological behavior, by providing a good indoor air environment while sustaining a comfortable, healthy, and productive internal climate.

5.3.2. Solar Shadings

External sunshades are the most effective for solar control, as they intercept direct solar radiation before it strikes the envelope. There are a multitude of shading systems on the market that can vary in design, size, material, and orientation, ranging from simple Venetian blinds to more advanced components, which can modify the entire building façade. Shading design should account for the building's orientation, the seasonal cooling needs of a building, and the sun's path throughout the year.

Shading systems are commonly classified according to their control possibilities; thus, they are separated into movable and fixed systems [42]. The first system offers the user

more options but incurs high maintenance costs, while the second is thought to be more efficient (if well designed), but does not consider the possibility of control from the user and can exhibit varying performance during the day. Movable systems are often referred to as adaptive because they adapt to the changing internal or external conditions. External shading devices have a remarkable impact on energy savings. Vertical and horizontal forms with 40–60 cm depth can lead to a 6–10% reduction in energy consumption, as these materials can avoid solar radiation from varying sun angles [43].

In Figure 10 the refurbishment of a post-war building block is represented. The building has south-oriented long balconies and the strategy to contain solar gains during the summer season and to reduce cooling consumption was to add mobile wooden panels.



Figure 10. Refurbishment of a building block from the 1960s by adding solar shadings. (a) The building before the intervention. (b) The building after the intervention of adding wooden mobile solar shading on the south façade. This intervention contributed to a reduction in energy consumption for cooling of about 30%; moreover, the loggias can be used as additional living space.

5.3.3. Cool/Green Roof

Considering that most of the solar radiation is incident on the roof surface, in addition to the façades, passive roof strategies are more effective than the other strategies.

Cool and green roofs play a significant role in enhancing the comfort level of occupants by reducing the temperature of the building.

A cool roof is made of materials that strongly reflect sunlight and solar energy and cools itself by efficiently emitting any heat that is absorbed. The main goal is to save energy and to improve the comfort level in buildings, mainly in Mediterranean and temperate climates. In the refurbishment of a building, substituting tiles with tiles of a highly reflective material can reduce heat transmission through the roof by about 40% [44].

In the refurbishment of existing buildings, the main goal is to reduce energy consumption by increasing the energy efficiency of the roof, which is the most relevant surface when it comes to high-rise temperatures and consequently increases the demand for air conditioning and energy consumption (Figure 11). Roofs contribute to building heat gain compared to vertical surfaces such as walls, mainly because the roofs are exposed to the sun throughout the daytime.

Green roofs are flat roofs made of a ground substrate 15–40 cm above the load-bearing layer. Especially in urban settings, where the heat island effect is very common, green roofs are considered to provide effective environmental solutions to mitigate severe heat, as the water content in green roofs and the ground thickness can significantly reduce the heat transferred to the interior space [45].

The green roof strategy's impact at the environmental level and its capability to improve air quality, enhance relative humidity, and reduce carbon dioxide emissions render it an extremely important issue. Green roofs should be designed properly based on the characteristics of the climatic condition, such as location, temperature, humidity, precipitation rate, availability of water, and wind.

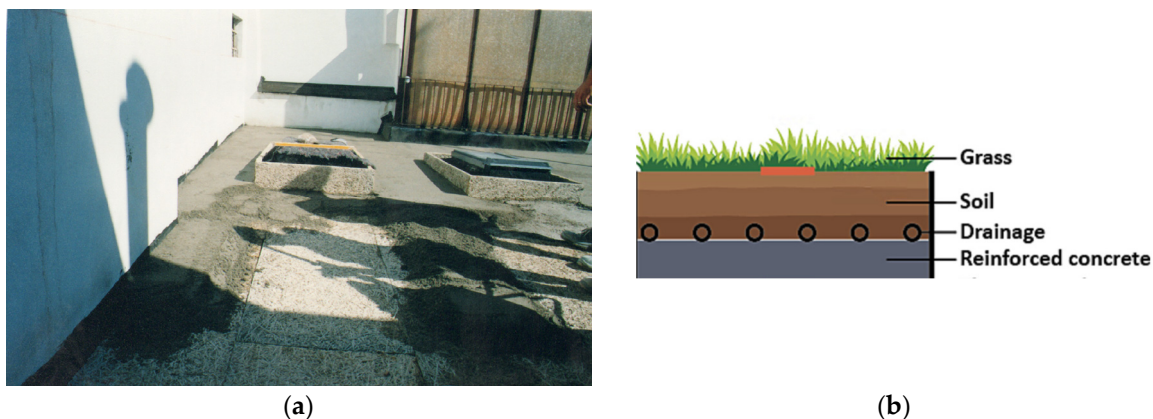


Figure 11. Refurbishment of a building block from the 1960s by reducing solar gains on the flat roof. (a) The refurbishment phase. The roof's original coating was a black bitumen membrane with a high absorption coefficient. (b) The refurbishment intervention included the realization of a green roof with 30 cm of soil.

However, the maintenance of the required waterproofing membranes is complicated; a green roof system requires complete coverage of its membrane, but leaks can still occur at the joints. Regular maintenance inspections should be scheduled as part of the standard roof installation.

6. Discussion

This study presents passive measures representative of environmental and bioclimatic design principles, aiming at the refurbishment of buildings that have very high energy consumption. Within this framework, the main actions to prevent/minimize the energy demand for heating and cooling involve the envelope. These actions can rather interact with and complement each other; thus, the design should also consider them in parallel or step by step in extensive renovations. The discussed measures have been summarized in Figure 3 according to how the heat is transmitted through the building envelope. Passive measures have been classified into heat protection, heat gain from the sun, and heat rejection.

After the appearance of energy legislation in 2005, a multitude of good practices of new sustainable architectures have been developed, with particular attention to passive and active energy strategies, with a great variety of approaches to design and technical issues, including passive solar design, day lighting, natural ventilation, night cooling, combined heat and power, photovoltaic systems, grey-water recycling, and the integration of landscaping. The contemporary challenge is focused on the refurbishment of existing buildings. The building envelope is the main component responsible for heating exchange and accounts for 50% of the overall energy balance.

In Table 2, the main new passive measurement strategies for improving building performance are summarized, highlighting what kind of passive envelope measure is used, and how it influences the existing building efficiency.

Table 2. Passive strategies applied in Italian building refurbishment.

Passive Measure	Passive Strategy and Properties	Envelope Efficiency Improvement	Building Envelope
ETICS *	Improving thermal insulation and reducing heat losses.	Building in Figure 3. Before: typical opaque post-war wall, hollow bricks—U value $0.5 \text{ W/m}^2 \text{ K}$ After: 12 cm polystyrene (EPS) Etics, U value $0.22 \text{ W/m}^2 \text{ K}$	Opaque wall

Table 2. Cont.

Passive Measure	Passive Strategy and Properties	Envelope Efficiency Improvement	Building Envelope
High-Performing Windows	Improving thermal insulation of and reducing heat losses.	Building in Figure 5. Before: Typical single-layer window, U value 5–2.5 W/m ² K After: Window replacement with high-performing one, U value 0.5–1 W/m ² K	Transparent wall and/or glazing components
Trombe Wall	Heat gain by solar energy capture and passive transfer by means of a thermal mass. Improving thermal inertia.	Dynamic heat transfer—passive gain, not measurable with standard units.	Opaque wall
Winter Garden and Solar Greenhouse	Livable buffer space for solar gain and passive transfer by means of a second glass layer or a thermal mass	Dynamic heat transfer—passive gain, not measurable with standard units. In Figure 6a, simulation of adding a solar greenhouse on a south façade is presented. Thermal transmittance of the inner wall reduced by 20% (exchange with buffer space instead of external)	Transparent wall
Double-Layer Glass Facade	Buffer space	Building in Figure 7. Before: Single-layer prefab concrete wall and single-layer glass windows, U value 0.8 W/m ² K and 3 W/m ² K After: Windows replaced with low-E, Venetian blinds, ETICS and a new glass façade, U value 0.2 W/m ² K Reducing air conditioning by 50%	Transparent wall or Hybrid wall (existent opaque wall/transparent layer)
Stack Ventilation	Passive cooling, reducing overheating	Building in Figure 9. Before: hollow brick wall, U value 0.5 W/m ² K After: ventilated façade 10 cm Eps, 5 cm air, brick tiles, U value 0.26 W/m ² K	Opaque wall
Solar Shading	Intercepting solar rays Reducing overheating	Performance can vary by orientation, climatic area. In the Italian example in Figure 10a, reduction by 30% in the air conditioning use is proved, due to the addition of moveable wood shadings on south façade.	Opaque and transparent wall
Green Roof	Reducing overheating, improving thermal inertia of roofs	Building in Figure 11. Before: Typical concrete roof with plaster membrane, U value 5–3 W/m ² K After: green roof 15 cm soil, U value 0.8–1.3 W/m ² K	Opaque roof

The proper design of building envelopes can considerably improve the thermal performance of residential buildings. The design choice of measures also affects the architectural quality of the building, as well as its functionality.

Therefore, this study could be helpful to designers and developers when applying a combination of passive design. Some general advice is summarized as follows:

- In refurbishment, light technologies, such as ventilated façades or external thermal insulation coatings, are characterized by high environmental sustainability. These technical solutions are totally dry-mounted; this favors partial or total dismantling and the recycling of the components.

- Heat transmission through opaque building walls is a significant energy loss, particularly in residential buildings. Adding insulation to very poorly insulated walls is highly effective. Thermal bridges are a common occurrence, mostly in buildings built under early regulations prescribing at least some insulation.
- To reduce the heating of external surfaces, two primary strategies have been reported: the use of ventilated external cladding systems that reduce the solar absorption (reduction of up to 2% in the building cooling load) [46], as well as the use of solar shadings. The new Italian decree about energy efficiency in Italy (D. Lgs 26/06/2015) [28] imposes the use of external solar shading, both in new buildings and in refurbishment, for buildings more than 1000 sqm in size. Starting from this regulation, it will be clear that more and more buildings will be designed using solar shading technologies.
- Overlapping a glass façade increases the thermal insulation of the wall, reduces heat transmission, cools, and reduces solar intake in summer, using solar shading devices. All these factors can contribute to a reduction in operating costs, due to the reduced use of HVAC (Heating Ventilation Air Cooling) systems. The running cost must be considered, taking into account the maintenance cost of the façade (substitution/repair of elements, cleaning of glass panes) and the reduction in consumption costs.
- The use of a double-layer glass envelope in residential buildings is, mostly in Italy, heavily conditioned by the climatic factor and the need for natural ventilation. Compared to north European solutions, a glass envelope must take in account the great incidence of solar gains and the risks of overheating during the summer season.

The deep renovation of the existing EU building stock by 2050 is an essential feature for meeting the long-term climate change goals. Refurbishment requires accurate data concerning the existing building stock for managing the design strategies and timesheet as well as for evaluating the impact of implemented measures.

A combination of different passive design strategies can help to significantly reduce annual energy consumption by 30–40% [47].

7. Conclusions

A deep renovation of façades takes large investments that are justified when, in addition to the architectural renovation, the global quality of the building is improved.

In addition to an environmental point of view, sustainability has to be treated from the economic point of view as well. Some solutions can be considered as standard interventions, such as ETICS, window replacement, or adding a ventilated façade. Costs for External Thermal Insulation can vary from EUR 60 to 80 per square meter; on the other hand, a ventilated façade medium costs about EUR 120–150 per sqm. Window replacement can vary according to the kind and number of windows [48]. A double-layer glass façade and a solar greenhouse can be considered as extraordinary interventions. Their cost depends on the dimensions of the intervention, and in any case, a double-layer glass façade can cost between EUR 1000 and 1300 per square meter.

Several funding policies have been recently promoted in Italy for the energy refurbishment of residential buildings. Incentives known as “Ecobonus” are provided when a tangible improvement of the energy efficiency of a dwelling or building as a whole (e.g., improvement of thermal transmittance of walls and windows) is documented, and can range from 50% to 65% of the overall capital cost of the energy.

By 2020, a new fiscal incentive known as “Superbonus 110%” has been introduced, bringing the possibility of obtaining funds from the state equaling up to 110% of the capital cost. In this case, it is possible to assign the credit to the contractors if they bear the capital costs, and the final user can benefit from the energy refurbishment without any charge. This funding strategy represented a very big push for energy retrofitting and is extremely attractive for residential users [49].

The study also presents several pathways for future research. Decision-making systems are needed to assist in classification and selection of the set of passive measures to develop functional and effective renovation plans.

This includes the investigation of the impacts of environmental factors (heat gains, lighting, ventilation, etc.) that could influence the performance of the added passive measures and how they contribute to slowing down the climatic change. Building a dynamic simulation of energy performance and emission inventories to investigate the impact of such interactions will be a future development of research.

The above conclusions indicate that very significant energy savings can be attained by addressing the building envelope and implementing passive strategies. Enterprising retrofit actions to the extensive post-war building stock is crucial to improve energy efficiency and provide a strong contribution toward mitigating the excessive energy consumption and environmental footprint of the EU. The integration of active solar technologies (e.g., semi-transparent photovoltaic cells) in solar systems represents a tangible perspective for combining the performance of shading and cooling with the production of energy.

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