POLITECNICO DI TORINO

Master's Degree Course in

ARCHITECTURE FOR SUSTAINABLE PROJECT

Master Thesis

Energy Performance Evaluation and Strategies for Sustainable Built Environments A case study in the city of Turin, Italy

Student

Atefeh Kalantari

Tutor

Prof. Mario Artuso

Tutor

Prof. Giacomo Chiesa

February 2024

Abstract

This thesis investigates the potential impact of passive design concepts and advanced materials on improving energy efficiency in residential buildings constructed in Turin, Italy.

In particular, residential buildings built between 1961 and 1970 were studied here. This choice is because this category includes a wide range of residential buildings in the city.

The study takes into account the broader consequences for urban sustainability due to the mitigation of carbon emissions. Significant throughout the work was the use of the DesignBuilder software to do a simplified simulation of a residential building to evaluate the effectiveness of techniques such as insulation, window alterations, and bioclimatic features at the district scale.

An investigation of passive cooling solutions has been carried out, followed by an evaluation of their application in the Turin environment, and a simulation-based assessment of their potential impact. The results point to a substantial reduction in energy usage by implementing passive strategies, highlighting the limited utilization of these approaches in present-day construction methods.

The conclusion emphasizes the necessity of including passive design components to attain energy efficiency and thermal comfort, providing realistic strategies to promote energy-efficient construction practices, implementing regulatory measures, conducting awareness campaigns, and fostering stakeholder collaboration. Pursuing these objectives would lead to the potential energy efficiency of the entire urban system.

Keywords: Passive Design, Sustainable Refurbishment, Energy performance, Urban Sustainability

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Chapter 1

Research Literature Review

1. Introduction

This research examines the important connection between passive design techniques and innovative materials in residential structures in Turin, Italy, considering the climate and the growing worldwide concerns about environmental sustainability and energy consumption. The necessity to tackle energy difficulties is emphasized by the consequences of climate change and the requirement to transition towards low-energy methodologies. Passive design, as an architectural concept, is a potential solution that focuses on incorporating environmental factors into the design process to reduce energy consumption and improve thermal comfort.

This thesis explores an important topic that requires a strong understanding of technical concepts. The necessary technical background is specialized, so I conducted thorough research, gathering insights from reliable sources, including:

1. "Refurbishment of Existing Envelopes in Residential Buildings: Assessing Robust Solutions for Future Climate Change" by Chinazzo Giorgia, Politecnico di Torino. [Link to the thesis: https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

2. "A Transformative Approach to Reach an Energy-Conscious District: A Case Study in the City of Turin, Italy" by Mahsa Asadi, Politecnico di Torino, 2022.

The study subject is complex, as it involves the increase in cooling energy needs caused by climate change and the lack of attention to passive methods in current construction practices, particularly in government residential buildings. The main objective of the project is to evaluate the feasibility of reinstating passive cooling techniques to reduce energy consumption in residential structures built between 1961 and 1970 in Turin.

The research methodology entails a comprehensive examination of several passive design typologies, an assessment of their influence on a specific case study, and a simulation-based evaluation of their feasibility in the local climate. The study aims to investigate the possible impact of introducing passive cooling strategies on urban sustainability in Italy, with a specific focus on Turin, a city renowned for its significant energy consumption levels.

The introduction sets the framework for a thorough examination of passive design characteristics, their historical efficacy, and their present-day underutilization. The research is significant because it contributes to sustainable architecture and provides real steps for achieving a more energy-efficient and ecologically conscious urban future. The subsequent sections of the study will analyze the theoretical framework, literature assessment, and methodology. These sections will establish a strong basis for a comprehensive examination of passive cooling technologies and their potential ramifications for Turin and other regions.

2. Research Questions and Objectives:

What are the benefits of incorporating sophisticated materials and passive methods, including natural ventilation and shading, to reduce energy consumption in buildings built in Turin, Italy between 1961 and 1970? How does this impact urban sustainability and the reduction of carbon emissions on a larger scale? In addition, the study examines the key issue of why passive design elements are not widely utilized, investigating possible factors, stakeholder responsibilities, and obstacles to adoption.

The main goal of this study was to identify and categorize the features, classifications, and types of passive cooling systems, in line with the overall research purpose. The present study conducts a comprehensive literature review that systematically covers the fundamental principles governing passive cooling in building design, as well as an examination of various methodologies. In addition, a comprehensive investigation was carried out to examine the use of passive techniques in the specific meteorological circumstances of Turin.

The research methodology evolved from a deliberate focus on assessing the efficiency and potential of implementing passive cooling strategies in the specific local climate of Turin. Within the expansive theoretical framework, numerous passive design strategies and techniques were elucidated. The subsequent stage involved a judicious selection of suitable strategies and techniques tailored to the unique climatic conditions of Turin. This rigorous process guided the execution of the study through distinct stages, unraveling key findings.

Firstly, the investigation brought to light that passive cooling strategies harbor substantial potential to affect a noteworthy reduction in the energy load of buildings. Secondly, the study systematically unveiled and discussed the diverse effects of the selected strategies, thereby providing a comprehensive guideline for end-users and stakeholders contemplating the application of these strategies.

The culmination of the study encompasses recommendations and a succinct discussion on the contemporary reluctance towards the adoption of passive strategies in an urban scale. This concluding section delves into the underlying reasons for the current abandonment of passive strategies, offering valuable insights for further consideration and exploration in the realm of sustainable building design. The systematic exploration of objectives, literature, and methodology positions this scientific inquiry as a foundational contribution to the discourse surrounding passive cooling strategies and their applicability in specific climatic contexts.

3. Research Problem

Contemporary global challenges underscore the significance of environmental and energy issues as the foremost global concern. The escalating impact of climate change, attributed to rising temperatures, has spurred widespread apprehension. In response, imperative actions to curtail energy consumption become unavoidable. The confluence of growing populations and heightened energy apprehensions necessitates an urgent shift towards low-energy practices. As a potential remedy, passive design has been advocated for in architectural contexts (Omer, 2008). Passive design, delineated as an architectural approach, integrates environmental considerations within the design process to minimize energy needs and enhance thermal comfort. This approach necessitates a holistic incorporation of the building's surroundings, ensuring responsiveness to the demands and potentials of the local climate, ultimately leading to a significant reduction in primary energy consumption. The ultimate objective of passive architectural design is the elimination of reliance on active mechanical systems, while concurrently sustaining optimal thermal comfort for occupants (Cheung, Fuller, & Luther, 2005; Mikler, Albert Bicol, Breisnes, & Labrie, 2008).

Strategic adaptation to local climate and site conditions emerges as a pivotal consideration, especially when coupled with the imperative of minimizing energy consumption. However, in recent decades, there has been a notable surge in dependence on mechanical equipment within residential buildings. Notably, locally oriented, simple passive strategies such as shading, orientation, thermal mass, daylighting, and natural ventilation are frequently overlooked in the architectural design process. This oversight is particularly pronounced in governmental residential projects that extensively employ prototypes, often neglecting factors like local climate, orientation, and site-specific considerations. This tendency towards prototyping contributes significantly to heightened energy consumption levels. Consequently, the focus of this research revolves around exploring the potential of reintroducing durable and low-tech passive cooling strategies as a pragmatic approach to mitigate energy consumption and conserve cooling energy.

The research problem is delineated based on two primary facets. Firstly, the exacerbation of cooling energy demands is attributed to the elevated temperatures resulting from climate change. Secondly, residential projects exhibit a pervasive utilization of prototypes, neglecting site-specific considerations and leading to substantial increases in energy consumption. Thus, the exploration of passive cooling strategies emerges as a promising avenue for effective energy needs control.

The core objective of this research is to assess the potential of reintroducing passive cooling strategies as an effective means of diminishing energy needs and enhancing thermal comfort in buildings. This overarching goal is pursued through a meticulous investigation into the impact of diverse passive cooling strategies on the cooling energy consumption rates of residential buildings within the climatic context of Turin, a significant urban area in Italy experiencing substantial local urban community expansion. The research methodology encompasses an exploration of various passive design typologies, an assessment of their effects on a locally selected case study, and an evaluation of their feasibility within the defined local climate. The viability of the passive strategies is measured through the requisite energy demand for cooling the building.

Moreover, this study is specifically tailored to Turin due to its notable energy consumption rate, with a focus on residential buildings. A preliminary examination of local climate data has been conducted to identify critical climatic challenges, subsequently informing the selection of suitable passive cooling strategies for further investigation. A reference building has been meticulously chosen based on predefined criteria for the experimental phase, conducted through the Design Builder platform utilizing Energy Plus as a simulation engine. This experimental phase scrutinizes several selected passive cooling strategies on the reference building, with a comprehensive aim to demonstrate the potential energy savings associated with each alternative. This approach raises crucial questions regarding the underutilization of passive strategies and prompts contemplation on the transformative impact that widespread applications of passive cooling strategies could have on residential buildings on an urban scale in Turin, Italy.

4. Research Background

Passive design and energy-efficient solutions in architecture have demonstrated a substantial decrease in energy usage in buildings. Gondal (2021) and Dan (2016) both highlight the significance of employing passive design solutions, such as solar energy use and optimizing building factors, to attain energy efficiency. Atwa (2016) and Zaki (2009) provide more evidence of the effectiveness of passive cooling solutions and climate-responsive architectural features in minimizing energy requirements, especially in hot and humid environments. These studies demonstrate the efficacy of passive design and energy-efficient solutions in attaining sustainable and comfortable interior settings.

Improving the thermal comfort of people within a building may be accomplished by implementing various passive solutions integrated into different components of the building envelope. The adoption of these measures is well documented in existing literature, highlighting their crucial significance in achieving energy-efficient buildings. Initial passive strategies encompassed shading methods, wall-mounted shelves for maximizing natural light, and features for facilitating natural airflow. Significantly, more than 50% of energy distribution in residential structures is impacted by the effectiveness of building envelopes.

Research conducted in Italy and other locations has examined the utilization of natural ventilation, as well as other passive methods, to provide optimal thermal comfort throughout the summer season while minimizing energy consumption. Studying the heat characteristics of building exteriors, including their shape and size, as well as the use of methods like evaporative cooling, night sky radiation cooling, and thermal energy storage systems, has played a crucial role in understanding how passive design strategies can improve the comfort and efficiency of homes. These findings have contributed to the development of zero energy buildings.

Implementing a more logical approach to energy usage in order to regulate the demand and supply of energy in public buildings might be an efficient technique for specific interventions that promote the sustainability of the urban environment. Extensive research has been carried out in Italy, with each study focusing on various areas of energy consumption optimization techniques and their influence on building energy requirements.

Several studies have done a thorough examination of materials and passive measures to enhance energy efficiency in urban structures in Turin, Italy. Zazzini's (Zazzini, 2018) research showcased the possibility of attaining substantial enhancements in energy efficiency for historical structures, even when faced with architectural and historical limitations. Carozza's (Carozza's, 2017) study emphasized the influence of urban design on the energy efficiency of residential structures, particularly focusing on the importance of building density, solar exposure, and outdoor surfaces. Todeschi's study emphasized the impact of urban morphology on building energy usage, specifically in relation to space heating. These studies emphasize the significance of taking into account many elements, such as building type, architectural limitations, and urban structure, when designing and implementing energy efficiency techniques in urban structures.

An extensive examination of materials and passive techniques in Turin, Italy indicates that the use of roof-integrated solar technology in public buildings has the capacity to achieve substantial energy conservation (Mutani, 2018). This is especially crucial considering the city's dedication to decreasing energy usage and CO_2 emissions. Omrany (2016) emphasizes that passive techniques, such as controlling heat losses and gains through the building envelope, play a crucial role in improving building energy efficiency. Furthermore, the influence of urban form on energy consumption for space heating is explored, with a focus on the potential for lower energy consumption in areas with medium urban building densities and high solar exposure (Mutani, 2016). These findings underscore the importance of a holistic approach to energy efficiency in urban buildings, considering both materials and passive strategies, as well as the urban context. The table below mentions some of the most important research in the field of optimizing energy consumption using passive solutions.

Table 01: Some research conducted in the field of energy consumption optimization of buildings in Italy.

Article title and Authors	Purpose
The effect of roof-integrated solar technologies on the energy performance of public buildings: The case study of the City of Turin, ***Multani, G. et al. 2018***	A more rational use of energy to manage energy demand and supply of the overall public buildings stock could be an effective strategy for targeted interventions that lead to a virtuous path toward the sustainability of the urban environment.
Optimization of Building Energy Performance through Passive Design Strategies ***Hossein Omrany, Abdul Marsono. 2016***	Passive strategies in the building sector can be a promising measure to enhance building energy efficiency.
Space heating energy consumption and urban form. The Case Study of Residential Buildings in Turin (Italy), ***Multani, G. et al. 2016.***	The energy consumptions vary as a function of the urban morphology and the solar exposure of outdoor spaces in Turin.
Urban morphology and energy consumption in Italian residential buildings, ***Delmastro, C. 2015.***	The space heating energy consumption at a single building level is affected by its relationship with its neighborhood.
Integrating Energy Efficiency and Urban Densification Policies: Two Italian case studies, ***Elisa Conticelli, et al. 2016***	Existing buildings and urban fabrics need to achieve higher performance in terms of statics and functional requirements and open space quality to increase energy efficiency and the sustainability of the city as a whole.

Energy-Efficiency Passive Strategies for Mediterranean Climate: An Overview. ***Matos, a, et al, 2022.***	Passive solar technologies can be a viable solution for Mediterranean-climate countries.
How to Prioritize Energy Efficiency Intervention in Municipal Public Buildings to Decrease CO2 Emissions? A Case Study from Italy, ***Pietrapertosa, F. 2022.***	Improvements in building envelopes, heating and lighting, and photovoltaic systems allow reducing CO2 emission by approximately 644 t/year.
A Comparative Study of Design Strategies for Energy Efficiency in 6 High-Rise Buildings in Two Different Climates ***Raji, B. et al. 2014.***	A double-skin facade with automated blinds and operable windows besides a narrow floor plan are the strategies that effectively can provide energy savings for tall buildings.
Passive building energy savings: A review of building envelope components ***Suresh B., 2011***	Thermal mass as an energy-saving method is more effective in places where the outside ambient air temperature differences between the days and nights are high.
Passive strategies for energy optimization of social housing in the Mediterranean, ***Fernández-Agüera, J. et al. 2016.***	The main energy improvement actions used take into account orientation as well as the combined energy performance of the thermal envelope, ventilation rate, and suitable solar protection.
A Holistic Approach for Energy Renovation of the Town Hall Building in a Typical Small City of Southern Italy, ***Assimakopoulos, M, 2020.***	The best combined renovation action is a system completely integrated into the roof.
Comfort and economic criteria for selecting the optimal passive measures for the energy renovation of residential buildings in Catalonia,	The method provides technical and economic information about a set of passive energy efficiency measures.

Ortz,J. et al, 2016	
Identification and prioritization of passive energy consumption optimization measures in the building industry: An Iranian case study ***Amirhossein Balali, et al. 2020.***	Passive measures are categorized into three groups (thermal, lighting, and acoustic) according to their nature.
Municipal Building Regulations for Energy Efficiency in Southern Italy, ***Elenora Riva, 2014.***	Local regulations are a key factor aiming at sustainable territorial planning.
Cost-effective analysis for selecting energy efficiency measures for refurbishment of residential buildings in Catalonia, ***Ortiz, J. 2016***	The method provides technical and economic information about energy efficiency measures.

The attainment of thermal comfort within a building is paramount for rendering it independent from mechanical cooling systems. Thermal comfort is influenced by two primary variables: microclimate and occupant adaptation (Auliciems & Szokolay, 1997).

Passive Architecture engenders a consequential impact termed as the "savings" in operational energy, denoted as the Energy Savings Benefit. This impact is substantiated through a comparative analysis of energy consumption in buildings of similar types. In this study, a representative house was selected as a sample building to quantify the Energy Savings Benefit.

The determination of the Energy Savings Benefit in the Improved Case was achieved by contrasting its resultant energy needs with that of the Actual Case. The integration of passive design strategies, coupled with the utilization of alternative energy resources such as solar photovoltaic and solar thermal, emerges as a pivotal approach for reducing energy consumption in buildings. Beyond the economic benefits reflected in reduced energy bills, these measures contribute significantly to climate change mitigation efforts.

Optimal solutions were derived through the amalgamation of passive measures, building optimization techniques, and the application of alternative energy resources. Conventional means of providing thermal comfort, such as heating, ventilating, and air conditioning applications, are not only resource-intensive but also rank as the highest consumers of building energy. This study establishes that strategic implementation of passive measures, including materials upgrade, natural ventilation, and shading in the design features of the building envelope, either during the planning and construction phase or through retrofitting, can effectively curtail overall energy needs without compromising occupants' comfort levels. These findings underscore the potential of Passive Architecture in fostering building independence from mechanical cooling systems while aligning with sustainable energy practices.

Chapter 2

The Essential Concepts

Introduction

In alignment with the overarching research objective, the primary aim was to delineate the characteristics, classifications, and typologies of passive cooling strategies. The literature review undertaken in this study systematically encompasses fundamental principles guiding passive cooling in building design, alongside an exploration of diverse techniques. Furthermore, an exhaustive analysis of passive strategies' applications within the climatic conditions of Turin was conducted.

The research methodology evolved from a deliberate focus on assessing the efficiency and potential of implementing passive cooling strategies in the specific local climate of Turin. Within the expansive theoretical framework, numerous passive design strategies and techniques were elucidated. The subsequent stage involved a judicious selection of suitable strategies and techniques tailored to the unique climatic conditions of Turin. This rigorous process guided the execution of the study through distinct stages, unraveling key findings.

Firstly, the investigation brought to light that passive cooling strategies harbor substantial potential to affect a noteworthy reduction in the energy load of buildings. Secondly, the study systematically unveiled and discussed the diverse effects of the selected strategies, thereby providing a comprehensive guideline for end-users and stakeholders contemplating the application of these strategies.

The culmination of the study encompasses recommendations and a brief discussion on the contemporary reluctance towards the adoption of passive strategies on an urban scale. This concluding section delves into the underlying reasons for the current abandonment of passive strategies, offering valuable insights for further consideration and exploration in sustainable building design. The systematic exploration of objectives, literature, and methodology positions this scientific inquiry as a foundational contribution to the discourse surrounding passive cooling strategies and their applicability in specific climatic contexts.

1. The refurbishment of Sustainable Homes

Sustainable development is a paradigm shift in which advancements are made in a manner that satisfies the requirements of the current generation while ensuring that future generations can fulfill their own needs without negatively impacting the environment or depleting critical resources (Chinazzo, 2013-14; World Commission on Environment & Development, 1987). Consistent with this principle and the critical need to decrease dependence on fossil fuels and greenhouse gas emissions, the rehabilitation of pre-existing structures assumes paramount importance. As stated in the previous chapter, buildings that are presently operational or in the process of being constructed account for over 40% of the total greenhouse gas emissions and roughly 30% of the energy consumption in European countries (Perez Lombard et al., 2008; Chinazzo, 2013-14).

In conjunction with the rise in indoor activities, a growing population, an increased demand for building services, and a focus on occupant comfort are anticipated to contribute to a steady increase in the energy consumption of structures. Strategic interventions are required due to the well-established correlation between increased energy consumption and suboptimal construction practices, in addition to the excessive utilization of heating, ventilation, and air conditioning (HVAC) systems to maintain thermal comfort. The adoption of bioclimatic design principles for the renovation of pre-existing, dilapidated, and aged structures is recognized as an exceptionally economical strategy for reducing energy consumption in developed countries (Smith, 2001; Chinazzo, 2013-14).

2. The Definition of Refurbishment

There are instances where the terms modernization, conversion, refurbishment, maintenance, and renovation are used interchangeably to refer to modifications made to existing structures. The lack of clarity surrounding these terms can be attributed to a multitude of factors. The extent of change denoted by each term is largely ambiguous, encompassing a wide range of activities from minor replacements and repairs to more substantial interventions. Moreover, every intervention fulfills a distinct function, which can be classified as technical, aesthetic, utilitarian, or operational. Complicating matters further is the consistent misuse of these terms when it comes to authentically representing the modifications' characteristics (Giebeler, 2009; Chinazzo, 2013-14).

As to Giebeler's findings in 2009, as cited by Chinazzo in the years 2013-2014[1]. Here are the meanings of the previously stated terms:

Renovation neither contributes new additions to the existing building stock nor does the refurbishment procedure avoids the complete replacement of aging structures with new ones. On the contrary, its objective is to preserve the functionality and worth of the current edifice (Chinazzo, 2013-14).

Maintenance operations are limited to the replacement or repair of defective building components. Between complete renovation phases, routine maintenance is critical and is typically the building management's responsibility; the design team is rarely required to be directly involved (Chinazzo, 2013-14).

Undoubtedly, the architectural composition of a structure is altered during conversion. The aforementioned phrase expands the meaning of refurbishment to include alterations to interior design and/or structural components (Chinazzo, 2013-14).

The process of refurbishment involves the preservation of ancient components or surfaces while substituting them. Refurbishment is distinguished from conversion by the absence of substantial alterations to the interior design or load-bearing structure (Chinazzo, 2013-14).

The degree of renovation might differ (Giebeler 2009; Chinazzo, 2013-14):

- Partial refurbishment refers to the renovation of a specific component or element of a structure that is directly related to it, such as the façade, ground floor, or east wing. (Chinazzo, 2013-14).
- Standard renovation: it encompasses the entirety of a structure or a distinct section of it. Demolition work is often limited to surface areas or used as a first step for enhancing re-protection, noise control, or thermal performance. Regarding infrastructure, modifications

[1] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

and updates are typically made, but total replacement is not commonly done. (Chinazzo, 2013-14).

- Total refurbishment: This process entails comprehensive demolition procedures until the structure is completely stripped down to its load-bearing framework, which often remains unaltered. For instance, a comprehensive refurbishment would entail the entire replacement of infrastructure and building components in accordance with the most up-to-date laws. (Chinazzo, 2013-14).

3. Refurbishing Dwellings for Sustainability

Interventions in existing buildings can reduce energy needs and contribute to greenhouse gas reduction. Refurbishment offers several advantages, as supported by various research (Papadopoulos et al. 2002; Gorgolewski 1995; Hong et al. 2006; Chinazzo, 2013-14). Additional benefits encompass enhancements in soundproofing, extension of the building's lifespan, mitigation of environmental harm, amelioration of internal thermal comfort conditions, and an overall augmentation in the building's worth. Refurbishment can be seen as sustainable in several respects. The Green renovation encompasses the entire structure, aiming to reduce the environmental effect of the home not only in the present but also in the future. (Chinazzo, 2013-14). This study will specifically examine the advantages of refurbishing in terms of energy consumption and its significant correlation with climate change.

The Trias Energetica, a model devised by the Delft University of Technology, outlines three approaches to achieve energy sustainability in the construction industry:

- Minimize energy consumption: this can be accomplished through several methods. Examples include utilizing well-insulated and airtight building structures, implementing effective heat recovery systems for ventilation air in the heating season, employing energy-efficient electric lighting and equipment, and guaranteeing little resistance in ventilation air pathways. (Cauberg Huygen Consulting Engineers and Per Heiselberg 2008; Chinazzo, 2013-14).

Further elaboration on this matter may be found in the subsequent chapter.

- Utilize sustainable energy sources to the fullest extent feasible, including passive solar heating, day lighting, natural ventilation, night cooling, earth coupling, solar collectors, solar cells, geothermal energy, groundwater storage, and biomass. Optimizing the utilization of renewable energy may be achieved through the implementation of low-exergy systems. (Cauberg-Huygen Consulting Engineers and Per Heiselberg 2008; Chinazzo, 2013-14).
- Utilize fossil fuels with maximum efficiency by employing the least environmentally harmful options, such as heat pumps, highly efficient gas-fired boilers, and gas-fired combined heat and power (CHP) units. (Cauberg-Huygen Consulting Engineers and Per Heiselberg 2008; Chinazzo, 2013-14).

These three sustainable measures may be categorized into two groups: passive and active measures. The first concept pertains to the decrease in energy requirements, while the second concept focuses on optimizing the remaining energy usage. The subsequent subsections will provide a comprehensive analysis of all the solutions under the two distinct categories. (Chinazzo, 2013-14).

- Passive Measures: minimize energy needs

Passive Architecture, characterized by its climate-responsive attributes, aims to create indoor environments that are naturally comfortable. Particularly during warmer seasons, this comfort is achieved through a strategic approach to building elements, including orientation, form, openings, and sun shading devices. These elements are meticulously coordinated to mitigate solar radiation, facilitate ventilation via prevailing winds, and ensure adequate daylight penetration into the building. As a consequential outcome, buildings designed with passive principles necessitate less reliance on mechanical cooling and artificial lighting, thereby reducing dependence on commercially supplied energy. The quantifiable reduction in operational energy, termed the Energy Savings Benefit, serves as a tangible demonstration of the efficacy of Passive Architecture. This is exemplified through a comparative analysis of energy needs between an actual case, devoid of Passive Architecture considerations, and a simulated version incorporating Passive Architecture design strategies (Improved Case).

The application of Passive Architecture is particularly pertinent in hot and humid climates. Here, the primary objective is to mitigate solar radiation, enhance natural ventilation, and optimize daylighting within the building. The strategic orchestration of building elements, including orientation, form, openings, and sun shading devices, plays a pivotal role in achieving these objectives (Olgyay, 1963; Hyde, 2000).

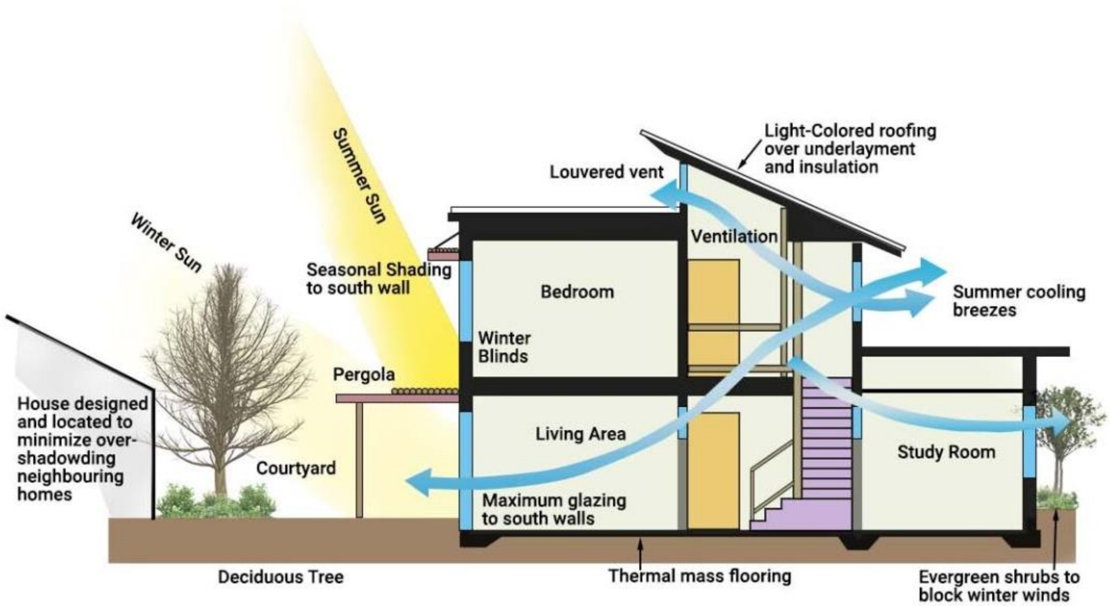

Fig 1. Passive Design Solution. (https://layakarchitect.com/passive-cooling/)

While the concept of Passive Architecture is not novel, traditional houses in tropical regions have long exemplified its principles. Elements such as raised floors, low thermal mass envelopes, and elevated or jacked roofs are employed to facilitate ventilation. Traditionally designed houses prioritize generous openings, strategically positioned windows, doors, and ventilation outlets to encourage natural airflow (Olgyay, 1963; Hyde, 2000). Additionally, these openings are carefully shaded to minimize heat gain, showcasing a nuanced understanding of climatic considerations.

Further studies support the efficacy of specific architectural choices in achieving optimal conditions in hot and humid tropical climates. For instance, buildings with shallow rooms elongated from east to west and facing north tend to outperform others in terms of creating comfortable indoor conditions (Hyde, 2000). This is attributed to the success of natural ventilation in slender rooms, as prevailing winds in the tropics typically exhibit lower velocities (Olgyay, 1963). In essence, Passive Architecture is a foundational approach that emphasizes Energy Conservation (EC) during the design phase, thereby reducing Operational Energy (OE) in buildings. This fundamental perspective positions Passive Architecture as an elementary yet essential strategy for achieving sustainable and energy-efficient building designs.

Passive cooling stands out as an exceptionally efficient method for conserving energy, boasting minimal economic impact when compared to mechanical systems. Numerous studies in hot climates consistently demonstrate that spaces employing passive cooling techniques tend to be the most energy efficient. Consequently, designers and architects have recently shown substantial interest in exploring passive cooling systems and strategies (Santamouris, 2007).

The passive cooling of buildings can be broadly categorized into three key sections (Geetha & Velraj, 2012). The initial stage involves the design of a building geared towards reducing and minimizing energy needs. This encompasses factors such as neighborhood planning, building layout, and orientation. A fundamental principle is designing a building that aligns harmoniously with the climate of its region and microclimate. Significantly, reducing internal gains within the building emerges as a pivotal aspect of enhancing the efficacy of passive cooling techniques. Site design and planning are critical factors influencing internal gains, considering economic considerations, zoning regulations, and adjacent developments. The primary goal in this stage is to control solar radiation, serving as the initial step in protecting against heat gain (Yannas, 1990).

Moving to the second stage, attention is directed towards modifying and modulating the gained heat through the building envelope, encompassing elements such as windows, walls, roofs, and shading components. Effective thermal management of a building has been identified as a crucial stage in achieving energy reductions. The building envelope serves as the principal tool for implementing the heat modulation strategy, absorbing heat during the day, regulating indoor temperature, minimizing peak cooling loads, and transferring absorbed heat to night hours. It plays a pivotal role in minimizing heat loss during winter and heat gain during summer.

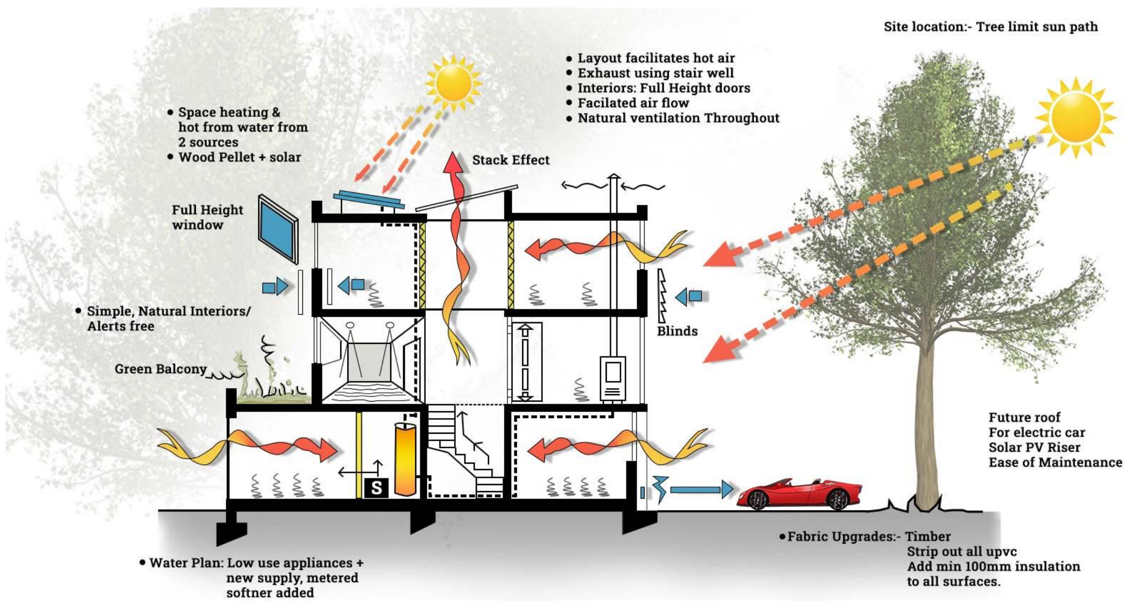

Fig 2. Passive Cooling Strategies. (NZED.in)

However, in certain scenarios, relying solely on modulation and solar protection strategies may fall short of achieving the desired thermal efficiency level. Consequently, the third stage focuses on expelling the accumulated heat from space, leveraging the upper atmosphere and ambient sky through natural heat transfer processes. Successful dissipation of excess heat hinges on two primary conditions: the presence of an appropriate environmental heat sink and the establishment of an effective thermal coupling between the building and the sink, coupled with a sufficient temperature difference for efficient heat transfer. This multi-faceted approach to passive cooling encompasses careful consideration and implementation across these three stages, ensuring a comprehensive and effective strategy for energy-efficient building design.

- Active Strategies: optimize remaining consumption effectively.

"...(i).....According to several scientific research, such as Chinazzo (2013-14)[2] active measures are distinct from passive measures since they utilize active building service systems to provide pleasant circumstances. These encompass various equipment such as boilers, chillers, mechanical ventilation systems, and electric lighting fixtures. Additionally, they make mention of utilizing sustainable energy sources such as photovoltaic (PV) systems, solar collectors, biomass, and geothermal energy. If the energy generated by these methods is inadequate for the building's operation, active measures involve enhancing the heating, cooling, and ventilation systems. This may be achieved by the implementation of heat pumps, heat recovery systems, and the adoption of more efficient technologies ...(i)..." (Chinazzo , 2013-14).

4. Passive Energy-Efficiency Strategies

This study will concentrate on passive measures pertaining to the building envelope. The term "building envelope" refers to the roof, walls, windows, and floors of a residential building.

We'll be focusing on the following topics in particular:

- Insulation
- Natural Ventilation
- Shading
- Airtightness

The four categories mentioned deal with the flow of heat in different ways.

As we can read an important scientifical thesis Chinazzo (2013-14) [3] we can point up that "...(i)..... Heat flow is the process by which thermal energy is transferred from one place to another. The precise mechanics involved include convection, radiation, and conduction. Convection entails the

[2] These themes are also present in depth in Chinazzo Giorgia's thesi s: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino."

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motion of a hot fluid, such as air. The rate of heat transfer is contingent upon the velocity of the transport medium (such as air or wind speed in the constructed area) and the disparity in temperature between the item and the fluid that is passing by. Radiation is the process of transferring energy in the form of electromagnetic radiation from one body to another. The amount of heat emitted is determined by the surface's emission coefficient and its temperature. Conduction is the process by which energy is transferred between neighboring molecules as a result of a difference in temperature. The heat conduction coefficient (λ) quantifies the rate at which heat is transported between two layers of material that are 1 meter thick and have a surface area of 1 m2, when there is a temperature differential of 1 K (1°C). Every material has its own capacity to conduct heat, which is known as its heat coefficient (λ). The higher the value of λ, the better the material is at conducting heat. Another important property of materials is their heating resistance, which can be calculated by multiplying the thickness of the material by the reciprocal of its heat coefficient (1/λ). …(i)…" (Chinazzo , 2013-14).

$$R = 1/\lambda \;\; d \; [\; m2 \;\; K/W \;]$$

Let's start by discussing insulation, which plays a crucial role in the process of heat conduction. Insulating the envelope of a building is an essential measure for improving energy efficiency because it helps to minimize heat transfer from the inside to the outside during winter and vice versa during summer. (Giebeler, 2009; Chinazzo, 2013-14). The main contributors to excessive energy usage, in both summer and winter, are unregulated heat transfer and infiltration across the building's outer shell. Figure 3 displays the proportion of heat dissipation during the winter season, whereas Figure 4 illustrates the heat acquisition during the summer season. (Chinazzo, 2013-14)

According to Douglas (2006), in homes without insulation, around 25% of heat is lost via the roof, 35% through the walls, 15% through the ground floor, 10% through the windows, and a further 15% through air leakage from doors and other openings. In addition, the Australian Greenhouse Office observed in 2010 that varying amounts of heat enter the building over the hot season, resulting in overheating and higher energy usage for cooling purposes. According to the given information, the heat distribution in this situation is as follows: 35% of the heat enters through the roof, 25% through the walls, 10% through the ground floor, 35% through the windows, and 5% through air leakage via doors and apertures (Chinazzo[4], 2013-14). The figures highlight the need of effectively controlling the transfer of heat, especially through windows, in order to achieve energy conservation goals (Chinazzo, 2013-14).

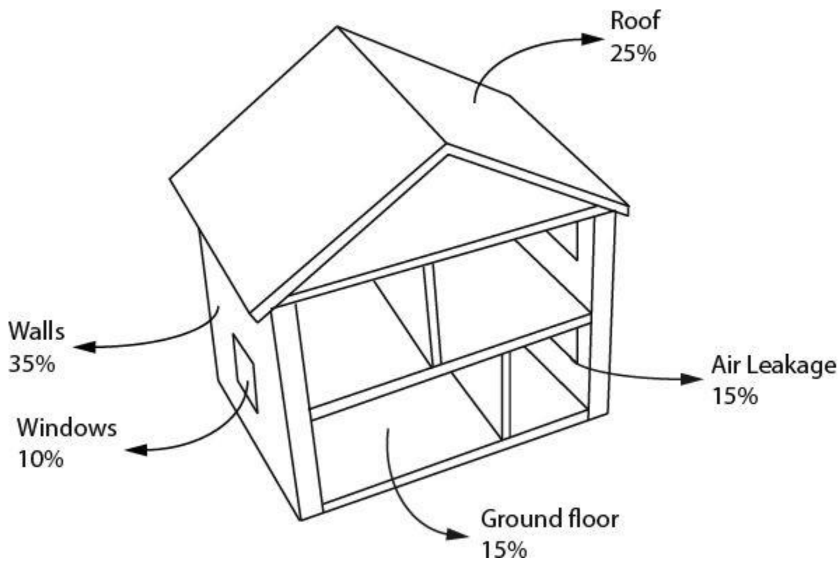

Fig 3. Percentage of heat losses in winter. (Chinazzo, 2013-2014)

[4] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

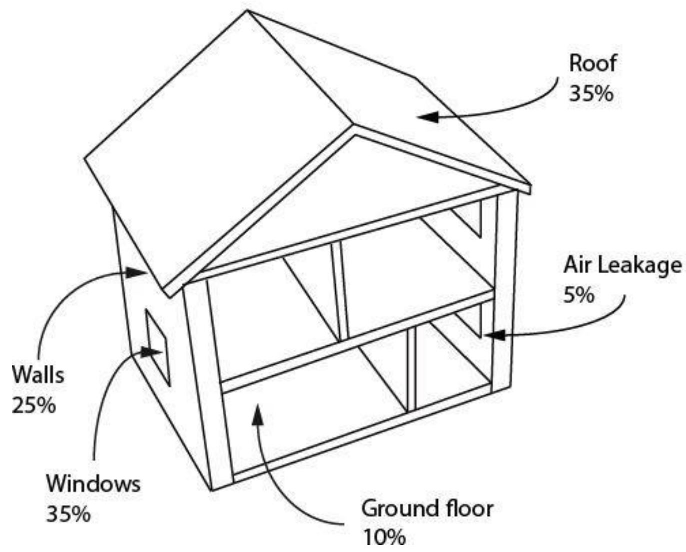

Fig 4. Percentage of heat gains in summer. (Chinazzo, 2013-2014)

" ….(i) …..The building envelope consists of several layers of materials, each with its own unique heat resistance properties. Comprehending the thermal transfers that occur through the building's outer layer is essential for accurately determining the energy needs of a structure. The U value is a crucial measure used to quantify the thermal efficiency of a building's envelope. It is used to distinguish between various insulation options for building envelope renovation. One more approach to energy saving is the reduction of heat by implementing shade devices. Within this particular circumstance, the fundamental physical process at play is thermal radiation resulting from the transfer of heat. Applying shading to both the building and outdoor areas is proven to be useful in reducing excessively high temperatures, improving comfort, and promoting energy conservation. It is crucial to shade windows in order to reduce unwanted heat absorption, as exposed glass is frequently the main cause of undesirable temperature rises in a house (i)…..". (Chinazzo[5], 2013-14).

[5] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

In conclusion, it can be argued that there are several measures to reduce energy needs that can be applied in a refurbishment. All these measures plus the appropriate heating, cooling and ventilation systems should be coordinated with each other in order to provide good thermal comfort inside and save energy. Only then can the refurbishment work be successful in the long term. (Chinazzo, 2013-14).

In the following sections, the main passive solutions are presented in detail by describing the insulation of the building envelope, including walls, roof, floors, and window. In addition, the other two measures will be explained, referring to the entire dwelling.

- Insulating walls

"….(i) ….. Insulation plays a vital role as a barrier to control the transfer of heat, guaranteeing that buildings maintain warmth during winter and stay cool during summer. The market provides a wide variety of insulating materials, principally differentiated by their thermal efficiency, which is shown by the U-value. Several aspects effect the choice of one material over another, including embodied energy, compatibility for the building, ease of installation, environmental impact, resistance, durability, and cost, as emphasized by Burton (2011) and Chinazzo[6] (2013-14). Table 2 presents the U-values of commonly used insulation materials in buildings. Among these materials, Aerogel stands out as the most favorable option due to its exceptionally low heat conductivity (U-value) compared to the others listed ….(i)…..". (Chinazzo, 2013-14).

[6] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

Table 02: Thermal conductivity of common insulation materials (Burton 2011).

Insulation materials	U-value ($\frac{W}{mK}$)
Aerogel	0.013-0.018
Phenolic foam	0.022
Polyurethane	0.023
Mineral wool	0.035
Expanded Polystyrene	0.038
Cellulose bre	0.040
Wood bre	0.044
Sheep s wool	0.04-0.057

A research undertaken by Giorgia Chinazzo and released in April 2013-14 fully discusses the efficacy of insulation installation in buildings. The study underscores the influence of incorporating insulation into houses that now lack it, underlining that the efficacy of this measure varies depending on the kind of structure and the specific area where the insulation is installed. To begin the insulation process for buildings with cavity walls, it is advised to fill the cavity with insulating material, as shown in Figure 5 (Chinazzo, 2013-14). The cavity insulation can be made of various materials and is injected through holes drilled in the outer layer. The most commonly used materials are polystyrene beads and mineral fibers. This method allows for a significant reduction in the value of a standard cavity wall with minimal disruption to the existing exterior or interior surface.

Depending on the size of the cavity and the type of insulation used, cavity wall insulation may not be sufficient. In such cases, other insulating solutions can be applied to solid walls. The first measure for improving insulation is to install external insulation. This approach has several advantages, including less disruption inside the house, retention of thermal mass, elimination of cold bridges, and providing a weatherproof barrier. It has some drawbacks, such as the need to expand the roof and opening sills, as well as relocate drainage pipes. Furthermore, external insulation can alter the outward appearance of a building. This can be a positive change if the current finish of the building is poor, but it can be negative if the building has good architectural features that may be covered up. This last factor can be crucial in deciding whether or not to choose external insulation. If the external walls are uninteresting and affected by dampness or cracks, then applying external insulation may be the ideal solution. It improves thermal performance, and appearance, and provides protection against external weather in a single operation.

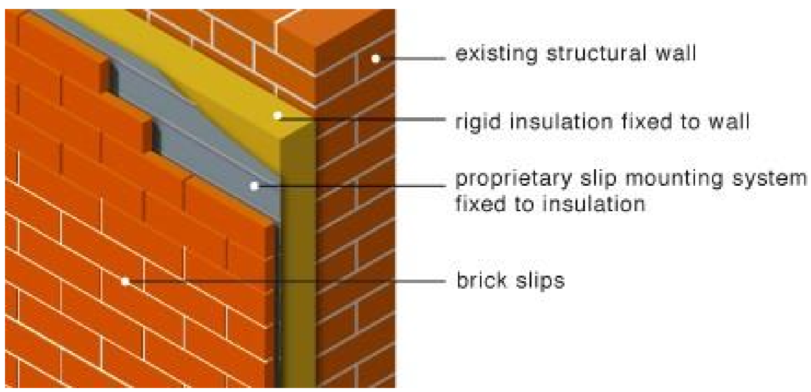

Fig 5. Cavity wall insulation (Source: www.greenspec.co.uk building design).

There are two methods for exterior insulating a building:

- The wet render system comprises various elements, such as insulant, adhesive mortar, mechanical fixings, profiles, edgings (utilized for corners and window reveals), a base coat render with integrated glass fiber, plastic, or metal mesh, and a topcoat render with or without a finish. According to Chinazzo (2013-14), Figure 6 illustrates that this technology is the most economically efficient choice among the available solutions for exterior insulation.

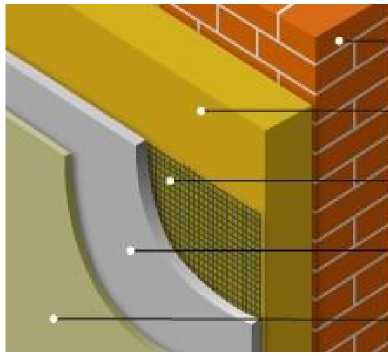

Fig 6. External wall insulation refers to the application of a wet render system onto an existing solid masonry wall. (Source: www.greenspec.co.uk building design), (Chinazzo, 2013-14)

- The Dry Cladding System is an alternative approach to insulating buildings outside. Unlike the wet render system, this kind of insulation attaches to particular locations on the exterior wall instead of covering the entire surface. This system consists of insulation, a supporting structure or cladding fastening system that is attached to the wall, a ventilated cavity, and cladding materials. The method shown in Figure 7 (Chinazzo, 2013-14) employs materials such as wood panels, stone or clay tiles, and brick lips.

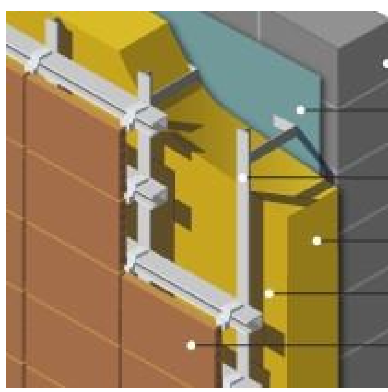

Fig 7. External wall insulation refers to a common method of applying a dry cladding system to an existing solid masonry wall. (Source: www.greenspec.co.uk building design), (Chinazzo, 2013-14)

Internal insulation is a measure that can be applied to both cavities and solid walls. It has some advantages. For instance, it doesn't change the external appearance of the building and is less expensive compared to external insulation. Additionally, It is impervious to exterior weather conditions and does not need scaffolding unless the ceilings are very high. However, there are also some disadvantages that come along with it. For example, it reduces the internal space and requires moving power points, skirting boards, radiators, and wall fittings. Additionally, it becomes challenging to securely attach bulky objects to the wall afterwards. Additional disadvantages include the occurrence of interstitial condensations and the inability to avoid structural cold bridging. (Chinazzo, 2013-14).

Three commonly used methods for interior insulation are:

- **Insulated Plasterboard:** In this method, thermal boards are securely attached to the inside walls using glue. Certain boards are provided with an integrated vapor control layer, which prevents the accumulation of moisture on the cold wall located beneath the insulation. For maximum efficiency, it is recommended to have a sleek and even inner wall texture. To ensure airtightness, consistently apply plaster glue along the perimeters of the wall, windows, and doors.. It is crucial to close any spaces between the board and the insulation and prevent air flow between the insulation and the inner wall, as seen in Figure 8 (Chinazzo, 2013-14).

- **Insulation and battens:** The wall must be fitted with battens in order to secure a strong insulation. The structure comprises vertical timber battens or metal furring that are securely attached to the wall. Between these battens, there are stiff or semi-rigid insulation boards, which are then covered with plasterboard. Furthermore, in this particular scenario, it is imperative to have a vapor check barrier positioned between the insulation and the plasterboard (Figure 9). (Chinazzo, 2013-14).

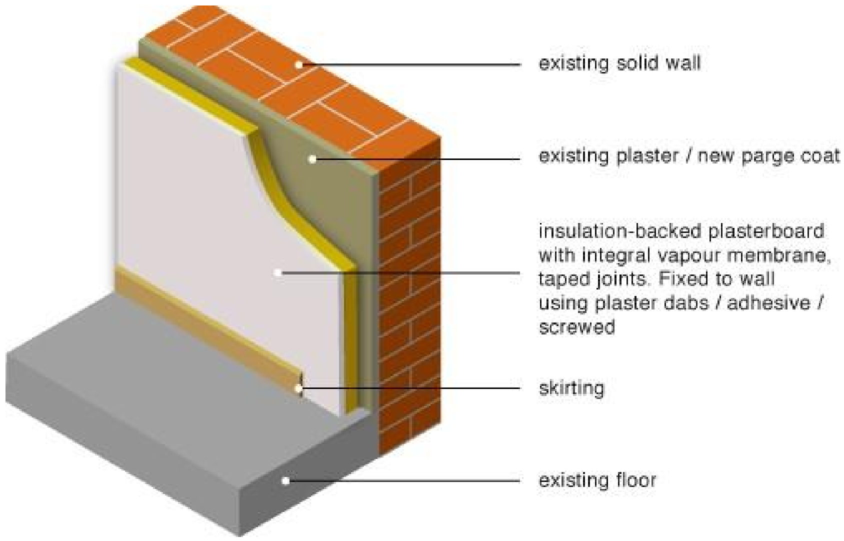

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Fig 8. Insulation of internal walls with insulated plasterboard. (Source: www.greenspec. co.uk building design), (Chinazzo, 2013-14)

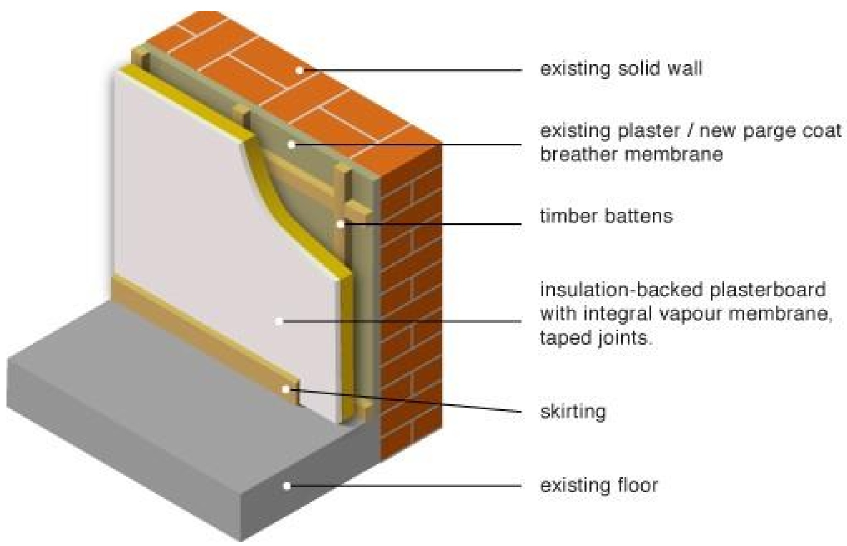

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Fig 9. Internal wall insulation: battens with insulation (Source: www.greenspec.co.uk building design).

- **Stud insulation:** It should be used on a wall that has already experienced dampness. By utilizing this technique, it becomes possible to create an empty area between the inner wall and the insulating substance. This procedure is very efficient when the wall displays bending or unevenness. The construction consists of a reinforced frame made of either lumber, extruded polystyrene, or metal, extending from the floor to the ceiling. The insulation is affixed to the frame, creating a 30 mm gap between the insulation and the wall. A hydrophobic barrier is installed between the vertical framing members and the wall, and gypsum board is utilized to complete the wall. The number of studworks depends on the planned use of the dwelling. Under some conditions, especially in the context of rental housing, a more robust structure is necessary. Nevertheless, it is crucial to bear in mind that augmenting the quantity of studwork will lead to a reduction in thermal efficiency due to the presence of thermal bridges (Figure 10). (Chinazzo, 2013-14).

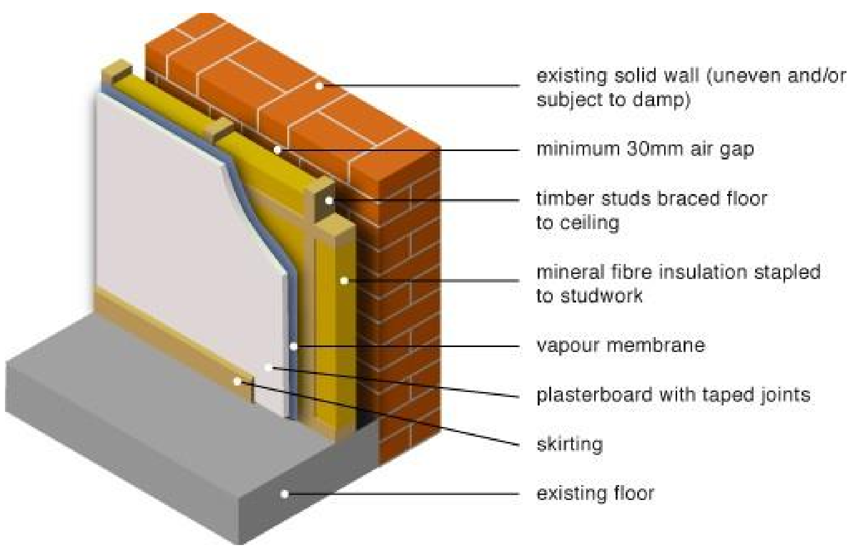


Fig 10. Insulating internal walls using studs and an air gap. (Source: www.greenspec. co.uk building design), (Chinazzo, 2013-14)

Occasionally, it may be justifiable to employ a blend of several restoration technologies. Nevertheless, in the majority of instances, employing a solitary method often proves to be a superior resolution. Several potential combinations of the three techniques include cavity insulation paired with either internal or exterior insulation, as well as internal insulation mixed with external insulation. (Energy Saving trust 2006a Highfield 2009 Burton 2011 Thorpe 2010), (Chinazzo, 2013-14).

- Insulating Ground and Exposed Floors

Underfloor insulation is a cost-effective measure to make existing houses warmer, healthier, and more comfortable. It is easy to install in homes with accessible underfloor spaces. Floor insulation is necessary in all floors that separate the interior space from the external environment. Different materials can be used for floor insulation, but the choice of material depends on the shape and type of the floor as well as the conductivity of the ground below it. The type of floor determines the principal difference in the materials used for insulation.

- Suspended Timber Floor (Figure 11): There are two regularly employed techniques for insulating suspended timber flooring. The initial method is raising the current flooring, inserting insulating material between the supporting beams, and then fastening a mesh over them. After completing this process, it is essential to restore the flooring and securely close any openings between the boards, skirting, and service entrance points. Alternatively, the second approach involves installing insulation between the floors and joists, sealing the seams between the boards, behind the skirting, and at the entrance service points. In order to finalize the procedure, plasterboard is securely attached to the lower side of the floor, thereby linking it to the joists (Chinazzo[7], 2013-14).
- Concrete Slab (Figure 12): In the case of structures that have solid concrete flooring, insulation can alone be put from the upper side. The procedure entails the placement of

[7] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

inflexible insulation over the concrete slab, subsequently followed by a vapor control layer and a floor finish. Nevertheless, this action might lead to an increased elevation, creating difficulties while navigating stairs and door thresholds. In addition, it is required to move skirting boards and electrical points (Chinazzo, 2013-14, Energy Saving Trust 2006a; Highfield 2009; Burton 2011; Thorpe 2010).

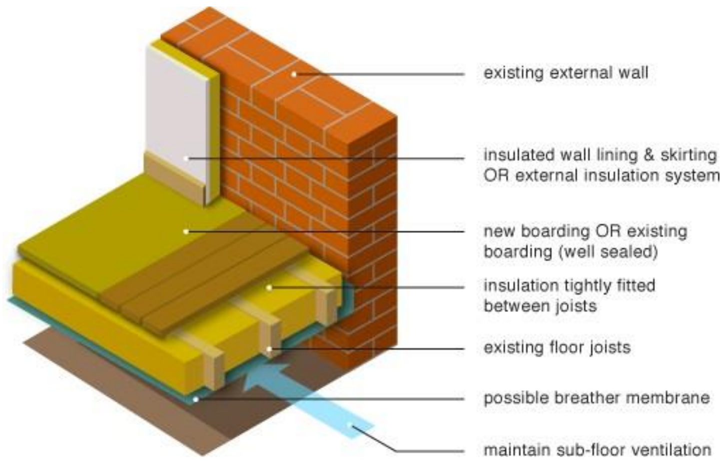


Fig 11. Timber ground floor insulation (Source: www.greenspec.co.uk buildingdesign).

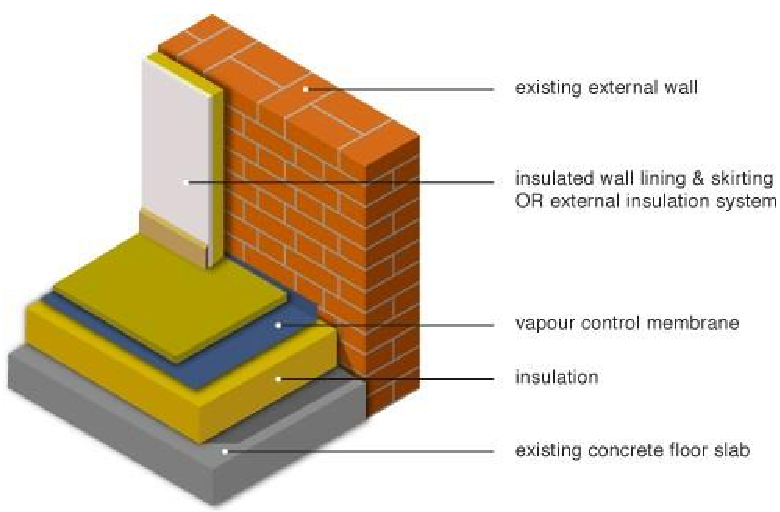


Fig 12. Concrete ground floor insulation (Source: www.greenspec.co.uk building design). (Chinazzo, 2013-14)

- Insulating roofs and exposed ceilings

The study conducted by Chinazzo (2013-14) emphasizes the need of insulating roofs and exposing ceilings. Current roofs, in addition to possible problems with faulty and deteriorating materials, frequently fail to fulfill present energy rules and optimal criteria for thermal efficiency and air tightness. Hence, roof insulation is a crucial measure to minimize energy requirements. There are several methods for improving roofs, and the process of renovating them may usually be carried out without causing significant disturbance to the building's framework. The selection of roof insulation methods is contingent upon the kind of roof, whether it is sloped or flat. The following list offers a succinct elucidation of prevalent roof insulation methods categorized by roof type. (Chinazzo, 2013-14).

- A pitched roof can be enhanced by adding an extra layer of insulation, either at the ceiling level or at the rafter level above or below. (Chinazzo, 2013-14).
- Internal roof insulation (Figure 13) is required at the rafter level to produce a warmer atmosphere beneath the roof when inhabitants want to use the roof area, as explained by Chinazzo[8] (2013-14). This approach is commonly utilized in houses that include attic rooms or loft conversions. In such instances, insulation is positioned between and beneath the rafters. This strategy is suitable for structures that do not have a ceiling and where the living space extends into the roof area. The benefits encompass little modification to the current roof structure and the incorporation of increased insulation thickness. Nevertheless, there are disadvantages associated with this approach, including a decrease in available interior space, which leads to a decrease in the height of the room, as well as the possibility of thermal bridging occurring via the rafters. On the other hand, if insulation is only applied between the rafters, it tries to maintain the height of the interior ceiling. However, this results in a thinner layer of insulation, which reduces the thermal qualities of the roof (Chinazzo, 2013-14).

[8] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

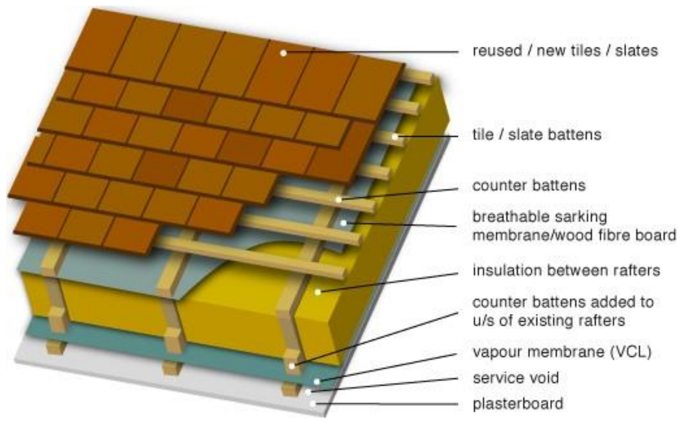


Fig 13. Roof insulation installed between and beneath the rafters (Source: www.greenspec. co.uk building design), (Chinazzo, 2013-14)

- External roof insulation (Figure 14) is a critical step in the replacement and rehabilitation of roof tiles. According to Chinazzo (2013-14), it is essential to insulate between and above the rafters during this process. While it may need a small increase in the height of the ceiling, this helps maintain the current interior space and headroom. This type of insulation is especially beneficial in cases where there is limited interior space and a need for excellent thermal efficiency. To achieve the best thermal efficiency, it is recommended to use thick insulating material both between and above the rafters, while also minimizing the transfer of heat through the rafters. (Chinazzo, 2013-14).

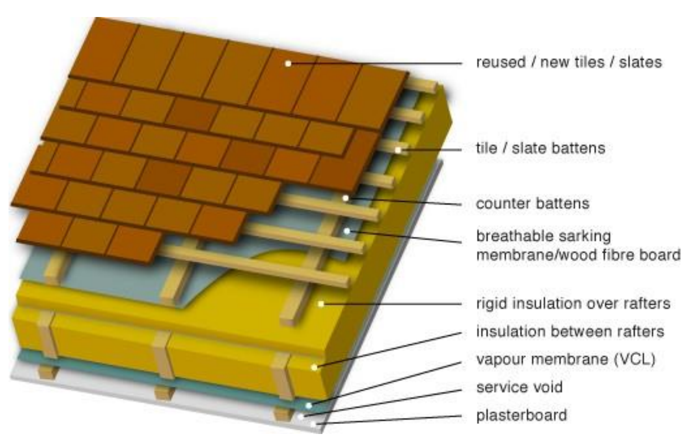


Fig 14. Roof insulation placed between and above the rafters. (Source: www.greenspec. co.uk building design), (Chinazzo, 2013-14)

- Loft Insulation (Figure 15) When there is a ceiling below the roof space and the roof space is not meant to be used, insulation can be added at the level of the ceiling to reduce the amount of heat that escapes into the empty area above and outside. Ceiling-level insulation entails the placement of insulating material between the joists of the ceiling, the addition of further insulation above the joists, the inclusion of a vapor control layer underneath the insulation, and the installation of a plasterboard ceiling. According to Chinazzo (2013-14), recessed lights that are located below the insulation in the ceiling should be sealed in airtight fireproof enclosures. This is necessary to prevent any disruptions in the vapor control layer and insulation.

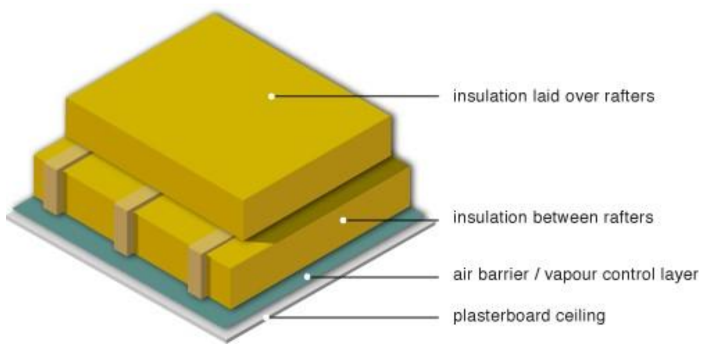


Fig 15. Loft insulation (Source: www.greenspec. co.uk building design).

- **Flat Roof:** The approach to enhancing the thermal efficiency of an existing flat roof relies on its construction type to some extent. There are primarily two types of flat roofs, the timber flat roof, and the concrete flat roof. In either case, the insulation can be installed in three different positions:
- **Arm roof** (Figure 16)**:** The roof deck is thermally insulated by positioning the insulation material above it. The waterproof membrane is positioned on top of the insulation, while the vapor control layer is situated beneath the insulation. (Chinazzo, 2013-14).

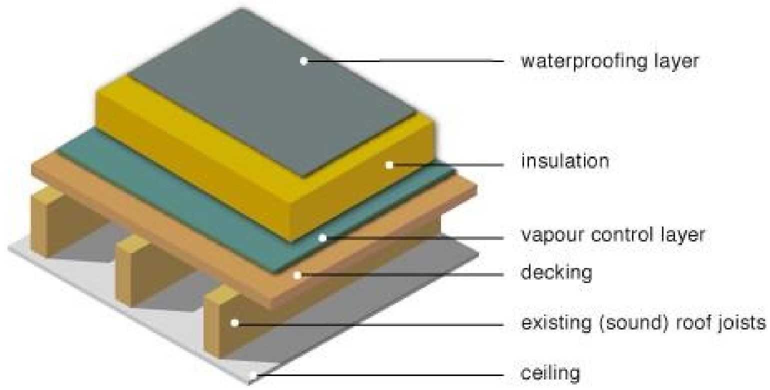


Fig 16. arm roof insulation (Source: www.greenspec.co.uk building design).

- **Inverted warm roof** (Figure 17)**:** In this type of roofing system, the insulation is placed above an existing waterproofing membrane. This insulation layer serves to protect the roof membrane from thermal stress, UV light, and mechanical damage. To prevent the insulation from lifting, a layer of ballast is added on top of it. However, It is important to emphasize that the insulation material utilized in this system must possess moisture resistance, as rainfall will consistently infiltrate the ballast and reach the insulation layer. (Chinazzo, 2013-14).

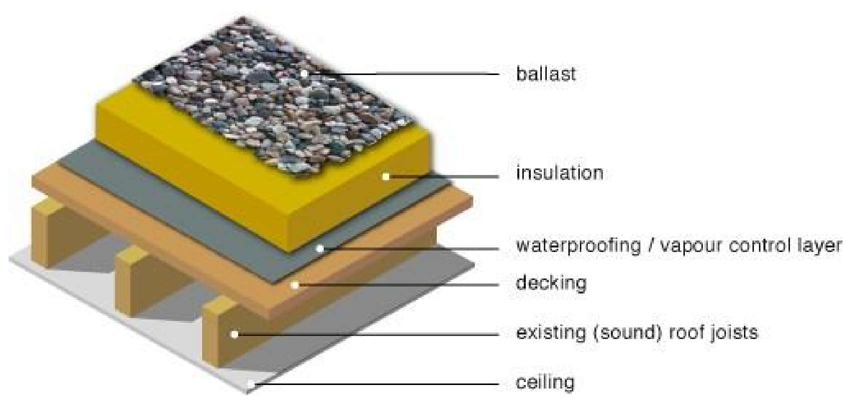


Fig 17. Inverted warm roof insulation (Source: www.greenspec.co.uk buildingdesign).

- **Cold roof** (Figure 18): When it is not possible to create a warm deck, internal insulation can be used instead. However, This design is prone to internal condensation on the cold deck surface due to the dispersion of any moist air that enters the roof through ventilation between the insulation and the underside of the deck. In order to avoid this, it is necessary to have a highly efficient internal vapor barrier that is fully sealed at wall joints and around any service penetrations. (Chinazzo, 2013-14). It is important to avoid upgrading methods that produce a cold roof, as this would require adequate ventilation to remove moisture. (Energy Saving Trust, 2006a; Highfield, 2009; Burton, 2011; Thorpe, 2010).

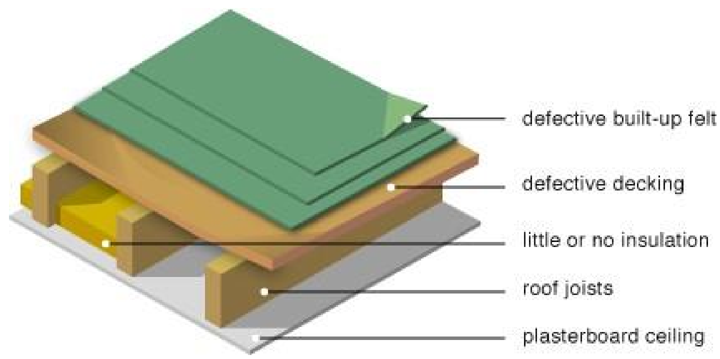


Fig 18. Cold roof insulation (Source: www.greenspec.co.uk building design).

- Insulating windows

During the summer, an average house receives around 35% of external heat through its windows, while in winter it loses about 10% of its heat through the same windows. The amount of solar heat entering the building greatly depends on the intensity of sunlight, angle of incidence, and the effectiveness of the glazing in transmitting, absorbing, or reflecting the energy. During winters, windows lose heat due to several phenomena. (Figure 19). The most significant one is radiation through the glazing, which accounts for about two-thirds of the heat flowing out of the house. Air leakage around the frame and opening sashes causes heat loss due to convection. If the window has double or triple glazing, convection within the glazing cavity also leads to heat transfer, although it is not as significant. Conduction is the last mode of heat transfer, where Heat is transferred via the window frame, and the rate of conduction is determined by the material of the frame. In double-glazed windows, heat is conducted through the aluminum spacer bars of the panes, although it is a relatively small part of the overall heat loss.

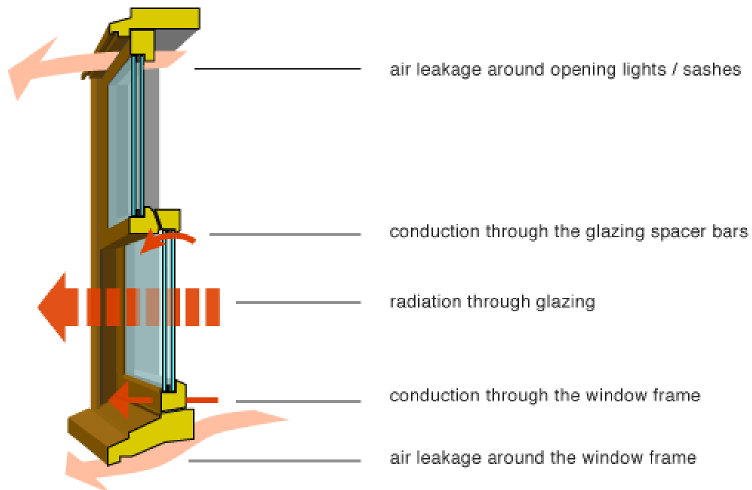


Fig 19. Heat losses through windows (Source: www.greenspec.co.uk buildingdesign).

On the other hand, Windows plays a crucial role in energy gain. Figure 20 illustrates " ….(i) ….. The process by which windows absorb heat is twofold: by direct transmission of solar energy, referred to as primary transmittance, and through the absorption of energy by the glazing, which is then transferred inside through convection and radiation, known as secondary transmittance. The G-value of a glass pane quantifies the extent to which glazing allows the transmission of heat from sunlight. Solar heat gain coefficient is a numerical representation of the proportion of solar heat that enters a window, ranging from 0 to 1. A glazing with a lower G-value transmits less solar heat. The Solar Heat Gain Coefficient (SHGC) is the US version of the G-value. However, it should be noted that the SHGC differs from the European G-value due to the utilization of a distinct air mass value. (Energy Saving Trust 2006b, Highfield 2009, Burton 2011, Thorpe 2010), ….(i)….." (Chinazzo, 2013- 14)

To summarize, when replacing windows during a refurbishment project, it is possible to control the amount of solar gain by adjusting various factors, as noted by Chinazzo (2013-14). These factors include the thickness of the panes, the number of panes (whether opting for double or triple-glazing), and the application of coatings on the glass, such as Low-E glass. By applying a layer of metal or metal oxide to the inner pane of glass, the building can allow short wave radiation from the sun to enter while reflecting long wave radiation, in the form of heat, back into the room. However, during summer months, the coatings may slightly decrease the amount of short-wave radiation that passes through the glass, which can contribute to the risk of overheating (Figure 21).

- cavity size
- cavity wall: When the space between the two glass panes of a window is filled with a gas that has low conductivity, such as argon, krypton, or xenon, it helps to reduce conductive and convective heat transfer. This technique is usually used in combination with low-emissivity coatings to improve the overall performance of the window.
- sealants (for gaps and leaks)
- frame materials.

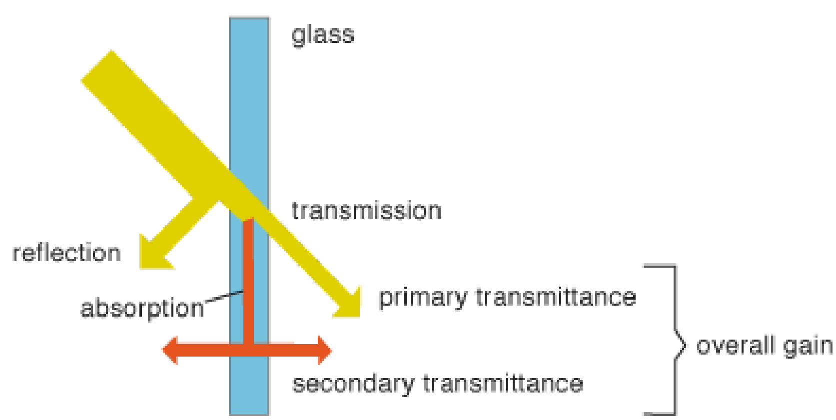


Fig 20. Solar gains through windows (Source: www.greenspec.co.uk buildingdesign).

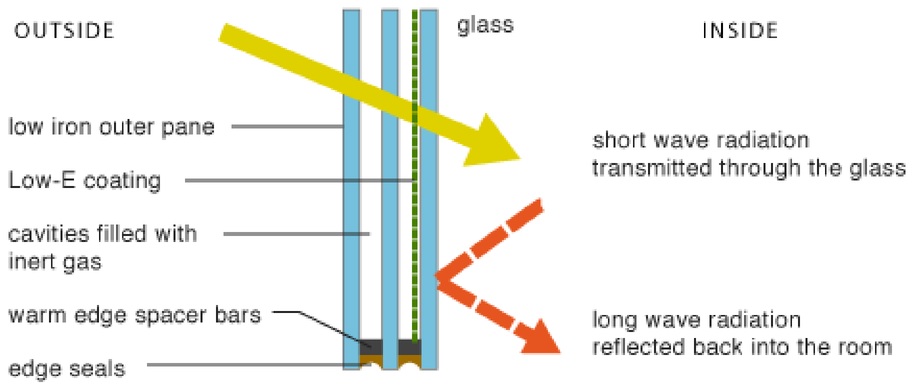


Fig 21. Low-Energy glazing (Source: www.greenspec.co.uk building design).

- Avoiding overheating with Natural Ventilation and shading systems

Shading systems have a strong connection to the thermal characteristics of windows and the transfer of heat through them. In order to mitigate the risk of overheating, it is imperative to put shade devices on all apertures, particularly those oriented towards the south. c

The shading systems can be shutters, blinds or curtains and they can be installed either inside or outside the building. Interior shading systems include bifold interior insulation shutters, manual or motorized interior curtains while exterior shading systems include shutters, roll-down shade screens, and retractable awnings. However, it is important to keep in mind that internal shading systems can cause overheating within the building. They absorb heat while sheltering the room from the sun's rays and then release it through convection. (Highfield, 2009, Burton, 2011, Thorpe, 2010).

- Enhancing the structural airtightness

Air infiltration is a major cause of energy inefficiency in buildings, accounting for up to 20% of the costs related to heating older dwellings. In modern homes, when heat is not effectively released through other means, the entry of outside air can account for up to one-third of the total heat loss, leading to increased energy use and the creation of uncomfortable inside conditions. (Shah, 2012), (Chinazzo, 2013-14).

Infiltration refers to the unintended flow of air into or out of a building through gaps and openings that are not designed for the purpose of ventilating stale air or introducing fresh air. These gaps are present in several areas of the structure, including below doors and door frames, around windows, through the eaves, and in numerous other locations. (Thorpe, 2010), (Chinazzo, 2013-14). Airtightness is quantified by the metric of air changes per hour (ACH), which is the frequency at which the air within a space is completely replaced by fresh air from the outside during a one-hour time frame. The air change rate (ACH) in an antiquated dwelling can vary from one to two volumes per hour, perhaps exceeding this range. On the other hand, a renovated and well-sealed home can reduce ACH values to 0.6 and 0.5. There are some easy steps that can be taken to enhance the airtightness of a building. One of the most cost-effective measures to use energy efficiently is draught proofing. It involves sealing all gaps, holes, and laps in membranes, along with setting up a continuous airtight barrier. After making the building airtight, mechanical ventilation becomes essential. (Chinazzo, 2013-14).

2.6. Towards Sustainable City

In recent decades, the construction sector has experienced a heightened awareness of the imperative for energy efficiency and carbon dioxide (CO_2) reduction in response to global warming. The elevated levels of CO_2 in the atmosphere are acknowledged as the primary driver of climate change. Estimates indicate a gradual increase in diurnal temperatures by approximately 0.1 °C per decade, with a projected 5 °C rise in the average global temperature by the year 2100 (Attia, 2017). Buildings constitute a significant contributor to this trend, accounting for over 36%

of the European Union's greenhouse gas emissions. Despite this, a substantial portion of the building stock projected for 2050 is yet to be constructed (Schnieders et al, 2015), presenting the construction sector with a substantial potential for carbon emission and energy consumption reduction (Causone *et al, 2014*). Research demonstrates that existing technologies in the market could lead to a 40% reduction in greenhouse gas emissions (Engelmann *et al, 2014),* making buildings a strategic sector for achieving the European Union's 2020 efficiency target (Figueiredo et al*,* 2016).

In response to these concerns, the European Parliament created Directive 2002/91/EC on the energy performance of buildings (EPBD), which was later revised in 2010 (Marie Robine et al. 2008). The main goal of this directive is to achieve an 80% decrease in greenhouse gas emissions from buildings by the year 2050. The aim is to accomplish this decrease by gradually implementing minimum energy performance standards, ultimately leading to the development of Nearly Zero Energy Buildings (NZEBs). Nearly Zero Energy Buildings (NZEBs) are distinguished by their outstanding performance and minimum energy requirements, which are mostly fulfilled by renewable sources (Giordano, 2017).

Although energy efficiency is a crucial element of sustainability, it should not be the only factor used to evaluate building performance. The notion of sustainability is examined in research that highlights the shortcomings of existing standards. These standards mostly emphasize measurable factors and overlook qualitative elements such as social, cultural, and environmental factors (Ascione, 2017). The measurement issues sometimes lead to the absence of qualitative characteristics in current standards and building codes. However, these factors are crucial for defining building sustainability (Zavadskas, 2017).

A substantial amount of worldwide energy consumption takes place in buildings, leading to efforts from investors, governments, and legislators to promote sustainability in different cities. Multiple studies have investigated the capacity of urban sustainable design to diminish energy use and develop communities with zero carbon emissions. Zaręba (2017), Lechtenböhmer (2010), Jenkins (2020), and Hamilton (2009) highlight the importance of sustainable design strategies, including sun access, natural ventilation, and the use of low and zero-carbon energy technology on site.The aforementioned techniques are in accordance with Jenkins' (2020) advocacy for a "urban-first" standpoint, which places emphasis on including stakeholders in the design process. Fouad et al (2020) present a novel Zero Energy Community (ZEC) concept that focuses on sustainability. They employ various building designs and simulations to create a community that relies exclusively on renewable energy sources. The findings demonstrate significant decreases in energy requirements and carbon dioxide discharges when compared to traditional communities, underscoring the crucial contribution of sustainable design in attaining urban energy demand reduction and zero-carbon communities. The user's text is empty.

This research seeks to illustrate, using a case study of a low-energy building, how the Active House Standard approach functions as a beneficial framework for a thorough assessment of building quality. The radar graph is a valuable tool for decision-making, providing designers with valuable insights into the potential consequences of various design methods during the building design process.

This research examines the crucial overlap between environmental issues, energy requirements, and architectural design, with a particular emphasis on the possibility of passive design solutions. The pressing worldwide needs to tackle climate change and increasing energy requirements highlights the necessity for inventive strategies in the construction sector. Passive design, based on the concepts of environmental responsiveness and energy conservation, is a viable approach to reduce energy requirements in buildings.

The study topic is well-defined, emphasizing the dual difficulty of increasing cooling energy needs caused by climate change and the widespread use of prototypes in residential constructions, which leads to higher energy consumption. The paper tackles these problems by conducting a thorough investigation of passive design solutions, especially customized to the climatic conditions in Turin, Italy. The study methodology utilizes a thorough approach that includes passive design typologies, a locally chosen case study, and an assessment of their viability in the specific local climate.

The study thoroughly examines Passive Architecture, highlighting its fundamental significance in attaining sustainable and energy-efficient building designs. This approach utilizes conventional concepts commonly found in tropical climates to demonstrate the historical effectiveness of passive tactics in establishing pleasant interior settings. The research thereafter proceeds to the pragmatic use of passive cooling, classifying it into three phases: reducing energy requirements through design, regulating accumulated heat through the building envelope, and removing surplus heat from the area. The multi-faceted method is portrayed as a thorough and efficient way for designing buildings that conserve energy.

Moreover, the research is in line with the worldwide necessity for sustainable urban design, recognizing the substantial impact of buildings on carbon emissions. This text offers an understanding of European directives that target the reduction of greenhouse gas emissions. It highlights the need to adopt a comprehensive approach to constructing sustainability that extends beyond measurable factors.

The case study presented in the study reinforces the potential of passive measures, building optimization techniques, and alternative energy resources in curbing energy needs while maintaining optimal thermal comfort. The findings underscore the transformative impact that widespread applications of Passive Architecture could have on residential buildings, aligning with the broader goals of energy efficiency and sustainability. In essence, this research contributes valuable insights to the ongoing discourse on environmentally responsive and energy-efficient building design. The findings advocate for the reintroduction and widespread adoption of passive cooling strategies as a pragmatic and effective means to address contemporary global challenges, reduce energy consumption, and foster sustainable urban development.

Chapter 3

The Case Study

Introduction

The objective of the project is to analyze the energy needs of residential apartment buildings constructed between 1961 to 1970 in Turin, Italy through investigates the possible refurbishment interventions in two level of “Standard”, and “Advanced”. The primary objective is to investigate the district-level impact of distinct energy-saving measures and evaluate their effectiveness in enhancing the energy performance of buildings and reducing carbon emissions. This section presents an overview of the materials and methods employed to achieve this objective. The base case is improved by implementing passive measures outlined in the previous chapter.

The research objectives play a pivotal role in shaping and delineating the appropriate methodology required to advance into the experimental stage of the research. The study's methodology unfolds across distinct stages, notably involving a stepped parametric analysis conducted on a residential building in Turin. A meticulous selection of passive refurbishment strategies, aligned with the climatic analysis of the location, forms the basis of the investigation. Each chosen strategy undergoes sequential scrutiny, and the comprehensive evaluation of the entire process is grounded in the discerned reduction in the cooling load. Furthermore, a comparative analysis between the base case and the final improved proposal, specifically in terms of the required cooling load, is executed to elucidate the efficacy of the applied strategies.

A critical practical consideration regarding passive design features underscores the imperative of incorporating these features during the early design stage, considering the climatic conditions and directional orientation of the building. Negendahl and Nielsen advocate for the integration of building performance simulation (BPS) tools in the early design stages, recognizing their beneficial impact on building performance aspects such as energy needs, daylighting, and thermal indoor environment. Similarly, Yigit and Ozorhon emphasize the importance of implementing simulation-based software during the preliminary design phase, as critical design decisions affecting the energy performance of buildings are made during this stage.

For the purpose of energy simulation, DesignBuilder was chosen as the simulation software. This platform encompasses a core 3D modeler and nine modules working cohesively to conduct in-depth analyses of energy use, consumption, and commitment for any building selected for analysis. DesignBuilder distinguishes itself by providing a comprehensive user interface compatible with the widely used energy simulation engine EnergyPlus and daylight simulation engines Radiance and DaySIM (Maile, Fischer, & Bazjanac, 2007). Leveraging the capabilities of DesignBuilder, all passive techniques pertinent to the research can be systematically investigated, and the parameters of each strategy will be meticulously detailed in their respective sections.

Input data from Table 1 were employed in the Design-Builder model. Subsequently, simulations were conducted in the base case to ascertain default cooling loads and indoor air temperatures, providing a baseline for the subsequent evaluation of the various studied strategies. This scientific methodology ensures a rigorous and systematic approach to investigating the potential of passive cooling strategies in residential buildings.

The research aims to assess if implementing refurbishment measures results in greater energy savings compared to the base scenario. Building energy simulations are employed to produce comprehensive data for every suggested solution. The next sections offer a thorough explanation of both the basic situation and the potential for improvement.

1. The Case Study at Building Scale

- Base-Case

The study analyzes an apartment residential building constructed between 1961 to 1970 that is located in the western part of the city of Turin, near Corsa Francia. The dwelling is composed of 10 floors, each floor has three flats. The house is situated on the main street shaded from other buildings.

The close proximity of nearby structures and plants may significantly affect the amount of sunlight that a building receives, therefore impacting its energy usage. (Misni and Allan 2010) (Chinazzo, 2013-2014).

It is modeled by the "PRELUDE project, POLITO_DAD research group", (for additional information see project Deliverable D7.3) (Figure 22).

DesignBuilder energy consumption simulation software is utilized to evaluate the effectiveness of various passive solutions. This software allows for accurate modeling and simulation of building energy performance, considering different variables and parameters. The software assesses the buildings' thermal characteristics and environmental impacts. It can analyze the building's cooling-heating loads, the influence of passive strategies on the energy needs level and estimate the quantity of solar radiation on the openings and different surfaces of the building. This software can model lighting, ventilation, and other energy flows as well as compute energy needs levels per hour, day, month, and year based on climate data and passive/active preparations planned for the construction. These features help designers to take appropriate measures in terms of building energy demand based on realistic data. Therefore, DesignBuilder is an ideal software to model the energy performance of the NZEB. The adequacy of the DesignBuilder software has been proved in different studies .Thus, one can refer to the software website, to see that it is acknowledged formally and validated by several decision-making bodies in England and many other countries. DesignBuilder software belongs to the UK and aims to help design and build efficient and healthy buildings as quickly as possible. All information related to the software as well as confirmations and instances of completed projects and acknowledgments are available on the software site. In this study, software version 7.0.2.006 was used.

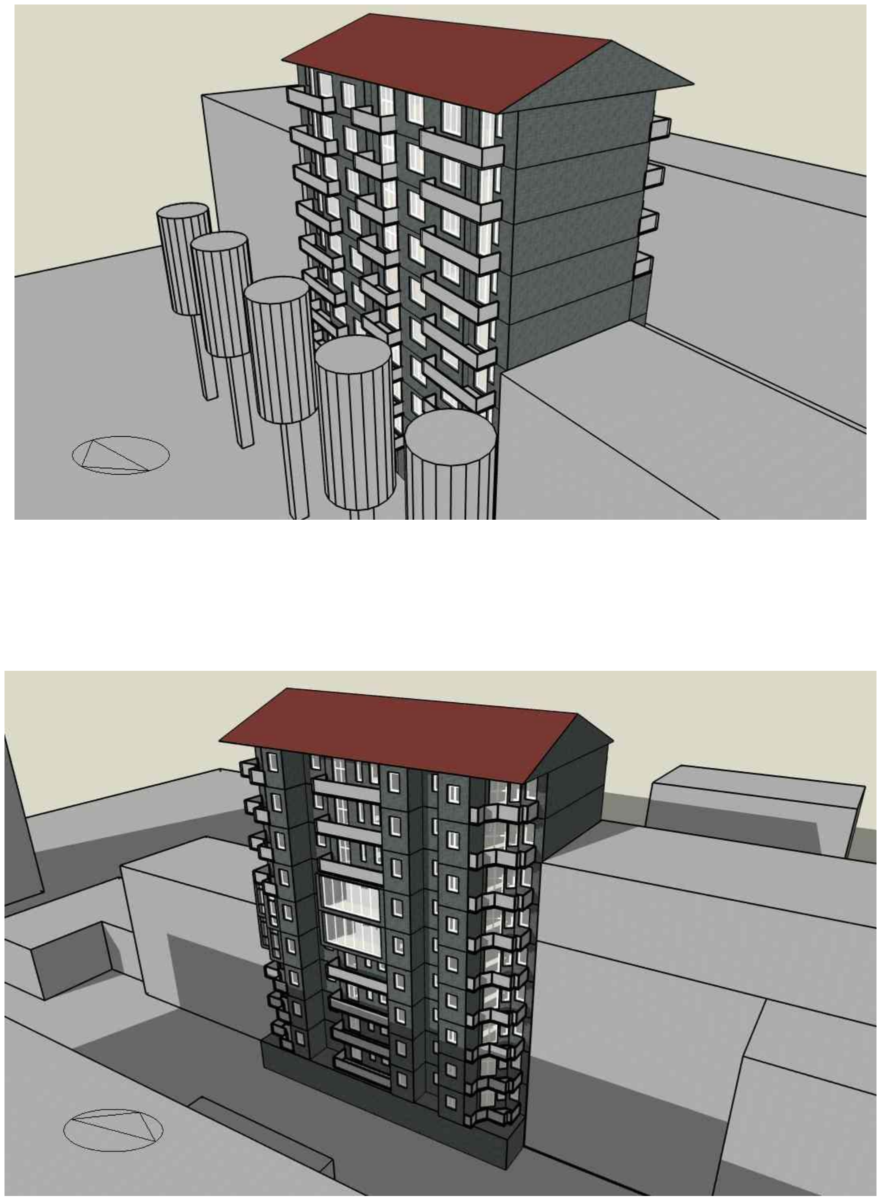


Fig 22. Building Model in Design-Builder software

- Construction Envelope

Specific input data corresponding to the building typology and simulation period were incorporated into the energy model, referencing the TABULA WEBTOOL. This input data encompassed information about building construction elements, lighting, and HVAC systems, activity data, and climatic data.

Each building type defined In the TABULA WEBTOOL and Italian TABULA Scientific Project Report from POLITO is characterized by envelope construction elements according to its "Building Age Classes" and "Building Size Classes" that are typical of the Italian building stock.

The building construction elements, as stipulated by TABULA, represent the various technologies employed in the building envelope characteristic of specific historical epochs. The building envelope components under consideration encompass roofing systems, walls, flooring, and windows.

This study seeks to achieve a comprehensive assessment of the energy needs of the apartment blocks in which the modeled building is considered in Class V, from 1961 to 1975 according to the Italian TABULA Scientific Report the constructive features of this building's age and size class are reported in Figure 23.

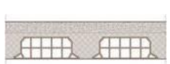
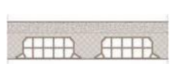
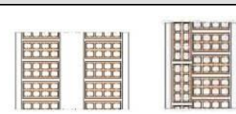
Building-type	ROOFS/CEILINGS(1)	FLOORS	WALLS	WINDOWS	DOORS
APARTMENT BLOCK  1961-1975	 Ceiling with reinforced brick-concrete slab	 Floor with reinforced brick-concrete slab	 Hollow wall brick masonry (40 cm). Hollow brick masonry (40 cm)	 Single glass, wood frame	-

Fig 23. Construction elements of building types (Source: TABULA Scientific Project Report, 2012)

The building uses a reinforced concrete structural frame consisting of pillars and beams. The walls are made of masonry block and brickwork, with an internal cavity. The ground floor and internal floors are made of concrete. The pitched roof is made of rafters and clay tiles. As the building was constructed before the 1970s, it lacks any insulation in its envelope.

The U-values for the basic case have been derived as follows:

- Walls: U_w = 1.04 W/m2K
- Roofs: U_r = 2.12W/m2K
- Internal floors: U_f = 1.81 W/m2K

The building's airtightness is deemed to be quite poor as a result of the outdated construction of the whole envelope. Due to this rationale, the cracks template in DesignBuilder is configured to have a significantly low quality. In the software, the natural ventilation is configured as "Calculated," the units for infiltration are "air changes per hour" (ach), and the airtightness technique is set to use a "Crack template" (Model Options/Data/Natural ventilation). This ventilation setting involves calculating the rates of natural ventilation and infiltration airflow by considering factors such as the size of openings and cracks, buoyancy, and wind pressure.

The windows have been designed with single glazing. The selected pane is a standard 6 mm thick transparent glass with a U-value of 5.77 W/m2K.

- Refurbishment Scenarios

The initial phase of this research methodology entails the simulation of the energy demands of the building under three distinct scenarios, namely the “Existing State,” a "Standard Refurbishment" scenario, and an "Advanced Refurbishment" scenario. The optimizing refurbishment strategies under examination encompass the addition of insulation, replacement of windows, integration of shading devices, and enhancements to ventilation systems tailored for cooling purposes. Subsequently, the study focuses on enhancing thermal performance of the “Advanced Refurbishment” building, incorporating two strategies for reducing energy needs: the implementation of natural ventilation and shading techniques. (Figure 24).

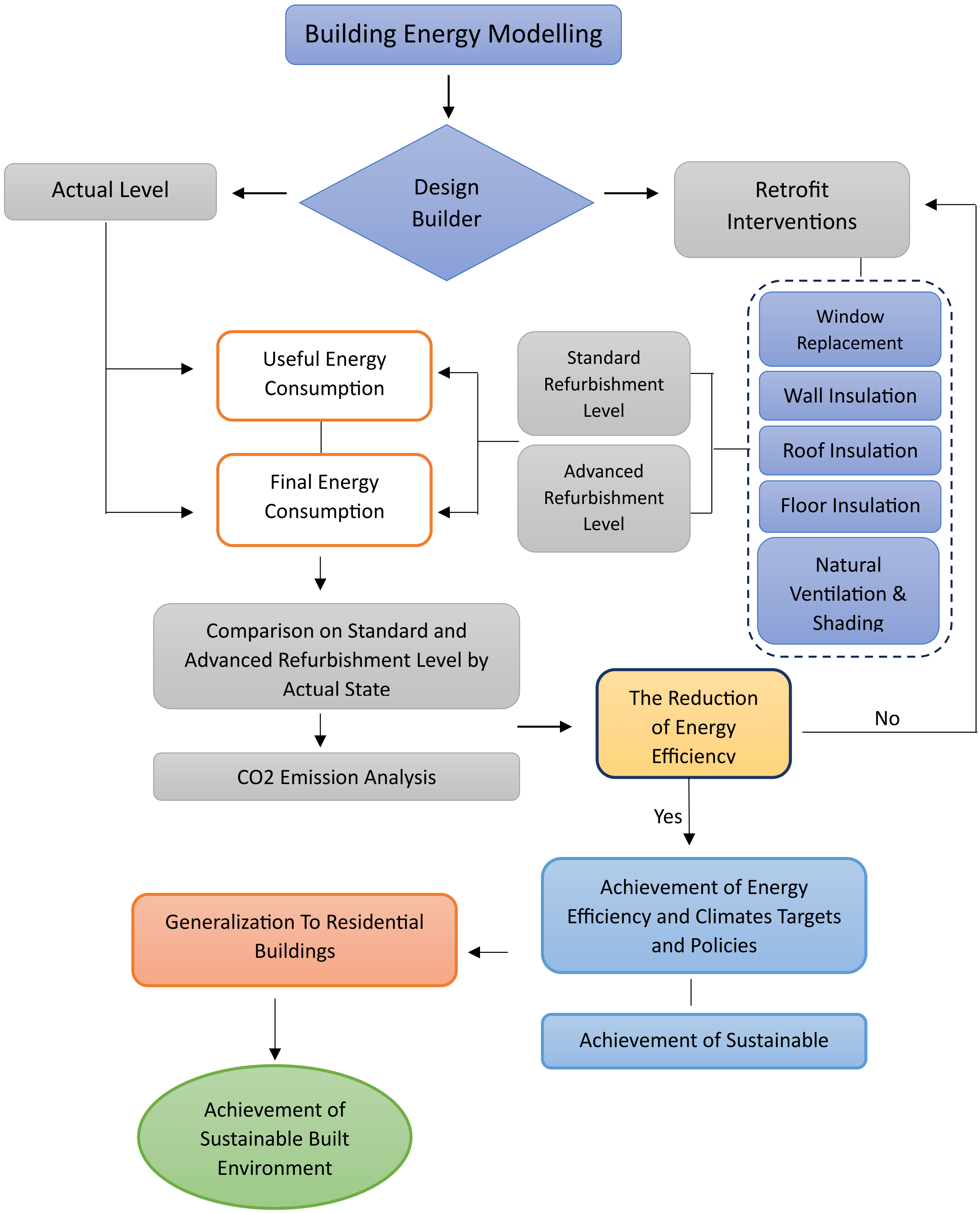


Fig 24. Study method strategies.

These simulations are conducted utilizing the DesignBuilder software, a computational tool underpinned by algorithms and mathematical models, facilitating the estimation of energy needs across different scenarios.

The principal parameters under investigation within this study revolve around the energy consumption patterns of buildings at each stage, serving as the yardstick to assess the energy-saving potential attributed to the implementation of diverse energy-efficient measures. Assumption underlying this investigation is that every passive measure is installed with the intention of optimizing its efficacy. Confirming the soundness of this assumption presents difficulties in practice. Gaterell and McEvoy (2005) and Chinazzo (2013-14) have both observed that apparently insignificant discrepancies from optimal installation conditions can significantly impact the real-world productivity of different solutions. The main characteristic that distinguishes distinct building configurations is the composition of the exterior walls and apertures.

- Definition of Standard and Advanced Refurbishment Scenarios

As we can read an important scientific Project Corrado.V, Ballarini.I, Corgnati.S P, (2012)[9] we can point up that "…(i)….. Various refurbishment strategies were taken into account for the various categories of buildings. Two levels of evaluation are applied to the retrofit actions on the building envelope for energy improvement measures: (TABULA Final Report Appendix, 2012)

- "Standard" renovation, taking into account the implementation of measures that are widely employed in the nation. (TABULA Final Report Appendix, 2012)
- "Advanced" refurbishment, considering the realization of measures that reflect the best available technology. (TABULA Final Report Appendix, 2012)

[9] These themes are also present in-depth Politecnico Scientific Project:
"National scientific report on the TABULA activities in Italy ." In:
https://iris.polito.it/bitstream/11583/2503215/1/Corrado_Ballarini_Corgnati
ScientificReport_POLITO_2012_10_08.pdf

The building envelope is upgraded in accordance with the subsequent "standard" procedures:

- construction of walls with an insulating material to achieve a U-value of 0.33 W/(m2K). (TABULA Final Report Appendix, 2012)

- implementation of insulation material in order to achieve a U-value of 0.30 W/(m2 K) on floors, roofs, and ceilings.
- Replace windows and doors to reach a U-value of 2.00 W/(m2K).

The building envelope is refurbished utilizing the subsequent "advanced" methods:

- wall insulation application in order to achieve a U-value of 0.25 W/(m2K)
- implementation of insulation material in order to achieve a U-value of 0.23 W/(m2K) on floors, roofs, and ceilings.
- window and door replacements in order to achieve a U-value of 1.70 W/(m2K)

The U-values under consideration align with the criteria set forth in the TABULA Final Report Appendix (2012), which pertain to the energy performance of structures in the Piedmont region and were established by the new regulations (D.G.R. no. 46-11968). In contrast to the criteria established by national legislation, namely Legislative Decrees No. 192/2005 and No. 311/2006, the U-values referenced in the TABULA Thematic Report N° 2 from 2012 are more rigorous. (TABULA Thematic Report N° 2, 2012). In accordance with the regulation for the Piedmont Region, the U-values utilized for the "standard" refurbishment are mandatory, whereas the U-values utilized for the "advanced" refurbishment are discretionary. (Scientific report polito, 2012). To achieve these performance levels, the following thicknesses of thermal insulation material have to be applied to typical building construction elements, Taking into account an insulation thermal conductivity of 0.04 W/(m K):

Taking into account an insulation thermal conductivity of 0.04 W/(m K):

- between 6 and 11 cm for walls, assuming a "standard" renovation.
- between 7 and 12 cm for floors and ceilings and roofs, assuming a "standard" renovation.

- 10 to 15 cm for walls, taking into account a "advanced" renovation.
- 11 to 16 cm for floors and ceilings and ceilings, with "advanced" renovations taken into account.

These variations are detailed in Table 03, thereby establishing a critical point of distinction among the three scenarios. The subsequent subsections describe in detail the presumed effects of each measure.

Table 03: The characteristics of scenarios

Scenarios/element	Existing State	Standard Refurbishment	Advanced Refurbishment
External Walls	Concrete Tile (15 mm) Cement/Plaster/Mortar (10 mm) Brick (200 mm) Air Gap (10 mm) Brick (200 mm) Gypsum Plaster Board (15 mm)	Concrete Tile (15 mm) Cement/Plaster/Mortar (10 mm) Brick (180 mm) Brick (140 mm) EPS Heavy Weight (75 mm) Gypsum Plaster Board (15 mm)	Concrete Tile (15 mm) Cement/Plaster/Mortar (10 mm) Brick (200 mm) EPS Heavy Weight (130 mm) Brick (200 mm) Gypsum Plaster Board (15 mm)
Roof (it is considered the layers of the under-roof slab)	Roof tile (30 mm) Brick Reinforced (250 mm) Plaster Board (15 mm)	Roof tile (30 mm) EPS Heavy Weight (120 mm) Brick Reinforced (250 mm) Plaster Board (15 mm)	Roof tile (30 mm) EPS Heavy Weight (150 mm) Brick Reinforced (250 mm) Plaster Board (30 mm)
Partition	Gypsum Plaster Board (15 mm) Brick (120 mm) Gypsum Plaster Board (15 mm)	Gypsum Plaster Board (15 mm) Brick (120 mm) Gypsum Plaster Board (15 mm)	Gypsum Plaster Board (15 mm) Brick (120 mm) Gypsum Plaster Board (15 mm)
Ground floor	Ceramic/Clay Tiles (15 mm) Magrone (50 mm) Solaio Areato (220 mm) Cement/Plaster/Mortar-Gypsum (15 mm)	Ceramic/Clay Tiles (15 mm) Magrone (50 mm) Solaio Areato (220 mm) Cement/Plaster/Mortar-Gypsum (15 mm)	Ceramic/Clay Tiles (15 mm) EPS Heavy Weight (115 mm) Brick Reinforced (250 mm) Cement/Plaster/Mortar-Gypsum (15 mm)
Internal Floor	Ceramic/Clay Tiles (15 mm) Brick Reinforced (250 mm) Cement/Plaster/Mortar-Gypsum (15 mm)	Ceramic/Clay Tiles (15 mm) EPS Heavy Weight (115 mm) Brick Reinforced (250 mm) Cement/Plaster/Mortar-Gypsum (15 mm)	Ceramic/Clay Tiles (15 mm) EPS Heavy Weight (115 mm) Brick Reinforced (250 mm) Cement/Plaster/Mortar-Gypsum (15 mm)
Opening	Single Clear 6 mm	Dbl Low-E Clr 3mm-6 mm Arg	Trp Low-E- Clr 3mm-13 mm Arg

- Evaluation of Natural Ventilation and Shading

The preservation of thermal comfort within architectural structures is of paramount significance, as it profoundly influences both the well-being of occupants and the overall energy efficiency of the building. Passive design strategies, such as natural ventilation and shading, serve as pivotal mechanisms in regulating indoor temperatures, thus significantly contributing to the attainment of optimal thermal comfort levels.

This scholarly investigation expounds upon a particular design framework for implementing natural ventilation and shading in a building. The focal point of this design approach centers on the intricate interplay between the internal and external air temperatures, with the objective of creating a harmonious indoor climate.

To gauge the impact of passive architectural solutions on the thermal comfort and energy consumption of the building, this study undertakes a meticulous evaluation of two distinct methods: natural ventilation and shading. It is essential to emphasize that the investigation purposefully excludes the incorporation of active cooling systems, a decision informed by the escalating global warming trends. Consequently, the role of these passive strategies becomes increasingly indispensable for maintaining a comfortable indoor environment, particularly during the sweltering summer months.

In order to quantify the efficacy of natural ventilation and shading, the present study employs the Design-Builder software, a sophisticated computational tool engineered to determine resultant variations in internal temperature and thermal comfort indices. Through this systematic analysis, we endeavor to shed light on the practicality and effectiveness of these passive design strategies in enhancing thermal comfort and curbing energy needs within the architectural domain.

- Natural Ventilation Design

The natural ventilation system has been meticulously engineered to be responsive to fluctuations in both indoor and outdoor air temperatures. When the indoor ambient temperature surpasses the threshold of 22 degrees Celsius and the external air temperature falls within the range of 18 to 24 degrees Celsius, a deliberate operational strategy is implemented. This strategy entails the deliberate opening of windows at a rate equivalent to 50 percent of the total glazing opening area, facilitating the creation of a conducive airflow regime. (Figure 25).

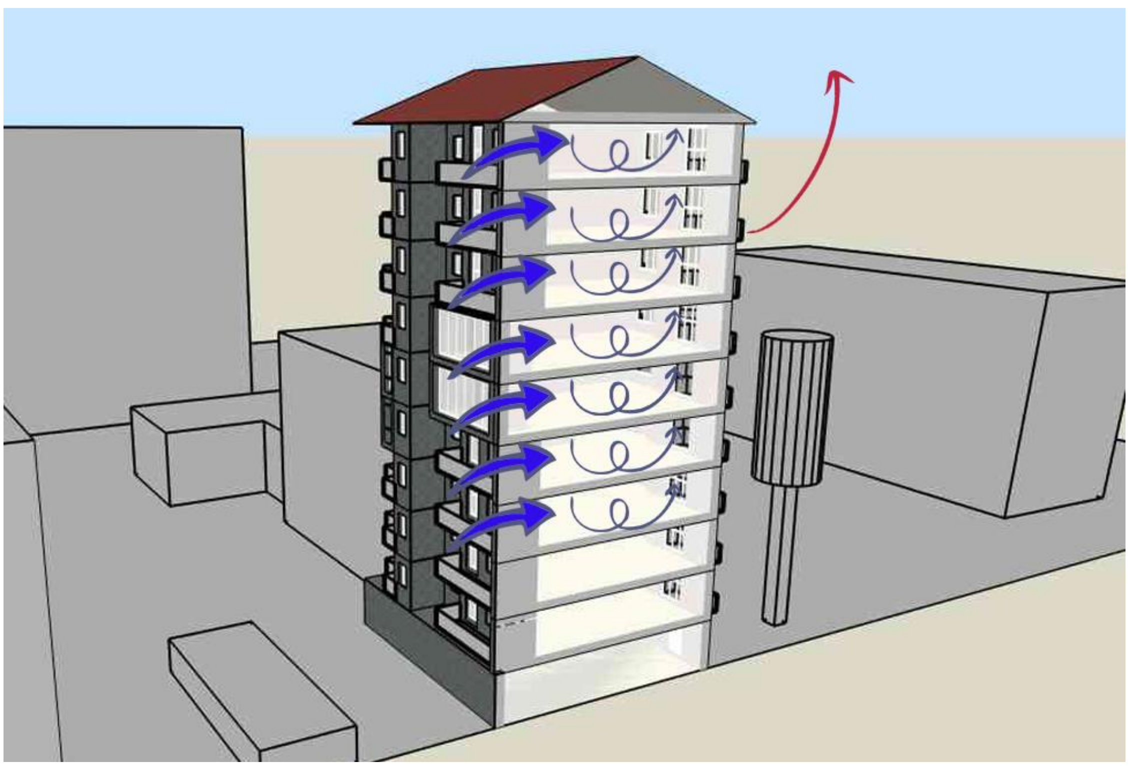


Fig 25. Natural Ventilation Scheme

This well-considered approach serves to facilitate the exchange of air between the indoor and outdoor environments, thereby engendering the concomitant benefits of cooling, refreshing the air quality, and augmenting the overall ventilation within the confines of the building. The decision to employ a window aperture size at 50 percent of the total glazing area is predicated upon the specific architectural design considerations and requisites of the structure in question. This measured aperture size has been judiciously selected to strike a balance between ensuring the sufficiency of airflow and concurrently upholding paramount considerations of security and precise control over the ventilation process.

By judiciously initiating the process of window opening when the indoor air temperature surpasses the predefined 22-degree Celsius threshold, the natural ventilation system effectively provides a passive avenue for cooling the indoor environment. This action, in turn, serves to reduce the reliance on energy-intensive mechanical cooling systems, thereby contributing to a consequential reduction in energy needs. Furthermore, this approach offers the ancillary benefits of delivering a constant supply of fresh and healthful air, enhancing the overall comfort and well-being of the building's occupants.

- Shading Design

In conjunction with natural ventilation, shading mechanisms assume a pivotal role in preserving thermal comfort within architectural spaces. Specifically, shading elements are strategically positioned above south-facing windows to mitigate the adverse effects of solar heat gain during periods of intense solar radiation (Figure 26). These shading components are designed with an overhang depth of 40 cm, a dimension calculated based on comprehensive considerations of solar angles. This depth parameter is determined through simulation processes, ensuring the optimal angle for maximum efficiency.

The utilization of a 40 cm depth is critical, as it guarantees the shading elements' ability to effectively obstruct direct sunlight from infiltrating the building interior. By limiting solar heat gain, this shading system curtails excessive temperature elevation within the indoor environment. Consequently, the systematic reduction of solar heat gain significantly contributes to the overall cooling of the interior space, fostering an environment conducive to occupant comfort.

This meticulous approach to shading design stands as a testament to the intersection of architectural precision and scientific methodology in enhancing thermal performance and occupant well-being.

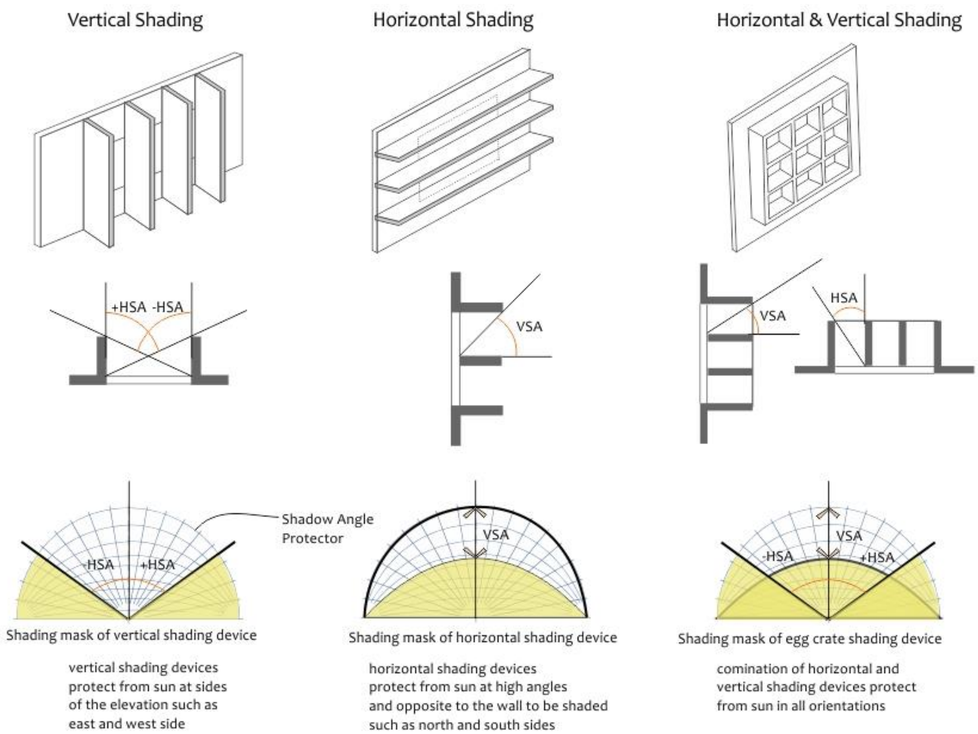


Fig 26. Shading performance. (Source: www.nzeb.in)

2. The Case Study at Urban Scale

- The City of Turin

According to El Jamous's[10] (2020) scientific thesis, it can be concluded that "...(i).....Turin is a city situated in the northwestern piece of Italy (Figure 27). This city is a significant business and social focus in northern Italy. It is the capital city of Piedmont and of the Metropolitan City of Turin and was the primary Italian capital from 1861 to 1865. The city is predominantly located on the west side of the Po River, encircled by the western Alpine curve and Superga Hill and located beneath its Susa Valley. The number of inhabitants in the city is 866,425 (31 August 2020) while the number of inhabitants in the metropolitan territory is assessed by Eurostat to be 1.7 million occupants. The Turin metropolitan zone is assessed by the OECD to have a populace of 2.2 million. The city's weather includes a European-Atlantic atmosphere, as does a large portion of northern Italy. Winters are decently cold and dry; however, summers are mellow on the slopes and very blistering in the fields. Throughout the colder time of year and fall months banks of mist, which are in some cases extremely thick, structure in the fields however infrequently in the city considering its area located towards the finish of the Susa Valley. Its situation on the east side of the Alps makes the climate drier than on the west side mainly due to the föhn wind impact. In fact, according to Italian standards, the city of Turin has a mainland temperature atmosphere with 2648 at 20°C warming degrees day. The warming period for the city of Turin is from October 15 to April 15 and covers a time of 183 days, in Turin, there are around 60 000 warmed structures, of which 75 percent are private condos and 80% of them were constructed before 1970". (Mutani and Todeschi, 2020) ....(i)....." (El Jamous, 2021).

[10] These themes are also present in depth in Bernadette El Jamous 's thesis: "The Impact of Building Variables on the Heating and Cooling Energy Consumptions. The Case Study of Turin. Politecnico di Torino, 2021"

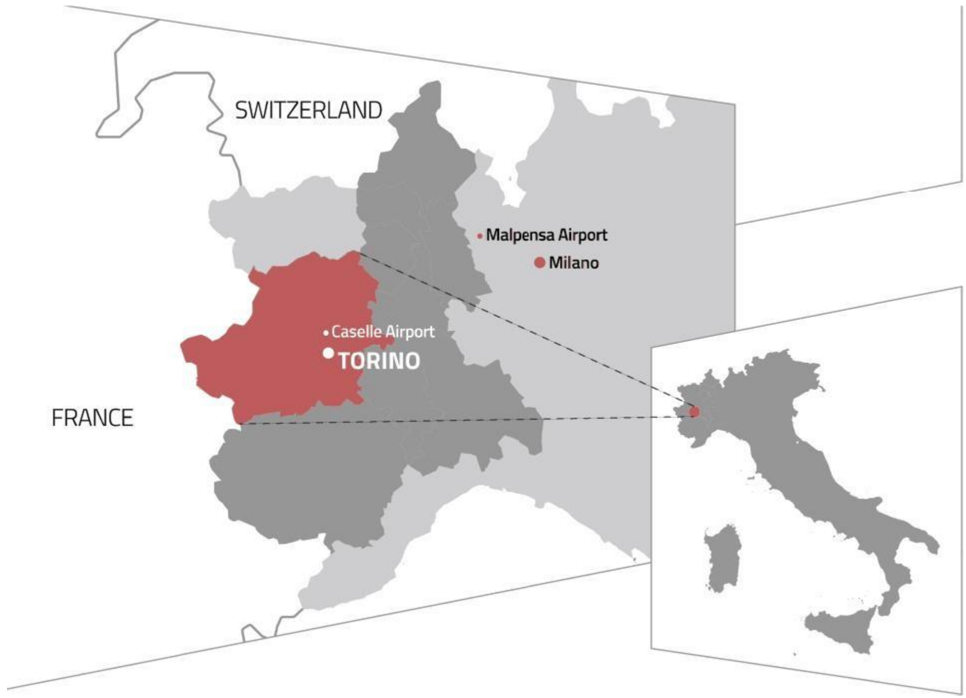


Fig 27: Location of the city of Turin, Italy (source: Bernadette El Jamous, 2021)

As we can read an important scientific thesis Asadi,[11] (2022) we can point up that "…(i)….. The Department of House and City at the Polytechnic University of Turin, which is now the Department of Architecture and Design, created 40 cadastral Micro zones in Turin. In accordance with DPR 138/98 and the Ministry of Finance's Regulation, the Municipal Council approved the Micro zones in June 1999. The Regulation states that a micro zone is often a portion of the municipal territory that must be uniform in terms of town planning and at the same time be a market for real estate. This region is indicated in the land registry by one or more map sheets. ("OICT - Microzones Definition" n.d.), (Asadi, 2021).

Focusing on the "building construction period" variable, underlying the historical territorial segmentation of the Micro zones, the building construction periods for each macrozone are

[11] These themes are also present in depth in Mahsa Asadi 's thesis: "A transformative approach to reach an energy-conscious district A case study in the city of Turin, Italy. Politecnico di Torino, 2022"

represented in the map below (Figure 28) (Barreca, Curto, and Rolando, n.d.), …(i)…” (Asadi, 2021).

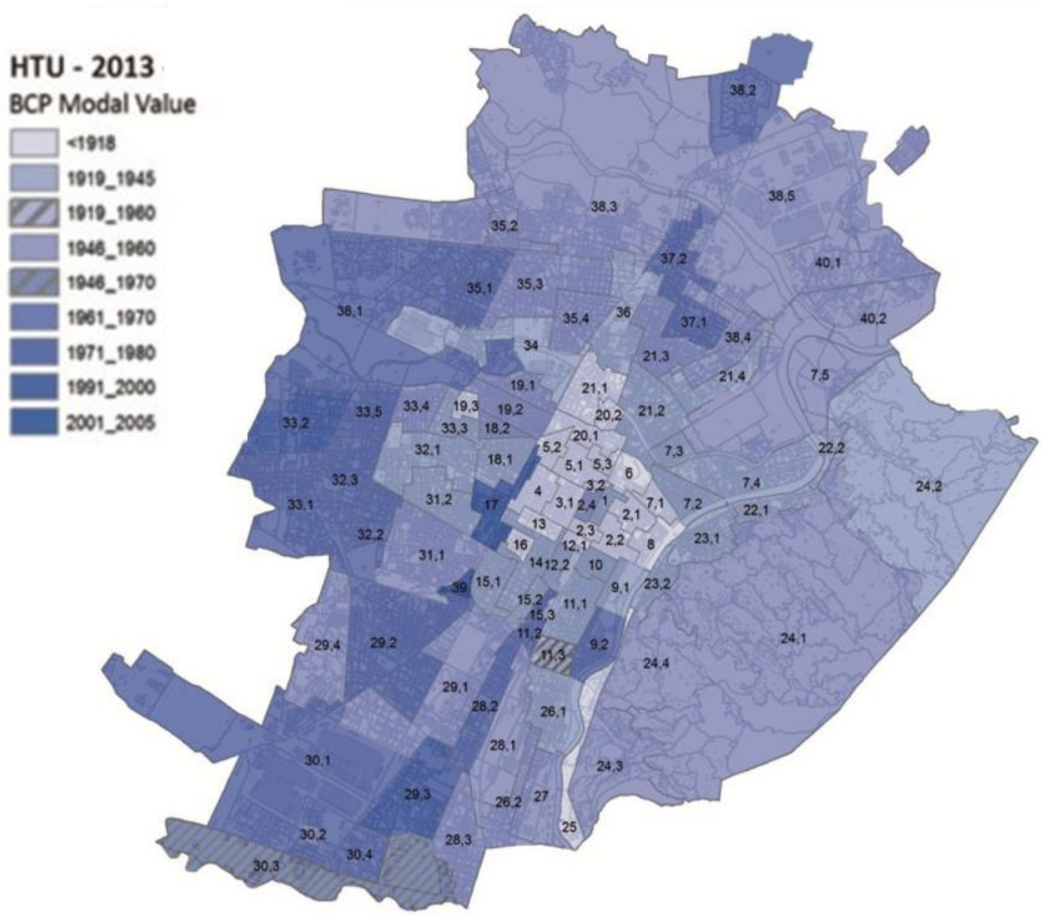


Fig 28. Microzones in Turin based on construction period (Barreca, Curto, and Rolando, n.d.), (Asadi, 2021).

The escalating environmental challenges faced by urban areas require innovative solutions that address both building and city-wide levels to achieve sustainability.

In this study, all the residential apartment buildings constructed in the city of Turin between the years 1961 and 1970 were chosen (Figure 29). The purpose is to generalize the renovation of these buildings and apply passive design scenarios to achieve significant reductions in energy needs and greenhouse gas emissions at the urban level. a methodology for supporting local authorities, researchers in investigating the impacts of strategies involving building refurbishment measures and new technological investment choices over long-term horizons in cities.

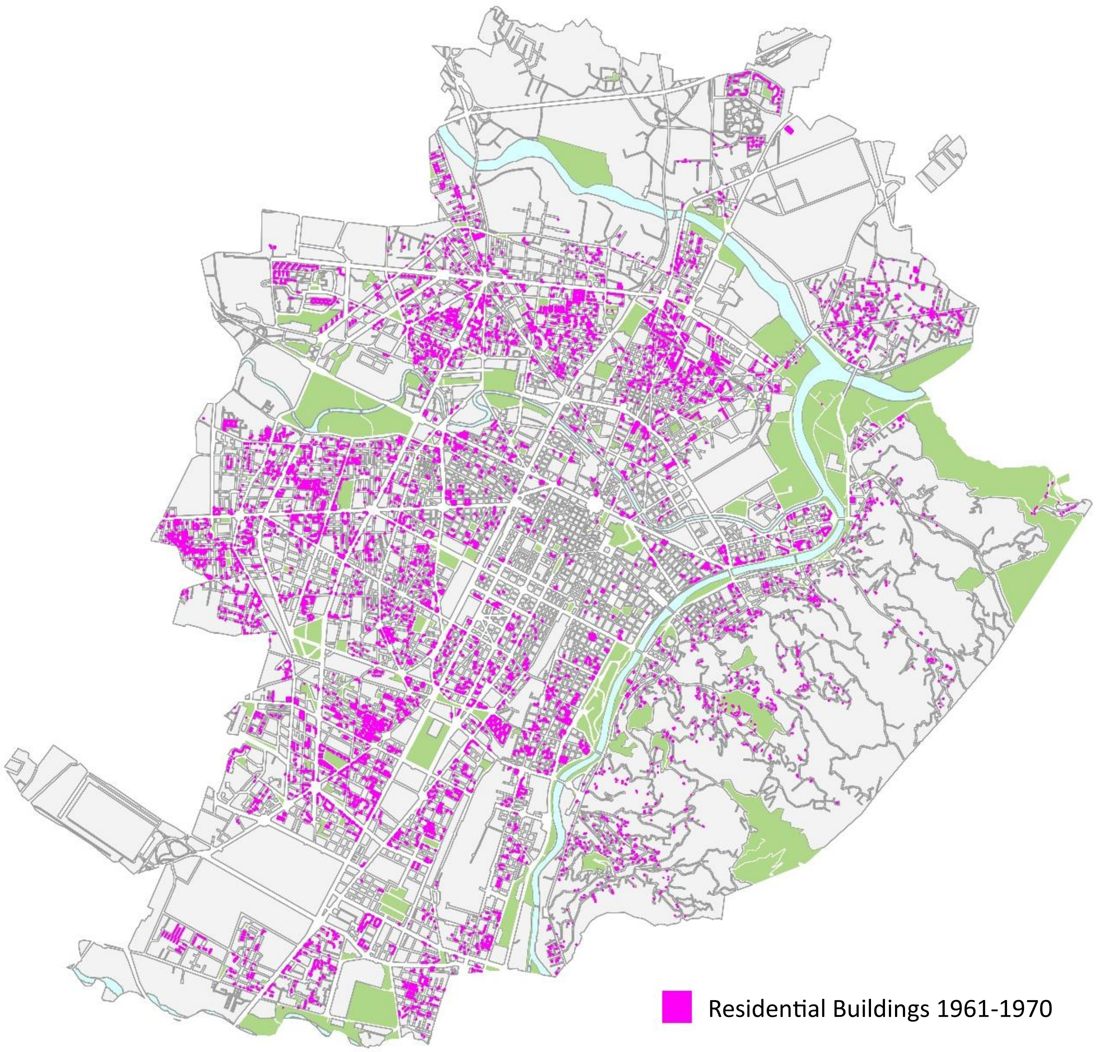


Fig 29. Total Residential buildings by the constructed period 1961 to 1970 in the city of Turin (data from LARTU facilities)

This study stands out for its distinct methodology, which focuses on a complete refurbishment plan for residential buildings. We have selected all the apartments constructed within a particular period to determine the effects of renovation efforts on a wider urban scale. The uniqueness of this study lies in the application of passive design scenarios, an eco-friendly approach that offers considerable environmental advantages. This research presents a comprehensive methodology to assist local authorities and researchers in evaluating the long-term consequences of sustainable strategies. In addition to analyzing the impacts of building refurbishment, it also investigates the effects of new technological investments. This study provides stakeholders with valuable insights that can aid in making informed decisions related to sustainable urban development.

The major accomplishment of this research lies in its potential to transform urban sustainability. The methodology provided can serve as a valuable tool for informed policies and practices that take into account long-term implications. By applying passive design scenarios to a specific historical urban context, this study demonstrates a practical approach to achieving significant reductions in energy consumption and greenhouse gas emissions. The findings of this research make a tangible contribution to minimizing the environmental impact of cities, marking a significant step forward towards a more sustainable urban future.

- Turin Existing Building Stock

The statistical data were derived from the "National Institute of Statistics" (ISTAT, 2011) and from the Italian "National Agency for New Technologies, Energy and Sustainable Economic Development" (ENEA, 2009).

The following graphs illustrate the ISTAT data that were analyzed to identify the frequency of the residential building types in the city of Turin. The total number of residential buildings in Turin split by age (Figure 30), the number of homes in each type of building (Figure 31), the total number of homes in residential buildings with 16 and more homes (Figure 32), and the number of homes in residential buildings with 16 and more homes the same city split by age (Figure 33).

According to the number of homes:

- A building having one or two homes could be supposed to be a single-family house.
- A building having three to fifteen homes could be supposed to be a multi-family house.
- A building having sixteen and more homes could be supposed to be an apartment block.

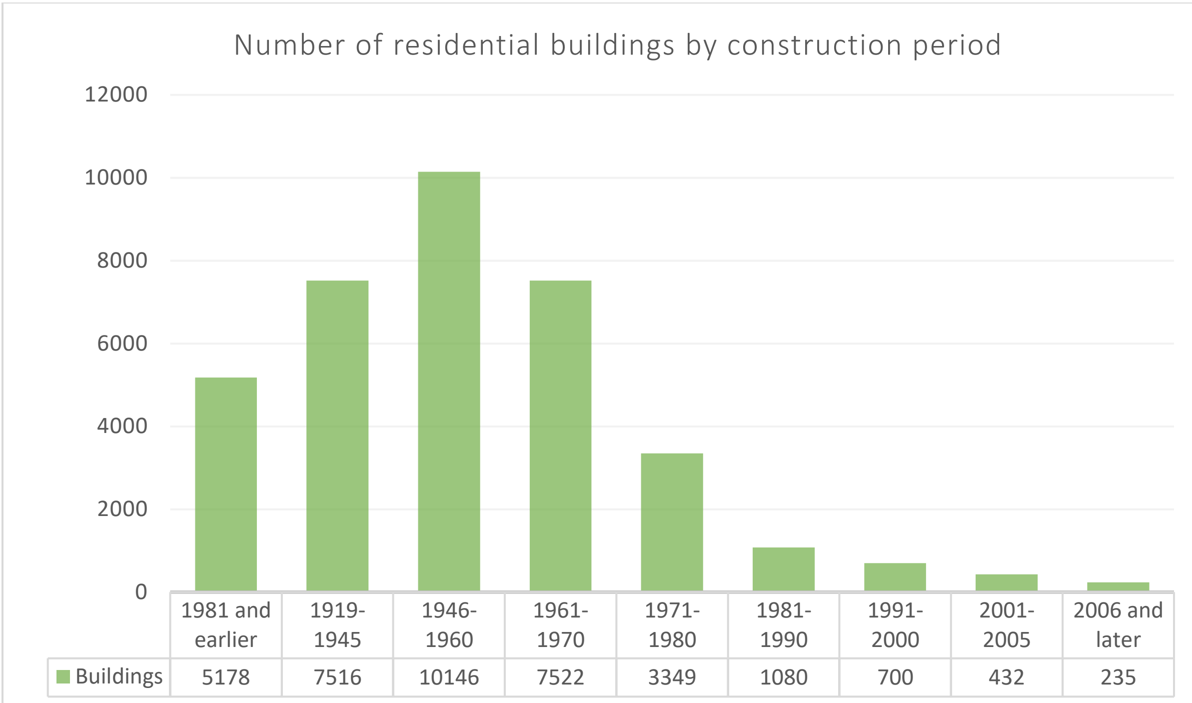


Fig 30. Number of residential buildings by construction period in the City of Turin (Source: ISTAT, report 2011)

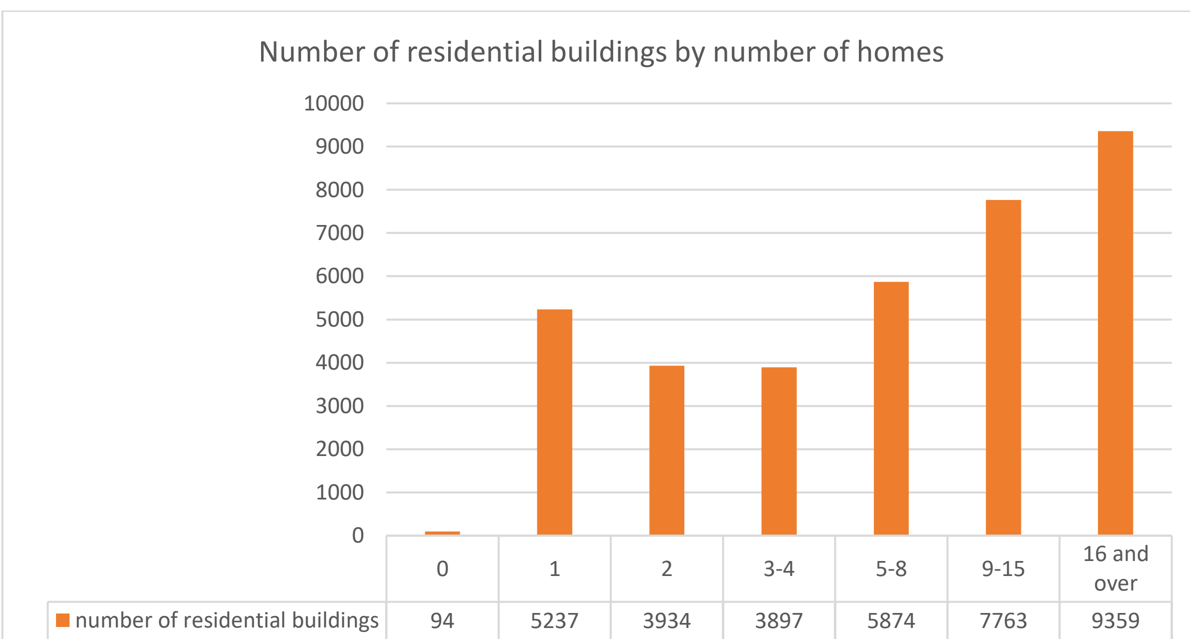


Fig 31. Number of residential buildings by number of homes in the City of Turin (Source: ISTAT, report 2011)

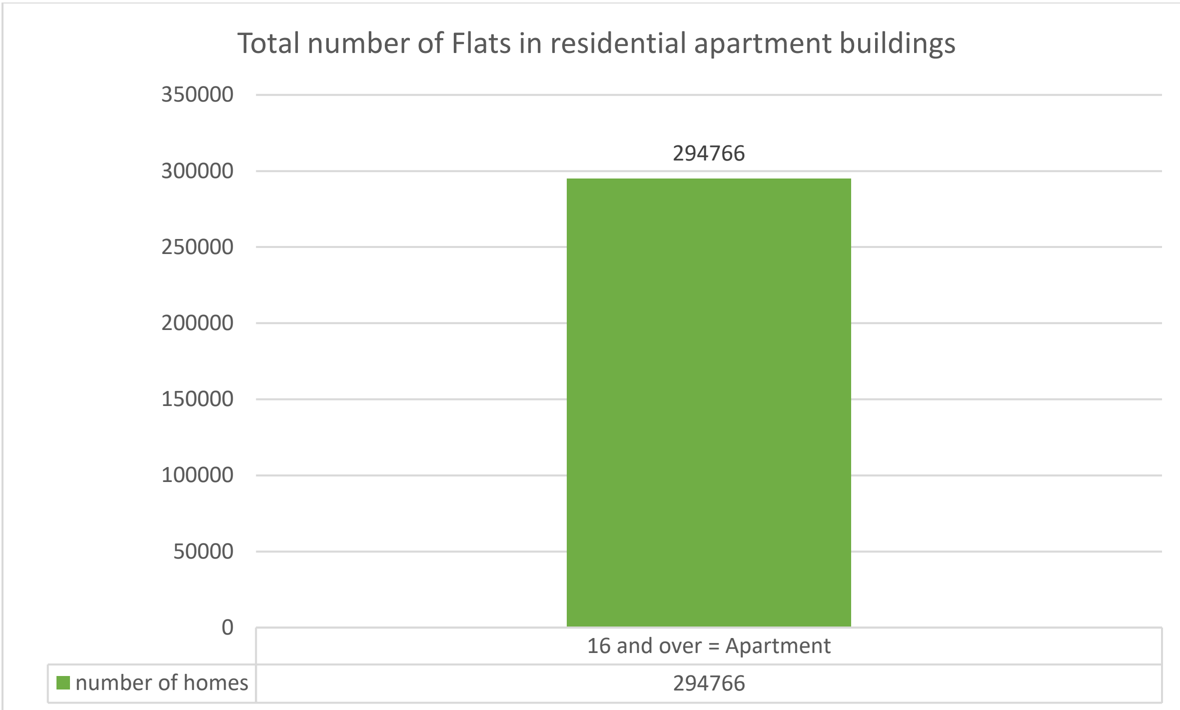


Fig 32. Total number of flats in residential apartments in the City of Turin (Source: ISTAT, report 2011)

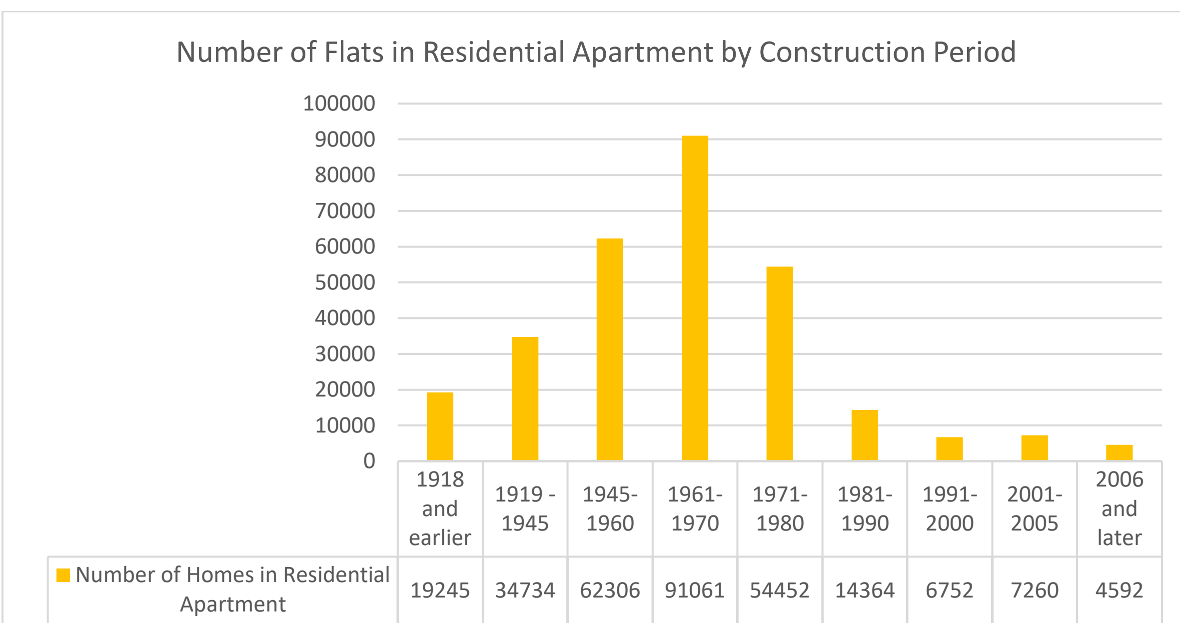


Fig 33. Number of Flats in Residential Apartments by Construction Period in the City of Turin (Source: ISTAT, report)

Knowing the composition of all types of existing residential building stock and residential apartment building stuck are fundamental to understanding the impact of refurbishment measures in terms of energy needs in the urban scale. With respect to building type, ISTAT data indicates that single family houses comprise more than half of the residential structures in Europe (25%), followed by multifamily buildings (48%) and apartment buildings (26 %) (calculated by the number of occupants). (Chinazzo, 2013-14). In this study the number of buildings having sixteen and more homes (which were supposed to be apartment blocks) in construction period 1961-1970 are considerable. However, there are According to the graphs from 30 to 34 and Also Figure 26, there are 294766 flats in residential apartments in the city of Turin which create 9359 residential apartment buildings in construction period from 1918 and earlier to 2006 and later. As the exact number of residential apartment buildings constructed between 1961 to 1970 is not available, we used the available graphs to calculate the approximate number using a specific formula:

$$\frac{\text{Number of Flats in Residential Apartments}}{\text{Number of Residential Apartments}} = \frac{\text{Number of Flats in Residential Apartments Between 1961- 1970}}{\text{Number of Residential Apartments Between 1961- 1970}}$$

$$\frac{294766}{9359} = \frac{91061}{X} \dashrightarrow X \approx 2891$$

$$\text{Percentage} = \frac{2891}{9359} \times 100 \approx 30.89\ \%$$

Therefore, approximately 30.89% of the units (91061 flats) would be used to build 2891 apartment buildings in Turin constructed between 1961- 1970. An important discovery from this succinct study is that around 7% of the residential buildings are within the age bracket of 0 to 40 years, whilst the remaining 93% are above 50 years old.

" ….(i) …..In addition to the fact that buildings typically have a lifespan of 50 to 100 years and require maintenance at various levels, it is important to mention that the majority of national construction laws concerning energy usage were implemented shortly after the 1970s. During that period, major industrialized nations had an energy crisis caused by a petroleum scarcity. This prompted the use of energy efficiency measures, such as thermal insulation of building envelopes, in the construction industry (Poel et al., 2007). Consequently, about half of the current houses in Europe exhibit subpar performance and consume excessive energy due to their inefficient building methods. Dismantling outdated structures may appear to be the most straightforward and expedient method of enhancing the overall energy efficiency of the building inventory and achieving energy objectives. Nevertheless, the process of destruction is characterized by a sluggish pace, significant financial expenses, and a lack of public support. (Power 2008) ....(i).....” (Chinazzo, 2013-14). For this reason, the interest is shifting towards renovation refurbishment, and adaptation of the building stock. The target performance level must be at least comparable to that of newly constructed dwellings.

- Turin Energy Demand

The study authored by Silvio De Nigris and Stefano Fraire, released in April 2013, provides a detailed coverage of Turin province's energy requirements. This study provides an illustration of how the primary energy is distributed among different sectors in the province. According to the study, a total of 55.8 TWh of energy was utilized in 2011 from various energy sources across different industries. The residential sector consumed 39% of the energy used in the City of Turin, which amounts to 20 TWh of energy use. Out of this, 15 TWh was dedicated to heating. The industry and commerce sectors accounted for the remaining energy use, with 10% dedicated to trade and commerce, which is expanding rapidly in correlation with economic growth. This study provides an illustration of how the primary energy is distributed among different sectors in the province. According to the study, a total of 55.8 TWh of energy was utilized in 2011 from various energy sources across different industries. The residential sector consumed 39% of the energy used in the City of Turin, which amounts to 20 TWh of energy use. Out of this, 15 TWh was dedicated to heating. The industry and commerce sectors accounted for the remaining energy use, with 10% dedicated to trade and commerce, which is expanding rapidly in correlation with economic growth. (Figure 34). (Asadi, 2022)

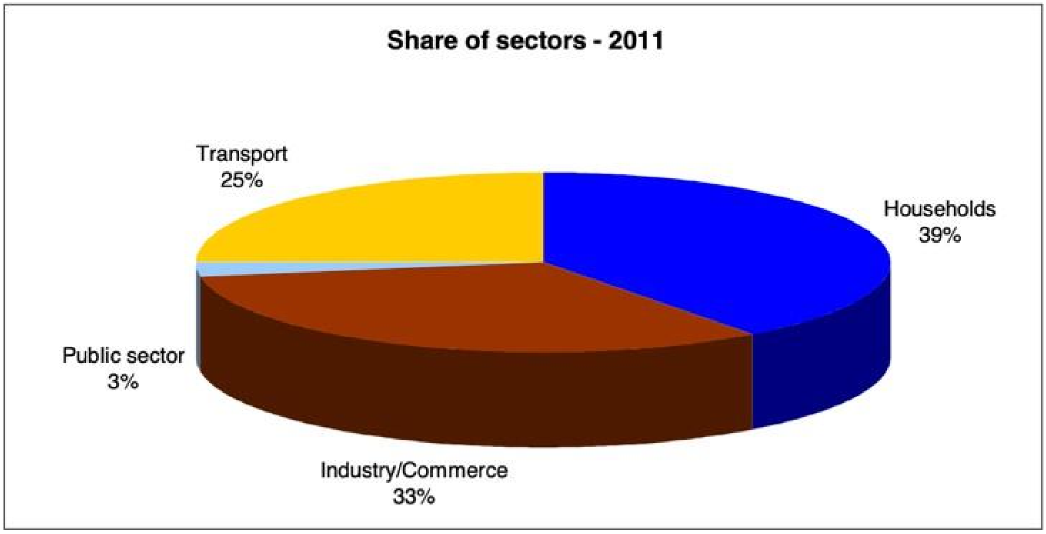
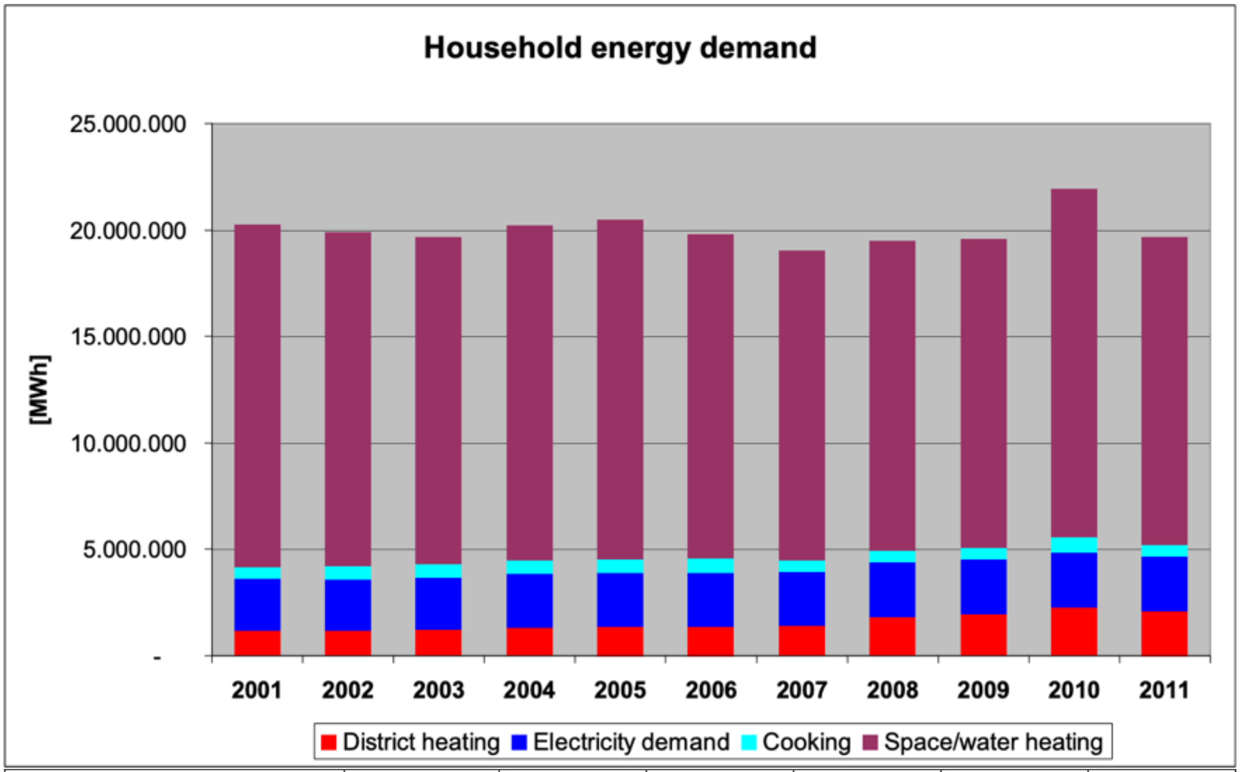


Fig 34. Energy demand in Turin (de Nigris and Fraire 2013)

- Households

According to Asadi's [12] (2022) scientific thesis, it can be concluded that "…(i)…. Private households are the largest segment of final energy users, accounting for over 40% of total energy consumption. Setting up an action plan to increase the use of renewable energy sources, reduce primary energy consumption, or reduce greenhouse gas emissions requires careful consideration of the energy performance of the building portfolio. This industry consumed 19.7 TWh of energy in 2011, which is 2,8% less than it did in 2001. As a result, the sector trend over the reference decade under study is rather constant, and the annual fluctuations are primarily brought on by climatic changes. If we merely take into account thermal consumption (heating plus the generation of hot domestic water), it is important to note that such energy use declined by 4%, mostly in the last five years. More than 84% of overall consumption is related to heating and producing hot water for home use, 13% are related to electric lighting and appliances, and 3% are related to cooking. (de Nigris and Fraire 2013) …(i)…" (Asadi, 2022).

[12] These themes are also present in depth in Mahsa Asadi 's thesis: "A transformative approach to reach an energy-conscious district A case study in the city of Turin, Italy. Politecnico di Torino, 2022"



Type of demand	2001	2002	2003	2004	2005	2006
District heating	1.154.323	1.160.958	1.235.970	1.306.002	1.351.894	1.352.229
Cooking	577.112	598.122	598.420	622.519	629.970	612.143
Electricity demand	2.459.649	2.444.341	2.458.689	2.557.797	2.553.503	2.592.000
Space/water heating	16.054.504	15.684.749	15.366.909	15.712.422	15.955.421	15.233.994
Total	**20.245.587**	**19.888.170**	**19.659.988**	**20.198.740**	**20.490.788**	**19.790.366**

Fig 35. households' energy demand (de Nigris and Fraire 2013)

" ....(i) ..... Natural gas accounts for more than 59% of the overall energy consumption in private households, followed by electricity (13%) and renewable wood (12%). Since the expansion of the gas grid was pushed in previous decades and the capacity for its spread out is already exhausted, the consumption of natural gas has been fairly consistent across all decades.

The data from 2010, which was an exceptionally cold year, is extraordinary and should not be considered. On the other hand, annual increases in biomass and electric usage both exceed 3 percent (by an average value of 1.7 percent per year). Between 2001 and 2011, the heating recovered by CHP (combined heat and power) and distributed through district heating systems nearly doubled, accounting for 11% of the total sector demand. Since the district heating system of the City of Turin and the surrounding municipalities is expanding significantly, forecasts for this carrier indicate that its share will increase in the near future. The CO2 emissions of private households will decrease as a result of this circumstance, which will be favorable. The need for natural gas may decline in the near future; in reality, district heating can only be spread out in this manner at the moment because diesel has no effect on private households' energy needs. Nevertheless, from 2.300 GWh in 2001 to 270 GWh in 2011, diesel consumption decreased. The only fossil liquid that is still increasing is liquid petroleum gas, which in 2011 was more than 2.5 times greater than diesel, reversing the trend from ten years earlier. The municipalities or regions not serviced by the natural gas grid are where such a carrier saw the most frequent use. The usage of oil is extremely limited and will end within the next few years since boilers that use this resource will no longer be available because they don't meet regional laws' environmental standards ...(i)..." (Asadi, 2022).

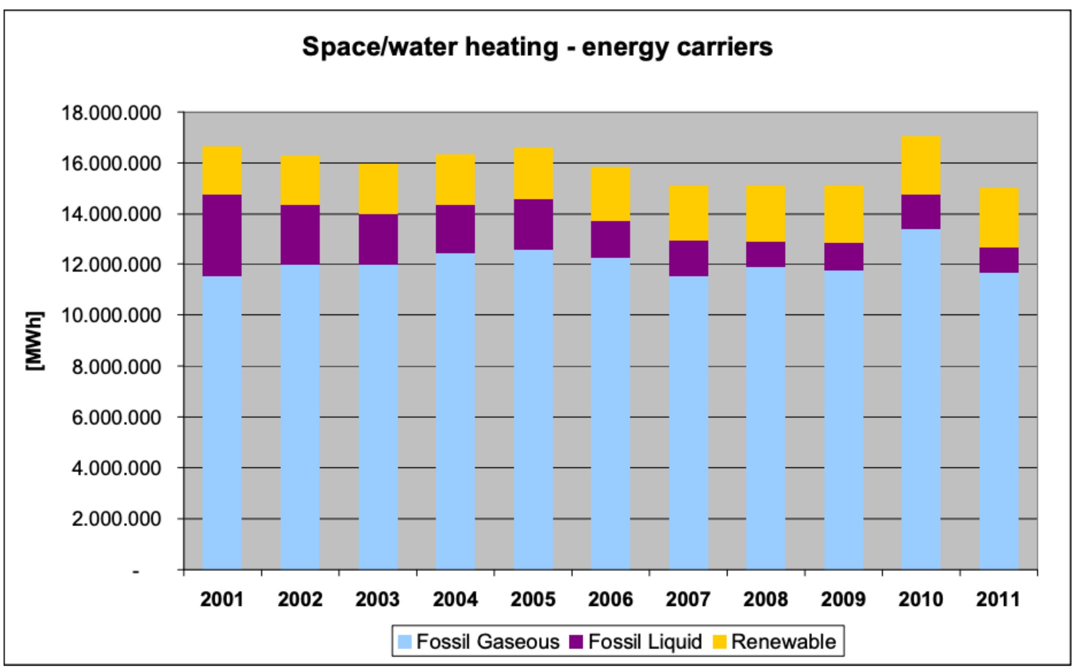


Fig 36. Share of energy carriers (de Nigris and Fraire 2013)

“ ....(i) ..... Aside from biomass, whose usage is historically significant, solar thermal energy shows a significant growth pattern even though its contribution to global demand is currently insignificant (0,2 percent). The contribution of geothermal energy is much more limited. With a widespread grid, fifteen utilities provide gas distribution service in the province of Torino. Only a few municipalities in the mountains, or about 1% of the population, are not served. Since an optimum basin for the administration of the gas grid will be introduced, the current chaotic and irrational condition of the gas distributors will change during the next three to five years. As a result, the service will only be run by 5 gas distributors. Although per capita consumptions show a different situation, with several mountain municipalities having top peak consumptions due to climatic conditions and their tourist attractions, the total consumption of natural gas is primarily concentrated in the City of Turin and the surrounding Municipalities. Aside from a few towns that are directly operating the service with their own utilities, the Province of Torino has two major utilities that cover practically the entire region in terms of the local electric grid. As depicted in the graph above, 59 percent of total energy carriers are natural gas followed by 13% electricity. Natural gas is the main source of space and water heating in residential sectors. This amount is easily redactable by reducing energy demands during winter months and replacing the source with passive and active solar energy ...(i)...” (Asadi, 2022).

- Turin Action Plan for Energy

In 2010, the City of Turin signed the Covenant of Mayors and approved the Turin Action Plan for Energy (TAPE). According to the TAPE, Turin’s medium-term goal is to reduce CO2 emissions by 60% by 2030. The long-term objective is a further reduction of emissions to reach net carbon neutrality by 2050. (Figure 37)

City's emissions reduction targets (add rows if needed for further commitments) Where possible please use 2005 as the base year for listing city reduction targets	Base Year	Target Year	% Reduction
	1991	2020	45
	1991	2030	60
	1991	2050	100
CO2 (and possibly other greenhouse gases) emissions		Units	Year of Data
Total CO2 emissions/capita	3.48	t CO2/capita	2017
Total transport CO2 emissions/ capita	0.77	t CO2/capita	2017
Total (less transport) CO2 emissions/capita	3.16	t CO2/capita	2017
Total CO2 emissions per year	3,479,063	t CO2	2017
Total CO2 emissions per MWh electricity consumed	1.06	t CO2	2017

Fig 37. Benchmarking Data- Climate Change: Mitigation (Torino 2030, 2022)

In order to achieve these goals, the City of Turin will integrate strategic actions in the relevant planning documents and tools available and will seek to implement them together with the cooperation of local stakeholders and residents.

Turin intends to become a model city of rational use of energy and quality of the environment.

The development and implementation of TAPE focus on two strategic lines:

- greater efficiency and energy saving, which affects all sectors of consumption and the entire urban area, i.e., all citizens. Starting from the increased efficiency of existing buildings, up to the reduction of emissions in transport: a global intervention strategy that makes use of measures and instruments of political control.

- A creation of a favorable and friendly climate towards good environmental and energy practices, containment of consumption, and local production of energy, with active measures from part of the city of Turin towards its citizens. This favorable attitude towards energy conversion infrastructure in an industrial metropolis is a complex task for which there are very few models. This strategy does not only concern the systems and buildings to be made more efficient from a technical point of view but also the places in Turin themselves. It is essential to involve and motivate numerous operators throughout the city and to obtain the support of the citizens of Turin, in an economic environment open to competition. (Torino 2030, 2022)

The Residential Sector, responsible alone for 40% of the total CO2 emissions of the base year 1991, is the object of some of the most important actions foreseen in the TAPE. (Figure 38). In order to achieve city's emission reduction target, the TAPE has introduced the eligible intervention actions aimed primarily at reducing the energy demand for residential buildings:

- energy-saving interventions to be carried out on the building envelope, heating, cooling, air conditioning, and ventilation systems, internal and external lighting systems as well as electric motors.
- use of possible renewable energy sources for the production of thermal and electrical energy such as solar thermal and photovoltaic, biomass, and geothermal energy.

In this study the strategies employed to enhance energy performance and CO2 emissions involve intervention in the building envelop through passive design and generalize these strategies for all the residential buildings with the specific construction period and typology (Residential Apartment buildings constructed between 1961-1970) in the Turin city scale to reach CO2 emission reduction targets and a sustainable environment according to TAPE.

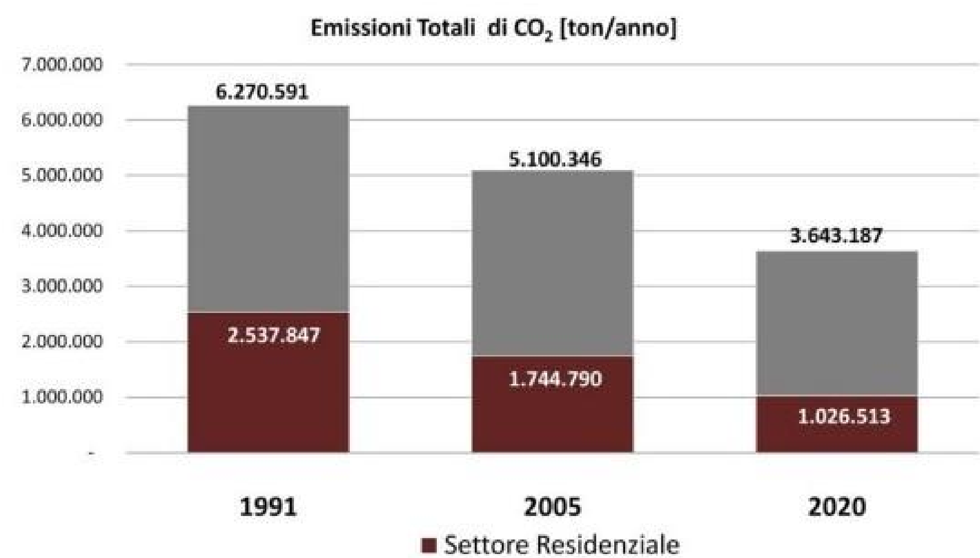


Fig 38. Total Emissions of CO2 in the Residential Sector (Source: Torino Action Plan, 2022)

Chapter 4

Survey, Results and Discussion

1. The Survey

- The Energy Assessment Methodology

The objective of this chapter is to examine the correlation between future sustainable urban energy and the evaluation of various renovation alternatives through the use of a simulation study. This research primarily investigates a residential apartment complex constructed between 1961 and 1970 in Turin, with a particular emphasis on renovating the building's exterior. Nevertheless, the identical methodology may be employed for different residential apartment complexes constructed within the same temporal framework.

The selected performance metric in our evaluation methodology is energy consumption, a quantifiable indicator that is influenced by several factors. This study focuses on analyzing the effects of different thermal properties of the building exterior arising from refurbishment procedures.

This study aims to present a systematic approach for assessing the impact of refurbishment techniques on the energy performance of residential buildings, with a particular emphasis on the influence of thermal modifications on the long-term sustainability of urban environments. In order to assess the influence of refurbishment procedures on the energy consumption estimate, it is important to analyze the impact of alterations in the thermal properties of the building envelope. By utilizing this approach, one may assess the durability of different renovations in terms of energy usage.

In the following paragraphs, we will explain the procedure for determining the energy performance of a building and its importance in assessing the structure's ability to efficiently use energy.

- Energy Efficiency of the Building

" ….(i) ….. It is important to clarify the meaning of certain energy-related terms before proceeding with the study. A comprehensive characterization of the energy present in a building can be achieved by considering four distinct perspectives, as delineated by Richarz and Schulz in 2013 and supported by Chinazzo[13] (2013-14). The first three viewpoints concern different stages of the energy lifecycle, beginning with its production and ending with its utilization within the structure. On the other hand, the fourth viewpoint pertains to the emission of carbon dioxide (CO2) that arises from the utilization of energy sources, as underscored by Chinazzo (2013-2014). In this section, we will provide a brief explanation of the differences between the three energy terms. ….(i) …..". Chinazzo (2013-2014)

The measurement and classification of energy within a structure encompasses a multitude of viewpoints, Chinazzo (2013-2014) providing essential definitions. The central emphasis is on energy consumption, which is alternatively referred to as energy need or effective energy. It denotes the amount of heat that heating or cooling systems must generate in order to sustain a predetermined temperature for a designated duration, with the purpose of ensuring the wellbeing of occupants (UNI EN ISO 13790). Frequently computed using energy tools and thermal equilibrium analysis, this value comprises heating, ventilation, and illumination requirements and is referred to as ideal or thermal loads. Thermal comfort conditions, functional floor area, building compactness, external temperature, and the quality of the building envelope are all influential factors. It is of utmost importance to distinguish between energy demand and consumption. Demand denotes the immediate rate of consumption in kilowatt-hours (kW), whereas consumption signifies the overall energy quantity added or removed (Chinazzo, 2013-14). Subsequently, we have final energy or energy consumption, which refers to the energy provided to the structure in order to operate the generators for ventilation and heating. This value encompasses the expenses that are linked to the generation, storage, distribution, and output of

[13] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

electricity. As an illustration, losses transpire via the boiler, hot water storage, distribution pipelines, and thermostatic valves in heating systems. In addition, the ultimate energy is influenced by auxiliary energy, which is utilized by technical apparatus such as pumps and blowers. Particular emphasis is placed on the energy consumption of cooling systems, particularly those that rely on electrical power for operation. To convert energy consumption into final energy, the primary sources necessary for electricity production must be taken into account, as frequently denoted by a primary energy factor. The performance factor of the national electric system in Italy is 0.46, which indicates that the consumption of final energy amounts to 2.17 kWhf for every kWhe of electricity produced (Chinazzo[14], 2013-14).

Primary energy, which is the last category, pertains to energy in its original state before any form of transmutation or alteration. Before the energy reaches a structure, it experiences losses during production and distribution, which require the application of a primary energy factor for correction and augmentation. This parameter represents the proportion of one or more primary resources that are employed in the process of energy production. The energy losses associated with the generation and distribution of these three forms within a room are depicted in Figure 39 (Chinazzo, 2013-14).

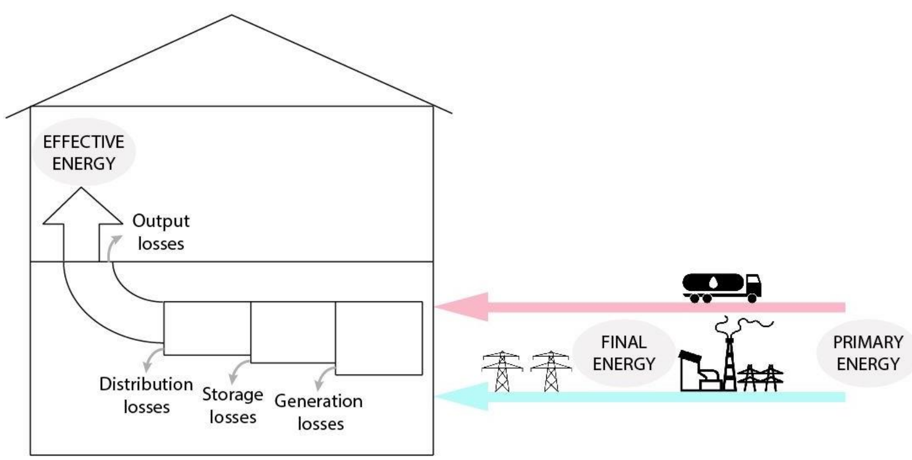


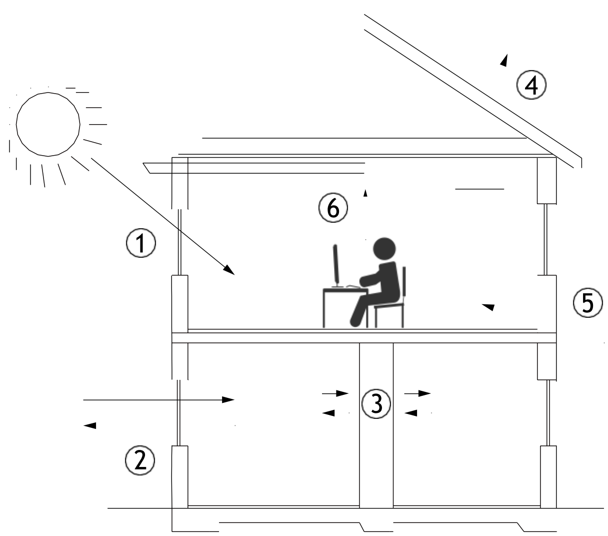
Fig 39. Energy losses occurring during the transmission of electricity from the power producing source to the residential building (in red the heating in blue the cooling), (Chinazzo, 2013-14)

[14] These themes are also present in depth in Chinazzo Giorgia's thesis: "Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino." In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

- Assessment of Energy Performance at Building Level

As previously explained, we assess the thermal efficiency of a building's envelope by analyzing its energy consumption. The energy consumption of a building can be obtained by calculating the energy needs and then applying the appropriate coefficient of performance.

Heat transfer occurs as a result of various mechanisms, including ventilation, heat absorption from within, and solar radiation. Figure 40 illustrates various thermal fluxes. Specifically, point one pertains to solar heat infiltrating the building through the windows, point two concerns heat transfer from the environment to the building via ventilation, point three concerns heat entrapment within the mass of heavy materials, point four concerns heat conductivity or insulation provided by the walls, point five concerns heat infiltration resulting from heat escape and entry into the building, and point six concerns heat emanating from personnel and devices within the building (Chinazzo[15], 2013-14).



1. GAINS FROM SUNSHINE HEAT

2. Losses and gains in heat via ventilation

3. HEAT RECOVERED FROM THE MASS

4. HEAT INSULTATION AND/OR CONDUCTION BY THE WALL

5. Heat entering the structure while escaping through insulation

6: INTERNAL HEAT GAINS

Fig 40. Heat flow diagram in a building. (Chinazzo, 2013-14).

[15] These themes are also present in depth in Chinazzo Giorgia's thesis: “Refurbishment of Existing Envelopes in Residential Buildings: assessing robust solutions for future climate change. Politecnico di Torino.” In: [https://infoscience.epfl.ch/record/203438/files/Giorgia_Chinazzo_MasterThesis.pdf]

2. Results

- Materials Upgrade

The simulations demonstrate the significant impact of changing building materials on the number of U-Values and building useful energy consumption. The materials attributed to each scenario are indicated in Figure 41.

In the existing state, without insulation and the use of single-glazed windows, the U-values of all building components include wall, roof, floor and window are relatively high. This makes the building more prone to heat transfer which leads to increased energy needs for heating and cooling. The high U-value of windows highlights the need for better energy-efficient features.

The adoption of the standard refurbishment level results in a substantial enhancement in insulation throughout all components of the envelope. Utilizing more effective materials and insulation techniques leads to significantly reduced U-values. Significantly, the U-value for windows undergoes a significant decrease, demonstrating a deliberate emphasis on improving energy efficiency in this critical domain.

The advanced refurbishment level demonstrates the utilization of state-of-the-art materials and techniques, resulting in U-values that are substantially lower than both the existing state and the standard refurbishment level. The U-value for windows experiences a significant decrease, demonstrating the efficacy of new three glazing and insulation techniques.

The U-values have a direct influence on the thermal efficiency of the building envelope. Lower U-values result in less thermal conductivity, leading to reduced heat transfer in colder seasons and minimized heat absorption in hot seasons. This contributes to the establishment of a more consistent and pleasant interior climate. Furthermore, the decreased U-values, particularly in windows, are in line with the overarching objective of sustainable building by limiting energy needs and mitigating the environmental footprint of the envelope.

The building's transition from its existing state to a more energy-efficient model is emphasized by a compelling storyline of decreased energy usage. The envelope, equipped with its current materials, requires a yearly energy production of 213,070 kilowatt-hours. This baseline acts as a standard for measuring the significant influence of future material interventions.

The implementation of standardized materials signifies a significant transition, resulting in a notable decrease in energy needs. By using these enhanced materials, the energy needs of the building decrease substantially to 129,300 kilowatt-hours. This decrease demonstrates the improved ability of the standard materials to conserve energy and provide better insulation, which is a visible progress towards sustainability and energy saving.

The use of sophisticated materials propels the envelope into an advanced level of energy efficiency. The utilization of advanced building materials leads to a significant reduction in energy needs, resulting in an annual consumption decrease of 113,310 kilowatt-hours. This advancement in sophisticated materials signifies the highest point in energy-conscious design, demonstrating the possibility for groundbreaking enhancements in energy efficiency.

The remarkable 47% decrease in energy usage, in comparison to the existing state, demonstrates the extensive consequences of careful material selection and inventive building methods. This impressive accomplishment demonstrates not just a dedication to sustainability but also a keen comprehension of the complex relationship between construction materials and energy preservation. The numbers depict a narrative of advancement, where each upgrade in materials represents a significant step towards a more sustainable and ecologically conscious future. (Figure 42)

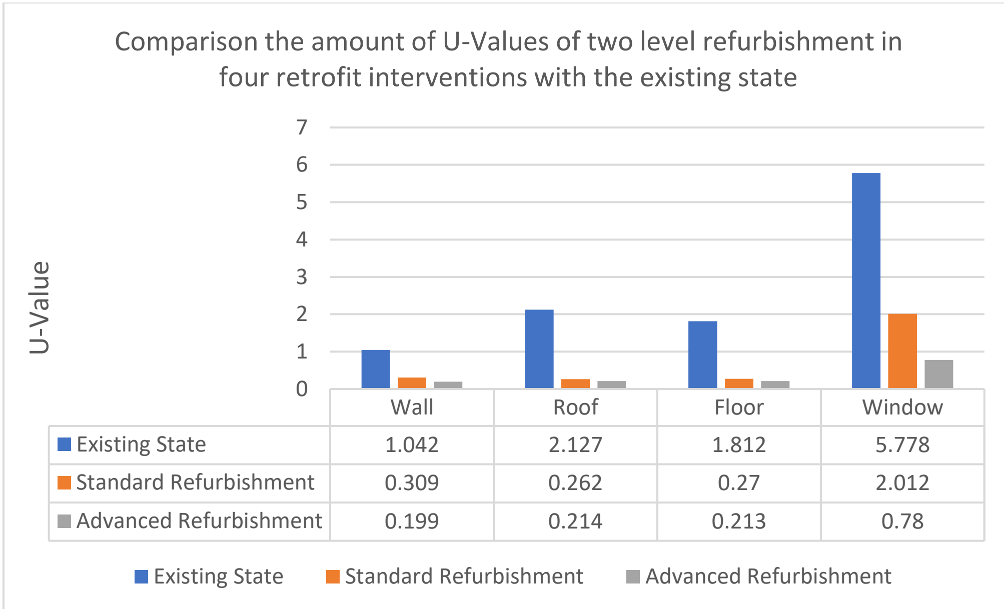


Fig 41. The materials attributed to each scenario.

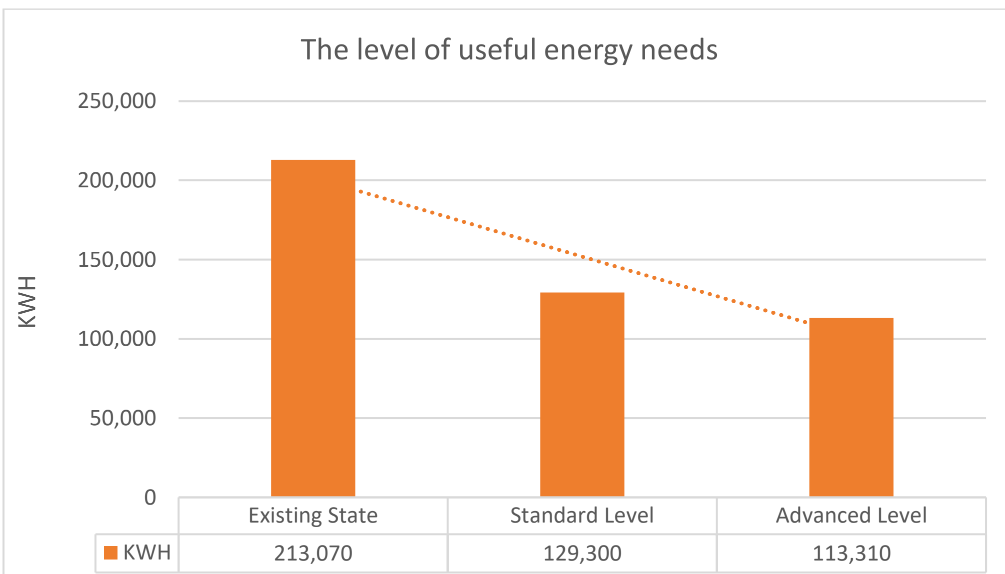


Fig 42. The level of useful energy needs by using 3 types of materials for external walls.

- Natural Ventilation and Shading

The study also evaluates the effectiveness of natural ventilation and shading in maintaining thermal comfort within the building. Without the implementation of these strategies, the advanced mode of the building achieves an annual average Fanger index of 0.46 and an average indoor air temperature of 24.84 degrees Celsius. However, when natural ventilation and shading techniques are incorporated, the Fanger index improves to 0.15, and the average indoor air temperature decreases to 23.83 degrees Celsius (Figure 43). These results indicate the substantial positive effect of natural ventilation and shading in achieving thermal balance and enhancing occupants' comfort.

This issue is mostly due to the reduction of the penetration of the sun's rays in hot seasons of the year, as well as the creation of effective air flow in order to cool indoor spaces with the effective use of natural ventilation.

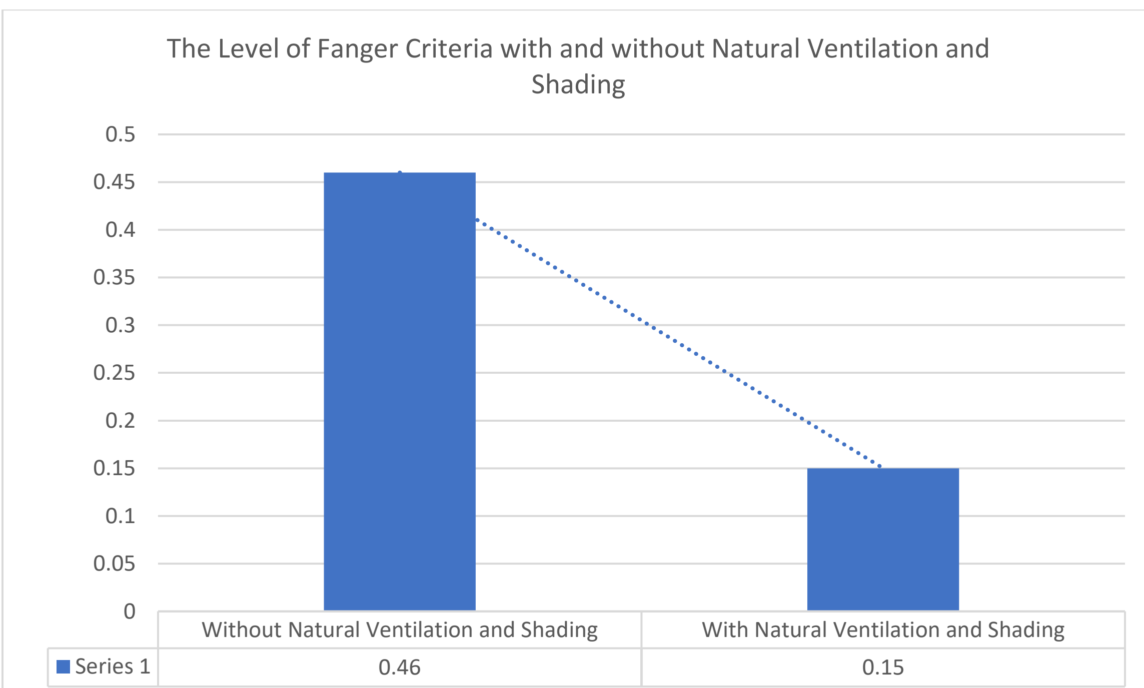


Fig 43. Thermal comfort and mean air temperature with and without using natural ventilation and shading.

3. Discussion

- Martials upgrade to optimize Energy Consumption

The analysis of building energy consumption plays a pivotal role in understanding the influence of different materials on a building's energy needs. In the context of buildings constructed between 1961 and 1970 in Turin, Italy, our study reveals insightful data on energy consumption patterns. The existing buildings, characterized by inefficient materials and construction practices, exhibit a high energy requirement of 213,070 kilowatt-hours per year. This inefficiency underscores the need for upgrading materials to enhance energy efficiency.

Through simulations, the study demonstrates the substantial energy savings achieved by adopting standard and advanced materials. The standard mode, which involves the use of energy-efficient materials, shows a notable drop in energy consumption to 129,300 kilowatt-hours per year, representing a 39.3% reduction compared to the current condition. The advanced mode, which employs materials possessing exceptional thermal resistance and insulating capabilities, demonstrates a remarkable 47% decrease, resulting in a reduction of energy requirements to 113,310 kilowatt-hours per year. The data highlights the essential importance of improved materials in attaining energy-efficient buildings, providing a hopeful pathway for decreasing the environmental consequences of current constructions.

- Evaluation of Natural Ventilation and Shading Results

In the aim of sustaining thermal comfort in buildings, particularly during hot seasons, natural ventilation and shading methods are necessary components. The utilization of passive cooling methods becomes necessary when active cooling technologies are not available. With an annual average Fanger index of 0.46 and an interior air temperature of 24.84 degrees Celsius, our research demonstrates that the advanced mode is subject to a modifiable degree of thermal discomfort when natural ventilation and shade are not present.

A significant improvement in thermal comfort is observed, however, when natural ventilation and shade are included in the design. There has been a major rise in levels of comfort since the yearly average Fanger index has greatly improved to 0.15. For further evidence that these passive measures are effective in reducing the accumulation of heat, the average temperature of the air within the building drops to 23.83 degrees Celsius. Overall, the advantages in terms of enhanced thermal comfort and lower energy consumption exceed this trade-off, even though there is a little rise in the heating sector as a result of reduced solar heat gain.

- Integration of Results

A summary of the findings from the research illustrates the complimentary benefits that occur from mixing contemporary materials, natural ventilation, and shading methods in the construction of buildings. To be more specific, the utilization of novel materials helps to significantly reduce the amount of energy that is required by lowering the amount of heat that is transmitted through the building envelope. Because of this reduction in heat exchange, there is an increase in the energy efficiency of the system. In the meantime, natural ventilation that has been carefully thought-out results in improved airflow, which in turn increases the thermal comfort of the building. Additionally, the use of shading methods is necessary for lowering the amount of solar heat that is taken in and further enhancing the conditions within. In its whole, this integrated method provides a comprehensive and all-encompassing solution that successfully fulfills the two objectives of enhancing thermal comfort and energy efficiency. When regarded as a whole, this strategy addresses both of these aims.

The seamless integration of cutting-edge materials, natural ventilation, and shading systems is an essential component of an all-encompassing strategy for achieving sustainable building performance, as discussed in the previous paragraph. A more comprehensive solution is created by the combination of these components, which not only reduces the amount of energy that is consumed but also helps to create an indoor climate that is more pleasant. The total of their individual contributions is less than the combination of their effects, which is bigger. A great illustration of a forward-thinking paradigm in architectural design, this method focuses equal attention on the well-being of occupants as well as the sustainability of the environment.

- Generalization to Buildings in Turin, Italy (1961-1970)

It is important to note that the implications of our study extend beyond the span of individual buildings and affect the whole metropolitan area. The results of this study are extremely important when considered in the broader context of residential constructions that were constructed in Turin, Italy, between the years 1961 and 1970.

Significant reductions in energy consumption and emissions of greenhouse gases may be accomplished on a city-wide scale through the utilization of cutting-edge materials and the incorporation of passive techniques such as natural ventilation and shading.

These findings have significant repercussions for the city of Turin, which is home to the municipal government. Increases in the energy efficiency of residential buildings located across the city would result in a considerable reduction in the overall amount of energy consumed by the city as well as the emissions of greenhouse gases. Taking into consideration the urgent need to address climate change and the substantial role that buildings play in contributing to global carbon emissions, this is of the utmost importance.

In accordance with the overarching goals of the study project, the current investigation targeted the evaluation of the thermal conductivity in advanced mode. Not only did the outcomes earn U-Values that were lower than the benchmarks that were established, but the findings also demonstrated that the outcomes satisfied the needed standards that were specified in the third chapter. Additionally, the study centered its attention on the need to lower carbon emissions within a typical architectural style that is representative of residential apartments that were constructed between the years 1961 and 1970.

As part of the research, advanced methods and materials were utilized to measure heat conductivity. These methods and materials included shading tactics and natural ventilation. A substantial decrease of 47% in the amount of carbon that was present in the structure that was being investigated was discovered by the examination. Taking this step to reduce carbon emissions is an important step toward achieving sustainability goals and reducing the ecological imprint that residential structures leave behind.

Furthermore, the study found that through meticulous material optimization and the incorporation of natural ventilation and shading measures, the existing model's useful energy consumption rate of 118.87 kilowatt hours per square meter could be lowered to 54.71 kilowatts. This is a significant reduction of 64167 kilowatts per square meter, which signifies a proportional reduction in energy consumption and carbon emission (Figure 44).

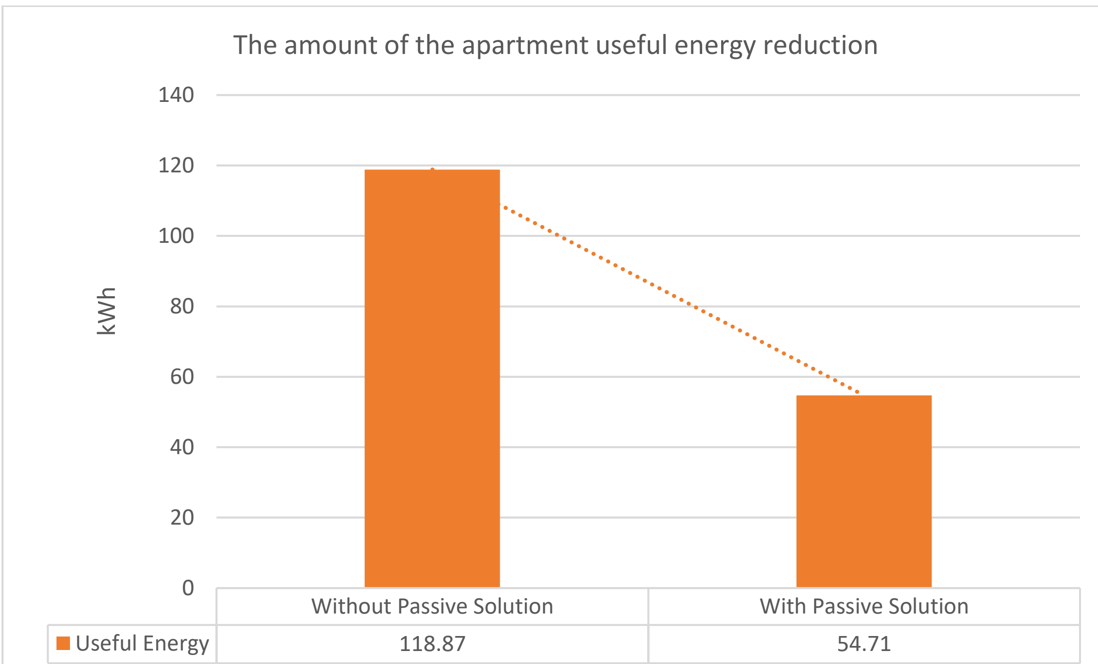


Fig 44. The amount of the apartment useful energy reduction using energy-efficient based on the simulated building

In relation to the amount of final energy, a significant difference was observed in the two basic and optimal states. According to the information obtained from the software, the amount of final energy in the existing state and without optimization measures, including the improvement of laterality and thermal resistance of materials, natural ventilation, and shade, is equal to 228387.22 kilowatt hours, and this amount is after applying the solutions. It has been mentioned that it is equal to 106944.22 kilowatt hours (Figure 45). This has resulted in a reduction of 121,443 kilovolts in energy consumption, which is equal to 53.2% of the building's energy needs in the final energy sector.

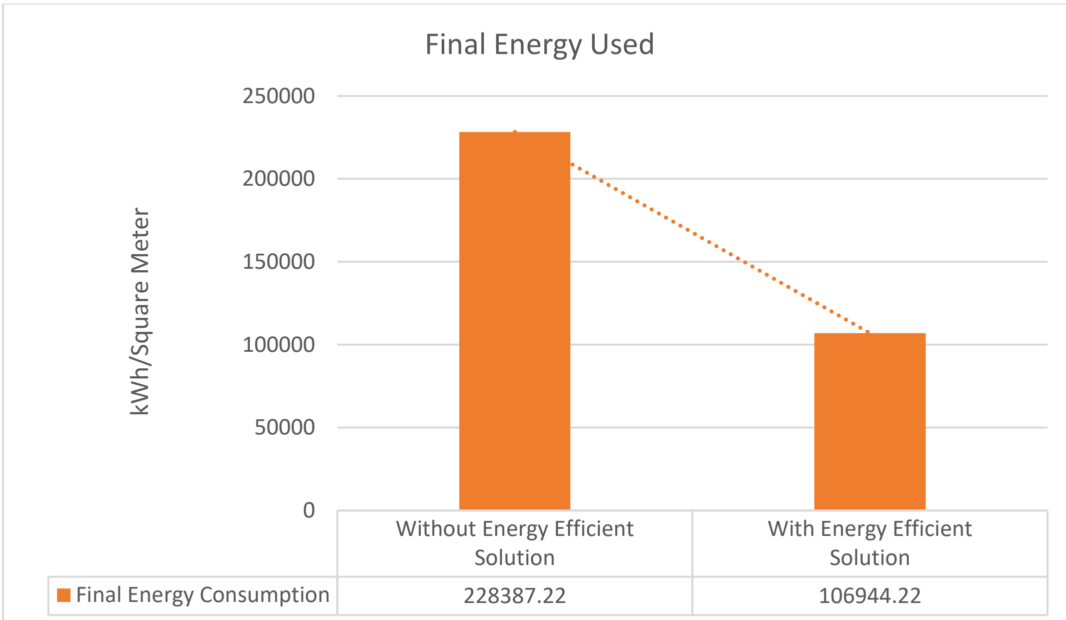


Fig 45: The level of Final energy used with and without energy-efficient solutions based on the simulated building

The analysis of building useful energy consumption underscores the transformative potential of adopting advanced materials. The simulations clearly illustrate the substantial energy savings attainable through these upgrades, with the standard mode achieving a 39.3% reduction and the advanced mode surpassing this with a remarkable 47% decrease. These results emphasize the pivotal role of building materials in reshaping the energy landscape of urban environments.

Furthermore, the evaluation of natural ventilation and shading techniques reinforces their effectiveness in enhancing thermal comfort without relying on energy-intensive cooling systems. The combined effect of these strategies significantly improves indoor conditions, creating a more comfortable environment for occupants. By extrapolating these findings to buildings across Turin, the city can substantially reduce its overall energy consumption, contributing to the mitigation of global warming and the urban heat island effect.

The significance of mitigating energy consumption in urban buildings extends beyond more energy conservation, as it plays a pivotal role in curbing carbon dioxide (CO_2) emissions. The reduction of

CO2 emissions is imperative, given its association with global warming, as depicted in Figure 46. The graph illustrates the direct correlation between fuel consumption within buildings, a primary contributor to CO2 emissions, and its adverse effects on the environment, particularly in exacerbating global warming, which serves as a precursor to climate change. Implementing solutions aimed at minimizing energy consumption in buildings emerges as a crucial strategy for mitigating this environmental concern.

For my thesis, I utilized the default CO2 emission factor provided by the DesignBuilder software version 7.0.2.006. The default CO2 emission factor in the DesignBuilder software is a predetermined value assigned to each type of fuel, representing the amount of carbon dioxide emitted per unit of fuel consumed during building energy simulations. This factor is integral to calculating carbon emissions within the software, offering a baseline for assessing the environmental impact of energy usage. Users can rely on this default factor for efficiency, or they have the option to customize it based on specific regional or contextual considerations for more accurate and tailored emission estimations in their analyses.

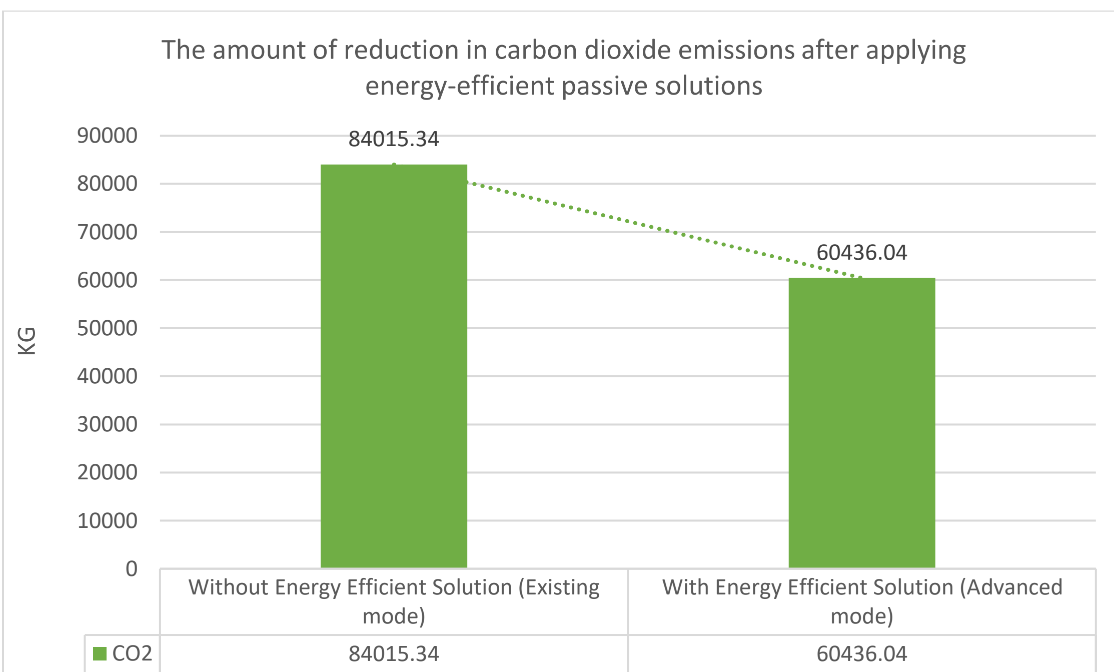


Fig 46. The amount of reduction in carbon dioxide emissions after applying energy-efficient passive solutions at the building scale

By adopting energy-efficient practices, the reduction in CO_2 emissions becomes tangible. These reductions, when implemented on a large scale across urban landscapes, have the potential to significantly mitigate global warming. Addressing the issue of CO_2 emissions at this scale holds promise in ameliorating the broader challenge of climate change and the accompanying menace of air pollution within urban environments. Therefore, emphasizing the reduction of energy consumption in city buildings not only serves as a prudent energy-saving measure but also as an indispensable stride toward a sustainable and ecologically balanced future.

Extending this evaluation to a broader context, when considering the entirety of residential apartments in the city of Turin constructed between 1961 and 1975—comprising 30.89% of the aggregate residential building infrastructure for that temporal epoch, equivalent to 61,428,641.1 square meters (the total infrastructure being 204,762,137 square meters)—the resultant reduction ratio attains a notable magnitude of 3,941,691,607,047 kwh for useful energy and 1,448,444,357,089.23 kg for CO_2 production. This numerical value underscores the significance of the implemented measures in effecting a substantial reduction in carbon emissions, thereby aligning with the fundamental goals of the project (Figure 47).

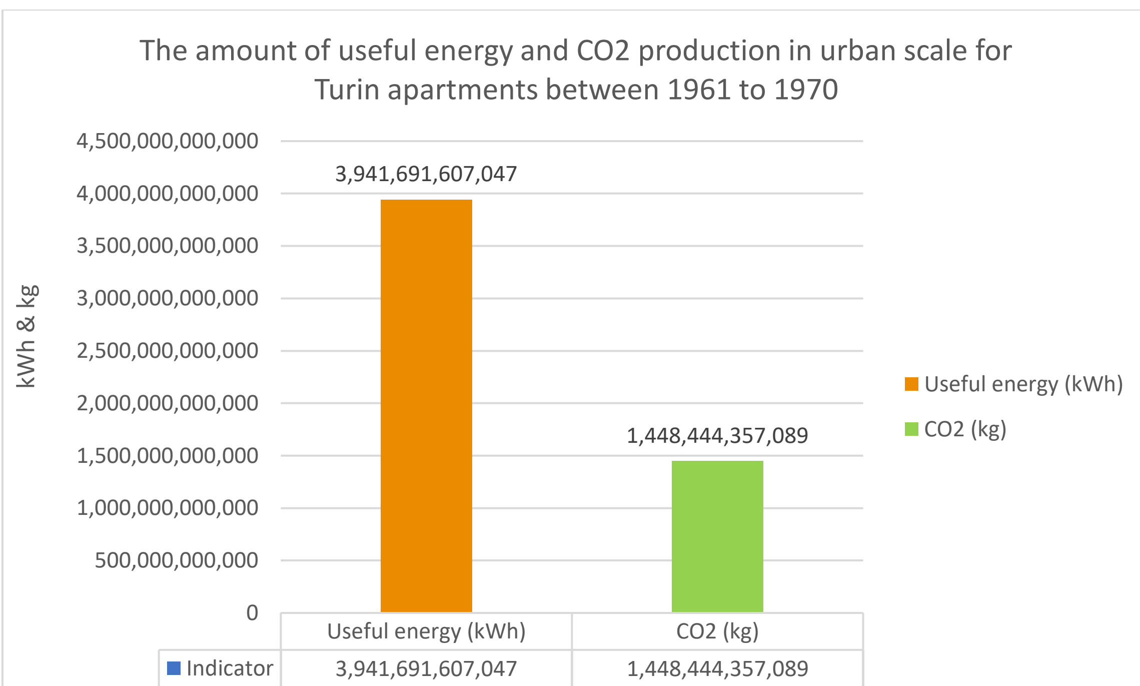


Fig 47: The amount of useful energy and co2 production in urban scale for Turin apartments between 1961- 1970.

Chapter 5

Conclusion

In conclusion, the comprehensive study on the optimization of energy consumption in buildings, particularly focusing on those constructed between 1961 and 1970 in Turin, Italy, has yielded significant insights that extend beyond individual structures to impact the entire urban landscape. The outcomes of our survey, spanning the evaluation of materials, natural ventilation, and shading strategies, underscore the transformative potential of adopting advanced methods at an urban scale. The effectiveness of these measures is paramount not only in achieving energy efficiency but also in contributing to broader environmental goals, particularly in reducing carbon emissions and mitigating the adverse effects of global warming.

To comprehensively comprehend the implications of material upgrades on energy consumption, it is imperative to delve into the underlying principles governing the efficiency of these materials. The dynamics of heat transfer, insulation properties, and the overall thermal performance of the building envelope become focal points of scrutiny.

The adoption of advanced materials is not merely a cosmetic enhancement but a strategic intervention in the battle against energy inefficiency. These materials, often characterized by enhanced insulation capabilities, reduced thermal conductivity, and improved resistance to external climatic conditions, create a formidable defense against the energy losses that plague conventional buildings.

Moreover, the simulations conducted to derive the aforementioned energy consumption patterns involve a nuanced exploration of building physics. The interaction between materials, climatic conditions, and internal heating or cooling systems forms a complex matrix that necessitates advanced computational tools. These simulations provide a dynamic understanding of how different materials respond to environmental stimuli and enable us to optimize energy efficiency based on real-world scenarios.

- The Architectural Symphony of Efficiency:

Beyond the realm of quantitative data lies the narrative of architectural innovation. The adoption of advanced materials is not a solitary endeavor but a symphony where each component, from the foundation to the roof, contributes to the harmonious balance between form and function.

Consider, for instance, the external envelope of a building. The choice of materials for walls, roofs, and floors significantly influences the building's response to external temperature variations. Advanced insulation materials, coupled with thermal resistance enhancements, orchestrate a ballet that minimizes heat exchange between the interior and exterior, reducing the reliance on energy-intensive heating or cooling systems.

This architectural symphony extends to the temporal dimension as well. The age of the buildings under scrutiny, constructed between 1961 and 1970, encapsulates a particular era of architectural design. The retrofitting or replacement of outdated materials with their modern counterparts not only ushers in energy efficiency but also breathes new life into these structures. It's a metamorphosis, where the echoes of the past harmonize with the efficiency demands of the present.

- Beyond Energy Metrics: Environmental Stewardship and Sustainability:

The impact of material upgrades extends beyond the realm of immediate energy metrics. The environmental ramifications of energy consumption and the broader commitment to sustainability become pivotal considerations in this discourse.

The prevailing inefficiencies in the existing building stock not only contribute to escalating energy bills but also cast a shadow on the ecological balance. The excessive energy demand often met through conventional fossil fuel sources, exacerbates carbon emissions, and accelerates climate change. The adoption of advanced materials, by their intrinsic efficiency, aligns with the broader narrative of environmental stewardship.

In the realm of sustainability, each material upgrade becomes a conscientious step toward a more ecologically balanced future. The reduction in energy consumption, as highlighted by our simulations, translates directly into a proportional reduction in carbon emissions. This reduction, when multiplied across the urban landscape, emerges as a tangible contribution to global efforts in mitigating climate change.

- Socio-Economic Implications:

While the focus thus far has been on the technical and environmental aspects of material upgrades, it is essential to cast a glance at the socio-economic dimensions. The retrofitting or replacement of materials is not a cost isolated to the construction site but a ripple effect that permeates the economic fabric.

Investments in energy-efficient materials stimulate local industries engaged in the production and supply chain of these materials. The demand for advanced insulation, eco-friendly roofing, and energy-efficient windows becomes a catalyst for innovation and economic growth. The skilled labor required for the installation of these materials, often a cornerstone of local employment, witnesses a surge in demand.

Furthermore, the long-term economic implications of reduced energy bills for building occupants contribute to a more sustainable socio-economic ecosystem. The financial burden on residents is alleviated, fostering a more resilient and equitable community.

- Concluding the Symphony: A Harmonious Future:

In conclusion, the upgrade of materials to optimize energy consumption is not merely a technical endeavor but a harmonious symphony encompassing architectural innovation, environmental stewardship, and socio-economic vitality. The adoption of advanced materials is a transformative act that transcends the boundaries of individual buildings, resonating across the urban landscape and contributing to a more sustainable and resilient future. The synergy between materials, technology, and human ingenuity is the cornerstone upon which we can build a harmonious and energy-efficient tomorrow.

- Outcomes of Survey:

The outcomes of our survey point to a substantial impact on energy consumption through the upgrade of building materials. By analyzing existing structures characterized by inefficient materials, we demonstrated the potential for remarkable reductions in energy requirements. The advanced mode, incorporating superior materials with enhanced thermal resistance, showcased an impressive 47% decrease in energy consumption. This finding emphasizes the pivotal role of advanced materials in reshaping the energy landscape of urban environments, promising a more sustainable future.

- Effective on an Urban Scale:

The integration of results from advanced materials, natural ventilation, and shading techniques highlights the synergistic effect of combining these strategies. The holistic approach not only reduces energy requirements by minimizing heat transfer but also enhances thermal comfort and minimizes solar heat gain. This effectiveness, when applied citywide to buildings constructed between 1961 and 1970, showcases the transformative potential of our recommendations. The overall reduction in useful energy consumption at an urban scale demonstrates a tangible contribution to environmental sustainability.

The evaluation extended to a broader context, encompassing the entirety of residential apartments in Turin from the specified period, illustrating a notable reduction ratio in carbon emissions. The implemented measures, including material optimization, natural ventilation, and shading, resulted in a 53.2% reduction in energy needs. Extrapolating this reduction to the aggregate residential building infrastructure of the city, comprising over 30% of the total, exemplifies the profound impact of our findings. The resulting reduction in carbon emissions aligns seamlessly with the fundamental goals of the project and emphasizes the effectiveness of these measures on an urban scale.

- **Difficulties:**

While our study provides valuable insights, it is essential to acknowledge the challenges and difficulties encountered during the research process. The implementation of energy-efficient solutions requires concerted efforts and cooperation from various stakeholders, including builders, policymakers, and residents. Overcoming resistance to change, financial constraints, and ensuring widespread adoption of these strategies pose significant challenges. Addressing these difficulties is crucial for the successful implementation of energy-efficient measures on an urban scale.

- **Suggestions:**

To address the challenges identified, it is imperative to develop comprehensive strategies that encompass policy interventions, financial incentives, and public awareness campaigns. Collaboration between government bodies, urban planners, and the construction industry is crucial for the successful implementation of energy-efficient practices. Creating awareness about the long-term benefits of adopting advanced materials and passive strategies is essential for garnering public support. Additionally, incentivizing builders and developers to adhere to energy-efficient standards can accelerate the transition to sustainable urban environments.

- **Future Topics:**

Our study opens avenues for future research in several key areas. Further exploration into innovative building materials, sustainable construction practices, and advanced technologies for energy optimization is essential. Investigating the adaptability and scalability of these strategies to different urban contexts and climate zones would contribute valuable insights. Additionally, longitudinal studies tracking the long-term performance of buildings undergoing energy-efficient upgrades would provide a comprehensive understanding of the durability and effectiveness of these measures.

- **Expanding the Vision: Effective Urban Transformation**

The core tenet of our research, encapsulated in the theme "Effective on an Urban Scale," serves as a launching pad for multifaceted future endeavors. The implications of our findings ripple beyond individual buildings, creating resonances in the realms of urban planning, regulatory frameworks, and citywide initiatives. As we delve into the vast expanse of urban landscapes, the imperative to scale up our insights becomes not just a suggestion but a mandate.

- **Urban Planning Paradigm Shift:**

The translation of our research into the fabric of urban planning heralds a paradigm shift. Cities, the epicenters of human civilization, are confronted with the ever-growing challenges of sustainability and resilience. Our findings, meticulously curated through the lens of energy-efficient practices, now stand poised to influence the very foundations of how cities envision their future.

Imagine an urban landscape where building regulations are crafted with a keen eye on the energy efficiency benchmarks laid out in our research. The blueprints of new constructions incorporate not just architectural aesthetics, but a symphony of materials geared towards optimal energy consumption. Zoning regulations become a tapestry woven with threads of sustainability, intertwining economic viability with environmental consciousness.

- **Policy Dynamics and Societal Impact:**

At the crossroads of policy dynamics and societal impact lies the transformative potential of our research. As we advocate for the economic, environmental, and social benefits of energy-efficient practices, the call for policy changes echoes with increasing urgency. It's not just about constructing buildings; it's about erecting a culture of sustainability that permeates every facet of urban life.

The economic benefits, evident in reduced energy bills and thriving local industries catering to advanced materials, become talking points in policy forums. Environmental considerations, with a sharp focus on carbon emissions reduction, find a seat at the policymaking table. Social welfare, an oft-overlooked dimension, takes center stage as resilient urban landscapes pave the way for equitable communities.

- Collaborative Synergy for Urban Transformation:

A key facet of our vision for urban transformation hinges on collaborative synergy. Research institutions, governmental bodies, and industry stakeholders must converge in a collective effort to realize the full potential of our recommendations. It's a call to action that transcends disciplinary boundaries, inviting architects, policymakers, environmental scientists, and urban planners to a shared table.

The partnership between academia and governance becomes a conduit for translating research insights into actionable measures. Industry stakeholders, buoyed by a shared commitment to sustainability, become the driving force behind the adoption of advanced materials and energy-efficient practices. This collaborative synergy isn't just a theoretical construct; it's the crucible in which the future of urban environments is forged.

- **The Inescapable Reality: Transform or Trudge**:

Inescapably, our research thrusts us into a dichotomy: the imperative to transform or trudge along the well-worn path of conventional urban development. The undeniable transformative potential of adopting advanced materials and passive strategies on an urban scale stands as a beacon, illuminating the path toward sustainability.

Reducing energy consumption isn't a mere statistic; it's a catalyst for change that reverberates through the corridors of environmental consciousness. The mitigation of carbon emissions isn't an abstract goal; it's a tangible contribution to the global fight against climate change. Enhancing the overall quality of urban living isn't an idealistic notion; it's a pragmatic pursuit that addresses the very essence of human well-being.

- Responsibility and Actionable Measures:

As we stand at the crossroads of potential and responsibility, the onus lies on us collectively to translate these findings into actionable measures. It's a responsibility that transcends academic corridors and policy chambers. Building resilient, energy-efficient, and environmentally conscious urban landscapes isn't a choice; it's imperative for the sustenance of our cities and the well-being of future generations.

The actionable measures emanate from a blend of vision and pragmatism. They encompass not just the deployment of advanced materials but the nurturing of a cultural shift towards sustainability. It's about infusing the urban psyche with an ethos that values efficiency, environmental stewardship, and the collective well-being of communities.

- Concluding Remarks: In Conclusion: Charting the Course for Urban Futures:

In conclusion, our research isn't a culmination but a catalyst for charting the course of urban futures. The undeniable transformative potential of our insights demands a recalibration of how we conceive, construct, and coexist in urban spaces. The narrative isn't just about buildings; it's about the very essence of urban life.

The journey towards sustainable and ecologically balanced urban futures is both a challenge and an opportunity. It's a challenge that necessitates breaking free from the shackles of convention, embracing innovation, and fostering collaborative endeavors. Simultaneously, it's an opportunity to redefine urban living, to sculpt cities that stand as testaments to human ingenuity and environmental stewardship.

In this juncture of responsibility and possibility, our research points the way forward. It beckons us to transform the urban landscape, not as an abstract ideal but as an inescapable imperative. The echo of our findings isn't confined to academic corridors; it resonates in the bustling streets, the towering structures, and the beating heart of cities. The time to act is now, and the canvas of urban transformation awaits the brushstrokes of sustainable innovation.

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