POLITECNICO MILANO 1863

School of Architecture, Urban Planning and Construction Engineering

An Assessment of Building Energy Efficiency Renovations: The case of Milan

Master of Science in Management of Built Environment

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Academic Year: 2023/2024

CONTENTS

List of Figures

List of Tables

Abstract

Renovations that prioritize building energy efficiency play a critical role in addressing climate change by mitigating greenhouse gas emissions and resource conservation. Moreover, these initiatives have the added benefits of promoting social equity, and fostering job creation, which collectively contribute to healthier and more equitable communities. Recognizing the significance of energy-efficient buildings is pivotal for a sustainable future.

The primary objective of this thesis is to evaluate the economic implications of building energy efficiency renovations on property values. To achieve this objective, the study employs Econometrics and the Hedonic Price methodology. The central focus of this research is to ascertain the extent to which enhancing Energy Performance Certificates (EPCs) impacts house price. Conducting an empirical case study that analyzed residential house price in Milan, it is evident that, the premium effect on house price resulting from upgrading the Energy Performance Certificate (EPC) level can cover the renovation costs. Therefore, from an economic perspective, the sustainability of building energy efficiency renovations is indeed feasible.

In addition, from an environmental perspective, building energy efficiency renovations typically involve more advanced and energy-efficient technologies and systems. This helps reduce the energy consumption of buildings, thereby decreasing dependence on non-renewable energy sources and lowering greenhouse gas emissions. From a social standpoint, building energy efficiency renovations not only create employment opportunities and reduce residents' energy bill expenses but also usually include improvements in thermal and acoustic insulation, enhancing indoor environments and, consequently, increasing residents' comfort and quality of life.

Keywords: building energy efficiency renovation, HPM, EPCs, residential market, decarbonization, building sustainability

Abstract in lingua Italiana

Le ristrutturazioni che danno priorità all'efficienza energetica degli edifici svolgono un ruolo critico nell'affrontare il cambiamento climatico mitigando le emissioni di gas serra e promuovendo la conservazione delle risorse. Inoltre, queste iniziative hanno i benefici aggiunti di favorire l'equità sociale e promuovere la creazione di posti di lavoro, contribuendo così a comunità più sane ed equilibrate. Riconoscere l'importanza degli edifici ad alta efficienza energetica è fondamentale per un futuro sostenibile.

L'obiettivo principale di questa tesi è valutare le implicazioni economiche delle ristrutturazioni energetiche degli edifici sui valori immobiliari. Per raggiungere questo obiettivo, lo studio utilizza l'econometria e la metodologia dei prezzi hedonici. Il focus centrale di questa ricerca è stabilire in che misura il potenziamento dei Certificati di Prestazione Energetica (EPC) influisce sul prezzo delle abitazioni. Attraverso uno studio di caso empirico che ha analizzato i prezzi delle case residenziali a Milano, è evidente che l'effetto premium sul prezzo delle case derivante dall'aggiornamento del livello di Certificato di Prestazione Energetica (EPC) può coprire i costi di ristrutturazione. Pertanto, dal punto di vista economico, la sostenibilità delle ristrutturazioni energetiche degli edifici è effettivamente realizzabile.

Inoltre, dal punto di vista ambientale, le ristrutturazioni energetiche degli edifici coinvolgono tipicamente tecnologie e sistemi più avanzati ed efficienti dal punto di vista energetico. Ciò contribuisce a ridurre il consumo energetico degli edifici, diminuendo la dipendenza dalle fonti di energia non rinnovabile e riducendo le emissioni di gas serra. Dal punto di vista sociale, le ristrutturazioni energetiche degli edifici non solo creano opportunità di lavoro e riducono le spese energetiche degli abitanti, ma includono anche miglioramenti nell'isolamento termico e acustico, migliorando gli ambienti interni e, di conseguenza, aumentando il comfort e la qualità della vita degli abitanti.

Parole chiave: ristrutturazione per l'efficienza energetica degli edifici, HPM, EPC, mercato residenziale, decarbonizzazione, sostenibilità degli edifici

1. Background and Development Process of the Energy Efficiency of Buildings

1.1 Climate Change and Decarbonization

Climate change refers to long-term shifts in temperatures and weather patterns. These shifts may be natural, such as through variations in the solar cycle. But since the 1800s, human activities have been the main driver of climate change, primarily due to burning fossil fuels like coal, oil and gas. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures.[1] The Earth's surface absorbs nearly half of the heat radiated by the sun, the atmosphere absorbs around 23% and the remaining 27% of solar radiation is reflected into space. The natural activities taking place on Earth release heat to ensure that the Earth receives and releases an equal amount of heat, thus maintaining a relatively stable temperature on Earth. But human activities are increasing emissions of greenhouse gases (GHGs). These greenhouse gases stay in the atmosphere, absorb the heat released by the Earth, and reflect it back to the Earth, causing the Earth's temperature to rise (absorption > release, more heat enters the Earth than leaves the Earth). Figure 1-1 shows a diagram illustrating how Earth's natural greenhouse effect works to maintain a comfortable temperature.

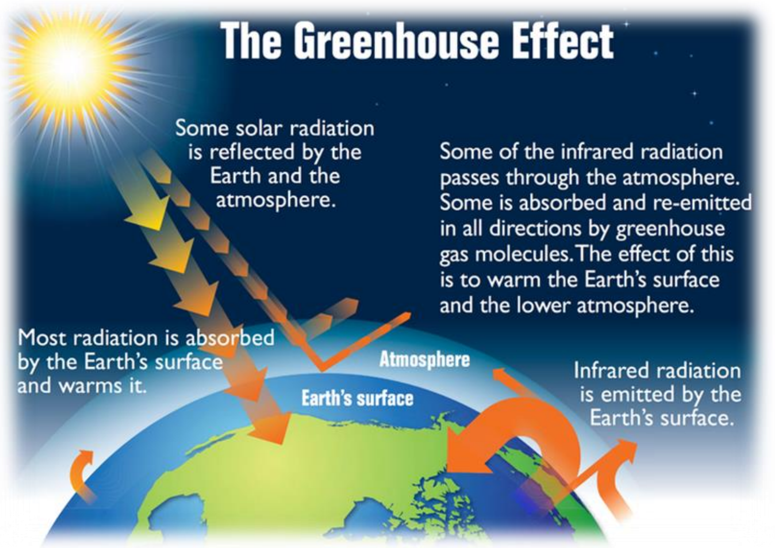

Figure 1-1: Wikimedia Commons. (August 6, 2015). Earth's Greenhouse Effect; Source: https://upload.wikimedia.org/wikipedia/commons/8/8e/Earth's_greenhouse_effect_(US_EPA,_2012).png

[1] UN explanation of Climate Change

The main greenhouse gases (GHGs) are listed in the following:

- Water vapour (water vapour), but it is not listed among the GHGs, because water vapour in the atmosphere basically comes from the process of releasing heat from the Earth's natural activities.

- Carbon dioxide (CO_2), which can remain in the atmosphere for up to 1,000 years.

- Methane, which can remain in the atmosphere for about 10 years.

- Nitrous oxide (N_2O), which can remain in the atmosphere for 120 years.

Fluorinated gases are emitted from a range of industrial processes, such as the production of refrigerants, aerosol propellants and fire extinguishing agents. These gases can remain in the atmosphere for thousands of years.

Measured over a 20-year period, methane is 80 times more potent in causing global warming than carbon dioxide (CO_2), while nitrous oxide is 280 times more potent than carbon dioxide (CO_2). F-gases are powerful greenhouse gases, with a global warming effect up to 25,000 times greater than carbon dioxide (CO_2).

Figure1-2 shows the breakdown of global emissions in 2020, measured on the basis of carbon dioxide-equivalents (CO_2 eq). Carbon dioxide was the largest contributor, accounting for around three-quarters (73.11%) of total emissions. Methane contributed 17.74%; Nitrous oxide, 6.58%; and other emissions (HFCs, CFCs, SF_6), 2.56%.

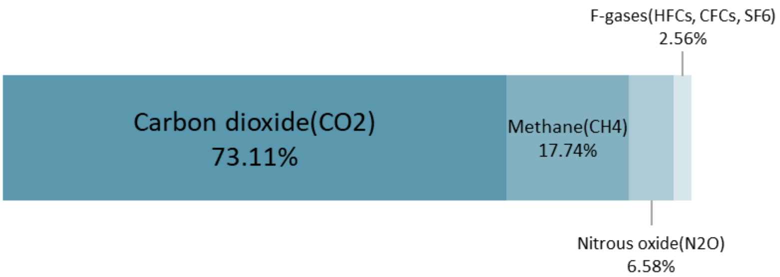

Figure 1-2: Global greenhouse gas emissions by gas in 2020;
Source: Climate Watch Historical GHG Emissions. 2022. Washington, DC: World Resources Institute.
Available online at: https://www.climatewatchdata.org/ghg-emissions
Note: Greenhouse gas emissions are converted to carbon dioxide-equivalents (CO_2eq) by multiplying each gas by its 100-year 'global warming potential' value: the amount of warming one tonne of the gas would create relative to one tonne of CO_2 over a 100-year timescale.

Coal, oil and natural gas are the main resources to provide energy for many activities around the world. Carbon is the main element of these fuels, which create and release carbon dioxide during conversion to energy when coal, oil and natural gas are burned to generate electricity, drive transport or provide heat. Of the methane produced by human activities, 55% comes from oil and gas extraction, coal mines and landfills, and 32% comes from livestock farming -- which releases methane as cattle, sheep and other ruminants ferment food in their stomachs. The decomposition of manure is another agricultural source of methane, which is also released from rice cultivation. Bacteria in soil and water naturally convert nitrogen, which is a major component of agricultural fertilizers, into nitrous oxide. For example, urea contains 46% nitrogen.

From Figure1-3, we can see that in 2019, 74.4% of emissions come from energy use; 11.6% from agriculture; and the remaining 14% from industry, land use change and waste. Road transport (12.6%) and residential buildings (11.5%) are the two biggest sectors that consume a lot of energy. Carbon dioxide (CO_2) was the most emitted gas, accounting for 74.1% of the total. From Figure 1-4, we can see that from 1990 to 2020, the quantity of greenhouse gas emissions from energy has increased significantly. On one hand, the increase in energy consumption leads to the release of more greenhouse gases, thus exacerbating global climate change. The growing impact of climate change also results in adjustments to people's daily activities, particularly in terms of transportation and residential needs, to enhance human comfort. This perpetuates a vicious cycle where the relationship between increased energy demand and human activities enters a self-reinforcing loop.

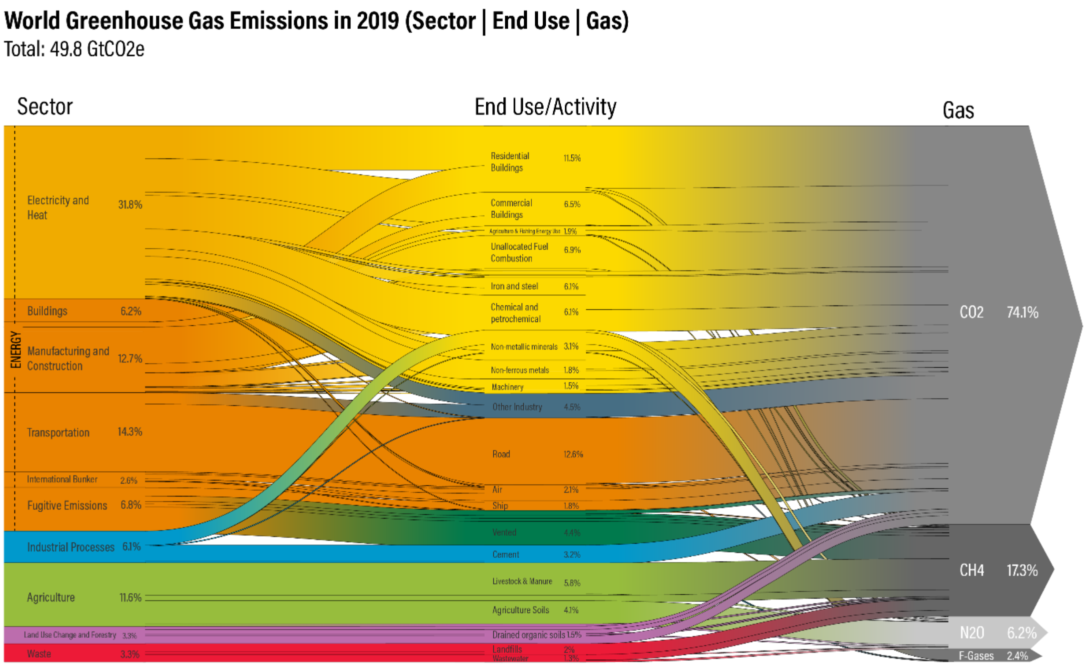

Figure 1-3: Global greenhouse gas emissions in 2019 by sector, end use and gas emissions; Source: Climate Watch Historical GHG Emissions. 2022. Washington, DC: World Resources Institute.

Available online at: https://www.climatewatchdata.org/ghg-emissions

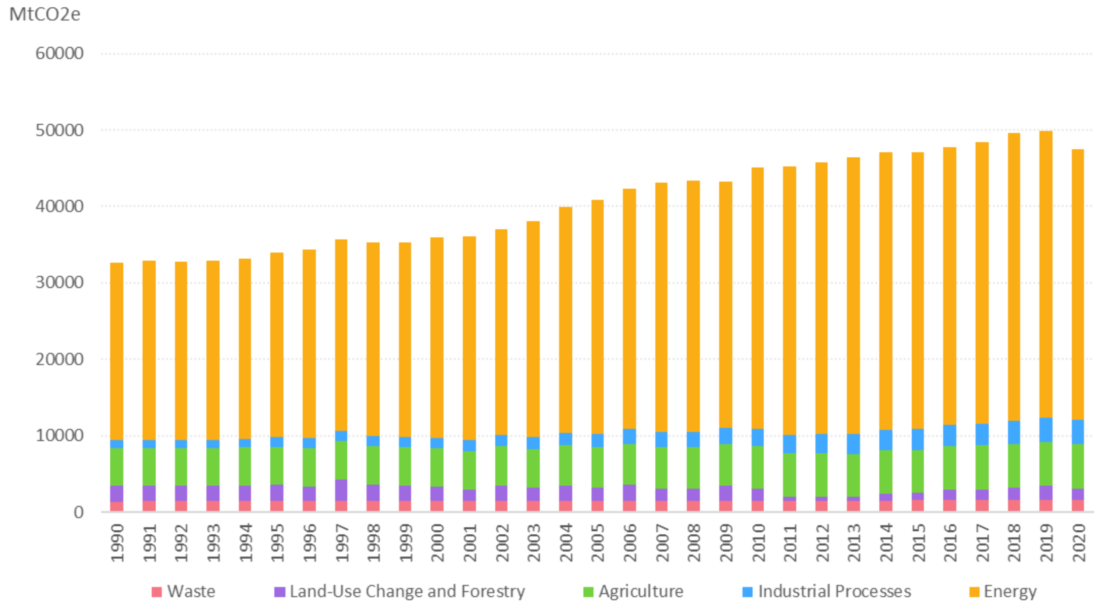

Figure 1-4: Global greenhouse gas emissions by sectors from 1900 to 2020; Source: Climate Watch Historical GHG Emissions. 2022. Washington, DC: World Resources Institute.

Available online at: https://www.climatewatchdata.org/ghg-emissions

Carbon dioxide (CO_2) emissions from fossil fuel combustion were almost zero before 1750. With the advent of the first industrial revolution, the United Kingdom became the world's first industrialized nation – and the first fossil-fuel CO_2 emitter. In 1751 its (and global) emissions were less than 10 million tonnes – 3,600 times less than global emissions today. When we look at the cumulative emissions of carbon dioxide in the world today, what becomes clear is that the countries with the highest emissions over history are not always the biggest emitters today. The UK, for example, was responsible for only 4.6% of global emissions in 2020. Reductions here will have a relatively small impact on emissions at the global level – or at least fall far short of the scale of change we need. This creates tension with the argument that the largest contributors in the past should be those doing the most to reduce emissions today. This is because a large fraction of CO_2 remains in the atmosphere for hundreds of years once emitted. It is important to note that, according to 2020 data, the US and EU countries rank first and second as the world's leading cumulative CO_2 emissions, with China ranking third, followed by the UK and India. It should be noted that, as developed countries, the UK, the US and the EU countries have shown a decreasing trend in their share of cumulative CO_2 emissions in recent decades. However, China and India, as developing countries, have shown an increasing trend in their share of cumulative CO_2 emissions year on year. (Figure1-5)

Figure 1-6 presents static statistics on greenhouse gas emissions for the year 2019.

Among the top ten countries or regions in terms of greenhouse gas emissions, there are both developed nations, exemplified by the United States and the 27 European countries, ranking second and fourth in greenhouse gas emissions, and developing countries, represented by China and India, ranking first and third in greenhouse gas emissions. The top 10 GHG emitters contribute over two-thirds of the global emissions.

The inequality of historical emissions and economic development are the two main reasons which make international agreement on who should take action so challenging.

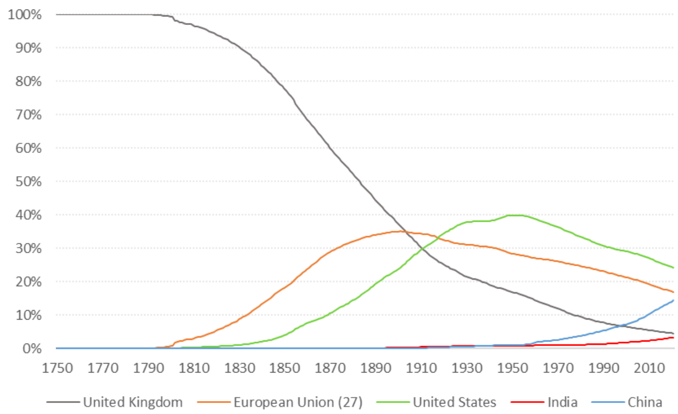

Figure 1-5: Share of global cumulative CO_2 emissions from 1750 to 2020;
Source: our world in data based on the global carbon project (2022)

https://ourworldindata.org/contributed-most-global-co2

Note: Cumulative emissions are calculated as the sum of annual emissions from 1750 to a given year. This measures fossil fuel and industry emissions. Land use change is not included.

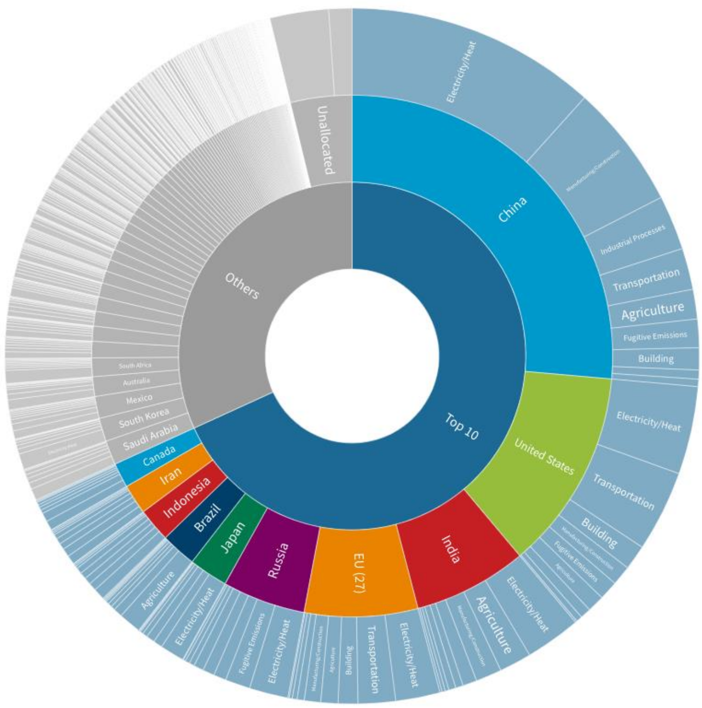

Figure 1-6: Top 10 greenhouse gas emitters in 2019;
Source: Climate Watch Historical GHG Emissions. 2022. Washington, DC: World Resources Institute.

Available online at: https://www.climatewatchdata.org/ghg-emissions

To avoid dangerous levels of global warming, the international organization has pledged to limit global temperature rise to less than 2°C above pre-industrial levels. This commitment requires rapid and sustained reductions in greenhouse gas (GHG) emissions over the next few decades from all of the world's major emitters. To meet this target, global emissions would likely have to peak in the next few years and decline 50% by the year 2050, according to the latest United Nations analysis. Table 1-1 shows countries that peaked or have a commitment to peak[2] and the percentage of global emissions covered, by decade. The percentage of global emissions in countries that peaked is shown in relation to 2010 rather than the decade in which the peak occurred.

Table 1-1: Countries that peaked or have a commitment to peak date in 2017; Source: WRI Turning Points report

Decade	Countries that peaked/will have peaked	Percentage of 2010 emissions from countries that peaked	Total countries that peaked
1990 or earlier	Azerbaijan, Belarus, Bulgaria, Croatia, Czech Republic, Estonia, Georgia, Germany, Hungary, Kazakhstan, Latvia, Moldova, Norway, Romania, Russian Federation, Serbia, Slovakia, Tajikistan, Ukraine	10%	19
2000 or earlier	France (1991), Lithuania (1991), Luxembourg (1991), Montenegro (1991), United Kingdom (1991), Poland (1992), Sweden (1993), Finland (1994), Belgium (1996), Denmark (1996), Netherlands (1996), Costa Rica (1999), Monaco (2000), Switzerland (2000)	15%	33
2010 or earlier	Ireland (2001), Micronesia (2001), Austria (2003), Brazil (2004), Portugal (2005), Australia (2006), Canada (2007), Greece (2007), Italy (2007), Spain (2007), United States (2007), San Marino (2007), Cyprus (2008), Iceland (2008), Liechtenstein (2008), Slovenia (2008)	36%	49
2020 or earlier	Japan, Malta, New Zealand, South Korea	40%	53
2030 or earlier	China (CO2 only), Marshall Islands, Mexico, Singapore	60%	57

Current policies to reduce, or at least slow down the growth of global temperatures, in CO_2 and other greenhouse gas emissions will have some impact on reducing future warming. As we can see in Figure 1-7, current policies presently in place around the world are projected to result in about 2.7°C warming above pre-industrial levels. NDCs alone will limit warming to 2.4°C. When binding long-term or net-zero targets are

[2] Emission peak is the point at which carbon dioxide emissions stop rising to the peak and then gradually fall back.

included warming would be limited to about 2.0°C above pre-industrial levels.

For the "optimistic" targets scenario analysing the effect of net zero emissions targets of about 140 countries that are adopted or under discussion. Even under the optimistic assumption that governments will achieve these targets, the median warming estimate is only limited to level of 1.8°C. It must be emphasised that the 'optimistic' assessment of end-of-century median warming of about 1.8°C is not Paris Agreement compatible and that warming higher that 2°C cannot be ruled out.

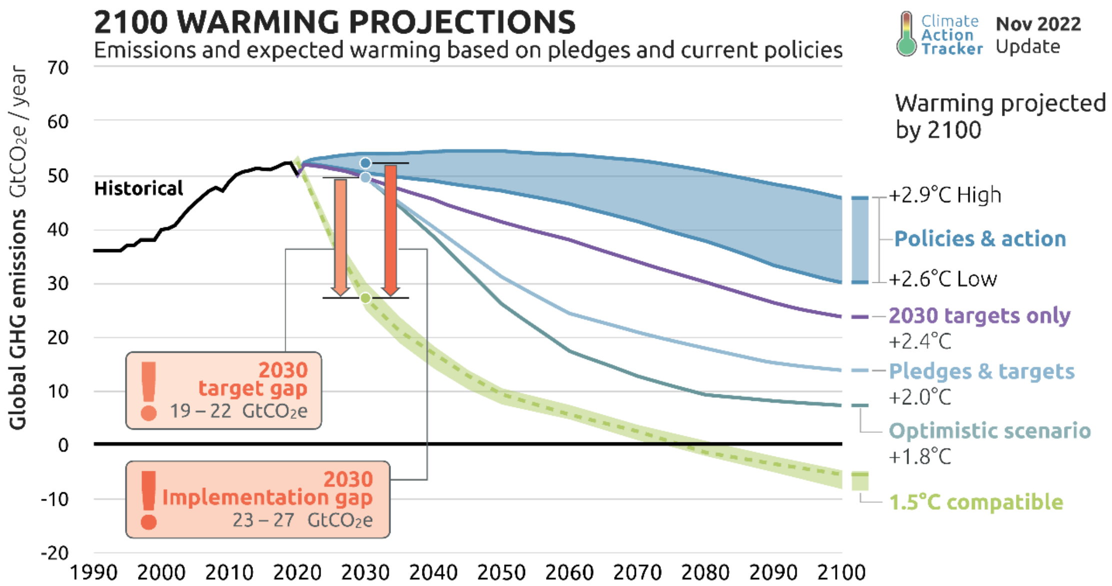

Figure 1-7: Global greenhouse gas emissions and warming scenarios;
Source: the Climate Action Tracker – based on policies and pledges as of November 2022,
https://climateactiontracker.org/global/temperatures/

In order to mitigate the impact of GHG emissions on global warming, carbon neutrality[3] and net-zero emissions[4] are now common countermeasures promoted by the international community, especially net-zero emissions. Limiting warming to 1.5°C above pre-industrial levels means that the greenhouse gas emissions need to be reduced rapidly in the coming years, about halved by 2030, and brought to zero soon after around mid-century. If emissions are not reduced by 2030, GHG will need to be substantially reduced thereafter to compensate for the slow start on the path to net

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[3] Carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in carbon sinks. Removing carbon oxide from the atmosphere and then storing it is known as carbon sequestration. In order to achieve net zero emissions, all worldwide greenhouse gas (GHG) emissions will have to be counterbalanced by carbon sequestration

[4] Net zero means cutting greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, by oceans and forests for instance.

zero emissions, but likely at a higher cost.

Nationally Determined Contributions – or NDCs - form the basis for countries to achieve the objectives of the Paris Agreement. They contain information on targets, and policies and measures for reducing national emissions and on adapting to climate change impacts. NDCs also contain information on either the needs for, or the provision of, finance, technologies and capacity building for these actions. Countries communicate new or updated NDCs every five years starting in 2020 (UN,2022). So far, all 193 Parties to the Paris Agreement have issued at least the first NDCs; 151 Parties communicated the new or updated NDCs as of 2 November 2021. NDCs factor in the understanding that countries have to balance emissions reductions with other critical demands like ending poverty. Further, the biggest emitters need to make the most dramatic and rapid cuts.

Total global GHG emissions (without LULUCF) taking into account implementation of the latest NDCs are estimated to be around 53.4 (51.8–55.0) Gt CO_2-equivalents in 2025 and 52.4 (49.1–55.7) Gt CO_2-equivalents in 2030, which are: (1) In 2025, 53.7% higher than in 1990 (34.7 Gt CO_2-equivalents), 12.6% higher than in 2010 (47.4 Gt CO_2-equivalents) and 1.6% higher than in 2019 (52.6 Gt CO_2-equivalents); (2) In 2030, 50.8% higher than in 1990, 10.6% higher than in 2010 and 0.3% lower than in 2019, as well as 1.9% lower than the estimated level for 2025, indicating the possibility of global emissions peaking before 2030.

Almost all Parties (97%) explained their approach to NDCs preparation and implementation. Many (57%) linked their NDCs to their commitment to transitioning to a sustainable and/or low-carbon and resilient economy, taking into account social, environmental and economic factors as well as the SDGs. In addition, many Parties (46%) indicated that they have integrated their NDCs targets, goals and policies into national legislative, regulatory and planning processes as a means of ensuring implementation (UN, 2022). Figure 1-8 shows the process of setting net-zero carbon emissions in each country or region of the world.

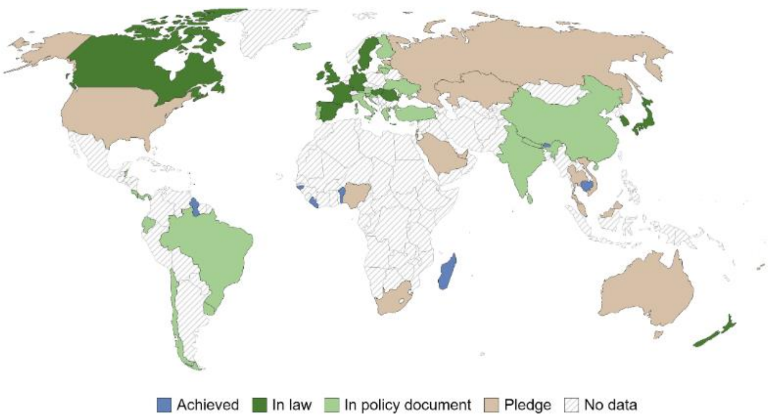


Figure 1-8: Status of net-zero carbon emissions targets; Source: our world in data,

https://ourworldindata.org/co2-and-greenhouse-gas-emissions

As shown in Figure 1-9, almost all Parties (97%) outlined domestic mitigation measures as key instruments for achieving mitigation targets for their NDCs and/or for priority areas, such as energy supply, transport, buildings, industry, agriculture, LULUCF and waste. Domestic mitigation measures for renewable energy generation (88%) were most frequently mentioned by Parties, followed by measures for improving the energy efficiency of buildings (70%) and for afforestation, reforestation and revegetation (54%). (*2022 NDC Synthesis Report | UNFCCC*, n.d.)

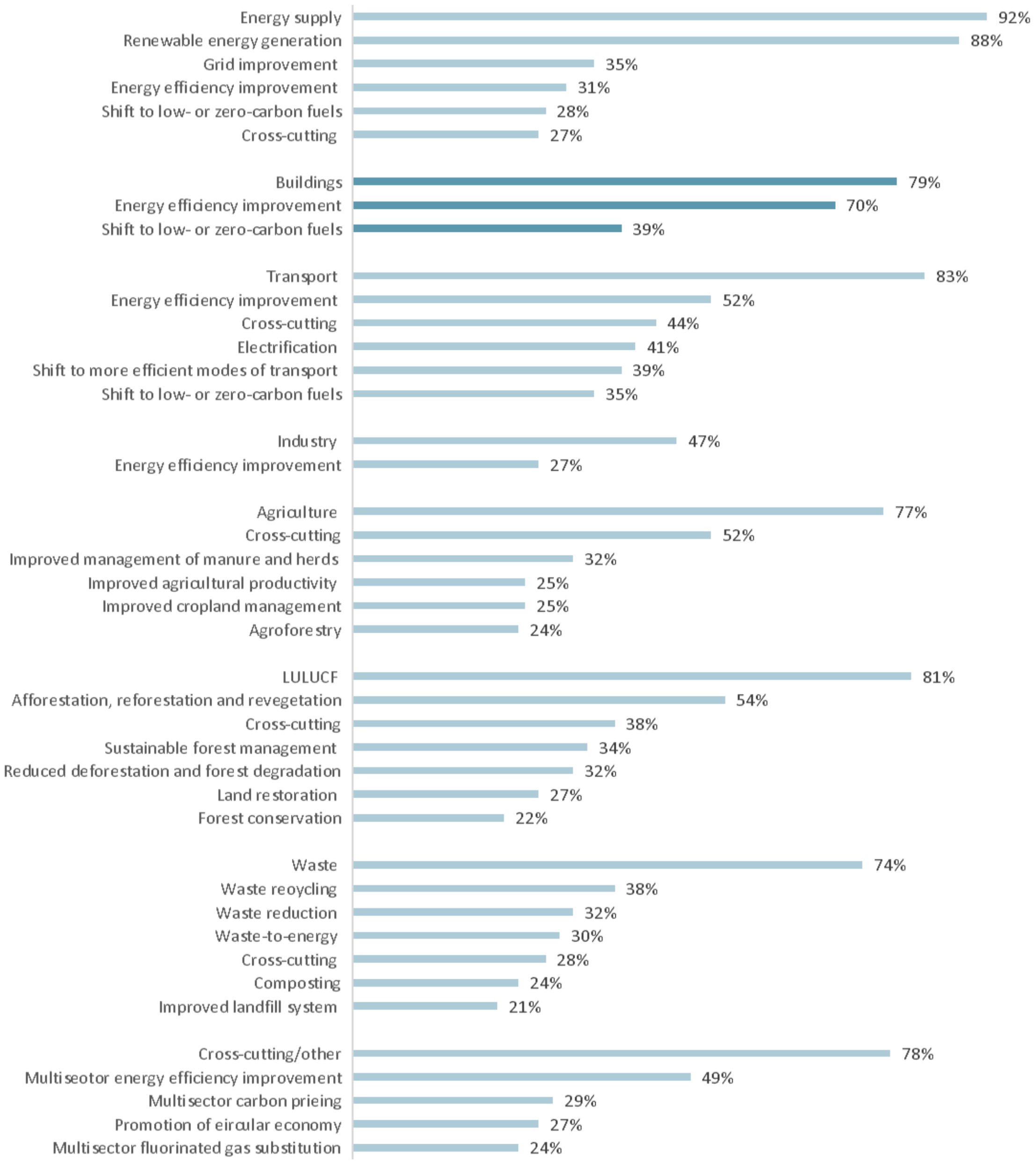


Figure 1-9: Share of adaptation components of nationally determined contributions referring to specific adaptation priority;

Source: 2022 NDC Synthesis Report; https://unfccc.int/ndc-synthesis-report-2022#Projected-GHG-Emission-levels

In summary, global warming is predominantly driven by the excessive emission of carbon dioxide, a critical factor intimately entwined with human socio-economic activities. In order to propose a programme to control the excessive release of carbon dioxide, fundamentally, it is necessary to start from two key perspectives.

The first is to control the source of carbon dioxide release. The main source of carbon dioxide is the combustion of coal, oil and natural gas, so from this perspective, we can consider what kind of alternative clean energy sources can be used to replace these traditional energy sources that emit large amounts of carbon dioxide.

Secondly, it is equally vital to focus on controlling carbon dioxide emissions from the demand side. Energy consumption is primarily geared towards facilitating human socio-economic activities. From this perspective, an examination of human activities is necessary. While maintaining the same level of comfort, we must explore alternative modes of social and economic life that reduce energy consumption, consequently lowering carbon dioxide emissions.

Despite the remarkable growth in renewable energy sources, finite and environmentally detrimental fossil fuels remain the primary energy source for the majority of the world's needs. This reliance on fossil fuels is further compounded by the ongoing trend of urbanization. According to the UN-Habitat World Cities Report 2022, the city population share doubled from 25% in 1950 to about 50% in 2020, it is projected to slowly increase to 58% over the next 50 years. The share of other settlements in the urban-rural continuum (towns and semi-dense areas as well as rural areas) is expected to decrease; towns and semi-dense areas are expected to drop to 24% (from 29% in 2020) and that of rural areas to 18% (from 22%).

Given that urban environments serve as hubs for a wide array of human activities, the building sector assumes a pivotal role in combatting the global greenhouse effect and reducing carbon dioxide emissions.

1.2 Buildings Sector and Decarbonization

According to the Global Status Report 2016, a document compiled by the Global Alliance for Buildings and Construction (GABC) in conjunction with the 22nd Conference of Parties (COP22) under the United Nations Framework Convention on Climate Change (UNFCCC), **the global floor area (GFA) in 2015 encompassed a vast 223.5 billion square meters**. Projections suggest that this figure will surge, potentially doubling **by the year 2050 to reach a staggering 415.1 billion square meters**. Notably, this anticipated expansion is driven by three prominent regions: China, India, and North America, which are expected to collectively account for half of the world's total building floor space by 2050. (Figure 1-10 & Table 1-2)

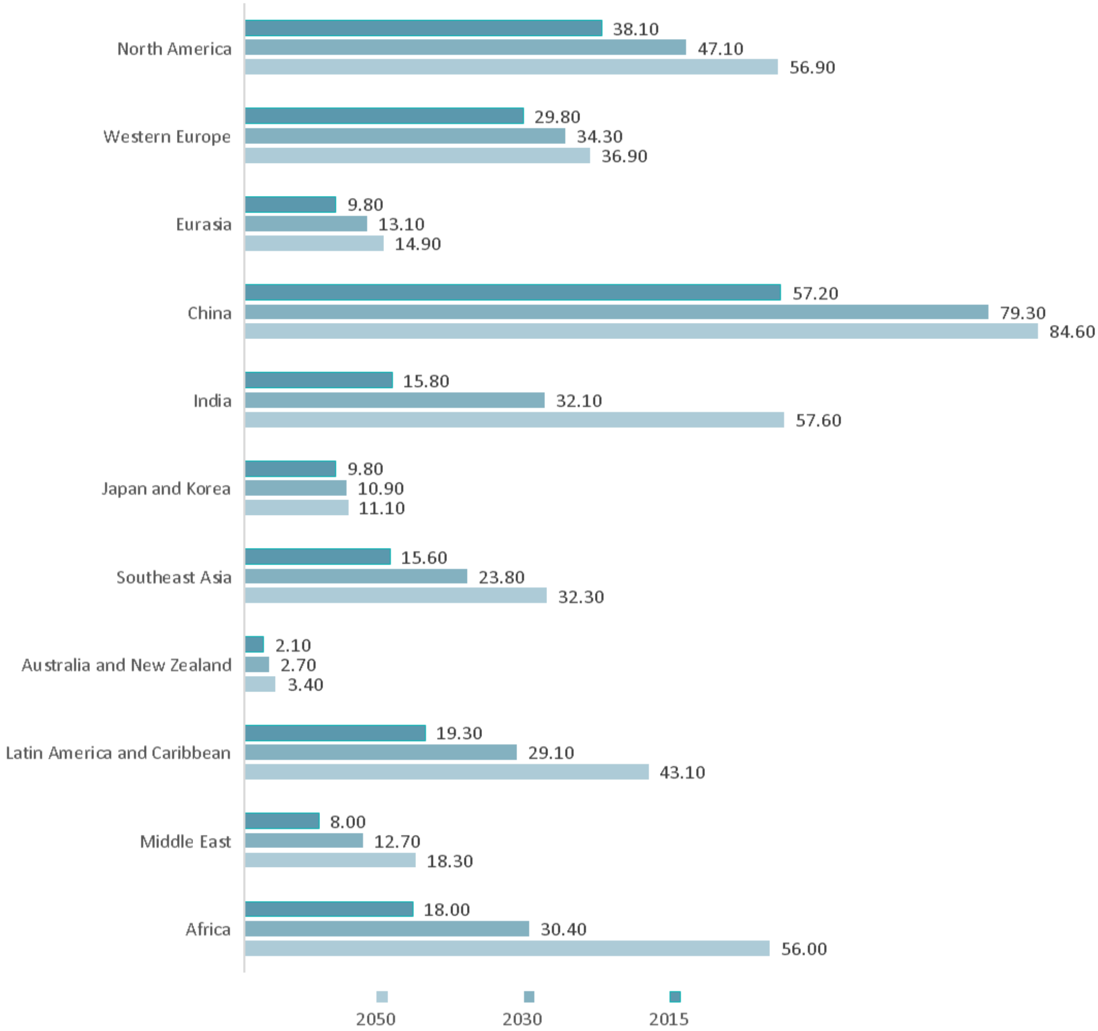


Figure 1-10: Projected growth of building floor area worldwide in 2015 with forecasts for 2030 and 2050, by region (in billion square meters);
Source: UNEP; IEA; GABC

When integrating population data for each region, a noteworthy observation emerges: there exists a substantial disparity in the per capita floor area across different regions. North America and Western Europe, in particular, exhibit significantly larger building floor areas per person in comparison to other regions. This discrepancy underscores the marked variations in the developmental trajectories of each respective region. (Table 1-2)

Table 1-2: Projected growth of building floor area, population and building floor area per person worldwide in 2015 with forecasts for 2030 and 2050, by region (in billion square meters);
Source: IEA (2016), Energy Technology Perspectives 2016, IEA/OECD, Paris. & UN (2015), World Population Prospects;

Regions	Projected growth of building floor area worldwide in 2015 with forecasts for 2030 and 2050, by region (in billion square meters)			Population worldwide in 2015 with forecasts for 2030 and 2050, by region (in billion persons)			Building floor area per person worldwide in 2015 with forecasts for 2030 and 2050, by region (square meters per person)		
	2015	**2030**	**2050**	**2015**	**2030**	**2050**	**2015**	**2030**	**2050**
North America	38.10	47.10	56.90	0.48	0.54	0.60	78.72	86.74	95.63
Western Europe	29.80	34.30	36.90	0.40	0.41	0.40	75.25	84.28	91.34
Eurasia	9.80	13.10	14.90	0.22	0.23	0.23	44.95	57.96	66.22
China	57.20	79.30	84.60	1.38	1.42	1.35	41.57	56.04	62.76
India	15.80	32.10	57.60	1.31	1.53	1.71	12.05	21.02	33.78
Japan and Korea	9.80	10.90	11.10	0.18	0.17	0.16	55.68	63.37	70.25
Southeast Asia	15.60	23.80	32.30	-	-	-	-	-	-
Australia and New Zealand	2.10	2.70	3.40	-	-	-	-	-	-
Latin America and Caribbean	19.30	29.10	43.10	0.63	0.72	0.78	30.44	40.36	54.97
Middle East	8.00	12.70	18.30	-	-	-	-	-	-
Africa	18.00	30.40	56.00	1.19	1.68	2.48	15.18	18.11	22.60
World	**223.50**	**315.50**	**415.10**	**7.35**	**8.50**	**9.73**	**30.41**	**37.11**	**42.68**

According to the global status report for buildings and construction in 2022 by GABC, in general, the total global building floor area has been increasing since 2015 as investments have increased. And in the interest of global warming, the task of energy efficiency and carbon reduction in the building sector cannot be delayed, with an increasing number of countries committing to energy efficiency in 2021 and providing extensive details of building decarbonisation in their Nationally Determined Contributions (NDCs), as well as developing relevant building codes at a national level. However, current observations show a negative rebound since 2020 in the decarbonization of the building sector, with increased energy intensity and higher emissions. This leads to a growing gap between the observed performance and the desired pathway, as shown in the lower part of Figure 1-11. The gap grew from 6.6 points in 2019 to 9.0 points in 2021.

The energy intensity of buildings, representing the total final energy consumption per square meter, has remained unchanged over the last three years at around 150kWh/m2. To achieve the needed pathway toward net zero carbon, the International Energy Agency estimates that intensity needs to drop by around 35% of its current level (152 kWh/m2 in 2021) to around 95 kWh/m2 (IEA 2022f). Unfortunately, energy intensity has largely been unchanged since 2019 and must improve at a rate of 5% per year by 2030 to achieve these targets. To do so, alongside decarbonization of the grid, the building energy renovation rate must increase to 2.5% per year (or 10 million dwellings per year) by 2030 in developed economies (IEA 2021b).

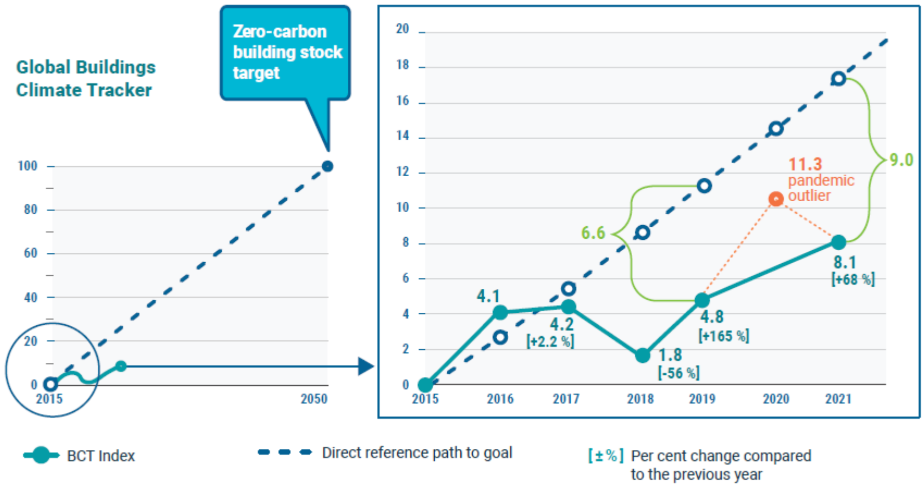


Figure 1-11 : Direct reference path to a zero-carbon building stock target in 2050(left); zoom into the period between 2015 and 2021, comparing the observed Global Buildings Climate Tracker to the reference path(right);
Source: UN, 2022 global status report for buildings and construction

Figure 1-12 provides details of the mentions of building sector within these new NDCs, as well as previously submitted versions. In 2021, 158 countries mentioned building sector in their NDCs, of which 118 refer to energy efficiency as a part of their emissions reduction strategy.

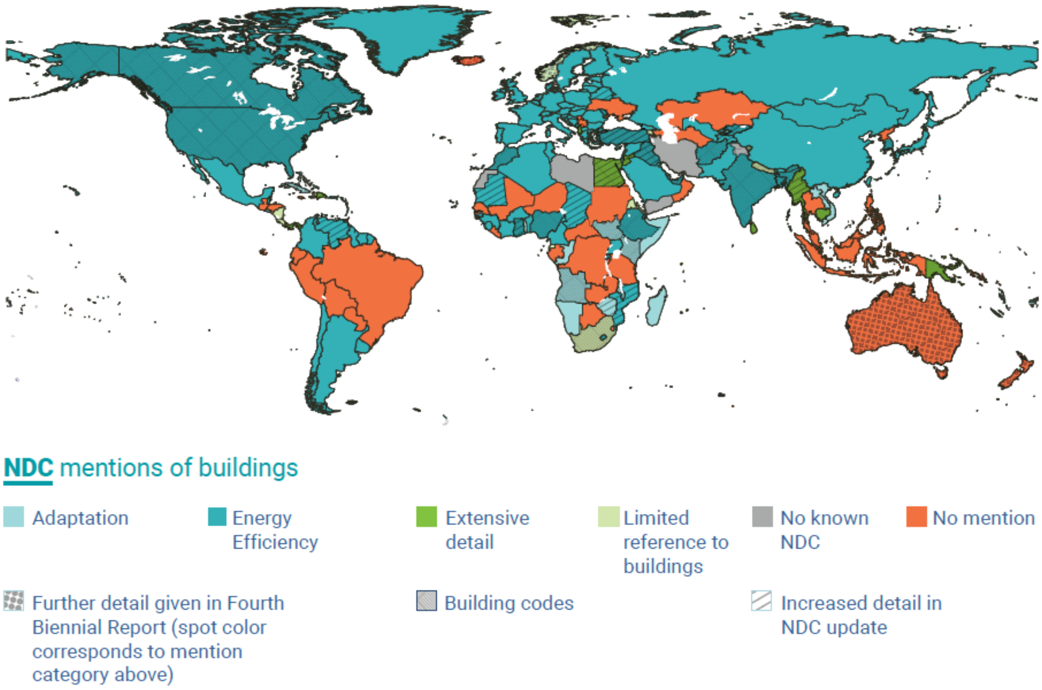


Figure 1-12 : Mentions of buildings across all countries' latest NDCs;
Source: UN, 2022 global status report for buildings and construction, UNFCCC

However, the ambition of NDCs must be matched by increased adoption of building energy codes. And under 20% of the world’s population still lives in countries whose NDC has no or limited references to buildings. What's encouraging, however, is that an increasing number of nations have taken substantial strides in articulating comprehensive plans within their NDCs to address climate change within the building sector. These plans encompass a multifaceted approach, encompassing elements of adaptation, mitigation, and the implementation of building codes to effectively tackle the challenges posed by climate change.

In addition to the measures taken by individual countries to promote emission reduction in the construction sector through the adoption of administrative regulations, the non-profit organisation Global Green Building Council (GGBC) promotes the Green Building Certification Systems, which is an important standard in the building codes system to measure the energy efficiency of buildings, and is of great significance to carbon emission reduction in the global building sector.

Recognition of Green Building Certification Systems is an ongoing global trend. Building energy and sustainability rating systems are in a constant state of evolution, adapting to address net-zero emissions and establishing comprehensive criteria for evaluating sustainable practices within the construction industry. These criteria encompass facets like energy, water, waste, transport, materials, resource consumption, pollution, land use, and health, providing a holistic assessment of sustainability efforts in the building sector.

These certifications serve as a compelling testament to the building sector's remarkable progress in adopting sustainable and eco-friendly practices in construction and development. As of 2021, the global landscape includes a total of 74 green building certification systems, with a majority administered by members of the World Green Building Council (WGBC). Notably, at least 184 countries have buildings that hold certifications under these systems, highlighting the widespread commitment to advancing sustainability in the built environment. (Table 1-3)

Table 1-3: Global building certification programmes;
Source: UN, 2022 global status report for buildings and construction

REGION	COUNTRY/AREA	RATING
Africa	Egypt	Green Pyramid Rating System
	Kenya	Green Mark
	South Africa	Green Star SA, Net Zero/ Net Positive
	Tunisia	EcoBat
	Uganda	Green Star Uganda
Americas	Brazil	GBC Brasil CASA, GBC Brasil Condomini, GBC Zero Energy
	Colombia	Casa (Colombia), ICONTEC
	Guatemala	Casa Guatemala
	United States of America	LEED, ILFI Zero Energy and Zero Carbon, Parksmart, PEER, RELi,SITES, TRUE, WELL
Asia	China	Assessment Standard for Green Building of China
	Hong Kong	BEAM Plus
	India	IGBC, GRIHA
	Indonesia	Greenship
	Japan	CASBEE
	Lebanon	ARZ rating system
	Malaysia	Green Building Index
	Pakistan	Pakistan Green Building Guideline (PGBG) BD+C
	Philippines	BERDE, Advancing Net Zero (ANZ/PH), PHILGBC Health and Well-being Tool for Buildings
	Saudi Arabia	saaf (Saudi Green Building Forum)
	Singapore	Green Mark, Singapore Green Building Product/Services Certification
	South Korea	Korea Green Building Certification
	Sri Lanka	GreenSL
	Turkey	B.E.S.T – Residential and Commercial Buildings Certificate
	United Arab Emirates	PEARL (Abu Dhabi), TARSHEED
	Vietnam	LOTUS
Europe	Austria	DGNB Austria
	Croatia	DGNB Croatia
	Denmark	DGNB Denmark
	France	HQE
	Germany	DGNB
	Ireland	Home Performance Index
	Italy	GBC Home, Historic Building, Quartieri, Condomini
	Latvia	BREEAM-LV
	Netherlands	BREEAM-NL, DGBC Woonmerk
	Norway	BREEAM-NOR
	Russia	OMIR
	Spain	DGNB Spain, VERDE
	Sweden	BREEAM-SE, Miljöbyggnad, Miljöbyggnad iDrift, CEEQUAL, NollCO2
	Switzerland	Minergie, SNBS, DGNB Switzerland
	United Kingdom	BREEAM, EDGE
Oceania	Australia	Green Star
	New Zealand	Homestar, NABERSNZ, Carbon zero

Note: The list is not comprehensive and includes some certification systems/rating tools which are not administered by members of WorldGBC.

To achieve the objectives outlined in the Paris Agreement, it is imperative that the global buildings and construction sector achieves net-zero carbon status by 2050, with all new buildings meeting this criterion from as early as 2030 (United Nations Environment Programme [UNEP] 2021; United Nations Framework Convention on Climate Change [UNFCCC] et al. 2021):

1) By 2030, the built environment should halve its emissions whereby 100% of new buildings must be net-zero carbon in operation;

2) By 2050, all new and existing assets must be net zero across the whole life cycle, including operational and embodied emissions.

To align towards meeting decarbonization targets, new buildings must be built to higher performance standards and codes. For existing buildings, the focus is to upgrade buildings – through either an incremental approach (e.g., adopting retrofits

when renovating a building or upgrading to a high-performance system at its end-of-life) or targeted deep renovations that upgrade a building through a multi-system upgrade to achieve a high-performance standard. Europe's Renovation Wave aims to at least double the annual energy renovation rate of buildings by 2030 and focus on deep energy renovations with a goal of renovating more than 35 million buildings – or 13% of the total – by 2030 (European Commission 2020).

Technological solutions for transitioning the global building stock toward sustainability are well-defined and encompass the use of high-performance, cost-effective insulation materials, advanced glazing units equipped with solar control films and gases, energy-efficient heating and cooling systems, high-performance appliances, and smart, digital control systems. (GlobalABC et al.2020).

In 2021, investments in energy efficiency within the global building sector witnessed a significant surge of approximately 16% compared to 2020, amounting to a total of around USD 237 billion, according to the International Energy Agency (IEA) in 2022. This uptick was especially pronounced in European countries with well-established public investment programs for enhancing efficiency, including Germany, the UK, and Italy. Meanwhile, the USA, Canada, and Japan sustained their investments in this sector.

1.3 Energy Efficiency of Buildings in Europe

1.3.1 Building stock and energy consumption in Europe

The EU Building Stock Observatory (BSO) was established by the European Commission in 2016 as part of the Clean Energy for All Europeans package, and aims to provide a better understanding of the energy performance of the building sector through reliable, consistent and comparable data.

In 2017, BSO reported that the EU27+UK had over 25 billion m2 of building stock. Of this, around 18.7 billion m2 belonged to the residential sector, making up 75% of the total floor area stock. The non-residential sector accounted for approximately 6.3

billion m2. When considering the building age, over 50% of the stock was constructed before 1979, with only 8% built after 2010. (Table 1-4)

As for Italy, according to the BSO database, the total floor area of building stock in Italy was 2,987.13 million m2. Of this, 85% (2,546.97 million m2) was in the residential sector, while the remaining 15% (440.16 million m2) was in the non-residential sector. Compared to the European level, Italy has a higher proportion of residential buildings. The analysis of the age of the buildings shows that 48% were built before 1979 and 11.7% after 2010. (Table 1-4)

Table 1-4: Building stock in Europe (EU+UK) or Italy in 2017; Source: EU BSO database

Construction period	Region	Building floor area(Mm2)			Percentage		
		Residential	Non-residential	Total	Residential	Non-residential	Total
< 1945	Europe (EU+UK)	3,626.82	1,531.12	5,157.94	19.34%	24.00%	20.52%
	Italy	405.61	123.93	529.54	15.93%	28.16%	17.73%
1945-1969	Europe (EU+UK)	3,729.09	1,192.51	4,921.61	19.89%	18.69%	19.58%
	Italy	386.50	69.70	456.20	15.17%	15.84%	15.27%
1970-1979	Europe (EU+UK)	2,671.36	630.20	3,301.57	14.25%	9.88%	13.14%
	Italy	394.74	50.15	444.89	15.50%	11.39%	14.89%
1980-1989	Europe (EU+UK)	2,404.40	867.16	3,271.56	12.82%	13.59%	13.02%
	Italy	369.05	55.87	424.92	14.49%	12.69%	14.23%
1990-1999	Europe (EU+UK)	2,108.46	855.64	2,964.09	11.24%	13.41%	11.79%
	Italy	344.48	42.18	386.66	13.53%	9.58%	12.94%
2000-2010	Europe (EU+UK)	2,486.15	850.52	3,336.67	13.26%	13.33%	13.28%
	Italy	338.99	56.17	395.16	13.31%	12.76%	13.23%
>2010	Europe (EU+UK)	1,725.66	453.35	2,179.01	9.20%	7.11%	8.67%
	Italy	307.59	42.16	349.75	12.08%	9.58%	11.71%
TOTAL	Europe (EU+UK)	18,751.94	6,380.50	25,132.44	100.00%	100.00%	100.00%
	Italy	2,546.97	440.16	2,987.13	100.00%	100.00%	100.00%

Based on data from the EU Building Stock Observatory, it was reported that in 2016, European countries (EU27+UK) collectively renovated a substantial 8,062.42 million square meters (Mm2) of building space. Remarkably, this accounted for 32.08% of the total building stock across Europe, as per the 2017 statistics. Within this impressive figure, approximately 12.83% was attributed to energy renovation, while 19.25% pertained to non-energy renovation. In the realm of residential buildings, the European region saw a significant 34.98% of them undergoing renovations in 2016, with 13.69% specifically aimed at enhancing energy efficiency (Table 1-5).

Turning our focus to Italy, it becomes apparent that the nation contributed significantly to the European building renovation field. In 2016, Italy successfully renovated an extensive 829.36 Mm2 of building space, amounting 10% of the total area renovated across Europe. In the context of Italy's building stock, this achievement accounted for an impressive 27.76% as per the 2017 statistics. Delving deeper, it is noteworthy that 11% of Italy's renovations were oriented towards energy efficiency improvements, while 16% encompassed non-energy-related renovation projects. Specifically, within the residential building sector, Italy registered a renovation rate of 26%, with 11.45% of these projects dedicated to enhancing energy efficiency. It is worth mentioning that Italy's overall renovation activity, while substantial, slightly trailed behind the European average. (Table 1-5)

Table 1-5: Building renovation in Europe (EU+UK) or Italy in 2016; Source: EU BSO database

Renovation category	Region	Building floor area(Mm2)			Percentage		
		Residential	Non-residential	Total	Residential	Non-residential	Total
All renovation (energy + non-energy renovation)	Europe (EU+UK)	6,560.33	1,502.09	8,062.42	34.98%	23.54%	32.08%
	Italy	662.04	167.32	829.36	25.99%	38.01%	27.76%
Energy renovation	Europe (EU+UK)	2,566.99	658.58	3,225.57	13.69%	10.32%	12.83%
	Italy	282.62	59.39	342.01	11.10%	13.49%	11.45%
Deep renovation	Europe (EU+UK)	21.22	22.06	43.28	0.11%	0.35%	0.17%
	Italy	4.40	2.15	6.55	0.17%	0.49%	0.22%
Light renovation	Europe (EU+UK)	731.57	209.85	941.42	3.90%	3.29%	3.75%
	Italy	74.59	17.39	91.98	2.93%	3.95%	3.08%
Non-energy renovation (i.e., esthetical renovation)	Europe (EU+UK)	3,993.35	843.50	4,836.85	21.30%	13.22%	19.25%
	Italy	379.42	107.93	487.35	14.90%	24.52%	16.31%
Building stock	Europe (EU+UK)	18,751.94	6,380.50	25,132.44	-	-	-
	Italy	2,546.97	440.16	2,987.13	-	-	-

Note: Renovated floor area from 2016 statistics, building stock from 2017 statistics

Table 1-6 displays the total final energy consumption in the building sector for both the European region and Italy from 2000 to 2018. It's evident that the primary source of final energy consumption in the building sector is residential buildings. Figure 1-13 illustrates the trends in final energy consumption for residential buildings from 2000 to 2018. While there was a modest increase followed by a slight decrease, the overall trend remained relatively stable. According to Table 1-6, in 2017, the total final energy consumption in the European building sector was 287,686.42 Mtoe, while in Italy, it was 32,916.89 Mtoe. Combining this data with the building stock data for Europe and Italy in 2017 from Table 1-4, we can calculate[5] that in 2017, the energy intensity of buildings in Europe was 132.84 kWh/m², and in Italy, it was 128.67 kWh/m².

As mentioned earlier, to achieve the necessary trajectory towards net-zero carbon emissions, the International Energy Agency estimates that energy intensity needs to decrease to around 95 kWh/m² (IEA 2022f). Therefore, there is a continued need to

[5] 1 Mtoe = 11,630,000,000 kWh

intensify efforts to promote energy efficiency and reduce energy consumption in the building sector.

Table 1-6: Final energy consumption of building sector in Europe (EU+UK) or Italy from 2000 to 2018;
Source: EU BSO database

	Europe (EU+UK)			Italy		
Year	Residential	Non-residential	Total	Residential	Non-residential	Total
2000	291,329.17	121.72	291,450.89	27,591.93	11.54	27,603.47
2001	305,732.19	128.83	305,861.02	28,907.18	11.99	28,919.18
2002	299,504.87	126.25	299,631.12	28,741.61	11.96	28,753.56
2003	309,529.52	139.23	309,668.74	31,590.24	13.22	31,603.46
2004	309,419.63	142.51	309,562.14	31,425.19	13.47	31,438.65
2005	310,858.55	144.30	311,002.85	33,921.57	15.05	33,936.62
2006	308,429.95	148.64	308,578.59	32,423.68	15.57	32,439.25
2007	290,527.06	141.57	290,668.63	32,339.58	15.18	32,354.76
2008	306,091.97	151.22	306,243.19	33,611.75	17.02	33,628.77
2009	303,272.47	149.99	303,422.46	34,040.64	16.92	34,057.56
2010	324,040.40	156.42	324,196.82	35,392.91	16.98	35,409.89
2011	288,306.70	144.11	288,450.80	32,378.06	15.75	32,393.81
2012	302,513.66	147.87	302,661.52	34,348.34	15.93	34,364.27
2013	306,295.20	149.75	306,444.95	34,230.62	15.85	34,246.47
2014	269,642.06	139.36	269,781.42	29,545.98	14.67	29,560.65
2015	281,142.14	146.94	281,289.08	32,494.48	15.39	32,509.87
2016	288,677.30	150.01	288,827.31	32,185.10	15.44	32,200.54
2017	287,532.90	153.52	287,686.42	32,898.65	18.24	32,916.89
2018	283,301.43	151.63	283,453.05	32,055.88	19.34	32,075.21

Note: The unit is Mtoe. The fuels include natural gas, petroleum products, solid fuels, electricity, derivated heat, renewables.

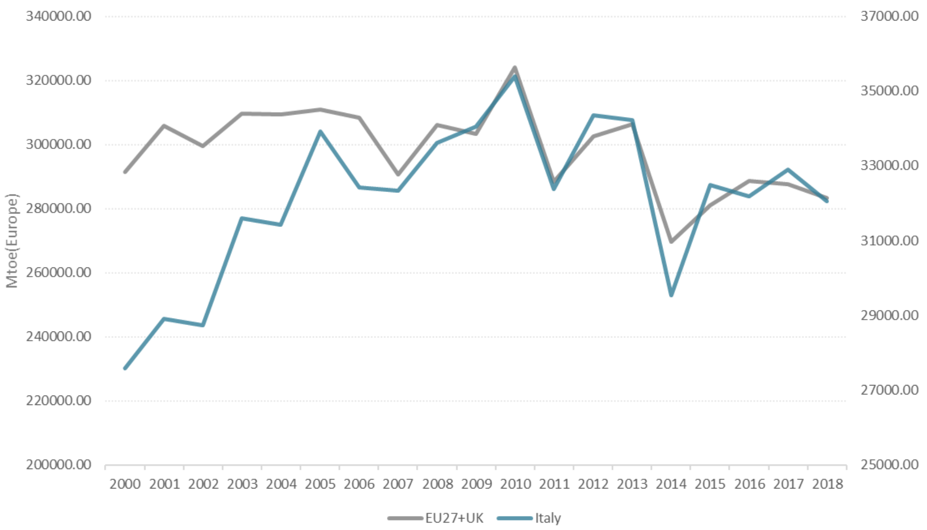
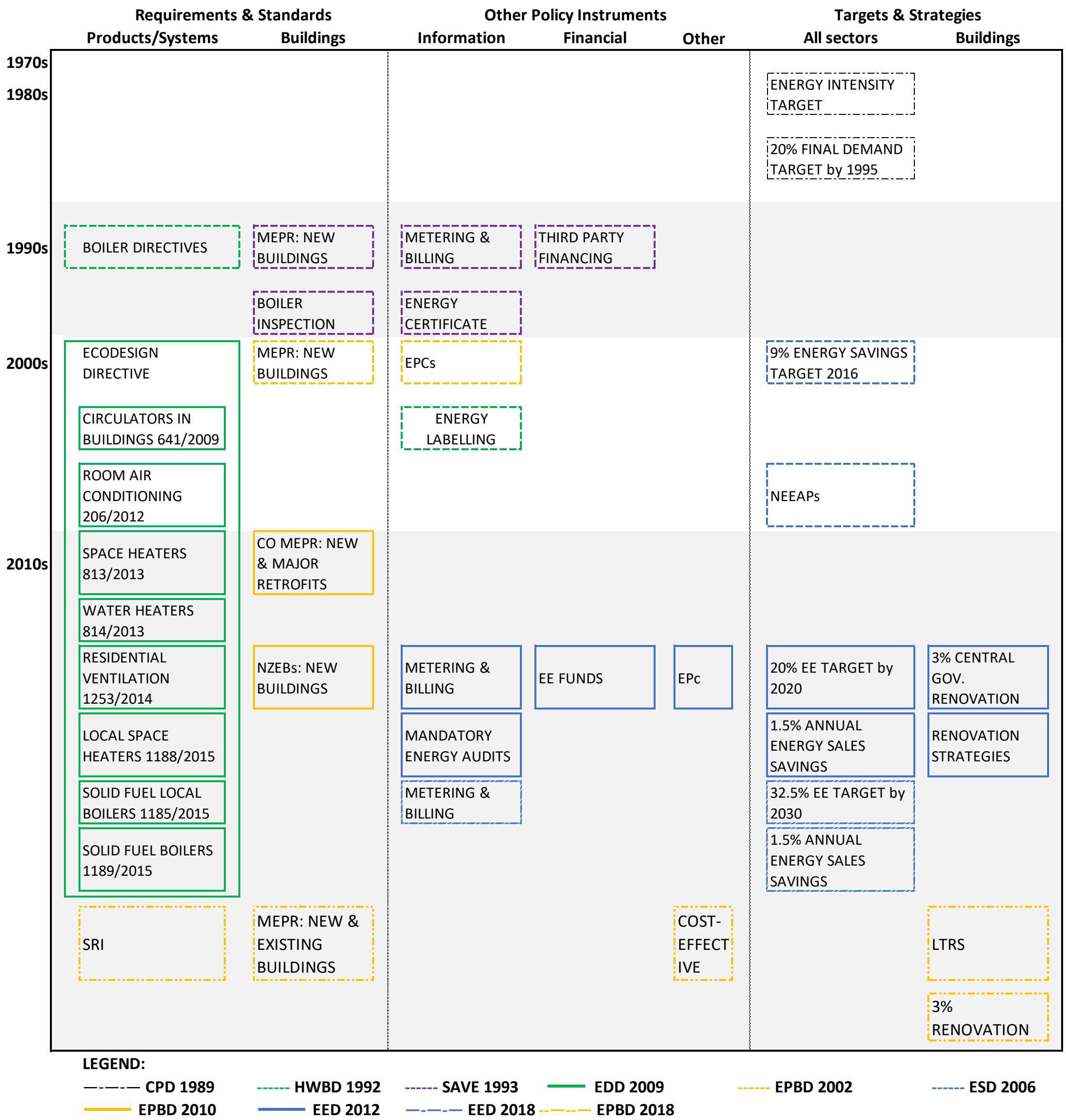


Figure 1-13: Final energy consumption of residential buildings in Europe (EU+UK) or Italy from 2000 to 2018;
Source: EU BSO database

1.3.2 Energy efficiency laws, regulations and administrative policies

In order to overcome the energy gap, governments have adopted several energy efficiency programmes, policies or packages of policies. In the EU, buildings have been an integral part of the EU energy and climate policy for several years. Energy efficiency policies for buildings can impact all end uses ranging from heating and cooling to lighting and appliances. They can take the form of regulatory or control instruments, building codes, consumer information campaigns and economic or financial incentives. Instruments of regulatory nature can include requirements on various household appliances, products, systems or entire buildings. Many of the energy efficiency measures can be encouraged or mandated through individual policies or policy packages.

Figure 1-14 summarises the EU's energy policies from the 1970s to the 2010s, particularly in relation to the building sector.



ABBREVIATIONS:

CPD 1989	Construction Products Directive(89/106/EEC)
MEPR	Minimum Energy Performance Requirements
NZEBs	Nearly Zero Energy Buildings
EPCs	Energy Performance Certificates
EPc	Energy Performance contracts
EPBD 2002	Energy Performance of Buildings Directive(2002/91/EC)
EPBD 2010	Energy Performance of Buildings Directive(2010/31/EU)
ESD 2006	Energy Services Directive(2006/32/EC)
EED 2012	Energy Efficiency Directive(2012/27/EU)
EDD 2009	Ecodesign Framework Directive(2009/125/EC)
RED 2009	Renewable Energy Directive(2009/28/EC)
HWBD 1992	Efficiency Requirements for liquid/gaseous fuel hot-water boilers(92/42/EEC)
EDD-CB	Ecodesign regulation for circulators in buildings(641/2009)
EDD-RAC	Ecodesign regulation for room air conditioning(206/2012)
EDD-SHR	Ecodesign regulation for (no biomass) space heaters < 400kW (813/2013)
EDD-WH	Ecodesign regulation for (no biomass) water heaters < 400kW (814/2013)
EDD-RV	Ecodesign regulation for residential ventilation(1253/2014)
EDD-LSH	Ecodesign regulation for local space heaters < 50kW(1188/2015)
EDD-SFB	Ecodesign regulation for local solid fuel boilers(1189/2015)
LTRS	Long-Term Renovation Strategies
SRI	Smart Readiness Indicator

Figure 1-14: Overview of 50-year policy evolution in the area of energy efficiency in buildings in the EU;

Source: M. Economidou, V. Todeschi, P. Bertoldi, D. D'Agostino, P. Zangheri, L. Castellazzi, 2020, 'Review of 50 years of EU energy efficiency policies for buildings', ELSEVIER, Volume 225, 13

As a result of the oil embargoes of the 1970s, energy policy initially focused on the security of energy supply. With the oil crisis in OECD countries between 1973 and 1974, energy efficiency began to emerge as an important policy response to enhance oil security. At the time, energy security was associated with the 'security of oil supply', but this evolved to focus on other energy carriers, including natural gas and renewable energy. In response to the impact of the oil crisis, in 1974 the European Council proposed a reduction in energy consumption, and in 1986 the European Council resolved that a solution needed to be found to balance energy and the environment, which was the first time the concept of energy efficiency (EE) was introduced in Europe. The EE target was defined as a minimum 20% improvement in the ''efficiency of final energy demand" -defined as the ratio of final energy demand to gross national product- by 1995(Economidou et al., 2020).

1989, CPD（Construction Products Directive）

The ''Construction Products Directive" (CPD) (89/106/EEC) intended to ensure that reliable information was presented in relation to the performance of construction products used in buildings and civil engineering works(Caluwaerts et al., 2014) . This was achieved by developing a common technical language through the introduction of harmonized standards(Bassi, 1995)(Sjöström et al., 2002). The CPD provided four main elements: i) a common system of technical specifications; ii) an agreed system of verification of conformity; iii) a framework of stakeholders; and iv) the CE marking[6] of products(Loveday, 1992). The CPD was repealed and replaced by the ''Construction Products Regulation" (CPR) (Regulation N. 305/2011)[7] in order to simplify and clarify the previous framework, and to improve the transparency and effectiveness of existing measures.

1992, HWBD (Hot Water Boilers Directive)

The Directive on Hot Water Boilers (HWBD) 92/42/EEC6[8], adopted in 1992, introduced common efficiency requirements for new hot water boilers fired with liquid or gaseous fuels in all Member States.

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[6] The letters 'CE' appear on many products traded on the extended Single Market in the European Economic Area (EEA). They signify that products sold in the EEA have been assessed to meet high safety, health, and environmental protection requirements. (EU)

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32011R0305&qid=1695111727155

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31992L0042&qid=1695113600199

1993, "SAVE" Directive

The ''SAVE" Directive (93/76/EEC)[9] of 1993 represents the first major EU policy on energy efficiency(Van Wees et al., 2002). The Directive required Member States to draw up and implement programmes to improve energy efficiency, especially to draw up and implement programmes introducing sufficient thermal insulation provisions in new buildings, with the aim to limit CO_2 emissions and to promote the rational use of energy(de Alegría Mancisidor et al., 2009). The main requirements in the SAVE are: i) the certification of buildings with the description of the building energy characteristics in order to provide the consumer information on the EE level(Richalet et al., 2001); ii) the billing of heating, air-conditioning and domestic hot water based on actual consumption including the right for building occupants to regulate their own consumption of heat, cold or hot water; iii) the facilitation of third-party financing for energy efficiency investments in the public buildings; iv) the thermal insulation of buildings, v) the regular inspection of heating installation larger than 15 kW and vi) the energy audits of undertakings with high energy consumption(Economidou et al., 2020).

The SAVE Directive was partly replaced by the Directive on the Energy Performance of Buildings in 2002 (as regards the efficiency standards, certification and boiler inspection articles), and the remaining articles were replaced by the Directive on Energy endues efficiency and energy services in 2006, it's no longer in force.

2002, EPBD 2002（Energy Performance of Building Directive）

The first cohesive European legal act on energy policy in buildings was the Energy Performance of Buildings Directive (EPBD,2002/91/EC)[10]. Overall, the EPBD policy framework laid down the foundation for(Economidou et al., 2020):

- Setting minimum energy performance standards in new buildings and existing buildings under major renovation. Under the EPBD provisions, the minimum energy performance requirements applied to both new and large (over 1000 m2 useful floor area) existing buildings under major renovation, where energy performance of a building was defined as the amount of consumed or calculated energy use, typically measured in kWh/m2 per year.
- Ensuring that prospective buyers or renters are well informed and thereby encouraged to choose higher than minimum standards in their decision-making processes. According to the EPBD provisions, EPCs with a 10-year validity must be made available to prospective buyers or tenants in real estate transactions. EPCs are a concise document displaying the energy performance of a building or building unit —

[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A31993L0076&qid=1695112178586

[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002L0091&qid=1695113399183

based on an energy class or continuous scale rating system— together with recommended actions on how to improve the existing energy performance. The primary scope of EPCs is to guide prospective buyers or renters in their decision-making process, increase demand in buildings of high energy efficiency and act as a driver for more energy renovations(BIS, Ronan, L., & IEEP, 2013)(De Ayala et al., 2016). Beyond their important awareness raising dimension, EPCs can also be used to monitor the overall energy performance of the building stock, thereby bringing more transparency to the property market(Arcipowska et al., 2014)(Beerepoot & Sunikka, 2005)(Davis et al., 2015). The EPBD 2002 was replaced by EPBD 2010, it's no longer in force.

2006, ESD (Energy Services Directive)

The Energy Services Directive (ESD – 2006/32/EC)[11] is broadly considered as a successor of the SAVE Directive and the predecessor of the EED. Adopted in 2006, the ESD laid out the foundation for setting indicative national targets equivalent to at least 9% energy savings by 2016 and introduced reporting obligations through the preparation of National Energy Efficiency Plans (NEEAPs)(Bertoldi & Economidou, 2018)(Ringel & Knodt, 2018). Whilst the ESD did not have any specific focus on buildings, it included some provisions on metering and billing, financing and energy performance contracts. These provisions were strengthened in the subsequent EED. ESD 2006 is no longer in force.

2009, EDD (Eco-design Framework Directive)

The Eco-design Framework Directive (EDD - 2009/125/EC)[12] establishes a framework for minimum eco-design requirements that goods that consume energy must meet before they can be used or sold in the EU. The key points include:

- Eco-design requirements cover all stages of a product's life: from raw materials, manufacturing, packaging and distribution to installation, maintenance, use and end-of-life.
- For each phase, various environmental aspects are assessed by bodies designated by EU countries. They verify aspects such as the materials and energy consumed, expected emissions and waste and possibilities for reuse, recycling and recovery.
- Manufacturers must construct an ecological profile of their products and use this to consider alternative design possibilities.

[11] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32006L0032&qid=1695115086847

[12] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009L0125&qid=1695116199153

- Products which satisfy the requirements bear the CE marking and may be sold anywhere in the EU.

Within the framework of the EED 2009, a series of EU regulations[13] [14] [15] [16] [17] have been introduced between 2009 and 2015 to improve the energy efficiency of various products. Each specific product regulation sets out detailed criteria for the respective product category, whilst adhering to the principles outlined in the EDD.

2010, EPBD 2010 (EPBD- 2010/31/EU)

The main purpose of the EPBD 2010/31/EU[18] was to ensure that national Minimum Energy Performance Requirements adopted by Member States had similar ambition levels in terms of energy savings and greenhouse gas emissions reduction. This is because some national standards were not ambitious and cost-effective enough(Ó Broin et al., 2015). To this end, Article 5 of the EPBD 2010 introduced the cost-optimal methodology as the guiding principle for setting building energy requirements and Article 9 introduced the concept of ''nearly zero-energy buildings" (NZEBs[19]) according to which all new private buildings will have to comply with nationally defined NZEB standards by January 2021. However, while reaching the NZEBs target in new buildings appears to be feasible according to studies on energy performance optimization(D'Agostino & Parker, 2018) the challenge remains for existing buildings(Belussi et al., 2019). Moreover, the existing stock is characterized by high heterogeneity in terms of uses, climatic areas, construction traditions and systems. The EPBD 2010 aimed to raise the importance of financial incentives to promote energy renovations and required Member States to identify and submit to the Commission national financial measures to improve energy efficiency. From the Commission's side, support was made available in terms of structural funds, European Investment Bank funds and other EU funds.

In particular, the EPBD 2010 requires that from the year 2020 onwards all new buildings will have to be 'nearly zero energy buildings', comply with high energy-performance standards and supply a significant share of their energy requirements from renewable sources. To achieve the objectives of the EPBD, it is necessary to

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[13] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009R0641&qid=1695118247519

[14] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32012R0206&qid=1695118334578

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R0813&qid=1695118544175

[16] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32013R0814&qid=1695118577908

[17] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32014R1253&qid=1695118608469

[18] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32010L0031&qid=1695499440371

[19] An NZEB is defined as a building of very high energy performance, where the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby.

consider renewable energy technologies, the dynamic nature of the building energy flows and occupancy behaviour. It is also necessary to establish a robust energy performance assessment for new and renovated buildings.

2012, EED 2012(EED, 2012/27/EU)

The legal basis of the 2020 targets and other provisions stipulated in the 2011 Energy Efficiency Action Plan was established in the Energy Efficiency Directive (EED, 2012/27/EU[20]) which was adopted in December 2012 as part of the European Energy and Climate Package. The Directive quantified the 20% energy efficiency target in terms of absolute primary and final energy consumption levels by 2020. The most important EED articles on buildings included the requirement for the public sector to renovate its central government building stock (Article 5), the setup of metering and billing requirements measures (Articles 9–11), the establishment of long-term strategies for national building stock renovation (Article 4), and annual new savings of 1.5 % of the annual energy sales to final customers of all energy distributors or all retail energy sales companies by volume (Article 7). To tap into the large cost-effective energy energy-saving potential of energy renovations across the EU, Member States were asked to develop long-term renovation strategies with the view of mobilising energy efficiency investments in residential and commercial buildings. The strategies were drawn up to provide (Article 4):

(1). an overview of the country's national building stock;

(2). identify key policies to stimulate renovations;

(3). provide an estimate of the expected energy savings and wider benefits;

(4). identify cost-effective approaches by building type and climatic zone;

(5). encompass a forward-looking perspective to guide investment decisions.

To promote energy savings through behavioural change, the EED (2012/27/EU) introduced a mandatory requirement of consumption-based cost allocation and billing of heating cooling and hot water in multi-apartment and multipurpose buildings with collective heating/cooling systems. Many studies(Fischer, 2008)(Zvingilaite & Togeby, 2015)(Karlin et al., 2015) have demonstrated that providing consumption feedback to energy users can influence their behaviour, which can lead to an average of 5%–10% final energy consumption reduction in households(Zangheri et al., 2019). The effectiveness of such measures depends on several conditions: feedback type and frequency, the accuracy of metering systems, the availability of heating controls and

[20] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012L0027

the capability of maintaining energy savings habits over time. Although the EU has promoted energy consumption individual metering for energy consumption since 1976/197722, the EED represents the legal foundation for accurate metering and billing of energy individual consumption in multi-apartment and multipurpose buildings in the EU(Economidou et al., 2020).

2018, EED 2018 (2018/2002/EU, EED)

This directive, as revised by Directive (EU) 2018/2002[21], along with the revised Renewable Energy Directive and a new Governance Regulation is part of the Clean Energy for All Europeans package. The main amendments to the 2012 directive include:

- Meeting a 32.5% energy efficiency target by 2030 and anticipating further improvements after that;
- Removing barriers in the energy market that obstruct efficiency in the supply and use of energy;
- From 2020, EU countries will require utility companies to help their consumers use 0.8% less energy each year (for Malta and Cyprus 0.24%), which will attract private investment and support new competitors in the market;
- Clearer rules on energy metering and billing, strengthening consumer rights, in particular for people living in multi-apartment buildings;
- EU countries must have transparent, publicly available national rules on the allocation of the cost of heating, cooling and hot water services in multi-apartment and multi-purpose buildings where these services are shared;
- Strengthening social aspects of energy efficiency by taking energy poverty into account in designing energy efficiency schemes and alternative measures.

2018, EPBD 2018 (2018/844/EU, EPBD)

On 19th June 2018, the new Directive (2018/844/EU[22], EPBD) was published and the revised provisions entered into force on 9th July 2018. The EPBD 2018 introduces targeted amendments to the current EPBD aimed at accelerating the cost-effective renovation of existing buildings, with the aim of a decarbonized building stock by 2050 and the mobilization of investments to reach this goal(Thonipara et al., 2019). The EPBD 2018 also supports electro-mobility diffusion by mandating electro-mobility infrastructure deployment in buildings' car parks. It also introduces new provisions to

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[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32018L2002

[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L0844&qid=1695282723844

enhance smart technologies and technical building systems, including building automation. Member States have 20 months to transpose the Directive into national laws (namely by 10th March 2020). In particular, the EPBD 2018 includes the following provisions:

- Member States shall establish more effective long-term renovation strategies (LTRS), identifying an adequate set of financial measures and consulting stakeholders in the preparation and implementation of their strategies;

- Stimulate cost-effective deep renovation encouraging more holistic approaches in energy renovation projects;

- Smart technologies and ICT in buildings will be promoted;

- Improving the transparency and quality of the EPCs;

- Health and well-being of building users will be promoted, for instance through an increased consideration of air quality and ventilation;

- Combatting energy poverty and reducing the household energy bill by renovating older buildings.

- According to the Commission's impact assessment, renovation would be needed at an average rate of 3% annually to accomplish the Union's energy efficiency ambitions in a cost-effective manner. Considering that every 1% increase in energy savings reduces gas imports by 2.6%, clear ambitions for renovation of the existing building stock are of great importance. Thus, efforts to increase the energy performance of buildings would contribute actively to the Union's energy independence and, furthermore, have great potential to create jobs in the Union, in particular in small and medium-sized enterprises. In that context, Member States should take into account the need for a clear link between their long-term renovation strategies and pertinent initiatives to promote skills development and education in the construction and energy efficiency sectors.

- It is important to ensure that measures to improve the energy performance of buildings do not focus only on the building envelope, but include all relevant elements and technical systems in a building, such as passive elements that participate in passive techniques aiming to reduce the energy needs for heating or cooling, the energy use for lighting and for ventilation and hence improve thermal and visual comfort.

- To meet the objectives of energy efficiency policy for buildings, the transparency of energy performance certificates should be improved by ensuring that all necessary parameters for calculations, both for certification and minimum energy performance requirements, are set out and applied consistently. Member States should adopt adequate measures to ensure, for example, that the performance of installed, replaced or upgraded technical building systems, such as for space heating, air-conditioning or water heating, is documented in view of building certification and compliance checking.

- According to the Commission's impact assessment, provisions concerning the inspections of heating systems and air-conditioning systems were found to be inefficient because they did not sufficiently ensure the initial and continued performance of those technical systems. Even cheap energy efficiency technical solutions with very short payback periods, such as hydraulic balancing of the heating system and the installation or replacement of thermostatic control valves, are insufficiently considered today. The provisions on inspections should be amended to ensure a better result from inspections. Those amendments should place the focus of inspections on central heating systems and air-conditioning systems, including where those systems are combined with ventilation systems. Those amendments should exclude small heating systems such as electric heaters and wood stoves when they fall below the thresholds for inspection under Directive 2010/31/EU as amended by this Directive.

- When carrying out inspections and in order to achieve the intended building energy performance improvements in practice, the aim should be to improve the actual energy performance of heating systems, air-conditioning systems and ventilation systems under real-life use conditions. The actual performance of such systems is governed by the energy used under dynamically varying typical or average operating conditions. Such conditions require at most times only a part of the nominal output capacity, and therefore inspections of heating systems, air-conditioning systems and ventilation systems should include an assessment of the relevant capabilities of the equipment to improve system performance under varying conditions, such as part load operating conditions.

To combat global climate change, energy efficiency (EE) and energy demand reduction have been highlighted as key mitigation options by several IPCC assessment reports and UNFCCC documents, protocols and international agreements. So far, the evaluation and assessment of existing policies for EE in buildings suggest that there is no single policy that alone can achieve a substantial transformation of the existing building stock and reduce significantly energy consumption. Therefore, identifying the barriers, or challenges, that currently exist in the process of energy efficiency renovation in the building sector will be of great help in improving and implementing the above policies.

1.3.3 Stakeholders and barriers in the field of building energy efficiency renovations

In the field of building energy efficiency renovation, various stakeholders play crucial roles in shaping policies, implementing projects, and influencing the overall direction of this field. These stakeholders often have diverse interests and responsibilities. Here are some key stakeholders:

- Government and Regulatory Authorities: Government bodies at the local, regional, national and European levels are instrumental in setting building codes, standards, and regulations related to renovation. They also develop and implement energy efficiency programs and financial incentives to promote renovations.

- Property Owners and Developers: Property owners, including individuals, real estate companies, are responsible for initiating and financing renovation projects. Their decisions impact the energy efficiency, sustainability, and overall quality of buildings. And the developers also focus on stimulating economic growth, including through the renovation of commercial and industrial properties that can revitalize communities and create jobs.

- Construction and Renovation companies: Contractors, architects, engineers, and construction firms are directly involved in planning, designing, and executing renovation projects. They ensure that renovations adhere to building codes and standards. Technology companies that develop and supply building renovation technologies, such as energy-efficient HVAC systems, insulation materials, and smart building solutions, are essential stakeholders.

- Financial Institutions and Banks: Banks, lending institutions, and investors provide financing options for renovation projects. They offer loans, mortgages, and financial incentives to property owners and developers.

- Energy Service Companies (ESCOs): ESCOs specialize in providing energy-efficient solutions. They conduct energy audits, recommend improvements, and often guarantee energy savings in renovated buildings.

- Environmental Organizations: Non-governmental organizations (NGOs) and environmental groups advocate for sustainable building practices, energy efficiency, and reduced carbon emissions in renovations. They often collaborate with governments and businesses to promote green building initiatives.

- Tenants and Building Occupants: Tenants and occupants have a stake in building renovation, as they benefit from improved comfort, safety, and energy savings. Their preferences and behaviours can influence renovation decisions.

- Research and Development Institutions: Universities, research institutions, and think tanks contribute to the development of innovative renovation technologies, materials, and methods. They conduct studies to improve building performance and sustainability.

These stakeholders often collaborate to promote building renovation that aligns with sustainability, energy efficiency, and regulatory requirements. Effective coordination among these groups is critical for achieving the goals of reducing energy consumption, mitigating climate change, and improving the quality of the built environment.

In 2018, Aliakbar Kamari, Stina Rask Jensen, Rossella Corrao, and Poul Henning Kirkegaard developed a holistic multi-methodology for sustainable renovation, which aims to deal with the complexity of renovation projects. It provides a framework through which to involve the different stakeholders in the design process to improve group learning and group decision-making, and hence make the building renovation design process more robust and efficient. Figure 1-15 illustrates the different stakeholders who are involved in a building renovation process, as well as the key factors which they each deal with.(Kamari et al., 2019)

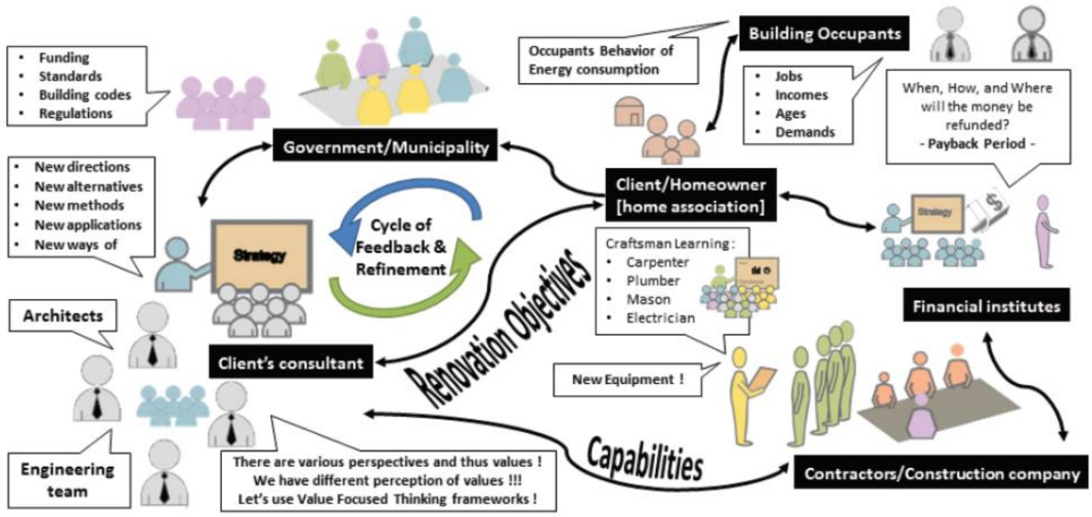

Figure 1-15: The key stakeholders involved in the process of a typical renovation project; Source: Aliakbar Kamari, a workshop regarding to the RE-VALUE project in November 2016.

Thus, building renovation projects need to face many barriers due to the large number of stakeholders involved, the many activities and procedures involved, and the relatively long construction period. According to a questionnaire launched by the European Commission in 2020, the main barriers to building renovation (including residential and non-residential) are shown in Figure 1-16:

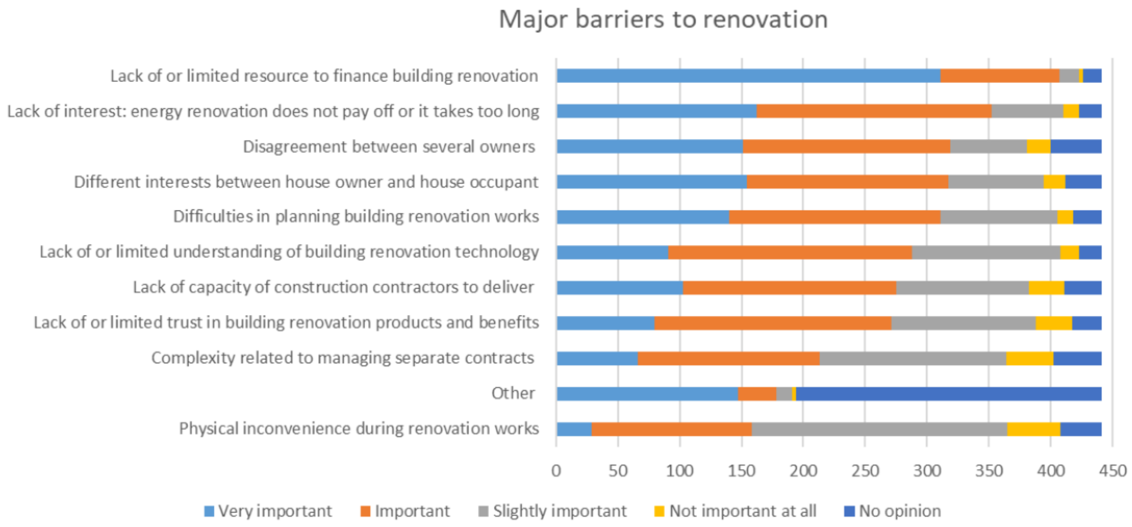

Figure 1-16: Results of the European Commission's questionnaire on the barriers to renovation from the Renovation Wave, 2020;
Source: synthesis report of stakeholder consultation on the renovation wave initiative.
Note: A total of 441 responses were received.

Zooming into barriers to renovation of residential buildings according to this report, the following emerge as top barriers[23]. (European Commission, 2020)

- Insufficient understanding of energy use and savings related to different energy efficiency measures: 85%
- Lack of simple, attractive and easily accessible public incentive measures for renovation (e.g., grants or tax incentives): 83%
- Energy renovation does not pay off in an acceptable timeframe: 82%
- Disagreement between several owners (e.g., multi-apartment buildings): 79%
- Lack of information/low awareness of available public and/or private financing products for building renovation: 77%
- Cumbersome procedures and/or financial constraints for accessing public financial support: 76%
- Lack of trust or guarantee that renovation will deliver the energy and money savings or other benefits, lack of quality assurance: 76%

[23] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12376-Energy-efficiency-in-buildings-consultation-on-renovation-wave-initiative/feedback_en?p_id=7855176

- Different interests between house owner and house occupant: 75%

- Lack of simple, attractive and accessible private financing products for renovation (e.g., loans): 74%

- Lack of interest – renovation to decrease energy consumption is not attractive to me, need for additional advantages: 70%

- Regulatory and administrative barriers and complexity in planning, including permits required, etc.: 70%

- Perceived lack of government support, and unambitious policies: 70%

Combined with the results of this report and other literature, the barriers to building renovation can be summarised as follows:

➢ Behavioural barrier

Research has shown that consumers are prone to behavioural flaws that distort their decision-making processes. First, energy efficiency investments are often simply not considered in the range of renovation options(Weiss et al., 2012). This can often be the result of a lack of credible information regarding energy renovations(Jakob, 2007). In addition to the scarcity of reliable information, undertaking an energy renovation is often seen as a complex and irreversible choice. Consequently, consumers tend to lean toward straightforward solutions and are inclined to stick with the existing status quo.

The Table1-7 summarizes four areas, where consumers typically experience high uncertainty, either due to lack of credible information or due to high perceived complexity.

Table 1-7: Behavioural barriers in building renovation;
Source: Copenhagen Economics, EMF-ECBC, 2020, Literature review of the energy efficiency gap.

Uncertainty	Explanation
Cost-effectiveness	Consumers struggle to assess whether an energy efficiency investment is cost-effective, i.e., **whether the cost of borrowing the required funds from a financial institution is fully covered by the expected benefit through a reduced energy bill or an increased value of the building**.(Golove & Eto, 1996)
Heavy discounting of future earnings	People tend to discount future earnings heavily, i.e., the incurred immediate costs of an energy renovation weigh heavier than potential benefits that only accrue in the future.(Behavioural Insights Team, 2011)
Increase in value of building	Energy renovations increase the value of the building. However, consumers perceive uncertainty as to how exactly the value of their building changes due to the renovation and how much the value increase covers the lending costs of capital necessary to conduct the renovation. (Copenhagen Economics & EMF-ECBC, 2020)
Environmental impact	The level of environmental impact is hard to measure, and consumers struggle to assess their impact correctly. (Copenhagen Economics & EMF-ECBC, 2020)

- Transaction cost barrier

The majority of transaction costs relate to the time spent by the consumer in relation to carrying out the renovation, which can be a troublesome process involving many stakeholders. At the start of an energy renovation decision-making process, numerous search cost aspects arise. Such as, searching for and acquiring the relevant information on the different energy renovation solutions. Once consumers have decided on a solution, they must find adequate service providers, which is often not a straightforward undertaking. How far governments' financial incentives offset the cost of prospecting remains difficult to grasp. During the renovation process, the building owner faces uncertainty about the contractor's reliability and thus must monitor the contractor. Moreover, if the building owner uses the building themselves, it can be challenging to live in the building during the renovation work and they may even relocate themselves during the renovation period. Some relevant studies have shown that transaction costs can range between 1% and 60%, depending on the size of the project, whereas smaller projects, mostly conducted by private customers, tend to exhibit higher transaction costs.(Copenhagen Economics & EMF-ECBC, 2020)

- Financial barrier

The availability of limited capital constitutes a significant impediment to energy efficiency investments. This challenge is particularly pronounced for building owners with constrained financial resources, as they may face substantial hurdles in securing the required funding for such initiatives(Brown, 2001)(Golove & Eto, 1996)(Wilson et al., 2015)(Gillingham et al., 2009)(Linares & Labandeira, 2010).

- Data insufficiency

The lack of data becomes apparent at various stages along the energy renovation decision-making process:

First, financial institutions lack information as to which customers could be eligible for and might be interested in an energy renovation.

Second, during the energy renovation decision-making process, consumers and lending institutions alike want to have a coherent overview of the actual energy consumption of a building. Measurement and verification of energy use of a building can be challenging. (Beillan et al., 2011)

Third, customers and lending institutions do not always have access to a full overview of possible energy renovation solutions. Different energy renovation solutions have different predicted energy savings, as well as different comfort perceptions by consumers. The lack of data on the long-term improvement of an energy renovation creates a large barrier to engage in such an undertaking. (Palm & Reindl, 2018)

- Regulation barrier

As introduced in the Chapter 1.3.2, there are many relevant regulations involving building energy efficiency renovations, and they are so complex that there is no uniform, concise and operable regulation. This often results in building owners and related stakeholders spending a lot of time and effort to understand the various regulations. The complexity of the regulations leads to barriers.

- Conflicting interest between landlord and tenant

When the building is not used by the owner themselves, but rented to a tenant, the interests of the landlord and tenant can conflict. The tenant could be in favour of an energy renovation which reduces their energy bill, whereas the landlord would be against such a renovation to avoid the investment costs if the associated costs cannot be passed on to the tenant with a higher rent. (Phillips, 2012)

In the European Union (EU), energy production and use are responsible for 80% of all GHG emission. Accounting for about 40% of the EU's final energy and 36% of CO_2

emissions, buildings are associated with a significant untapped energy-saving potential. According to the EU Building Stock Observatory under the European Commission, non-residential building energy efficiency renovations achieve higher rates of energy savings than residential renovations. In 2016, residential building energy renovations in Europe could achieve energy savings of 7.25%, and residential building energy renovations in Italy could achieve energy savings of 9.19%, slightly higher than the overall European average.

In 2016, the investment in residential building renovation in 28 European countries was 709.8 billion euros, and the average cost of residential building renovation was 89.58EUR/m2. Among them, the investment in residential renovation in Italy was 54.47 billion euros, and the average cost of residential building renovation was 68.2EUR/m2, the average cost of residential building renovation in Italy is slightly lower than the overall European average. Combined with the building stock data of 28 European countries and Italy, it can be seen that a large capital investment is still needed to realise the popularity of building energy-efficiency renovations. (Table1-8)

Table 1-8：Energy savings, investment, cost of renovation in 2016;
Source: EU BSO database

		Europe (EU+UK)	Italy
Average energy savings achieved by the energy renovation (ex post) (%)	Residential	7.25%	9.19%
	Non-residential	17.12%	18.91%
Renovation investment (energy and non-energy renovation) (Billion EUR)	Residential	709.80	54.47
	Non-residential	-	-
Energy renovation cost (EUR/m2)	Residential	89.58	68.20
	Non-residential	113.73	120.67
Building stock(Billion m2)	Residential	18.75	2.55
	Non-residential	6.38	0.44

Note: Renovated renovation from 2016 statistics, building stock from 2017 statistics

In conjunction with the various barriers to building renovation analysed earlier, the cost of renovation and capital investment is a pivotal concern. In particular, there is also a huge gap between the current capital required for renovation and the actual capital invested. It is worth noting that in some European countries, there is now a legal requirement to disclose a building's Energy Performance Certificate in property advertisements for sale or rent. If a higher energy efficiency class could bring a premium when selling or renting a property, it might incentivize more house owners to willingly allocate a portion of their budget to undertake energy efficiency renovations.

Before delving into the question of whether the premium effect from building energy efficiency renovations is substantial enough to drive the construction industry's sustainable commitment to energy renovations, this thesis initially seeks to explore the degree of premium effect on house prices attributed to the improvement of building energy efficiency class.

As previously mentioned, Italy stands out as one of the pioneers in the execution of policies aimed at enhancing building energy efficiency renovations in Europe. Italy leads the way not only in terms of financial investments in building energy efficiency renovations but also in the research, development, and promotion of innovative construction technologies. Additionally, Italy's building stock, both in terms of quantity and age distribution, closely mirrors the aggregate data for the 28 European countries. Consequently, in the following sections, this thesis has chosen Italy as the focal point for an in-depth exploration and research into the field of energy efficiency renovations within the construction industry. Italy's experiences and practices could offer valuable insights and lessons for the broader European context.

2. Real Estate Sector and Building Renovation in Italy

2.1 Overview of Italy

Italy lies between the 35th and 47th parallel north, with an extensive coastline that stretches for around 7,458 km. The terrain is predominantly hilly (41.6%), with some mountainous (35.2%) and lowland areas (23.2%). The average altitude is approximately 337 meters above sea level. Due to its latitude, Italy's climate ranges from a Mediterranean subtropical climate in the south (with summer temperatures that can exceed 40 °C), to a continental temperate climate in the north (where temperatures can fall to -20 °C in winter). The climate is therefore extremely variable, as shown by the number of 'degree days'[24], which range from 568 in Lampedusa (province of Agrigento) to 5,165 in Sestriere (province of Turin). The global solar radiation incident on a horizontal surface is also affected by the different latitudes in Italy, ranging from 1,214 kWh/m2 in Ahmtal (province of Bolzano) to 1,679 kWh/m2 in Pachino (province of Siracusa), with an average of 1,471 kWh/m2 (0.127 toe/m2). These data illustrate Italy's unique climate and the difficulties in defining clear building and technical standards and solutions that can be adapted to the diverse conditions.

The Italian economy is ranked as the third-largest economy in the Eurozone and the eighth-largest economy in the world in terms of nominal GDP. Italy is a founding member of the G7, G8, the Eurozone and the OECD. Italy plays an important role in the regional and global economy. It is a leading country in world trade, exports and tourism. After the effects of the COVID-19 crisis, Italy's economy has rebounded considerably in 2021, driven by domestic demand. The annual growth rate of real GDP in Italy in 2021 was about 6.3% and the inflation rate is 2.9%.

The Italian Consumer price index reached 6% on average in 2021. The high level of inflation is caused in particular by international trade and supply chain bottlenecks, and by rising energy costs due to the pandemic period and the War in Ukraine.

- Economic growth: Italy has recovered from the COVID-19 crisis: it is growing

[24] A degree day is a measure of heating or cooling. Total degree days from an appropriate starting date are used to plan the planting of crops and management of pests and pest control timing. Weekly or monthly degree-day figures may also be used within an energy monitoring and targeting scheme to monitor the heating and cooling costs of climate-controlled buildings, while annual figures can be used for estimating future costs.

quickly in comparison with other comparable countries in the EU. The annual growth rate of real GDP in Italy in 2021 was about 6.3%.

- Population: It is expected to suffer from population ageing as with most developed nations. 2020 was the worst year for the newborn since the First World War.

- Public debt: Italy has a very high level of public debt. It will require significant effort, and political will, to achieve only modest reductions. The situation worsened with the pandemic crisis.

- Inflation: After the pandemic crisis there was an inflation increase in the EU. Italy has a similar trend to the EU, with a high increase in Consumer Price Index (+1,9%).

- Exports: Recent years have seen a recovery in exports, a key driver of Italian growth. The main boost to overall export growth came from the pharma, refined petroleum products, and clothing sectors.

- Unemployment: The unemployment rate in 2018 in Italy was 2.2% above the Euro area states' average of 7.5%. In 2019 this rate reached the threshold of 10%. In 2021 the rate decreased by up to 9%.

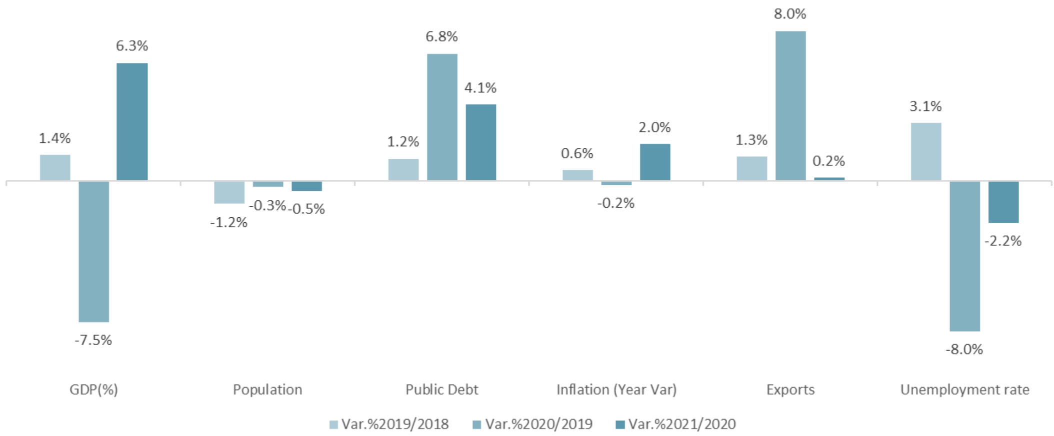

Figure 2-1: The general economic indicators;
Source: PwC analysis on Italian National Statistical Institute (INSI).

2.2 Real Estate Market in Italy

The INSI (Italian National Statistical Institute) Index for Building Construction 2021 records an increase of 20.7% compared to 2020 in terms of total investment volume. The rebound of the economy after the pandemic crisis has recorded a positive trend both in the residential and non-residential private sectors. The growth in 2021 is higher than the previous pandemic period (+9% compared to 2019). Total investments in

2021 reached almost 150 billion euros: in residential new buildings the investment volume was 16 billion euros, while 55 billion euros was the amount of investments in residential renovation. Non-residential market private and public has recorded the 52% of total investment volume. (Figure 2-2)

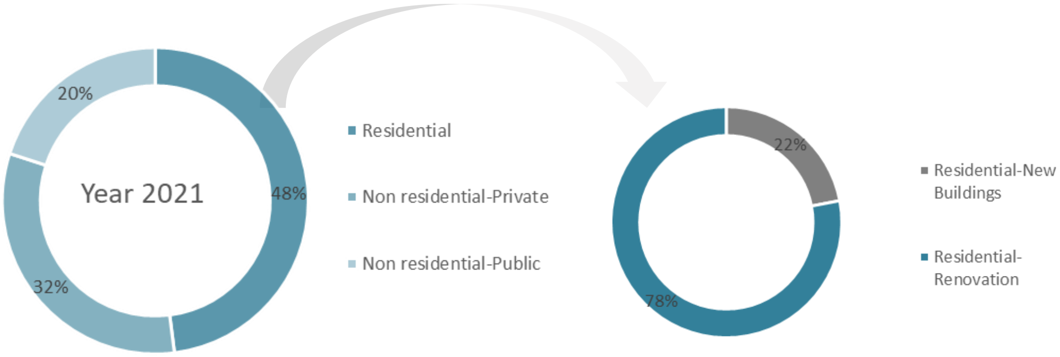

Figure 2-2: Construction investments for buildings 2021;
Source: ANCE, Osservatorio congiunturale sullindustria delle costruzioni (Economic observatory on the construction industry), 2022

Before the 2000s, Italy's residential real estate market experienced steady but relatively slow growth. The market was influenced by historical and architectural factors, with a focus on preserving cultural heritage. The early 2000s saw a surge in property prices, driven by strong demand, low interest rates, and economic growth. This period marked a real estate boom. The global financial crisis in 2008 had a significant impact on Italy's real estate market. Property prices declined, and the market experienced a period of stagnation. Many construction projects were put on hold. From 2014-2021, the residential real estate market was finally able to put an end to the long and sharp drop that started in 2007, recording substantial, consistent growth and highlighting clear signs of recovery. The number of residential transactions reached approximately 748k in 2021. The positive turnaround registered in 2014 was mainly influenced by lower registration costs that came into effect on January 1, 2014, for mortgages and cadastral documents, which apply to the transfer of real property (Article 10 of D.lgs 14 marzo 2011, n. 23). Since 2014, the market has recorded six consecutive years of growth. Due to the Covid-19 pandemic situation the 2020 residential transactions suffered a significant decrease, down by 7% compared to the previous year. The pre-crisis level was exceeded in 2021, with residential transactions increasing by 24% compared to 2019. (Figure 2-3)

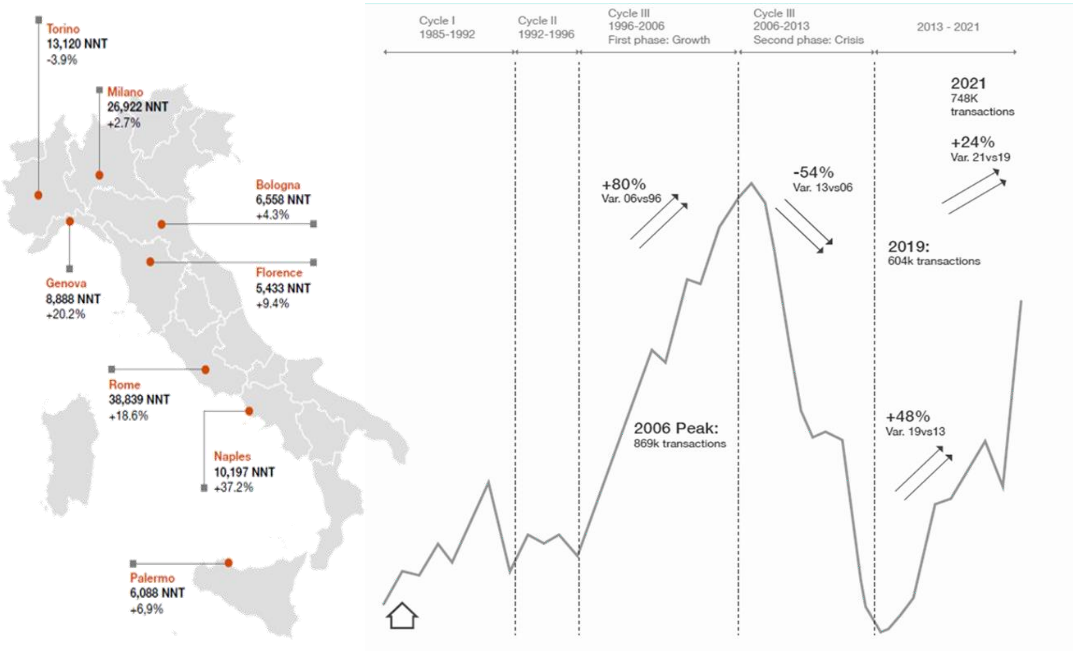

Figure 2-3: (Left) Number of property transactions and variance in major Italian cities (2021 vs 2019); (Right) Historical number of residential transactions (1985-2021); Source: PwC analysis on Italian IRS and Nomisma data

In 2021, a total of 10.6 million square meters of residential properties were sold in Italy's eight main cities, marking a 12.3% increase compared to 2019 when the average square meters sold was 90.7 (in 2020, the average was 91.1). Among these cities, Rome and Milan ranked first and second in terms of the number of property transactions. Seven of the Italian cities predominantly saw transactions for properties between 50 and 115 square meters, while Palermo stood out with a higher demand for spacious properties above 115 square meters.

Analyzing the distribution of transactions by residence type in the major cities, it's noteworthy that, in 2021, transactions for residences ranging between 50 to 115 square meters constituted a significant 79% of the total. In Milan, properties between 50 and 145 square meters accounted for nearly 84% of the total transactions in the city. (Table 2-1)

Table 2-1: Percentage of property transactions by floor area in major Italian cities (2021); Source: PwC analysis on Italian IRS data

	Milan	Turin	Bologna	Genoa	Rome	Florence	Palermo	Naples
Up to 50 sqm	21%	13%	14%	6%	9%	10%	10%	15%
Between 50 and 85 sqm	43%	43%	43%	38%	42%	37%	22%	36%
Between 85 and 115 sqm	20%	25%	26%	34%	27%	29%	25%	26%
Between 115 and 145 sqm	8%	11%	10%	13%	12%	13%	23%	13%
145 sqm and above	8%	8%	7%	9%	10%	11%	20%	10%

2.3 Energy Performance of Buildings in Italy

The civil sector is currently responsible for around 45% of final energy consumption and 17.5% of direct CO_2 emissions in Italy. These figures show the importance of upgrading the energy efficiency of buildings in this sector in order to achieve the energy and emission reduction targets set out in the Integrated National Energy and Climate Plan (INECP), while also guaranteeing economic and social benefits.

On 21 January 2020, the Ministry of Economic Development (MISE) submitted the final text of the Integrated National Energy and Climate Plan (NECP) for the years 2021-2030 to the European Commission. The main objective of the NECP concerning energy efficiency consists of a reduction of primary energy consumption by 43%, compared to PRIMES 2007 projections, higher than the overall EU target of 32.5%.

At the internal legislative level, Directive 2018/844/EU has been implemented by Decree 10.06.2020 n.48, which introduced the necessary changes to Legislative Decree 192/2005[25]. Decree 192/2005, modified by Legislative Decree 311/2006[26], set the basis for the EPBD implementation in Italy. It was followed by a number of complementary legal acts updating the minimum energy performance requirements for buildings, building components and technical building systems, while extending the calculation to cooling and lighting systems and providing guidelines for energy performance certificates (2009) and defining requirements for assessors as well as specifications for the inspection of technical building systems (2013).

In Italy, the concept of major renovation has been defined under Law No 90/2013[27] and the Ministerial Decree 26.06.2015[28] 'Minimum Requirements', distinguishing between various types of intervention. Demolition and reconstruction and expansion of existing buildings with a new system (with a gross air-conditioned volume in excess of 15 % of the existing volume or more than 500 m2) are also included in and are considered to constitute new construction projects. By contrast, 'major renovation' is defined as work on the integrated elements and components making up the building envelope that divides a temperature-controlled volume from the external

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[25] DECRETO LEGISLATIVO 19 agosto 2005, n. 192 Attuazione della direttiva 2002/91/CE relativa al rendimento energetico nell'edilizia. https://www.gazzettaufficiale.it/eli/id/2005/09/23/005G0219/sg

[26] DECRETO LEGISLATIVO 29 dicembre 2006, n. 311 Disposizioni correttive ed integrative al decreto legislativo 19 agosto 2005, n. 192, recante attuazione della direttiva 2002/91/CE. https://www.gazzettaufficiale.it/eli/id/2007/02/01/007G0007/sg

[27] LEGGE 3 agosto 2013, n. 90. Conversione in legge, con modificazioni, del decreto-legge 4 giugno 2013, n. 63, recante disposizioni urgenti per il recepimento della Direttiva 2010/31/UE del. https://www.gazzettaufficiale.it/eli/id/2013/08/03/13G00133/sg

[28] https://www.gazzettaufficiale.it/eli/id/2015/07/15/15A05198/sg

environment or non-air-conditioned rooms, covering more than 25% of the total gross dispersing surface of the building. Major renovations are divided into first-level and second-level renovations.

The Italian authorities started implementing NZEBs in 2019 for public buildings, which will be fully implemented by 2021 for all new buildings. And from 2021, all new buildings or buildings subject to a 'first-level major renovation' must meet the technical and performance requirements imposed by Annex 1 of the Ministerial Decree 06/26/2015 for NZEBs. The steps and indicators for calculating the energy efficiency of new buildings are as follows:

- Specific energy needs for heating ($\mathrm{EP_{H,nd}}$), cooling ($\mathrm{EP_{C,nd}}$) and domestic hot water ($\mathrm{EP_{C,nd}}$);

- Energy performance indices for heating ($\mathrm{EP_H}$), cooling ($\mathrm{EP_C}$), domestic hot water ($\mathrm{EP_W}$) and ventilation ($\mathrm{EP_V}$) for residential buildings, plus lighting ($\mathrm{EP_L}$) and transport ($\mathrm{EP_T}$) for non-residential buildings, expressed in non-renewable and in total primary energy [kWh/$\mathrm{m^2}$];

- Global energy performance index $\mathrm{EP_{gl}} = \mathrm{EP_H} + \mathrm{EP_C} + \mathrm{EP_W} + \mathrm{EP_V} + \mathrm{EP_L^*} + \mathrm{EP_T^*}$ expressed in non-renewable and in total primary energy [kWh/$\mathrm{m^2}$](lighting and transport services for non-residential building only);

- Minimum requirements are defined according to the 'reference building[29]' (see Table 2-2 and Table 2-3);

- A new building (or majorly renovated building) satisfies the minimum requirements if the specific energy needs for heating and cooling ($\mathrm{EP_{H,nd}}$, $\mathrm{EP_{C,nd}}$) and the global energy performance $\mathrm{EP_{gl}}$ are lower than those calculated for the reference building;

- In case the required RES integration should not be feasible, the building has to adhere to a proportionally lower$\mathrm{EP_{gl}}$ limit value;

- The designer has to justify compliance or non-compliance of the project to minimum energy performance requirements in a report (model provided in one of the 2015 decrees). This validation is compulsory to obtain the construction license.

[29] Decreto interministeriale 19 giugno 2017 – 'Piano per l'incremento degli edifici a energia quasi zero (PANZEB)'

Controls from local authorities to check compliance are performed on demand.

Table 2-2: Reference building - Performance of single building elements; Source: Decree 26.06.2015, appendice A, https://www.mimit.gov.it/images/stories/normativa/DM_requisiti_minimi_appendiceA.pdf

Elements / Components	Validity period	Thermal transmittance U [W/m².K](including thermal bridges)				
		Climatic Zone				
		A and B	C	D	E	F
Envelope – walls	From 2015	0.45	0.38	0.34	0.30	0.28
	From 2019/2021	0.43	0.34	0.29	0.26	0.24
Envelope – roofs	From 2015	0.38	0.36	0.30	0.25	0.23
	From 2019/2021	0.35	0.33	0.26	0.22	0.20
Envelope – floors	From 2015	0.46	0.40	0.32	0.30	0.28
	From 2019/2021	0.4	0.38	0.29	0.26	0.24
Doors, windows and shutter boxes	From 2015	3.20	2.40	2.00	1.80	1.50
	From 2019/2021	3.00	2.20	1.80	1.40	1.10
Indoor partitions	From 2015	0.80	0.80	0.80	0.80	0.80
	From 2019/2021	0.80	0.80	0.80	0.80	0.80
		Total solar energy transmittance g_{gl+sh} [-]				
		A and B	C	D	E	F
Windows with shading devices	From 2015 From 2019/2021	0.35				

Table 2-3: Reference building – technical building systems efficiency; Source: Decree 26.06.2015, appendice A, https://www.mimit.gov.it/images/stories/normativa/DM_requisiti_minimi_appendiceA.pdf

	Thermal energy production			In situ electricity production
	Heating (H)	**Cooling (C)**	**Water (W)**	
Heat generator - liquid fuels	0.82	-	0.80	-
Heat generator - gas fuels	0.95	-	0.85	-
Heat generator - solid fuels	0.72	-	0.70	-
Heat generator - solid biofuels	0.72	-	0.65	
Heat generator - liquid biofuels	0.82		0.75	
Heat pump with electrically driven compressor	3.00	(*)	2.50	
Chiller with electrically driven compressor	-	2.50	-	
Absorption heat pump	1.20	(*)	1.10	
Indirect power absorption chiller	-	0.60 x η_{gn} (**)	-	
Direct-fired absorption chillers	-	0.60	-	
Combined heat power systems	0.55	-	0.55	0.25
Electrical heating	1.00	-	-	-
District heating	0.97	-	-	-
District cooling	-	0.97	-	-
Solar collectors	0.3	-	0.3	-
Photovoltaic systems	-	-	-	0.1
Mini wind turbinesand small hydro-systems	-	-	-	(**)
	Thermal energy use (***) η_u			
	H	C	W	
Water based systems	0.81	0.81	0.70	
AC systems	0.83	0.83	-	
Mixed distribution	0.82	0.82	-	

(*) For reversible heat pumps the value of the correspondent chiller is assumed.
(**) The efficiency of the system installed in the real building is assumed.
(***) Including emission, control and distribution.

In the national plan for NZEBs (PANZEB), priority is given to ambitious renovation rather than new constructions, which have a very low rate in Italy. Energy performance requirements for existing buildings are identical regardless of whether they concern residential or non-residential buildings. Minimum requirements are differentiated according to the extent of the renovation intervention:

• First-level major renovations are defined as 'refurbishment of at least 50% of the envelope and renovation of the heating and/or cooling plant of the entire building'. Requirements for new buildings apply to the whole building, limited to the considered energy service(s). For building extensions (new volume >15% of the existing volume or >500 m3), these requirements apply only to the new volume.

• Second-level major renovations are defined as 'refurbishment of at least 25% of the external surfaces of the building with or without renovation of the heating and/or cooling plant'. The U-value of the concerned surfaces is lower than the limit values (Table 2-4). The mean transmission heat transfer coefficient H'_T of refurbished building elements is lower than the limit value (Table 2-5). The mean efficiencies of renovated technical building systems are higher than the reference values.

• Minor renovations are defined as 'refurbishment of less than 25% of the external surfaces of the building and/or modification of the heating and/or cooling plants)'. The performance of single components and technical building systems has to comply with mandatory limit values.

Table 2-4: U-value limits for second level major renovation and minor renovation.; Source: Decree 26.06.2015, appendice B,
https://www.mimit.gov.it/images/stories/normativa/DM_requisiti_minimi_appendiceB.pdf

Elements / Components	**Validity period**	**Thermal transmittance U [W/m^2.K](including thermal bridges)**				
		Climatic Zone				
		A and B	**C**	**D**	**E**	**F**
Envelope – walls	From 2015	0.45	0.40	0.36	0.30	0.28
	From 2021	0.40	0.36	0.32	0.28	0.26
Envelope – roofs	From 2015	0.34	0.34	0.28	0.26	0.24
	From 2021	0.32	0.32	0.26	0.24	0.22
Envelope – floors	From 2015	0.48	0.42	0.36	0.31	0.30
	From 2021	0.42	0.38	0.32	0.29	0.28
Doors, windows and rolling shutter boxes	From 2015	3.20	2.40	2.10	1.90	1.70
	From 2021	3.00	2.00	1.80	1.40	1.10

Table 2-5: H'_T maximum limit value;
Source: Decree 26.06.2015, appendice A,
https://www.mimit.gov.it/images/stories/normativa/DM_requisiti_minimi_appendiceA.pdf

S/V ratio of the building	Climatic Zone				
	A and B	C	D	E	F
S/V > 0.7	0.58	0.55	0.53	0.50	0.48
0.7 > S/V > 0.4	0.63	0.60	0.58	0.55	0.53
0.4 > S/V	0.80	0.80	0.80	0.75	0.70
Second level major renovation (>25% envelope)	0.73	0.70	0.68	0.65	0.62

Note: S is the total surface of all elements of a building that delimits the conditioned volume (V) with respect to outdoors, the ground, environments with different temperatures or non-conditioned environments

Since Law 90/2013 has implemented Directive 2010/31/EU, introducing significant changes to the first 2005 implementation. In June 2015, three inter-ministerial decrees (26 June 2015)[30] completed the EPBD transposition, which also established stricter minimum requirements for new buildings and major renovations, defined NZEB as well as rules for taking Renewable Energy Sources (RES) in buildings into account, and provided new national guidelines for Energy Performance Certificates (EPCs).

A national Information System (SIAPE) for Energy Performance Certificates (EPCs) has been created and a national register for the inspection of technical heating/cooling systems is under development, although regions and the autonomous provinces are still in charge of managing their own databases and for related monitoring and control.

The SIAPE, created and managed by ENEA, is supplied with data from the Regions and the Autonomous Provinces. Access is granted to Regions and Autonomous Provinces on the basis of their geographical area of competence; data relating to the rest of the national territory can only be consulted in aggregated form. This second form of access is also open to citizens, as is the opportunity to generate statistics relating to existing Energy Performance Certificates (EPCs). Until to 18/09/2023, the database contains data around 4,933,946 APE (Attestati di Prestazione Energetica).

The new EPC layout (Figure 2-4) is more user-friendly and provides more useful

[30] Decreto interministeriale 26 giugno 2015 – 'Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici'
Decreto interministeriale 26 giugno 2015 – 'Adeguamento linee guida nazionali per la certificazione energetica degli edifici'
Decreto interministeriale 26 giugno 2015 – 'Schemi e modalità di riferimento per la compilazione della relazione tecnica di progetto ai fini dell'applicazione delle prescrizioni e dei requisiti minimi di prestazione energetica negli edifici'

information; it shows the performance of the envelope, both in winter and summer time, and the performance of single energy services. Additionally, it displays energy sources used, allows for comparison of the overall performance with similar units/buildings (new and existing) and clearly indicates if the NZEB standard has been attained. A new energy rating system has been established based on energy performance expressed in non-renewable primary energy $EP_{gl,nren}$, through comparisons with ten fixed energy classes (from G to A4).

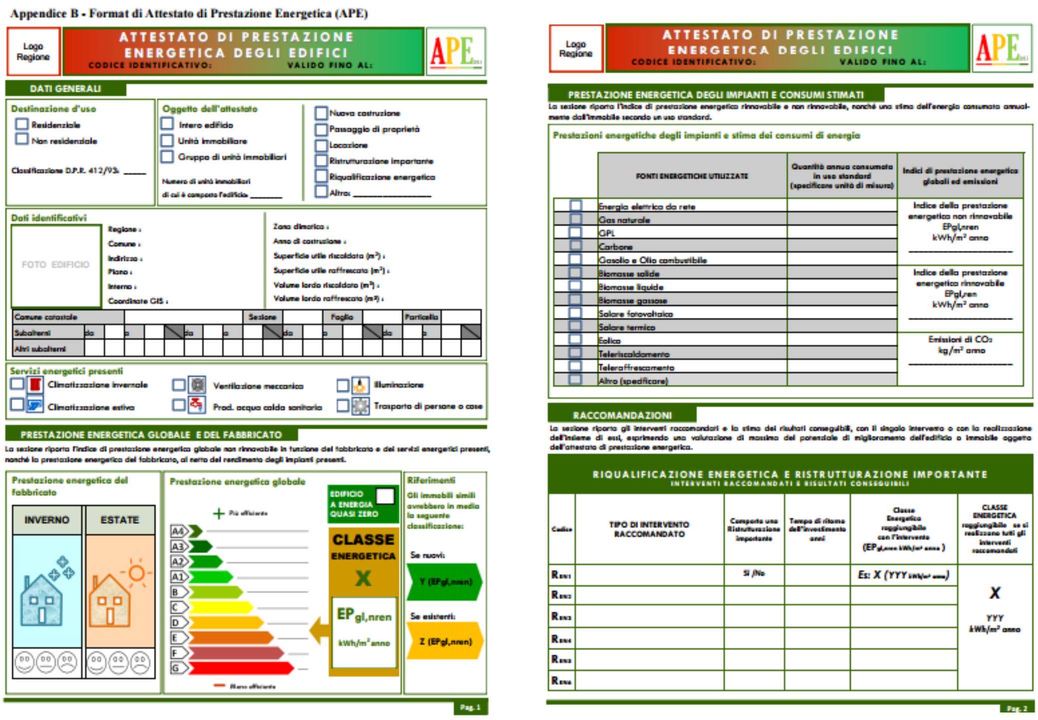


Figure 2-4: National EPC layout from October 2015, first and second pages; Source: CENED, ARIA, https://www.cened.it/modelli-ape

Better quality is achieved through a mandatory visit to the unit/building before issuing the EPC, while better knowledge of the technical building system is achieved through a link to the heating and air conditioning (HAC) inspection database. An EPC is valid only if the 'HAC log-book' from regular inspections is attached.

Recommendations for improvements are mandatory with evidence of payback periods and class/performance, achievable through measures carried out in connection with major renovations, and measures for individual building elements or technical building system(s). The expert will report on the feasibility of recommended measures and their cost-effectiveness, together with calculations and verifications certifying compliance of the new or renovated building with the standards. The report is not mandatory for minor measures (e.g., replacement of boilers with power <50kW or replacement of a traditional boiler with condensing boilers).

According to Presidential Decree 75/2013[31], the EPC experts have to be qualified for building design (registered at engineers/architects/other experts' associations) or attend a training course (80 hours) in which they undergo final examinations. Wider use of databases has been experienced in some regions, opening the way for energy planning, insight from local authorities and studies from agencies and academia. In Lombardy, access to the EPC database (CENED14) is completely open, allowing useful utilisations by industry leaders and investors.

Currently, it is mandatory to draw up the EPC in the cases of sale, rental and transfer of the property (except in the case of leasing a single real estate unit). The transposition of Directive 844/2018, DL 48/2020, made it mandatory to include the EPC with the contract. Fines set at the national level range between 3,000 € and 18,000 €. Regions and autonomous provinces are in charge of control.

Since January 2012, it is mandatory to display the EPC rate in the commercial announcements of real estate agencies and, since October 2015, it is mandatory to display a plaque reporting the non-renewable and renewable energy performance index in terms of primary energy, the energy class and the envelope transmission performance (Figure2-5). Fines range between 500 € and 3,000 € for people responsible for defaulting announcements.

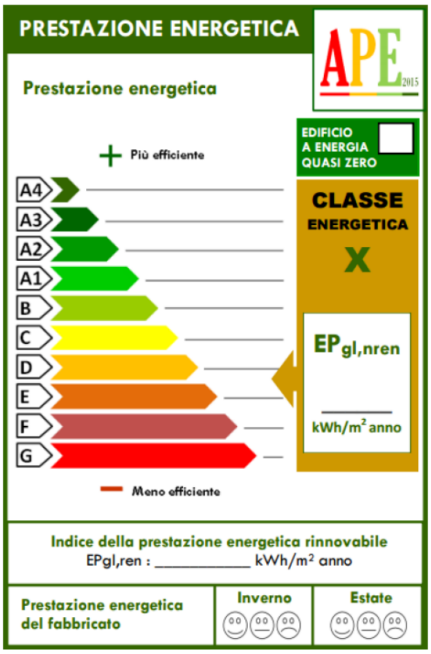


Figure 2-5: Plaque in commercial advertisements from October 2015; Source: CENED, ARIA, https://www.cened.it/modelli-ape

According to the official data until 18/09/ 2023 from the SIAPE, created and managed by ENEA, the year of construction partly explains the large number of buildings in the worst energy classes, showing that most of the national building stock (38%) dates from the period between 1945 and 1972(Figure 2-6). In addition, an analysis of the reasons for drawing up an energy performance certificate reveals that it is predominantly due to a transfer of ownership and leasing (82% of cases), procedures which do not lead to improvements in energy performance. 3.4% of the energy performance certificates analysed relate to major renovations, followed by new constructions (3.9%) and energy renovations (4.8%) (Figure 2-7). More than half of the

[31] 'Sistema Informativo sugli Attestati di Prestazione Energetica' (SIAPE), set by the Decree of 26 June 2015 'Guidelines for Energy Performance Certification' and managed by ENEA. https://www.gazzettaufficiale.it/eli/id/2013/06/27/13G00115/sg

Italian building stock for which energy certificates have been obtained is in the lower energy efficiency classes F and G. In particular, the Italian market is characterised by poor quality properties with significantly lowest energy ratings, with G accounting for 30.7% of the total. The building stock decreases as the energy efficiency class increases. Only 12.5% of the building stock has an energy efficiency rating of B or higher (Figure 2-8).

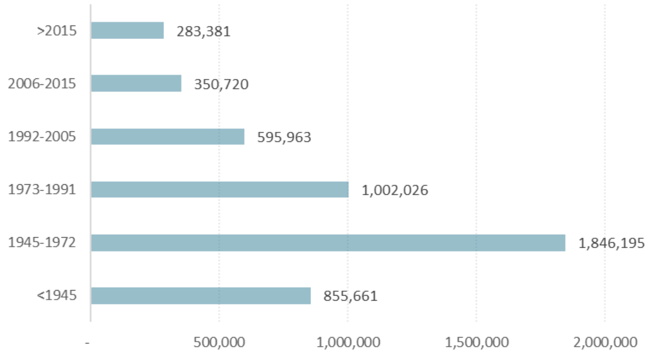


Figure 2-6: Building stock with energy performance certificates (APE) by year of construction 18/09/2023;

Source: ENEA, SIAPE [*https://siape.enea.it/analisi-territoriali*](https://siape.enea.it/analisi-territoriali)

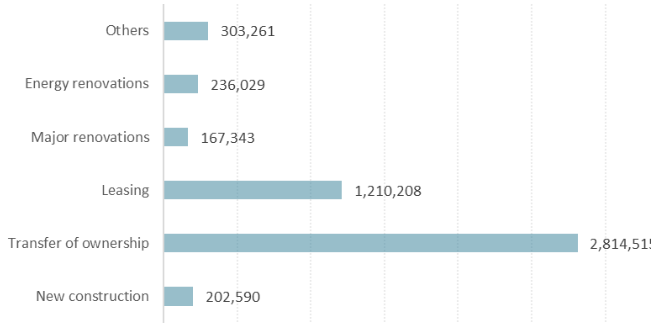


Figure 2-7: Motivation to apply for energy performance certificates (APE) 18/09/2023;

Source: ENEA, SIAPE [*https://siape.enea.it/analisi-territoriali*](https://siape.enea.it/analisi-territoriali)

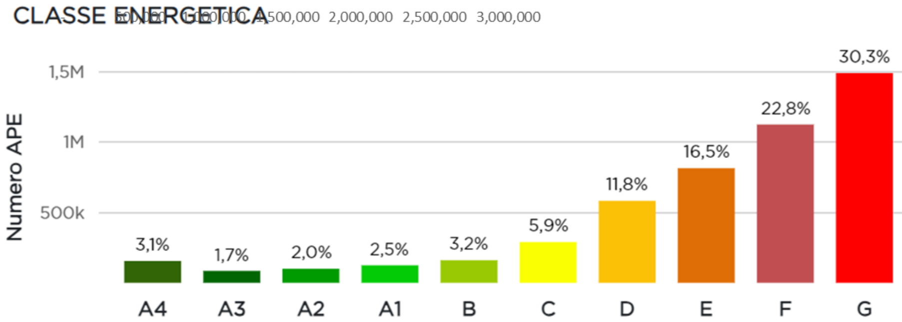


Figure 2-8: Building stock with energy performance certificates (APE) by energy class, 18/09/2023;

Source: ENEA, SIAPE [*https://siape.enea.it/analisi-territoriali*](https://siape.enea.it/analisi-territoriali)

The Italian Government has provided strategic incentives in this regard, such as the 'Ecobonus' and the 'Sismabonus' which are granted for increasing the energy efficiency and improving the seismic risk class, respectively, of existing buildings in Italy. Both measures have recently been upgraded, with a priority focus on more cost-effective measures in apartment buildings.

In view of these new opportunities, which bring economic benefits not only to the individual user but also to the nation as a whole, it is hoped that the energy renovation of the existing building stock can be integrated with improvements to its earthquake protection and fire safety. As a result, Italy would see a further increase in the indirect benefits of energy efficiency: huge losses would be avoided following an earthquake, not only financially but also in terms of human lives.

Reducing carbon emissions within the building sector carries immense importance in enhancing environmental conditions and addressing the global challenge of climate change. One highly effective approach for achieving carbon emissions reduction in the building sector involves the enhancement of building energy efficiency ratings. The current situation reveals a significant challenge: the building stock across Europe, including countries like Italy, typically exhibits low energy efficiency ratings. The process of building renovations is inherently intricate, involving multiple stakeholders, and it faces numerous barriers that hinder its progress. Central to these challenges are the considerations of costs and benefits associated with building renovation projects.

While the Government has allocated funds to incentivise building energy efficiency renovation measures, the most effective way to implement building energy efficiency renovations is to make the benefits of these renovations not only offset, but also outweigh, the costs borne by owners. In essence, the key is to ensure that the benefits derived from these efforts outweigh the financial investment required for implementation.

The Energy Performance Certificate (EPC) system effectively bridges two distinct markets: the property transactions (both sales and rentals) and the renovation market, which involves the implementation of energy-efficient measures and compliance with minimum energy performance requirements (MEPR). Based on the relevant literature review, it is evident that Energy Performance Certificate (EPC) system can indeed lead to a premium effect on house prices. To further compare this premium effect with renovation cost, the first step is to quantify the monetary extent of the impact of Energy Performance Certificate (EPC) system on house prices. The standard method for assessing the influence of a particular property characteristic, such as the presence of an EPC, on its value is through a form of hedonic regression analysis. Thus, this thesis employs the Hedonic Price methodology and the Econometrics. By doing so, this thesis aims to determine the extent to which enhancing Energy Performance Certificates (EPCs) impacts house prices. This analysis is pivotal in illustrating both the sustainability and the economic viability of building energy efficiency renovations, thus establishing the feasibility of such initiatives from a cost-effectiveness perspective.

3. Introduction to the Theories of HPM and Econometrics

3.1 Introduction to the Hedonic Price Methodology

Definition:

The Hedonic Price Method (HPM), also known as hedonic regression, is used for estimating the value of a commodity or the demand for a commodity. The idea behind the HPM is that the commodities are characterized by their constitute properties, hence the value of a commodity can be calculated by adding up the estimated values of its separate properties [Herath, S. K. & Maier, G.,2010].

The development of the hedonic price method:

There is no consensus among scholars as to who first introduced the method of hedonic regression even though most of the scholars agree that it was Court (1939) who first used the HPM. Accordingly, Bartik (1987), Goodman (1998), Robert and Shapiro (2003) among many others argue that the first actual estimation of a hedonic price model was a hedonic price index for automobiles by A.T. Court (1939). These scholars document that the methodology was popularised by Zvi Griliches in the early 1960s [Herath, S. K. & Maier, G.,2010].

Court (1939) states that passenger cars serve many diverse purposes and suggests to combine several specifications to form a single composite measure in price index procedures. He went on to use the term ‘hedonic’ for the first time, to explain the weighting of the relative importance of the various components including horsepower, braking capacity, window area, seat width, and tire size. The relation between prices and hedonic content of all cars offered at any period provides a Hedonic Price Index. One reason to consider Court’s study as a significant contribution is that it deals with problems of nonlinearity and with changes in underlying goods bundles (Goodman, 1998).

A second group of scholars pioneered by Colwell and Dilmore (1999) demonstrate that Haas (1922a, 1922b) conducted a hedonic study more than fifteen years before A. T. Court even though he never used the term ‘hedonic’. Haas analysed price per acre adjusted for year of sale, road type, and city size, using data on 160 sales transactions gathered from farm sales in Minnesota. The independent variables in the hedonic analysis included the depreciated cost of buildings per acre, land classification index, soil productivity index, and distance to the city centre. Colwell and Dilmore (1999) argue that Haas was influential but deny making a comprehensively strong case for Haas as the pioneer to estimate a hedonic model. Surprisingly, their alternative hypothesis is not Court (1939), but Wallace (1926), who used data aggregated by county to calculate comparative farm land values in Iowa [Herath, S. K. & Maier, G.,2010].

The most important theoretical foundations of the HPM are Lancaster's consumer theory and Rosen's model. Lancaster's and Rosen's ideas differ from each other basically in two ways: the functional form of hedonic regression and the answer to the question of whether the consumers buy a bundle of goods or separate goods. The fact that a bundle of goods or separate goods are purchased has an impact on the implicit market as follows. The Lancastrian Index (1966) is based on the idea that the usefulness of goods depends on their characteristics, and goods can be arranged into groups based on their characteristics. Consumers buy goods within groups based on the number of characteristics they possess per dollar. According to Lancaster, the consumer's utility originates from the different characteristics (not just the quantities of the different goods) that the goods themselves provide. Goods are members of a group and some or all of the goods in this characteristic group are consumed in combinations, subject to the consumer's budget. Accordingly, the Lancastrian index is more appropriate for consumer goods. Rosen's model (1974), on the other hand, has two distinct steps: an initial step involving an estimation of the marginal price for the attribute of interest (by regressing the price of a commodity or good on its attributes), and a second step to identify the inverse demand curve (or the marginal willingness to pay function) from the implicit price function estimated in the first stage. Rosen maintains that there is a range of goods, but that consumers typically do not acquire preferred attributes by purchasing a combination of goods, rather each good is chosen from the spectrum of brands and is consumed discretely. Accordingly, Rosen's model looks appealing to estimate demand for durable goods. Model specifications in these two theories differ as well. Lancaster's consumer theory assumes a linear relationship between the price of goods and the characteristics contained in those goods. On the other hand, Rosen's model assumes a nonlinear relationship between the price of goods and their inherent attributes [Herath, S. K. & Maier, G.,2010].

Background of applying HPM in Real Estate:

The heterogeneous nature of houses, buildings and other real estate justifies the use of HPM to estimate their demand or value. Houses, buildings and plots are different, at least in terms of location, and it is therefore difficult to estimate their demand in general terms. Therefore, the HPM considers the attributes of a property separately and estimates prices on the assumption that these attributes can be separated into a number of characteristics, such as attributes of the structure of the property (size of the property, number of bedrooms, bathrooms, whether it is renovated, the energy efficiency of the building, etc.), infrastructure and location attributes (including distance from the city centre, distance from public transport), natural environment, social environment, ecology, and quality of design and architecture. We need to note that housing choice confers on the owner/tenant consumption not only of the property and structural housing characteristics, but also of all the location attributes of the property, such as proximity to environmental amenities and discomfort. Thus, the observed housing choices reveal information to the researcher about underlying preferences for these amenities or other features of interest. Another issue to consider is what price is used to represent the value of a property, the sale price, rent or mortgage prices?

There is also a prolonged argument that rent values do not represent the actual value of real estate. On the one hand, rent values may need adjustments for tax payments, depreciation and other transaction costs etc. On the other hand, rents are based on current demand and supply conditions rather than the actual value of underlying real estate. However, since it is almost impossible practically to obtain the actual values of real estate, most studies consider rent values to be proxies for the value of the real estate in empirical analyses. Can rent value represent the actual value of real estate? On the other hand, recent sales 'prices' (house values from observed recent transactions) have some obvious advantages as dependent variables. Recent transaction data may present less potential bias, and greater potential precision, than occupants' or owners' self-assessments. But recent sales are not necessarily a random draw from the total housing stock. If the purpose is to index the market of available units, this may not be of great concern, but if the purpose is to index the total stock, we much concern ourselves with possible selection bias. Several papers such as Gatzlaff and Haurin (1997) have tested the presence of such biases. Test statistics often reject the null, but so far, most studies have found the magnitude of the bias to be modest [Malpezzi, S.,2002].

Theoretical Foundations of Hedonic Modelling, Rosen (1974)

Assumptions:

- A perfectly competitive market with many buyers and sellers;
- A continuum of house attributes is available.
- The competitive equilibrium price of housing is taken as exogenous by each consumer and producer.

FOR CONSUMERS:

Assume consumer utility is defined over two goods, Z and X, a composite numeraire.

Consumer j with demographic characteristics α^j has utility defined as:

$$U^j(X, z_1, z_2, \dots, z_n, \alpha^j). \quad (3.1)$$

Where:

U^j: utility of consumer *j*;

X: goods X

Z: a housing bundle with characteristics $Z = z_1, z_2, \dots, z_n$;

α^j : demographic characteristics.

If we assume the consumer *j* only purchases one unit of housing, the budget constraint is given by $y^j = X + P(z)$. The consumer *j* seeks to maximize utility by choosing *X* and each element of *Z.*

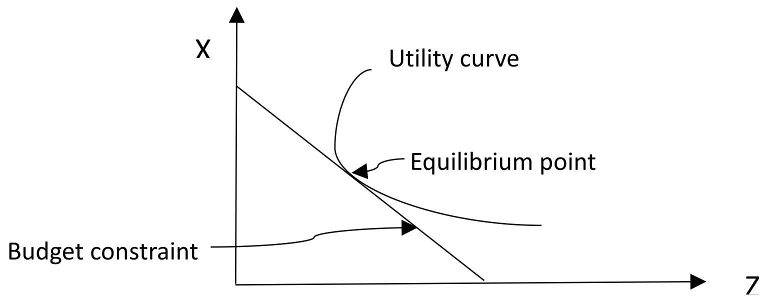


Figure 3-1: Equilibrium point based on the utility curve and budget constraint line

Equilibrium point:

$$\frac{\partial P(z)}{\partial Z_i} = \frac{\partial U}{\partial Z_i} \Big/ \frac{\partial U}{\partial X} \ . \quad (3.2)$$

Now we need to introduce the price that consumers are willing to pay for house *Z*. The bid function, θ, describes the relationship between the bid consumer *j* will make for house *Z* as one or more of its component characteristics are changed, while utility (U_0)

and budget (y_0) remain constant. Thus:

$$U^j\left(y_0 - \theta, z_1, z_2, \dots, z_n, \alpha^j\right) = U_0. \quad (3.3)$$

Equation 3.3 indicates how a consumer's optimal bid must vary in response to changes in *Z* if utility and budget are held constant. Solving equation 3.3 for θ indicates that $\theta^j = \theta(Z, y_0, U_0^j, \alpha^j)$. For maximizing the utility of consumer *j*, the marginal bid a consumer place for any house characteristic (*i*) must equal the marginal price of that characteristic, i.e.:

$$\theta_{zi} = \frac{\partial \theta}{\partial z_i} = \frac{\partial P}{\partial z_i} = P_{zi}. \quad (3.4)$$

<u>FOR FIRMS/SUPPLIERS:</u>

Assuming the housing supply is fixed, supply is easily modelled in the perfectly competitive framework considered by Rosen. Allow a firm with characteristics δ^k to maximize profits:

$$\Pi^k = H * P(z) - C(H, z, \delta^k). \quad (3.5)$$

Where:

Π^k: profit from the firm *k* production of housing *Z*;

H: the number of housing units of type *Z* that the firm *k* produces;

$C(H, z, \delta^k)$: a well-behaved cost function;

δ^k : characteristics of firm *k*.

For firm *k*, when the marginal profit equals to 0, the profit of firm is maximized. So, for a firm, the equilibrium point is:

$$\frac{\partial P(z)}{\partial Z_i} = \frac{\partial C(H,z,\delta^k)}{\partial Z_i} * \frac{1}{H} \ . \quad (3.6)$$

Now we need to introduce an offer function for the firm which describes the amount of money firm *k* is willing to accept (φ) for any particular house type *Z,* holding constant (*H*) the number of units produced and its level of profit (Π_0), thus:

$$\Pi_0^k = H * \varphi_{zi} - C(H, z, \delta^k). \tag{3.7}$$

Solving equation 3.7 for φ indicates that $\varphi^k = \varphi(Z, H, \Pi_0^k, \delta^k)$. So, combining Equation 3.6, the profit (Π_0^k) of firm K is maximized when the marginal price of any house characteristic (i) the firm is willing to accept is equal to the marginal price of that characteristic, i.e.:

$$\varphi_{zi} = \frac{\partial P(z)}{\partial Z_i} = \frac{\partial C(H,z,\delta^k)}{\partial Z_i} * \frac{1}{H} \ . \tag{3.8}$$

The bid, offer, and hedonic price functions are depicted in Figure 3-2, which first appears in Rosen (1974). P(z) is shown to be a nonlinear function of *Z*, a relationship we often expect to be the case. However, because P(z) is an envelope function, it may take any form. Properties of the bid function are easily described using Figure 3-2, which depicts the bid functions for two consumers, $\theta^1$and θ^2. Bid functions are concave in *Z* and higher levels of utility for the consumer are represented by bid function contours closer to the horizontal axis (i.e.,$U_2^1 > U_1^1 > U_0^1$ in Figure 3-2). Similarly, offer functions for two firms, $\varphi^1$and φ^2, are also depicted with higher levels of profits being indicated by offer functions which are further from the horizontal axis. As indicated in Figure 3-2, offer functions are convex in *Z*.

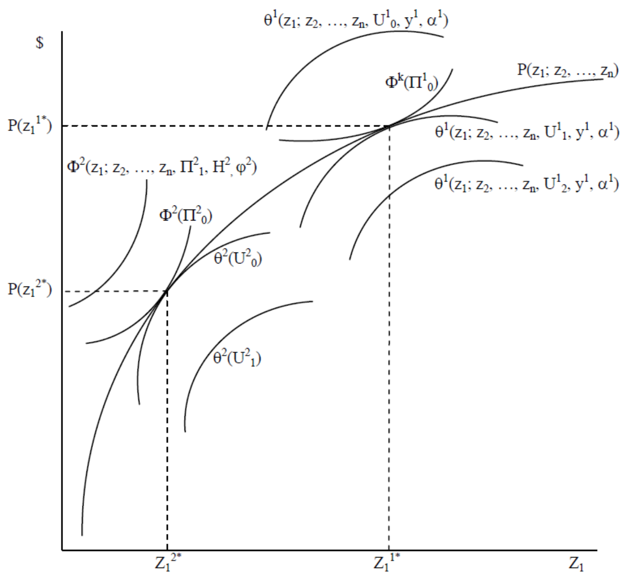


Figure 3-2: Hedonic equilibrium; Source: Taylor (2003)

Based on the characteristics revealed by Rosen's proposed hedonic equilibrium theory, we now need to further model and analyze the data using econometrics method to obtain more precise values for the quantitative analysis and explanation of each characteristic contributing to the equilibrium point.

3.2 Introduction to the Econometrics

Econometrics is the application of statistical and mathematical models to develop theories or test existing hypotheses in economics and to forecast future trends from historical data. According to Ragnar Frisch (1933) said of the Econometric Society that:

Its main object shall be to promote studies that aim at a unification of the theoretical-quantitative and the empirical-quantitative approach to economic problems and that are penetrated by constructive and rigorous thinking similar to that which has come to dominate the natural sciences. However, econometrics is by no means the same as economic statistics. Nor is it identical with what we call general economic theory, although a considerable portion of this theory has a definitely quantitative character. Nor should econometrics be taken as synonymous with the application of mathematics to economics. Experience has shown that each of these three viewpoints, that of statistics, economic theory, and mathematics, is a necessary, but not by itself a sufficient, condition for a real understanding of the quantitative relations in modern economic life. The unification of these three aspects constitutes econometrics.

There are two types of econometrics. Microeconometrics is characterized by its analysis of cross-section data and panel data and by its focus on individual consumers, firms, and micro-level decision makers. Practitioners rely heavily on the theoretical tools of microeconometrics including utility maximization, profit maximization, and market equilibrium. Macroeconometrics is involved in the analysis of time-series data, usually of broad aggregates such as price levels, investment, crime rate, public policies, investment, economic growth and so on. This thesis focuses on the microeconometrics, analysing the components that affect house prices at a given time.

When applying the econometrics method, building a linear model for testing hypotheses and forecasting future trends is also an important step of the process. Dependent and independent variables are identified, a functional form is specified, and in most cases, at least a qualitative statement is made about the directions of effects that occur when independent variables in the model change. The linear model is only a simplification of reality.

A linear model is a mathematical representation that assumes a linear relationship between the dependent variable (the variable we want to predict or explain) and one or more independent variables (also called predictor variables or regressors). The general form of a linear model is:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon$$

Where Y is the dependent variable, β_0 is the intercept term, β_1, β_2 ..., β_k are the coefficients or slopes associated with the independent variables X_1, X_2, ..., X_k, and ε is the error term representing the random variability or unexplained variation in the data. Linear regression, on the other hand, is a specific technique used to estimate the parameters (coefficients) of the linear model. It aims to find the best-fitting line that minimizes the sum of squared differences between the observed values of the dependent variable and the predicted values based on the linear equation.

The linear regression model consists of a set of assumptions about how a data set will be produced by an underlying Data-Generating Process (DGP). The hypotheses of the classical linear regression model are:

- Linearity: $Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_k X_k + \varepsilon$. The model specifies a linear relationship between Y and X_1, X_2, ..., X_k.

- Full column rank of matrix X: there is no exact linear relationship among any of the independent variables in the model. This assumption will be necessary for the estimation of the parameters(coefficients) of the model.

- Expected value of residuals equal to zero: $E[\varepsilon|X]=0$. This states that the independent variables will not carry useful information for the prediction of ε.

- Homoscedasticity and non-autocorrelation: $Var[\varepsilon|X] = \sigma^2$. Each residual has the same finite variance, σ^2, and is uncorrelated with every other residual.

- X is a non-stochastic matrix. This states that vectors of variables are measurable observations of an economic phenomenon.

- Model residuals are normally distributed: $\varepsilon|X \sim N(0, \sigma^2 I_n)$.

According to the classical linear regression model, to check the validity of the data set and measure the goodness of fit of the model, we need to apply statistics. Statistics is a science concerned with the collection, analysis, and interpretation of data obtained from observation or experiment. The subject has a coherent structure based on the theory of Probability. (E.Pearson, 1936)

The observation of some aspects of the economy is taken as the outcome of a random process that is almost never under control. In the current literature, the descriptive term data generating process, or DGP is often used for this underlying mechanism. The observed(measured) outcomes of the process are assigned unique numeric values. The assignment is one to one, each outcome gets one value, and no two distinct outcomes receive the same value. This outcome variable, X, is a random variable because, until the data are actually observed, it is uncertain what value X will take. Probability is associated with outcomes to quantify this uncertainty.

There are two types of variables. A random variable is discrete if the set of outcomes is either finite in number or countably infinite. The random variable is continuous if the set of outcomes is infinitely divisible and hence, not countable. Consider an experiment whose sample space is S. Any event A and B belong to S, there are three properties:

- P1: for any event A, the probability of A is a number between 0 and 1: 0≤P(A)≤1.
- P2: the probability of sample space S is 1: P(S)=1.
- P3: the probability of the union of event A and event B, the probability of all outcomes that are either in A or in B is: P(AUB) =P(A)+P(B)-P(A∩B).

The moments of a probability distribution are four:

- The first moment is the expected value (i.e., the mean): $E_N(X) = \frac{1}{n}\sum_{i=1}^{n} X_i$.

  Other measures of central tendency are the median and the mode.

- The second moment is variance: $Var_N(X) = E_N(X^2) - (E_N X)^2 = \frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^2$. This function is a measure of the dispersion of a distribution.

  To describe a distribution, we usually use the standard deviation, which is the square root of variance. The standard deviation can be interpreted as having the same units of measurement as the x_i.

- The third moment is skewness: $\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^3$.
- The fourth moment is kurtosis: $\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})^4$.

Skewness is a measure of the asymmetry of a distribution. For asymmetric distributions, the skewness will be positive if the "long tail" is in the positive direction. Kurtosis is a measure of the thickness of the tails of the distribution.

Before attempting to estimate the parameters(coefficients) of a population or fit models to data, we normally examine the data themselves. In raw form, the sample data are a disorganized mass of information, so we will need some organizing principles to distil the information into something meaningful. In most cases, we shall use some summary statistics to describe the sample data. Of most interest are measures of location (the centre of the data) and scale (the dispersion of the data). Commonly used measures include mean, median, and standard deviation. The shape of the distribution of values is often of interest as well. The box and whisker plot is a graphical device which is often used to capture a large amount of information about the sample in a simple visual display. This plot shows in a figure the median, the range of values contained in the 25th and 75th percentile, some limits that show the normal range of values expected, such as the median plus and minus two standard deviations, and in isolation values that could be viewed as outliers. For the sample that contains data on more than one variable, we will also be interested in measures of association among the variables. A scatter diagram is useful in a bivariate sample if the sample contains a reasonable number of observations. If the sample is a multivariate one, then the degree of linear association among the variables can be measured by the pairwise measures of the covariance matrix and correlation matrix.

THE ORDINARY LEAST SQUARES ESTIMATOR(OLS)

After checking the quality of the data set, we need to build a linear regression model to fit the observed data. Assume there is a sample of observations about the house price and floor area. The regression line that can represent the actual relationship between the house and floor area can be expressed as:

Population regression : $Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$

In a practical situation, the intercept β_0 and the slope β_1 of the population regression line are unknown. Therefore, we need to use data to estimate these unknown coefficients. And regression line obtained from the experimental sample data can be expressed as:

Sample regression: $y_i = b_0 + b_1 x_i + e_i$

A plot of these 1,743 observations on the house sale price and floor area is shown in Figure 3-3. If we draw a straight line through these observed data, then the slope of this line would be an estimate of β_1 based on these data. However, we can draw many different estimated lines, how could we choose a “perfect” line to fit the sample data as more as possible?

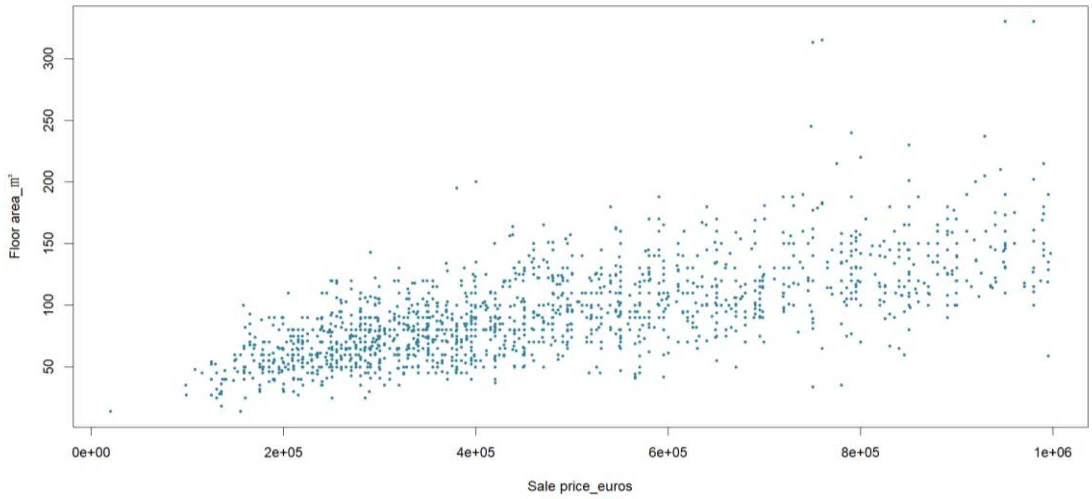


Figure 3-3: Plot between house sale price and floor area;
Source: R

By far the most common way is to choose the line that produces the "least squares" fit to these data. The ordinary least squares (OLS) estimator chooses the regression coefficients so that the estimated regression line can fit the observed data as more as possible.

Let b_0 and b_1 be some estimators of β_0 and β_1. The regression line based on these estimators is $b_0 + b_1 X$, so the value of Y_i predicted using this line is $b_0 + b_1 X_i$. Thus, the mistake made in predicting the i^{th} observation is $Y_i - (b_0 + b_1 X_i) = Y_i - b_0 - b_1 X_i$. The sum of these squared prediction mistakes over all *n* observations is:

$$\sum_{i=1}^{n}(Y_i - b_0 - b_1 X_i)^2 \quad (3.9)$$

And follow the best linear unbiased estimator (BLUE), that is, the sample mean provides the best fit to the data in the sense that the mean squared differences between the observations and sample mean are the smallest of all possible estimators. Just as there is a unique estimator, mean sample, that minimizes the differences squares, so there is a unique pair of estimators of β_0 and β_1 that minimizes Expression (3.9).

The estimators of the intercept and slope that minimize the sum of squared mistakes in Expression (3.9) are called the ordinary least squares (OLS) estimators of β_0 and β_1. The OLS estimators of β_0 is denoted $\widehat{\beta_0}$, and the OLS estimators of β_1 is denoted $\widehat{\beta_1}$. The OLS regression line, also called the sample regression line or sample regression function, is the straight line constructed using the OLS estimators: $\widehat{\beta_0} + \widehat{\beta_1}X$. The predicted value of Y_i given X_i, based on the **OLS regression line**, is $\widehat{Y_i} = \widehat{\beta_0} + \widehat{\beta_1}X_i$. The residual for the i^{th} observation is the difference between Y_i and its predicted value $\widehat{Y_i}$: $\widehat{\varepsilon_i}=Y_i - \widehat{Y_i}$.

The OLS estimators, $\widehat{\beta_0}$ and $\widehat{\beta_1}$, are sample counterparts of the population coefficients, β_0 and β_1. Similarly, the OLS regression line, $\widehat{\beta_0} + \widehat{\beta_1}X$, is the sample counterparts of the population regression line, $\beta_0 + \beta_1 X$; and the OLS residuals, $\widehat{\varepsilon_i}$, are sample counterparts of the population errors, ε_i.

The OLS estimators of the slope β_1 and the intercept β_0 are:

$$\widehat{\beta_1} = \frac{\sum_{i=1}^{n}(X_i-\bar{X})(Y_i-\bar{Y})}{\sum_{i=1}^{n}(X_i-\bar{X})^2} \tag{3.10}$$

$$\widehat{\beta_0} = \bar{Y} - \widehat{\beta_1}\bar{X} \tag{3.11}$$

The OLS predicted value $\widehat{Y_i}$ and residuals $\widehat{\varepsilon_i}$ are:

$$\widehat{Y_i} = \widehat{\beta_0} + \widehat{\beta_1}X_i, i = 1, \dots, n \tag{3.12}$$

$$\widehat{\varepsilon_i} = Y_i - \widehat{Y_i}, i = 1, \dots, n \tag{3.13}$$

The OLS regression line, $\widehat{\beta_0} + \widehat{\beta_1}X$, for the sample of these observations on the house sale price and floor area is shown in Figure 3-4.

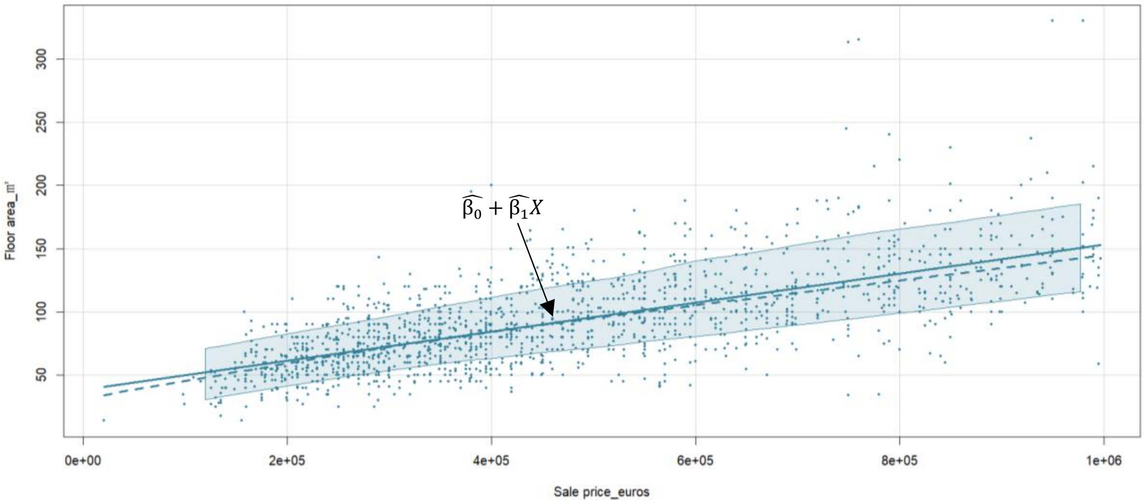


Figure 3-4: Scatter plot between list price and floor area;
Source: R

Ease of computation is one reason that ordinary least squares is so popular. However, there are several other justifications for this technique. First, ordinary least squares is a natural approach to estimation, which makes explicit use of the structure of the model as laid out in the assumptions. Second, even if the true model is not a linear regression, the regression line fit by ordinary least squares is an optimal linear predictor for the dependent variable. Thus, it enjoys a sort of robustness that other estimators do not. Finally, under the very specific assumptions of the classical model, by one reasonable criterion, ordinary least squares will be the most efficient use of the data.

MEASURES OF FIT IN MULTIPLE REGRESSION

After obtaining the OLS regression line, we need to measure the fit of the regression. Three commonly used summary statistics in multiple regression *n* are the standard error of the regression, the regression R^2, and the adjusted R^2 (e.g., $\overline{R^2}$). All three statistics measure how well the OLS estimate of the multiple regression line fits the data.

The R^2 ranges between 0 and 1 and measures the proportion of the variance of Y_i that is explained by X_i. Mathematically, the R^2 can be written as the ration of the explained sum of squares (ESS) to the total sum of squares (TSS):

$$ESS = \sum_{i=1}^{n}(\widehat{Y_i} - \bar{Y})^2 \qquad (3.14)$$

$$TSS = \sum_{i=1}^{n} (Y_i - \bar{Y})^2 \quad (3.15)$$

$$R^2 = \frac{ESS}{TSS} \quad (3.16)$$

Also, the R^2 can be expressed by the residual sum of squares (RSS):

$$R^2 = 1 - \frac{RSS}{TSS} \quad (3.17)$$

If $\widehat{\beta_1} = 0$, then X_i explains none of the variation of Y_i, and the predicted value of Y_i is $\widehat{Y_i} = \widehat{\beta_0} = \bar{Y}$. In this case, the ESS is 0 and the RSS equals the TSS, thus R^2 is 0. In contrast, if X_i explains all of the variation of Y_i, then $Y_i = \widehat{Y_i}$ for all i, and every residual is 0, thus R^2 is 1. In general, the R^2 does not take on the extreme value of 0 or 1 but falls somewhere in between. An R^2 near 1 indicates that the regressor is good at predicting Y_i, while an R^2 near 0 indicates that the regressor is not very good at predicting Y_i.

Because the R^2 increases when a new variable is added, an increase R^2 does not mean that adding a variable actually improves the fit of the model. In this sense, the R^2 gives an inflated estimate of how well the regression fits the data. The adjusted R^2, or $\overline{R^2}$, is a modified version of the R^2 that does not necessarily increase when a regressor is added.

$$\overline{R^2} = 1 - \frac{n-1}{n-k-1}\frac{RSS}{TSS} = 1 - \frac{n-1}{n-k-1}(1 - R^2) \quad (3.18)$$

There are three useful things to know about the $\overline{R^2}$. First, $(n-1)/(n-k-1)$ is always greater than 1, so $\overline{R^2}$ is always less than R^2. Second, adding a regressor has two opposite effects on the $\overline{R^2}$. On the one hand, the RSS decreases. On the other hand, the factor $(n-1)/(n-k-1)$ increases. Whether the $\overline{R^2}$ increases or decreases depends on which of these two effects is stronger. Third, the $\overline{R^2}$ can be negative. This happens when the regressors, taken together, reduce the RSS by such a small amount that this reduction fails to offset the factor $(n-1)/(n-k-1)$.

The R^2 and $\overline{R^2}$ can tell us whether the regressors are good at predicting or explaining the values of the dependent variable in the sample of data on hand. If the R^2 or $\overline{R^2}$ is nearly 1, then the regressors produce good predictions of the dependent variable in that sample in the sense that the variance of the OLS residual is small compared to the variance of the dependent variable. However, the R^2 and $\overline{R^2}$ can not tell us whether: (1) an included variable is statistically significant; (2) the regressors are a true cause of the dependent variables; (3) there is omitted variable bias; (4) the regression includes the most appropriate set of regressors.

The standard error of the regression (SER) is an estimator of the standard deviation of the regression error ε_i. The units of ε_i and Y_i are the same, so the SER is a measure of the spread of the observations around the regression line, measured in the units of the dependent variable.

$$SER = \frac{RSS}{n-k-1} \tag{3.19}$$

STATISTICAL HYPOTHESIS TEST

The starting point of statistical hypotheses testing is specifying the hypothesis to be tested, called the null hypothesis. Hypothesis testing entails using data to compare the null hypothesis to a second hypothesis, called the alternative hypothesis, that holds if the null does not. For example:

$null\ hypothesis: H_0: \beta_1 = 0$

$alternative\ hypothesis: H_1: \beta_1 \neq 0$

A statistical hypothesis test can make two types of mistakes: type one, in which the null hypothesis is rejected when in fact it is true; type two, in which the null hypothesis is not rejected when in fact it is false. The prespecified rejection probability of a statistical hypothesis test when the null hypothesis is true is the significance level of the test. The p-value, also called the significance probability, is the probability of obtaining a test statistic, by random sampling variation, at least as adverse to the null hypothesis value as is the statistic actually observed, assuming the null hypothesis is correct. Equivalently, the p-value is the smallest significance level at which can reject the null hypothesis.

Logical steps to apply the hypothesis test:

(1) Compute the standard error of $\widehat{\beta_i}$;
(2) Compute the t-statistic;

$$t = \frac{estimator - hypothesized\ value}{standard\ error\ of\ the\ estimator}$$

(3) Compute the p-value. Reject the hypothesis at the 5% significance level if the p-value is less than 0.05.

The F-statistic is used to test a joint hypothesis about regression coefficients. The joint hypothesis is a hypothesis that impose two or more restrictions on the regression coefficients. For example:

$null\ hypothesis: H_0: \beta_1 = 0\ and\ \beta_2 = 0$

$alternative\ hypothesis: H_1: \beta_1 \neq 0\ and/or\ \beta_2 \neq 0$

Confidence interval for β_i

A 95% two-sided confidence interval for β_i is an interval that contains the true value of β_i with a 95% probability; that is, it contains the true value of β_i in 95% of all possible randomly drawn samples. When the sample size is large, it is constructed as:

95% confidence interval for β_i = $[\widehat{\beta_i} - 1.96SE(\widehat{\beta_i}), \widehat{\beta_i} + 1.96SE(\widehat{\beta_i})]$

3.3 Advantages and Limitations

The Hedonic Price Method is a versatile approach used in property valuation. It comprehensively assesses the value of a house by considering various attributes, including size, location, and amenities. This method's adaptability extends to a wide range of property types, from residential houses to commercial buildings, making it suitable for diverse real estate markets and contexts. Recognizing the inherent diversity of real estate properties, the Hedonic Price Method dissects properties into individual characteristics, enhancing the accuracy of value estimation.

One of its key strengths lies in its ability to pinpoint the contribution of each attribute to a property's overall value, shedding light on the most influential factors affecting prices. Furthermore, it effectively controls for external factors impacting property values, such as location-specific amenities. Importantly, this method relies on real market data, offering a practical and empirical basis for property valuation. It's also adaptable when certain property attributes have missing data, utilizing statistical techniques for estimation.

In summary, the Hedonic Price Method stands out for its comprehensive, adaptable, and data-driven approach to property valuation, making it an invaluable tool in real estate analysis and assessment.

While the Hedonic Price Methodology (HPM) is extensively utilized and established, its effective application demands a high level of analytical and technical proficiency for both data development and interpretation. Consequently, the HPM does have some limitations.

- **Omitted variable bias**

If the regressor is correlated with a variable that has been omitted from the analysis and that determines, in part, the dependent variable, then the OLS estimator will have omitted variable bias. Omitted variable bias occurs when two conditions are true: (1) the omitted variable is correlated with the included regressor and (2) the omitted variable is a determinant of the dependent variable.

- **Multicollinearity**

Perfect multicollinearity arises when one of the regressors is a perfect linear combination of the other regressors. One possible source of perfect multicollinearity arises when multiple binaries, or dummy, variables are used as regressors. If there are *G* binary variables, if each observation falls into one and only one category, if there is an intercept in the regression, and if all *G* binary variables are included as regressors, then the regression will fail because of perfect multicollinearity. This situation is called the dummy variable trap. The usual way to avoid the dummy variable trap is to exclude one of the binary variables from the multiple regression, so only *G-1* of the *G* binary variables are included as regressors. In this case, the coefficients on the included binary variables represent the incremental effect of being in that category, relative to the base case of the omitted category, holding constant the other regressors. Alternatively, all *G* binary regressors can be included if the intercept is omitted from the regression. The software cannot compute the OLS estimator if there is a perfect multicollinearity in the regression. However, imperfect multicollinearity does not pose any problems for the theory of the OLS estimators. When multiple regressors are imperfectly multicollinear, the coefficients on one or more of these regressors will be imprecisely estimated, that is, they will have a large sampling variance.

4. Case Study: Determinants of Residential House Price in Milan

4.1 The Objectives of Case Study

This thesis focuses on analysing the impacts that can be brought about by the energy efficiency policies of buildings in Europe, mainly from an economic perspective and an environmental perspective. From the environmental point of view, each country actively promotes the building energy efficiency labelling system, encourages house owners to improve the energy efficiency of buildings, and thus reduces the release of carbon dioxide from buildings and building-related activities, which has a positive effect on environmental protection and combating global warming. However, in reality, the financial problems faced in implementing these policies are an important factor in determining the progress and popularity of this policy. Based on Eurostat data, in the EU in 2021, 70 % of the population lived in a household owning their home, while the remaining 30 % lived in rented housing. The situation in Italy is similar to the EU overall average. In Italy in 2021, 73.7 % of the population lived in a household owning their home, while the remaining 26.3 % lived in rented housing.

For the self-occupation market, building energy efficiency renovations at the house owner's own expense can save on energy costs (e.g., electricity, gas) and improve living comfort on the one hand. For the rental market, however, the fact that it is the landlord who pays for the building energy efficiency renovations and the tenant who enjoys the benefits of the renovations often leads to landlords being reluctant to carry out building energy efficiency renovations. Taking advantage of the regulatory mechanism of the economic market, if building energy efficiency renovations can drive up house prices, and if the magnitude of this premium increase exceeds the cost of the building renovation, then, to some extent, utilizing market economic mechanisms to promote the sustainable development of building energy efficiency renovations is feasible.

This thesis posits the hypothesis that building energy renovations can yield a premium benefit for house prices. To examine this hypothesis, a specific city is chosen for testing. As previously mentioned, Italy's building stock closely mirrors the aggregate data for the 28 European countries in terms of quantity and age distribution. Milan, being a highly representative city in Italy, is selected as the case study for this thesis.

4.2 Residential Real Estate Sector in Milan

Milan, the capital of Lombardy in northern Italy, is a city renowned for its rich history, cultural heritage, and dynamic atmosphere. With a population of over 1.3 million people, Milan serves as a global hub for fashion, design, finance, and commerce. It boasts a strategic location at the crossroads of Europe, making it an attractive destination for both residents and investors. The city stands out with a significantly higher concentration of companies in the services sector (53.3%) compared to the national average (36.3%), which is also reflected in a larger share of employment (59.8%) compared to the national average (49.7%). This emphasizes the city's dominance as a hub for diverse service-oriented industries. The real estate sector in Milan is experiencing significant growth, fueled by a strong economy and increasing demand. The city offers a diverse range of properties, from historic buildings in the city center to modern developments in the surrounding areas. Key factors driving the real estate market include excellent transportation infrastructure, world-class educational institutions, and a thriving business environment. Milan's cultural attractions, vibrant nightlife, and the culinary scene also contribute to its appeal as a desirable place to live and invest.

From 2004 to 2021, the Milan real estate market has demonstrated a consistent upward trend, with a total stock of over 800,000 units in 2021(Figure 4-1). Real estate transactions often involve price negotiations, resulting in a final sale price that may be lower than the initial asking price. In recent years, Milan's residential real estate market has seen a significant uptick in average transaction prices, primarily driven by a substantial increase in initial asking prices. Specifically, the weighted average asking prices in Milan's OMI areas have surged by approximately 39.09% since 2015, partially reflecting the rise in average transaction prices, which increased by 21.42%. However, it's important to note that the increase in asking prices did not uniformly translate into a proportional growth in actual transaction prices. For instance, certain OMI areas, such as the North Semi-center, witnessed substantial increases in both asking prices (+49.86%) and transaction prices (+25.28%). In contrast, areas like the East Periphery experienced the fourth-lowest increase in asking prices (30.59%) but still observed the most significant growth in transaction prices (+34.47%) (Figure 4-2, Figure 4-3).

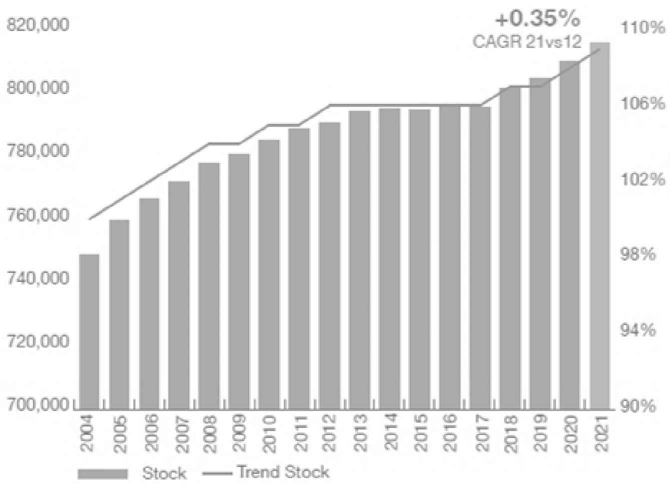
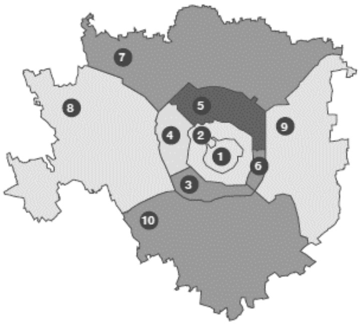
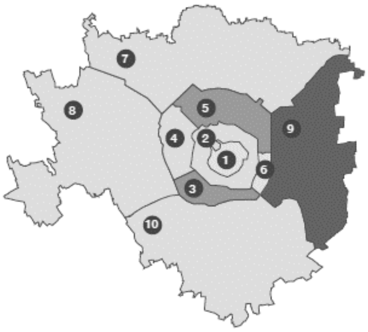


Figure 4-1: Trend of Milan real estate stock from 2004 to 2021; Source: PwC analysis on Italian IRS data



	Milan's OMI areas	Asking prices
1	Historic center	25,91%
2	Center	30,57%
3	South Semicenter	38,60%
4	West Semicenter	36,83%
5	North Semicenter	49,86%
6	East Semicenter	41,15%
7	North Periphery	42,80%
8	West Periphery	27,69%
9	East Periphery	30,59%
10	South Periphery	38,83%

Figure 4-2: Variance percentage in asking prices between 2015 to 2022 in Milan; Source: PwC analysis on Italian IRS data and Immobiliare.it



	Milan's OMI areas	Real prices
1	Historic center	7,07%
2	Center	15,03%
3	South Semicenter	26,31%
4	West Semicenter	20,68%
5	North Semicenter	25,28%
6	East Semicenter	13,23%
7	North Periphery	16,88%
8	West Periphery	18,63%
9	East Periphery	34,47%
10	South Periphery	20,63%

Figure 4-3: Variance percentage in transaction prices between 2015 to 2022 in Milan; Source: PwC analysis on Italian IRS data and Immobiliare.it

Since SIAPE only covers geographical units at the provincial level, according to the statistics for the Province of Milan as of 18/09/2023, a total of 386,061 buildings in the Province of Milan have got the APE. 81.1% of these building stocks are residential buildings. 44.4% of the Milan building stock for which energy certificates have been obtained is in the lower energy efficiency classes F and G. Only 11.2% of the building stock has an energy efficiency rating of B or higher (Figure 4-4).

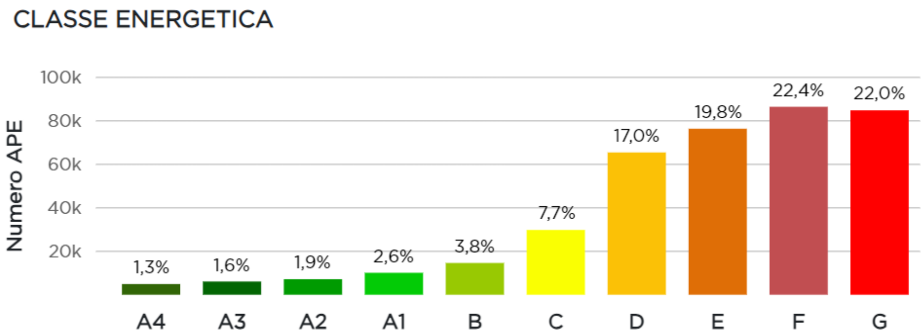


Figure 4-4: Building stock with energy performance certificates (APE) by energy class in Milan province, 18/09/2023; Source: ENEA, SIAPE https://siape.enea.it/analisi-territoriali

4.3 Dataset Collection

Biases and random variation are two sources of error or uncertainty that can affect statistical results. Biases refer to systematic errors or deviations from the true value or population parameter. In order to avoid biases, at the stage of designing the collection of the dataset, by specifying the research methodology, i.e. HPM, and the research purpose, i.e. the premium effect of building energy efficiency renovation on house price, this thesis designed what information to be included in the data set should to be collected, such as, property transaction price, structural characteristics of houses, building energy performance certificate of houses, facilities and amenities in the neighbouring area of houses, etc. However, during the practical data collection process, it was found that it was difficult to obtain housing transaction prices that included information on the structural characteristics of the houses and the surrounding facilities, so the information to be collected for the data set was adjusted. The list price of houses is collected through the housing transaction website, of course, there will be a certain error between this price and the real transaction price, but since the "systematic error" is distributed on the overall sample, it does not affect the results significantly.

A basic data set of properties for sale on the *immobiliare.it* housing transaction website as of 2 February 2023 was obtained through the Kaggle website. The information contained in the data set is as follows: the number of rooms, the number of bathrooms, the floor area, the floor level, listed sale date, the type of house, the type of contract, the total number of floors in the building, the listed sale price, the building condition, the energy efficiency of the building, the neighbourhood where it is located, the presence of car parking, the presence of lifts, the heating system, the air conditioning system, and other information. The total number of data is 2,130, after filtering and removing some invalid data, the total number of valid sample data is 1,986. The online on-sale time of the housing samples is mainly concentrated in January and February 2023. A small number of samples were on sale in 2022.

Since the obtained data set did not provide the specific locations of the houses, the housing samples are divided into 143 neighbourhoods where the houses were located as provided in the data set. The core location of each neighbourhood is selected to measure the distance to the centre of Milan (Duomo di Milano), and the distance to the nearest metro stations, hospitals, schools, supermarkets and other amenities in each neighbourhood is measured. The obtained distance data is then assigned to each house according to the neighbourhood in which it is located. The 1,986 houses are distributed across 143 neighbourhoods. The core location of each neighbourhood and the distribution of the number of houses contained are shown in Figure 4-5:

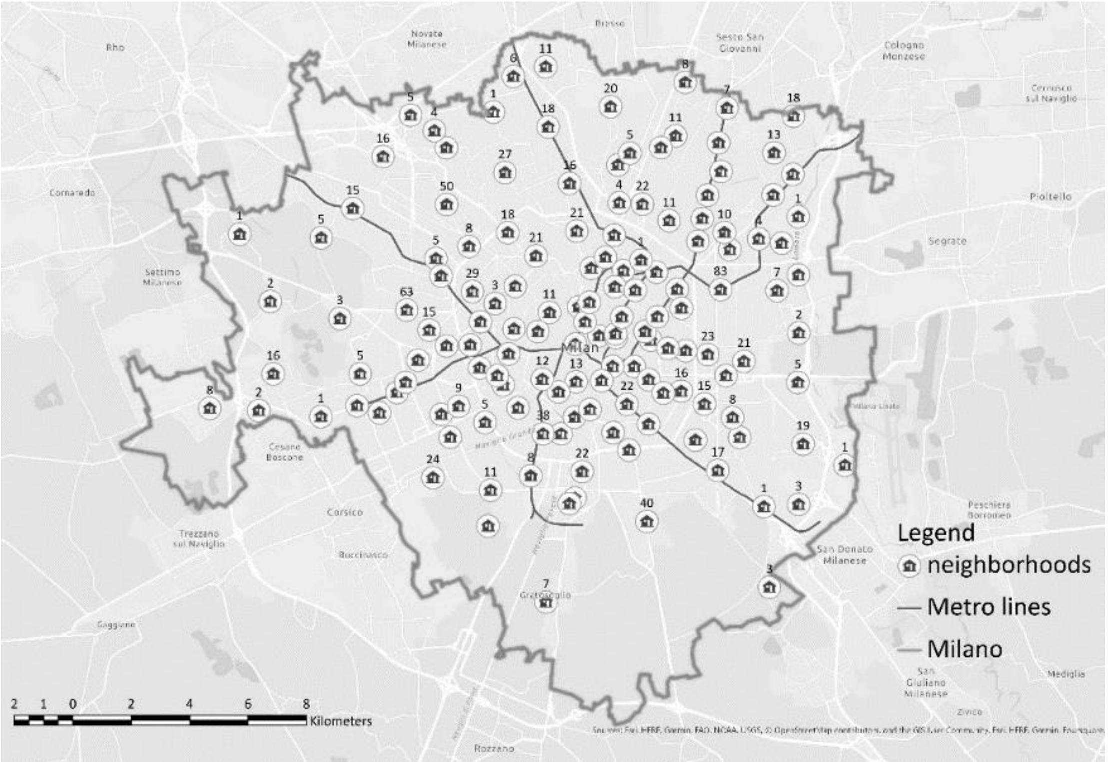


Figure 4-5: Distribution of observed sample in Milan;
Source: ArcGIS Pro

4.4 Data Preprocessing

4.4.1 Preliminary processing of raw data

Structural data

The data set is collated according to the neighbourhood in which the house is located. Information such as the type of house, time of registration of the house for sale, listed sale price of the house, floor area, number of rooms, number of bathrooms, floor and total number of floors, energy efficiency of the building, age of the building, presence of car parking, presence of lifts, building condition, heating system, air-conditioning system, etc., are retained in the raw data.

Accessibility data

Accessibility data is collated on the accessibility around the neighbourhood where the property is located by applying the ArcGIS software and the data includes:

- Schools in the neighbourhood of the house (kindergarten, primary school, secondary school)

The official data obtained from the Municipality of Milan[32] is imported into the ArcGIS software to obtain the distance to the nearest school around each neighbourhood. During the analysis of the sample, 27 kindergartens, 140 primary schools and 90 secondary schools are involved.

- Supermarkets in the neighbourhood of the house

Data on the location of retail shops in Milan are obtained from the *datiopen.it*[33] website and filtered by selecting Carrefour, Conad, Esselunga, In's mercato, Ipercoop, Lidl, Pam, Penny market, Punto sma, Unes as representative brands of supermarket chains. These data are imported into ArcGIS software, there are individual samples with positional errors, after eliminating these error samples, the distance to the nearest supermarket around each neighbourhood is obtained. A total of 140 supermarkets are involved in the sample analysis process.

- Hospitals in Milan:

The location distribution data of Milan's hospitals are obtained from the *datiopen.it* website and imported into the ArcGIS software, with individual samples having positional errors, which are removed to obtain the distance to the nearest hospital in the vicinity of each neighbourhood. A total of 16 general hospitals are involved in the sample analysis process.

- Milan metro station locations:

The location distribution data of Milan metro stations are obtained from the *datiopen.it* website and imported into ArcGIS software to obtain the distance of the nearest metro station around each neighbourhood. A total of 93 metro stations are involved in the sample analysis process.

- Milan City Centre (CBD):

Duomo di Milano is selected as the location of Milan's city centre, and ArcGIS software is used to measure the distance from each neighbourhood to the city centre.

Integrating the structural data and accessibility data, then get the data set. According to the data set, this thesis presents a statistical analysis of the distribution of the sample number of housing, property types, floor area, building age and building

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[32] *Data source:* *https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=a7395207c19448dbb8ac16060842cad5&mobileBreakPoint=300*

[33] *Data source:* *http://www.datiopen.it/it/catalog/%20supermercato*

energy efficiency, etc.

4.4.2 Statistical analysis of sample data set

The distribution of the number of houses in each neighbourhood is shown in Figure 4-6 below: the distribution of the number of houses in each neighbourhood is relatively close to the average, with a few neighbourhoods containing far more houses than the average of 13.88. The distribution of the number of houses in each neighbourhood suggests that the data sample is both random and representative.

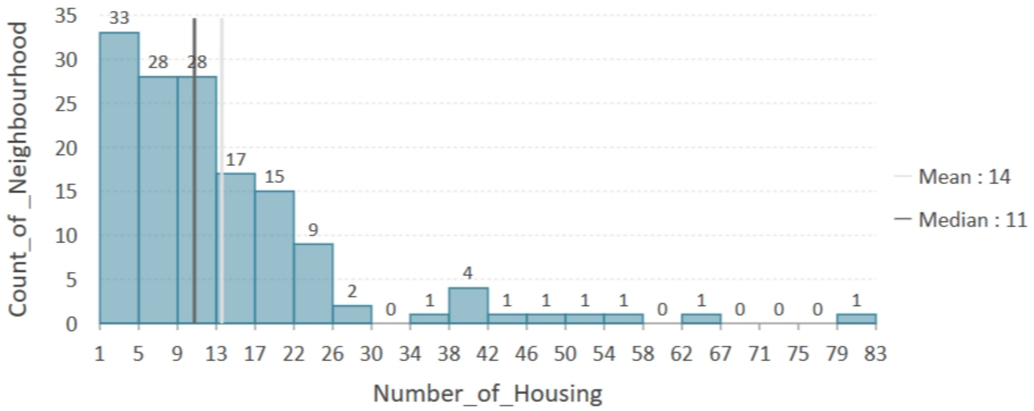


Figure 4-6: Distribution of the number of houses in different neighbourhoods; Source: ArcGIS Pro

For the classification of housing types in the sample, we process the raw data and classify “Detached Villa”, “Terraced House”, “Semi-Detached Villa”, “Multi-Family Townhouse” as "Villa". “Open space”, “Palace building” are classified as "others". In addition, the types of houses involved are “apartment”, “attic”, and “lofts”. The distribution of the types of houses involved in the sample and the percentage of the sample are as shown in Figure 4-7: more than 90% of the housings are apartments.

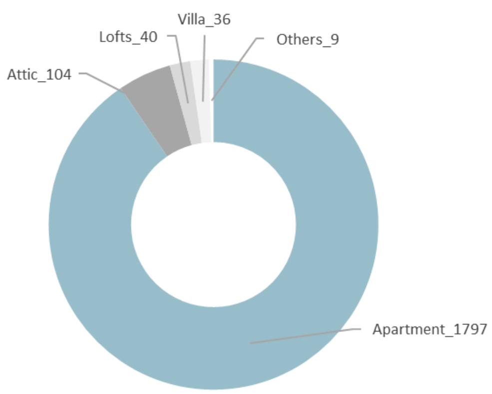


Figure 4-7: Distribution of observed sample houses by typology; Source: excel, author’s ownership

According to the floor area of the sample houses, the average floor area of the sample is 119.8 m^2. The Milan market offers a wide range of residential units, with small, medium and large sizes, but residential buildings of 60-120 m^2 account for half of the total number of units for sale in Milan. Overall, the supply of small and medium-sized houses is greater than the supply of medium and large-sized houses. (Figure 4-8)

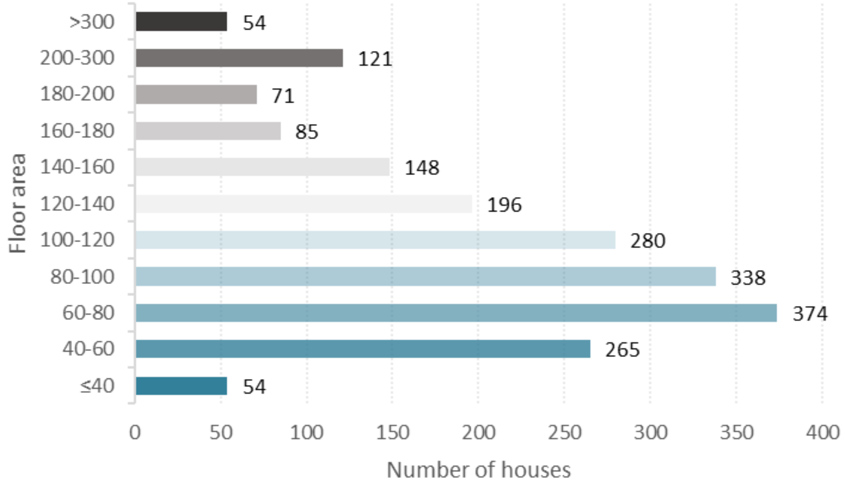
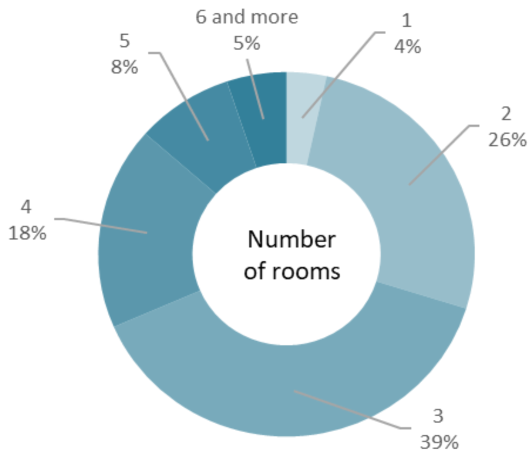


Figure 4-8: Distribution of the number of observed sample houses by floor area; Source: excel, author's ownership

Based on the analysis of the number of rooms in the observed sample, it is evident that by the end of 2022 and the beginning of 2023, the majority of houses available on the market primarily consist of 2 to 4 rooms in size (Figure 4-9).The demand for house size in the Milan residential market can be obtained directly through questionnaires, but in this thesis, the demand for house size in the market is analysed indirectly by taking the statistics of the Milan government on house size. Table 4-1 shows that compared to 1971, the number of household size in Milan has decreased dramatically since 2001, with the average household size decreasing from 2.8 in 1971 to 2.1 in 2008. And in 2008, the proportion of 1-person households' size was 42%, and 2-3-person households' size was 44.6%, which indirectly indicates that there is a large demand for small and medium-sized houses in Milan (Figure 4-10). From the distribution of the number of rooms in the sample, it is also evident that the market is meeting the demand for medium-sized and smaller housing units.

Table 4-1: Distribution of households' size by number of family members in Milan city in different years;
Source: WILCO Publication no. 23, City report, Milan, page 20. (Costa & Sabatinelli, n.d.)

	1971	2001	2007	2008
Nr. of family members				
1	19.4%	37.3%	41.3%	42.0%
2	27.4%	31.2%	29.2%	29.0%
3	25.7%	17.8%	16.0%	15.6%
4	18.1%	10.9%	10.5%	10.4%
5	6.4%	2.4%	2.5%	2.5%
6 and more	3.0%	0.4%	0.5%	0.5%
Total	100.0%	100.0%	100.0%	100.0%
Average family size	2.8	2.1	2.1	2.1



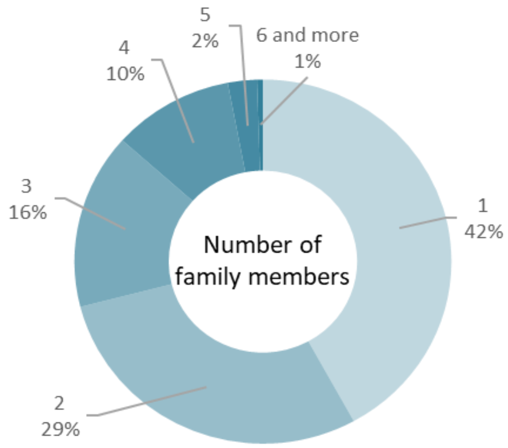


Figure 4-9: (Left) Distribution of households' size by number of rooms in the observed sample in Milan city in 2023;

Figure 4-10: (Right) Distribution of households' size by number of family members in Milan city in 2008;

Source: excel, author's ownership

When examining the sample based on the age of the buildings, it becomes evident that 68% of the houses in the observed sample are constructed before 1979, while 23% are newer buildings built after 2000. Comparing these findings to the statistics from the EU Building Stock Observatory (BSO) in 2017, Italy's building stock distribution by age generally aligns with that of the EU. However, notable differences exist between the age distribution of buildings in the sample data and the overall building stock in Italy. (Table 4-2)

Specifically, according to the 2017 statistics from the EU BSO, the proportion of buildings constructed before 1979 is smaller than what is observed in the sample data, while the proportion of buildings constructed between 1980 and 2010 is larger than the sample data. This indicates that there is a relatively large number of old buildings still on the market in a state of pending sale. Although the representativeness of the sample concerning building age may not be immediately evident, this particular indicator has limited influence on the primary focus of the thesis research, which is the premium effect of building energy efficiency on house prices.

This is because if, according to the sample data, the older the building, the higher energy efficiency class can bring a premium effect to the building, then relatively speaking, the younger building energy efficiency renovations will be less costly, and the cost to achieve the same premium effect will be less. Such findings can be advantageous for advocating policies aimed at promoting building energy efficiency renovations.

Table 4-2: Distribution of number of building stocks by building age;
Source: EU BSO

Year_of_build	Observed Smaple	Italy_2017	EU_2017
<1945	25%	16%	18%
1945-1969	33%	15%	20%
1970-1979	10%	15%	15%
1980-1989	1%	14%	13%
1990-1999	2%	14%	11%
2000-2010	5%	13%	13%
>2010	17%	12%	9%
N/A	7%	/	/

The distribution of the building energy efficiency class in the observed sample shows that the largest share of the energy efficiency class is G, at 32%. This is followed by classes A and F, both at 16%. This is followed by class E at 13%. In addition, 6% of the houses in the observed sample are in the process of being certified. The overall building energy efficiency class of the observed sample is low (Figure 4-11). In the observed sample, there is a higher percentage of buildings falling into the high-energy efficiency classes A and B compared to the figures presented on the Italian Energy Efficiency Certificates for Buildings website. Conversely, the proportion of buildings within the observed sample categorized under the medium-energy efficiency classes C, D, and E is smaller than what is reported on the website of the Italian Energy Efficiency Certificates for Buildings. Notably, the share of buildings in the observed sample falling into the low-efficiency classes F and G is approximately consistent with the figures found on the Italian Energy Efficiency Certificate website (Table 4-3).

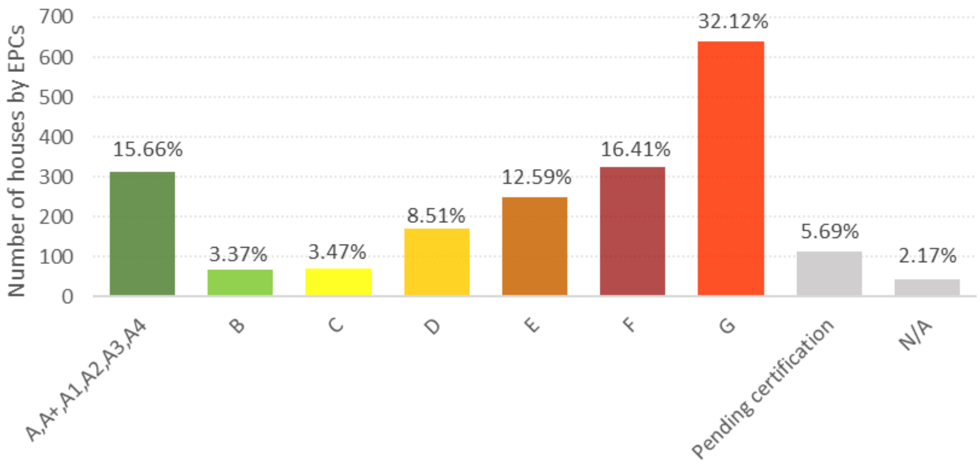


Figure 4-11: Distribution of number of houses by Energy Performance Certificates in the observed sample;
Source: excel, author’s ownership

Table 4-3: Distribution of building stocks by Energy Performance Certificates (EPCs); Source: ENEA, SIAPE

Building energy class	Number of different energy classes				Percentage of different energy classes			
	Observed sample	Milan Province	Lombardy	Italy	Observed sample	Milan Province	Lombardy	Italy
A,A+,A1,A2,A3,A4	311	28,260	119,006	464,140	15.66%	7.32%	11.26%	9.41%
B	67	14,616	47,239	160,277	3.37%	3.79%	4.47%	3.25%
C	69	29,813	79,843	289,778	3.47%	7.72%	7.55%	5.87%
D	169	65,505	155,403	583,350	8.51%	16.97%	14.70%	11.82%
E	250	76,432	178,458	815,884	12.59%	19.80%	16.88%	16.54%
F	326	86,537	207,172	1,127,233	16.41%	22.42%	19.60%	22.85%
G	638	84,898	269,901	1,493,284	32.12%	21.99%	25.53%	30.27%
N/A	156	-	-	-	7.85%	-	-	-
Total	1,986	386,061	1,057,022	4,933,946	100.00%	100.00%	100.00%	100.00%

Note: Province of Milan, Lombardy Region, Italy in ENEA, SIAPE statistics as of 18/09/2023

In addition, according to the observed sample to analyse the relationship between building energy efficiency class and building condition, the houses with building energy efficiency class "A, A+, A1, A2, A3, A4 and B" are either newly built houses or refurbished houses.

The building condition in the observed sample is shown in Figure 4-12 below, which shows that more than 90% of the houses provided by the market are in good condition, with some of the houses needing to be repaired and renovated.

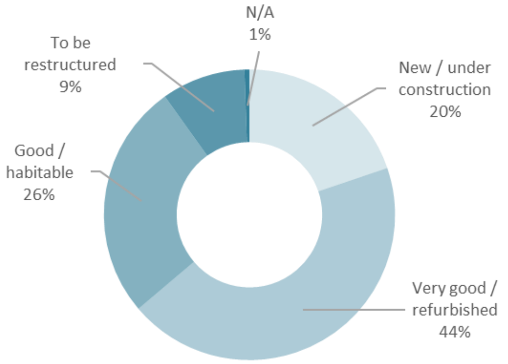


Figure 4-12: Distribution of number of houses by building condition; Source: excel, author's ownership

According to the relevant regulations and the MEPR in the previous, the air conditioning and heating systems in a building are important for occupant comfort as well as building energy efficiency.

Autonomous AC units are specifically engineered for localized climate control within individual rooms or designated spaces. These self-contained systems operate independently, often requiring no complex installation. They include their own components like compressors and condensers and are commonly installed in windows or through walls. Autonomous AC systems provide a high level of occupant comfort, as they allow precise control of temperature in each area where they are used. Additionally, they tend to be energy-efficient when used appropriately, as they cool or heat only the spaces that require it. This makes them a favourable choice for smaller areas or for occupants who prefer personalized temperature control.

Central AC, in contrast, is engineered to condition the air throughout an entire building or a large area. It's a comprehensive system characterized by a single, often large, central unit typically located outside the building. Central AC uses a network of ducts to distribute conditioned air to various rooms or zones within the building. While it offers centralized temperature control and is ideal for cooling or heating large spaces, it may not provide the same level of energy efficiency as autonomous units in smaller areas, as it conditions the entire building regardless of specific needs.

Air Conditioning System Preparation refers to the proactive steps taken to ensure that a building is ready to accommodate the installation of an air conditioning system in the future. This preparation involves having the necessary infrastructure in place, which could include electrical connections, ventilation ducts, and designated spaces for equipment. While there may not be an active air conditioning system at the time of preparation, the goal is to make the building "ready" for such an installation when the need arises. This approach allows for flexibility and scalability, ensuring that the building can adapt to changing temperature control requirements over time.

Autonomous heating systems, also referred to as decentralized or individual heating systems, are designed to provide heating to single buildings or residential units independently. In this setup, each building has its own dedicated heating unit, which could be a furnace, boiler, or heat pump. So, autonomous heating systems are particularly common in areas where centralized heating infrastructure may be lacking or in smaller, stand-alone buildings. They offer the advantage of individual control and customization, allowing occupants to tailor their heating preferences to their needs. However, they may be less efficient in terms of energy consumption, especially when compared to centralized systems serving multiple buildings.

Centralized heating systems, also known as district heating or central heating, in this setup, a single heating plant or facility generates heat from a central source, often a power plant, boiler, or renewable energy source. This heat is then distributed through a network of pipes to multiple buildings or homes within the vicinity. Centralized heating systems are commonly found in urban areas and regions with a well-developed heating infrastructure. They are known for their efficiency and cost-effectiveness, as they can serve multiple buildings with a single heating source. This can lead to energy savings and reduced environmental impact, especially when cleaner energy sources are used for centralized heating.

Gas/Methane Heating relies on the combustion of fossil fuels. Photovoltaic/Solar-Powered Heating utilizes solar panels to generate electricity and often benefits from incentives to promote renewable energy. Heating powered by a heat pump involves the use of a heat transfer process to extract heat from the environment (air, ground, or water) and transfer it into the building. Heat Pump Heating is highly energy-efficient and may be supported by policies promoting energy efficiency and environmentally friendly technologies.

And at the end of the heating systems, homeowners can independently adjust room heating temperatures by controlling the radiator switches, contributing to energy savings to some extent.

Statistical analysis of the air conditioning and heating systems of the observed sample shows that 57% of the houses are provided with autonomous air conditioning system; 71% of the houses are provided with centralised heating system (Figure 4-13). In terms of how the heating system radiates, 65% of the houses radiate heat through radiators.

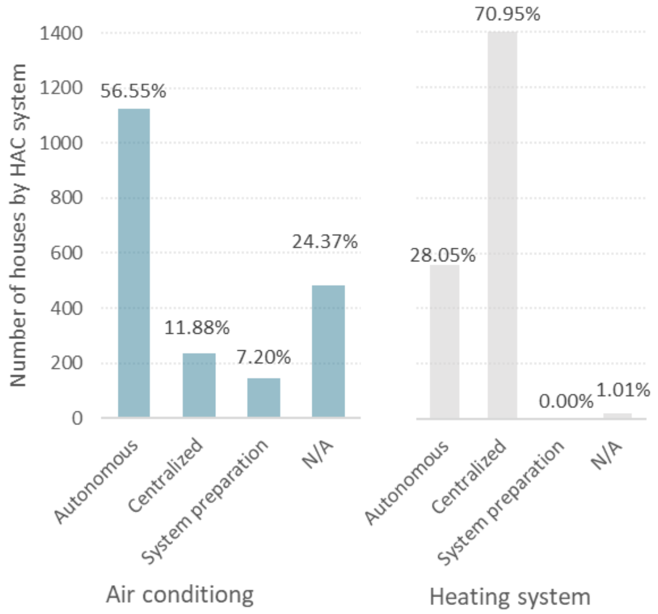


Figure 4-13: Distribution of number of houses by Heating and Air Conditioning systems; Source: excel, author's ownership

In the observed sample, the energy sources of the heating systems are photovoltaic powered and solar powered mainly in new buildings with energy efficiency class A and above. In 70% of the houses, the energy source of the heating system is methane and gas (Figure 4-14).

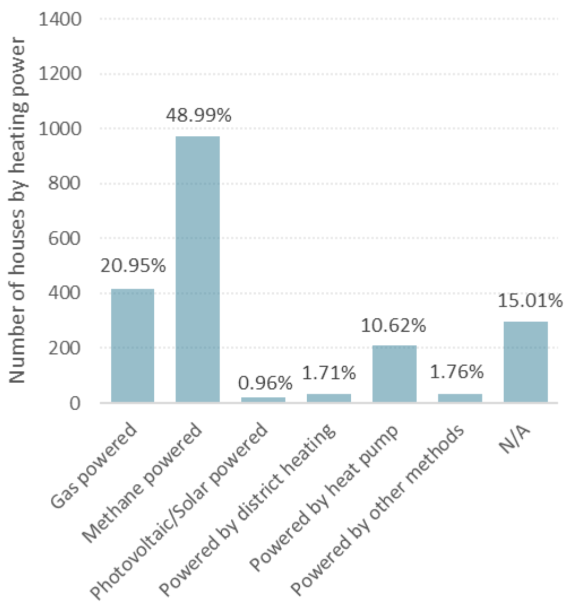


Figure 4-14: Distribution of number of houses by Heating power; Source: excel, author's ownership

4.4.3 Data Generating Process

Transformation of independent variables

(1) The primary objective of the case study is to estimate the average premium effect, in terms of house price per square meter, resulting from each incremental increase in

building energy efficiency level through energy efficiency renovation activities. Building energy efficiency improves as moving energy performance certificate level from G to A, and as such, the variable representing building energy efficiency is transformed into a discrete numerical variable. Houses with an EPC of G are assigned a value of 1; with an EPC of F are assigned a value of 2; and so on, with the EPC levels of A, A+, A1, A2, A3, and A4 being assigned values from of 7. After removing data from the data set that lacks EPC information, we have 1,830 valid data in the data set. (2) According to the housing types, the dummy variable is grouped into five groups: apartment; attic; lofts; villa; others. (3) The dummy variable is grouped by building condition into five groups: new/under construction; very good/refurbished; good/habitable; to be restructured; NA. (4) According to the air conditioning system, the dummy variable is divided into four groups: autonomous system; centralised system; system preparation; NA. (5) The heating system is divided into three groups: autonomous system; centralised system; NA. (6) According to the heating system of radiating, the dummy variable is divided into four groups: to radiators; by air; on the floor; NA. (7) According to the energy source of the heating system, the dummy variable is divided into five groups: gas/methane powered; photovoltaic/solar powered; powered by heat pump; powered by other methods; NA. (8) According to the year of built, the dummy variable is divided into eight groups: built before 1945; 1945-1969; 1970-1979; 1980-1989; 1990-1999;2000-2010; built after 2010; NA.

Three dummy variables are also set for the presence or absence of car parking, the presence or absence of a lift, and whether it is a nearly zero energy or not. 28% of the houses in the observed sample provide car parking, and 83% of the houses provide a lift.

Numeric transformations

Due to the data recognition problem of R software, for the case that the data under some variables in the original data set is "⩾ a certain value or a certain value +", it will be converted to a value greater than or equal to that value.

- Number_of_rooms: “5+” transforms into “6”;
- Number_of_bathrooms: “3+” transforms into “3”;

By considering the total sale price and the floor area, we can calculate the house price per square meter. We have chosen the unit sale price of a house as the dependent variable. To avoid issues of multicollinearity, it is necessary to exclude the variable of floor area from the independent variables.

After the above data grouping and transformation, the data set for R software analysis is initially obtained. (Table 4-4)

Table 4-4: Initial data set including all variables for the linear regression model; Source: excel, author's ownership

Data	Variables
Dependent variable:	
House price per square metre	in euros
Structural characteristics:	
Number of rooms	discrete number
Number of bathrooms	discrete number
Total floor	discrete number
Floor level	discrete number
EPC (Energy Performance Certificate) level	discrete number
Nearly zero energy buildings	yes=1; no=0
Presence of car parking	yes=1; no=0
Presnece of elevator	yes=1; no=0
Housing type	
Apartment	yes=1; otherwise=0
Attic	yes=1; otherwise=0
Lofts	yes=1; otherwise=0
Villa	yes=1; otherwise=0
Others	yes=1; otherwise=0
Year of built	
<1945	yes=1; otherwise=0
1945-1969	yes=1; otherwise=0
1970-1979	yes=1; otherwise=0
1980-1989	yes=1; otherwise=0
1990-1999	yes=1; otherwise=0
2000-2010	yes=1; otherwise=0
>2010	yes=1; otherwise=0
NA	yes=1; otherwise=0
Building condition	
New / under construction	yes=1; otherwise=0
Very good / refurbished	yes=1; otherwise=0
Good / habitable	yes=1; otherwise=0
To be restructured	yes=1; otherwise=0
NA	yes=1; otherwise=0
Air conditioning	
Autonomous system	yes=1; otherwise=0
Centralized system	yes=1; otherwise=0
System preparation	yes=1; otherwise=0
NA	yes=1; otherwise=0
Heating system	
Autonomous system	yes=1; otherwise=0
Centralized system	yes=1; otherwise=0
NA	yes=1; otherwise=0
Radiation of heating system	
By radiator	yes=1; otherwise=0
By air	yes=1; otherwise=0
On the floor	yes=1; otherwise=0
NA	yes=1; otherwise=0
Heating power of heating system	
Gas/Methane powered	yes=1; otherwise=0
Photovoltaic/solar powered	yes=1; otherwise=0
Heating pump	yes=1; otherwise=0
Others	yes=1; otherwise=0
NA	yes=1; otherwise=0
Accessibility characteristic:	
Distance to city centre (Duomo)	in meters
Distance to Metro stop	in meters
Distance to kindergarden	in meters
Distance to primary school	in meters
Distance to secondary school	in meters
Distance to supermarket	in meters
Distance to hospital	in meters

The analysis to this point has assumed that the data in hand, X and y, are well measured and correspond to the six assumptions of the linear regression model. However, in the real world, the observed nonexperimental data fail to meet the assumptions. Failure of the assumptions generally has implications for the performance of the estimators of the model parameters—unfortunately, none of them are good.

Outliers

Identify potential outliers in the data that could significantly influence the results. Use statistical methods, such as box plots or z-scores, to detect outliers. Consider the nature of the outliers and decide whether they should be removed or handled separately.

In R, the list price of the sample is analysed and the average price of the houses is 5,921 euros per square meter. The box and whisker plot graph shows that there is a portion of the sample that has a list price higher than 11,771.92 euros per square meter, which belongs to the outliers (Figure 4-15). For the outliers, although in the luxury real estate, extreme high-priced houses could be considered outliers but may also be the focus of the analysis. The data represented by this fraction of outliers is subjected to a linear regression analysis, it was found that the impact of building energy performance certificates on the houses produced is not significant. This is because the focus of the analysis is on the premium effect of building energy efficiency on house prices in the general residential market. In the luxury real estate market represented by this set of outliers, the main factors affecting house prices are the location and floor area of the house, compared to which the building energy efficiency class has a negligible effect on house prices. Therefore, the data for these outliers is removed. After removing the outliers, we have 1,772 valid data in our sample pool. The density of the list house price data with outliers removed shows a distribution much closer to normal (Figure 4-16).

According to *immobiliare.it*, the average transaction price in the Milan residential market in February 2023 is 5,199 euros per m2. After removing the outliers, the average house price of the sample is 5,653 euros per m2. The average price of the sample is slightly higher than the overall average transaction price of the website, because the asking price in website adverts is often higher than the actual transaction price, as described in Chapter 4.2.

```
List_price_Euros_per_m2
Min.   : 1739
1st Qu.: 4083
Median : 5425
Mean   : 5921
3rd Qu.: 7158
Max.   :25641
```

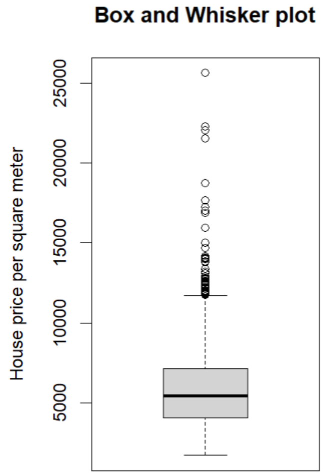


Figure 4-15: Statistics of sale price of residential houses in Milan before deleting outliers; Source: R

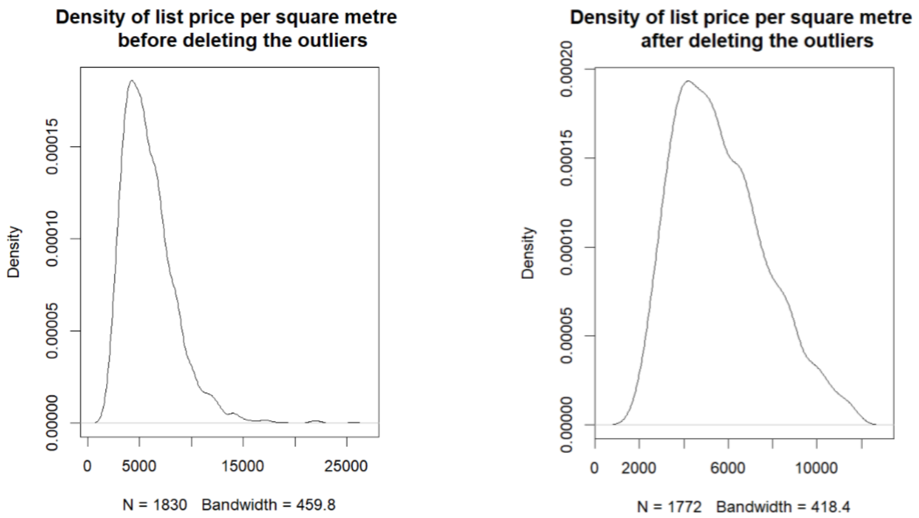


Figure 4-16: Density plot of list house price per square meter before and after deleting the outliers;
Source: R

Missing values

Gaps in X and/or y can be harmless. In many cases, the analyst can simply ignore them, and just use the complete data in the sample. In other cases, when the data is missing for reasons that are related to the outcome being studied, ignoring the problem can lead to inconsistency of the estimators.

The variables in the data set that involve missing values are "number of bathrooms", "total floors", and "floor level”. For missing values in the variables "number of bathrooms", "total floors", and "floor level", the sample median of the existing values are considered to replace the missing values.

Due to the data recognition problem of R software, for the case that the data under some variables in the original data set is "⩾ a certain value or a certain value +", it will be converted to a value greater than or equal to that value as mentioned before.

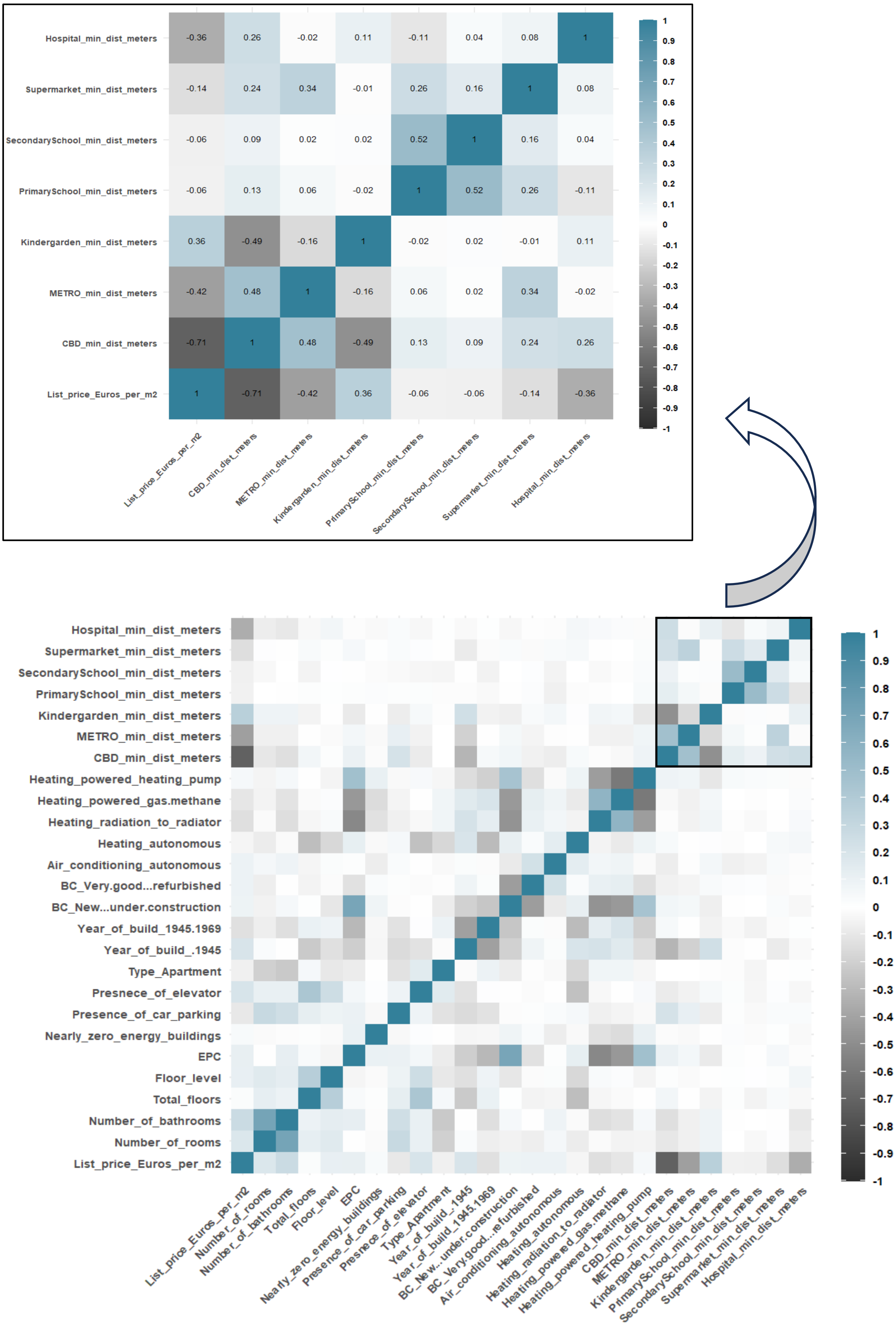
Correlation analysis

Select variables and perform correlation analysis. The correlation coefficient is a statistical measure that quantifies the strength and direction of the linear relationship between two variables. The value of the correlation coefficient is bounded in the interval [-1,1]. A positive value indicates a positive correlation, meaning that as one variable increases, the other variable tends to increase as well. Conversely, a negative value indicates a negative correlation, where one variable tends to decrease as the other variable increases. The magnitude of the correlation coefficient indicates the strength of the relationship. A value close to +1 or -1 indicates a strong correlation, meaning that the variables are closely related and their data points align closely around a straight line. A value close to 0 indicates a weak correlation, implying that there is little or no linear relationship between the variables.

As can be seen from Figure 4-17 below, the house price shows a strong negative correlation with the distance to the city centre, the distance to the metro stations, and the distance to the hospital; and a strong positive correlation with the number of bathrooms, and the distance to the kindergarten.

In terms of the independent variables, the variable of number of rooms shows a strong positive correlation with the number of bathrooms. The level of an energy performance certificate for a building exhibits a strong correlation with the building's construction year, its overall condition, and the heating system. Notably, there is a strong positive correlation between newly constructed buildings and their level of EPCs. The variable of whether a building is nearly zero-energy has less significant correlation with other factors. Additionally, it's worth noting that there is a strong negative correlation between the distance to a kindergarten and the distance to the city center. Given that the distance to the city center has a strong negative impact on house prices, this, in turn, affects the influence of the distance to a kindergarten on house prices. The independent variables of distance to primary school and distance to secondary school are not highly correlated with house prices, but there is a strong positive correlation between these two independent variables.

Figure 4-17: Correlation heatmap among variables, Source: R



VIF analysis

In order to detect multicollinearity between independent variables, VIF is computed for independent variables in the model. The value of VIF is a real number greater than or equal to 1. Usually, the larger the value of VIF, the stronger the correlation between the independent variable and other independent variables, and the more serious multicollinearity problem exists. In general, a VIF is considered "excessive" when its value is greater than 5. If the multicollinearity between the independent variables is severe, further DGP analysis of the independent variables is required.

In order to avoid the dummy variable trap, remove the "others" dummy variable in the category of housing type, remove "N/A" dummy variable in the categories of year of built, building condition, air condition, heating system, heating radiation, heating power. Subsequently, the remaining independent variables are added to Model 1 to calculate VIF values, and the results are shown in Model I of Table 4-5. It is found that the independent variables with VIF values greater than or equal to 5 are dummy variables, especially variables under building type, building condition, and heating system show very high VIF values. These results may still be caused by the dummy variable trap.

Adjust the dummy variables to be deleted under each category, and remove the dummy variable with the highest proportion in each category, remove the dummy variable "apartment" under housing type category. Remove "1945-1969" dummy variable in the categories of year of built. Remove the dummy variable "Very good / refurbished" for building condition, "Autonomous" for air conditioning, and "Autonomous" for heating system. Remove the dummy variable "To radiators" for heating radiation. Remove the dummy variable "Methane/gas powered" from the category of heating power. Then, the remaining independent variables are added to Model II to calculate VIF values, and the results are shown in Model II of Table 4-5. This time, the VIF values of all independent variables are less than 5.

Table 4-5: VIF values of independent variables in different models; Source: R

Independent variables	VIF values	
	Model Ⅰ	Model Ⅱ
Structural characteristics:		
Number of rooms	2.32	2.31
Number of bathrooms	2.23	2.24
Total floor	1.50	1.50
Floor level	1.35	1.35
EPC (Energy Performance Certificate) level	3.05	3.06
Nearly zero energy buildings	1.14	1.14
Presence of car parking	1.33	1.33
Presnece of elevator	1.50	1.50
Housing type		
Apartment	20.21	-
Attic	12.70	1.18
Lofts	5.78	1.10
Villa	4.67	1.18
Others	-	1.06
Year of built		
<1945	4.53	1.70
1945-1969	5.09	-
1970-1979	2.77	1.23
1980-1989	1.27	1.09
1990-1999	1.42	1.15
2000-2010	2.09	1.40
>2010	4.97	3.74
NA	-	1.34
Building condition		
New / under construction	36.33	2.64
Very good / refurbished	54.11	-
Good / habitable	43.90	1.43
To be restructured	19.70	1.36
NA	-	1.11
Air conditioning		
Autonomous system	1.83	-
Centralized system	2.05	1.53
System preparation	1.45	1.18
NA	-	1.40
Heating system		
Autonomous system	28.03	-
Centralized system	28.41	1.57
NA	-	1.30
Radiation of heating system		
By radiator	6.61	-
By air	2.78	1.51
On the floor	5.56	1.81
NA	-	1.79
Heating power of heating system		
Gas/Methane powered	2.92	-
Photovoltaic/solar powered	1.22	1.18
Heating pump	2.71	2.04
Others	1.24	1.08
NA	-	1.66
Accessibility characteristic:		
Distance to city centre (Duomo)	2.40	2.40
Distance to Metro stop	1.57	1.57
Distance to kindergarden	1.53	1.53
Distance to primary school	1.56	1.56
Distance to secondary school	1.44	1.44
Distance to supermarket	1.29	1.29
Distance to hospital	1.33	1.33

4.5 Building Linear Model and Regression Analysis

After completing the basic preprocessing of the data set, as well as checking for correlation and multicollinearity issues, we will proceed to establish a linear model using the processed data set in R software and conduct regression analysis.

The statistical principle behind the linear model function in R is the method of least squares. The linear regression model estimated by linear model aims to minimize the sum of squared residuals, which is the difference between the observed values of the dependent variable and the predicted values from the linear equation.

The method of least squares assumes that the relationship between the dependent variable and the independent variables can be modelled by a linear equation. It seeks to find the best-fitting line that minimizes the overall discrepancy between the observed data points and the predicted values. This discrepancy is quantified as the sum of squared residuals, and the goal is to minimize this value.

The linear model function estimates the coefficients (slopes) and the intercept of the linear equation by calculating the values that minimize the sum of squared residuals. It uses mathematical techniques such as matrix algebra and optimization algorithms to perform this estimation.

Once the coefficients are estimated, various statistical measures are calculated, such as standard errors, t-values, p-values, and the R-squared value. These measures provide information about the significance of the coefficients, the overall fit of the model, and the strength of the relationship between the variables.

By minimizing the sum of squared residuals, the linear model function provides a statistical framework for estimating the parameters of a linear regression model and assessing the goodness of fit. It allows researchers to make inferences about the relationships between variables and make predictions based on the estimated model.

4.5.1 OLS linear regression models

First, considering all types of independent variables, we input all the observed data from the data set into R software to establish an OLS linear regression model. The results are shown in Table 4-6.

In this OLS linear regression analysis, there are 1,772 valid observations. The dependent variable is the house sale price per square meter. For the fit of the OLS model, the value of 88.47 based on the F-statistic with a p-value of 0.00 indicates that the model is statistically significant. R^2 is 0.68, indicating that approximately 68% of the variance in the dependent variable is explained by the model. And $\overline{R^2}$ is 0.67.

The estimated constant value is 7,266.14, which means that the mean value of house price, without considering the effect of the independent variables listed in the Table 4-6 on house price, is 7,266.14 euros per square meter.

For the estimated coefficients of the independent variables, a positive coefficient indicates a positive relationship between the independent variable and the dependent variable. For example, the estimated coefficient for "Number of bathrooms" is 289.07, which means that, with all other variables held constant, for every additional bathroom, the estimated house price per square meter increases by 289.07 euros. And the estimated coefficient for "Energy Performance Certificate level " is 54.66, which means that, with all other variables held constant, for each level increase in EPC, the estimated house price per square meter increases by 54.66 euros.

A negative coefficient indicates a negative relationship between the independent variable and the dependent variable. For example, the estimated coefficient for "Distance to city centre" is -0.4. This means that for every additional 1,000 meters a house is located away from the city centre, the house price will decrease by 400 euros per square meter, holding all other variables constant.

For the dummy variables, holding other variables constant, a building with an elevator has a positive impact on house price, with the house price per square meter increasing by 568.47 euros. For the dummy variable by categories, in the case of building condition, for example, since the dummy variable for “building in very good or refurbished condition” is excluded from the OLS linear regression model, the estimated coefficients for the other types of building condition represent the difference in the impact on the mean house price per square meter between that building condition and the building in very good or refurbished condition. For example, holding other variables constant, the average value of the house price per square meter is 179.29 euros higher for the house with a building in new or under construction condition than for the house with a building in very good or refurbished condition.

Table 4-6: OLS linear regression model including all variables; Source: R

	Est.	2.50%	97.50%	t val.	p	VIF
(Intercept)	7266.14	6895.13	7637.15	38.41	0.00	-
Structural characteristics:						
Number of rooms	6.70	-66.24	79.65	0.18	0.86	2.31
Number of bathrooms	289.07	171.96	406.19	4.84	0.00	2.24
Total floor	-29.67	-56.17	-3.17	-2.20	0.03	1.50
Floor level	123.97	93.75	154.18	8.05	0.00	1.35
EPC (Energy Performance Certificate) level	54.66	10.43	98.89	2.42	0.02	3.06
Nearly zero energy buildings	-353.57	-817.03	109.90	-1.50	0.13	1.14
Presence of car parking	-93.86	-236.40	48.68	-1.29	0.20	1.33
Presnece of elevator	568.47	391.43	745.52	6.30	0.00	1.50
Housing type						
Attic	274.86	8.12	541.60	2.02	0.04	1.18
Lofts	-172.77	-577.89	232.35	-0.84	0.40	1.10
Villa	504.42	32.26	976.58	2.10	0.04	1.18
Others	-1414.52	-2260.70	-568.34	-3.28	0.00	1.06
Year of built						
<1945	284.73	121.53	447.93	3.42	0.00	1.70
1970-1979	-59.06	-260.00	141.87	-0.58	0.56	1.23
1980-1989	-122.81	-668.26	422.64	-0.44	0.66	1.09
1990-1999	294.67	-143.35	732.68	1.32	0.19	1.15
2000-2010	517.93	230.08	805.78	3.53	0.00	1.40
>2010	-136.28	-425.29	152.72	-0.92	0.36	3.74
NA	41.65	-223.71	307.00	0.31	0.76	1.34
Building condition						
New / under construction	179.29	-47.52	406.11	1.55	0.12	2.64
Good / habitable	-359.15	-507.02	-211.27	-4.76	0.00	1.43
To be restructured	-639.23	-858.54	-419.91	-5.72	0.00	1.36
NA	-1375.64	-2194.30	-556.97	-3.30	0.00	1.11
Air conditioning						
Centralized system	506.85	284.53	729.17	4.47	0.00	1.53
System preparation	-297.73	-530.16	-65.29	-2.51	0.01	1.18
NA	-177.83	-329.07	-26.59	-2.31	0.02	1.40
Heating system						
Centralized system	71.35	-79.80	222.51	0.93	0.35	1.57
NA	-442.95	-1087.51	201.61	-1.35	0.18	1.30
Radiation of heating system						
By air	332.58	40.30	624.87	2.23	0.03	1.51
On the floor	226.34	43.89	408.79	2.43	0.02	1.81
NA	219.20	-82.34	520.74	1.43	0.15	1.79
Heating power of heating system						
Photovoltaic/solar powered	-68.96	-649.93	512.02	-0.23	0.82	1.18
Heating pump	42.90	-197.80	283.60	0.35	0.73	2.04
Others	88.06	-356.27	532.39	0.39	0.70	1.08
NA	226.06	16.79	435.33	2.12	0.03	1.66
Accessibility characteristic:						
Distance to city centre (Duomo) (in meters)	-0.40	-0.43	-0.37	-23.76	0.00	2.40
Distance to Metro stop (in meters)	-0.38	-0.45	-0.31	-10.17	0.00	1.57
Distance to kindergarden (in meters)	0.19	0.12	0.25	5.78	0.00	1.53
Distance to primary school (in meters)	-0.26	-0.51	-0.01	-2.08	0.04	1.56
Distance to secondary school (in meters)	0.00	-0.19	0.19	0.01	0.99	1.44
Distance to supermarket (in meters)	0.22	0.10	0.34	3.63	0.00	1.29
Distance to hospital (in meters)	-0.29	-0.32	-0.25	-15.05	0.00	1.33

MODEL INFO:	MODEL FIT:
Observations: 1772	*$F(42,1729) = 88.47$, $p = 0.00$*
Dependent Variable: House price per square metre	*$R^2 = 0.68$*
Type: OLS linear regression	*Adj. $R^2 = 0.67$*
Standard errors: OLS	

Subsequently, in order to further refine the selection of independent variables, the model in Table 4-6 is used as **Model 1** to compare with other models. By adjusting the independent variables included in different models, we systematically examine the statistical significance of the independent variables.

In the previous correlation analysis, a strong positive correlation between the independent variable "number of rooms" and the variable "number of bathrooms" is observed. However, as indicated by the results presented in Table 4-6, the P-value for the variable "number of rooms" is 0.86, significantly greater than 0.05. This suggests that there is no significant linear relationship between the independent variable "number of rooms" and the dependent variable “house price”. Consequently, in Model 2, the variable "number of rooms" has been excluded compared to the Model 1. The subsequent results are shown in **Model 2**.

Model 3 analyses the impact of the convenience of surrounding amenities on house price. From the earlier correlation analysis, it is evident that there is a weak correlation between the dependent variable “house price” and the independent variables “distance to primary school” and “distance to secondary school”, while the correlation between these two independent variables is stronger. Additionally, based on the results of Model 1 and Model 2, it is clear that the p-value for the independent variable “distance to secondary school” is relatively high, indicating that this variable does not significantly explain the variance in the dependent variable. To simplify the variables and eliminate non-correlated variables, the independent variable “distance to secondary school” has been removed in the subsequent computation of Model 3 based on Model 2. The R^2 values for Model 1, Model 2, and Model 3 are all 0.68, with Model 3 showing an improvement in the Adj. R^2 value from 0.67, compared to Model 1 and Model 2, to 0.68. This indicates a better fit for Model 3.

Model 4 removes the "housing type" independent variables from Model 3 to analyze the impact of such variables on the model's goodness of fit. The results from Model 4 show that the Adj.R^2 value decreases from 0.68 to 0.67 when these variables are removed, indicating a decrease in the overall model fit. Therefore, for simplification, these variables will be adjusted to "whether the housing is an apartment, yes=1, no=0."

From the results of Model 1, Model 2, and Model 3, it can be observed that the independent variables of "year of built" have relatively high p-value, indicating that these variables do not significantly explain the dependent variable “house price”. **Model 5**, based on Model 3, removes the " year of built " category of independent variables. Looking at the results of Model 5, the Adj. R^2 value decreases, indicating that removing these variables negatively impacted the overall model fit. Based on the analysis of building stock in Chapter 1.3.1, a significant portion of the building stock in Europe predates 1979. Therefore, to further simplify the treatment of these variables, the "year of built" variables will be adjusted to " whether the building was built before 1979, yes=1, otherwise=0."

Based on the p-values in the results of Model 1, Model 2, and Model 3, the "building condition" category of independent variables is statistically significant in explaining the dependent variable “house price”. **Model 6**, which removes the "building condition" independent variables based on Model 3, shows that both Adj.R^2 and R^2 values decrease, indicating a decrease in the model's fit. According to the analysis in Chapter 4.4.2, high levels of building energy efficiency (A+B) fall under the category of “new or refurbished” building condition. Therefore, to simplify the "building condition" independent variables, these variables will be adjusted to " whether new/refurbished, yes=1, otherwise=0".

Model 7 removes the "air conditioning systems" category of independent variables from Model 3 to perform a comparative analysis of the impact of these variables on the model's fit. The Adj. R^2 value decreases, indicating that removing this category of independent variables results in a decrease in the overall model fit. According to the statistical analysis in Chapter 4.4.2, 57% of the sampled houses have automatic air conditioning systems, which have a positive impact on energy savings and occupant comfort. Therefore, for the category of "air conditioning systems”, the variables will be simplified to "whether it is an automatic air conditioning system, yes=1, otherwise=0."

Model 8 removes all the independent variables related to heating systems from Model 3. The results of Model 8 show a decrease in the Adj. R^2 value. According to the statistical analysis in Chapter 4.4.2, 70% of the sampled houses have centralized heating systems, and radiators are the primary method of heat radiation at the end of the heating systems. The combination of centralized heating and radiator-based heat radiation is effective in maximizing energy savings while ensuring occupant comfort, both on the supply and usage sides. Therefore, the variables related to heating systems and radiation methods will be simplified into "whether it is centralized heating with radiator radiation, yes=1, otherwise=0".

Additionally, the analysis in Chapter 4.4.2 reveals that heating pump-powered supply accounts for about 10% of the sample statistics. While this is not a large percentage, heating pump-powered systems significantly improve the energy efficiency of buildings. As a result, the variable related to heating power will be simplified to "whether it is heating pump-powered, yes=1, otherwise=0" to assess its potential impact on house prices. The promotion of heating pump-powered supply is mainly related to community-level decisions rather than individual homeowners. If there is a premium effect on house price and considering the environmental benefits, it should be encouraged from a public policy perspective.

The results of different OLS linear regression models are shown in Table 4-7.

Table 4-7: The estimated results of different OLS linear regression models; Source: R

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
(Intercept)	7266.14 ***	7273.32 ***	7273.37 ***	7233.43 ***	7496.41 ***	7106.51 ***	7114.61 ***	7367.35 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Structural characteristics:								
Number of rooms	6.70	-	-	-	-	-	-	-
	(0.86)	-	-	-	-	-	-	-
Number of bathrooms	289.07 ***	296.04 ***	296.04 ***	311.17 ***	293.07 ***	288.89 ***	317.95 ***	311.02 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Total floor	-29.67 *	-29.60 *	-29.60 *	-29.14 *	-39.17 **	-29.89 *	-33.07 *	-27.03 *
	(0.03)	(0.03)	(0.03)	(0.03)	(0.00)	(0.03)	(0.01)	(0.04)
Floor level	123.97 ***	124.04 ***	124.04 ***	130.47 ***	117.97 ***	118.84 ***	126.72 ***	124.38 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
EPC (Energy Performance Certificate) level	54.66 *	54.68 *	54.68 *	56.55 *	54.53 **	92.07 ***	66.14 **	67.62 **
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
Nearly zero energy buildings	-353.57	-353.71	-353.73	-353.75	-338.10	-277.30	-103.82	-281.26
	(0.13)	(0.13)	(0.13)	(0.14)	(0.15)	(0.25)	(0.66)	(0.23)
Presence of car parking	-93.86	-91.61	-91.62	-78.28	-78.22	-129.62	-77.92	-76.84
	(0.20)	(0.20)	(0.20)	(0.27)	(0.27)	(0.07)	(0.28)	(0.28)
Presnece of elevator	568.47 ***	568.63 ***	568.62 ***	576.72 ***	592.63 ***	533.40 ***	566.58 ***	579.57 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Housing type								
Attic	274.86 *	276.06 *	276.07 *	-	306.42 *	280.14 *	308.52 *	237.89
	(0.04)	(0.04)	(0.04)	-	(0.02)	(0.04)	(0.02)	(0.08)
Lofts	-172.77	-173.60	-173.58	-	-192.18	-91.00	-186.26	-143.07
	(0.40)	(0.40)	(0.40)	-	(0.35)	(0.66)	(0.37)	(0.49)
Villa	504.42 *	510.16 *	510.17 *	-	555.47 *	444.49	508.29 *	487.87 *
	(0.04)	(0.03)	(0.03)	-	(0.02)	(0.07)	(0.03)	(0.04)
Others	-1414.52 **	-1409.61 **	-1409.62 **	-	-1425.33 ***	-1365.94 **	-1386.03 **	-1339.25 **
	(0.00)	(0.00)	(0.00)	-	(0.00)	(0.00)	(0.00)	(0.00)
Year of built								
<1945	284.73 ***	285.47 ***	285.47 ***	289.38 ***	-	286.61 ***	322.88 ***	234.95 **
	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.00)	(0.00)	(0.00)
1970-1979	-59.06	-58.56	-58.55	-78.35	-	-52.88	-41.66	-77.26
	(0.56)	(0.57)	(0.57)	(0.45)	-	(0.61)	(0.69)	(0.45)
1980-1989	-122.81	-122.34	-122.32	-146.35	-	-187.70	-55.20	-198.11
	(0.66)	(0.66)	(0.66)	(0.60)	-	(0.50)	(0.84)	(0.47)
1990-1999	294.67	293.86	293.86	329.84	-	322.61	325.65	226.53
	(0.19)	(0.19)	(0.19)	(0.14)	-	(0.15)	(0.15)	(0.30)
2000-2010	517.93 ***	516.42 ***	516.44 ***	542.08 ***	-	595.87 ***	623.44 ***	476.61 ***
	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.00)	(0.00)	(0.00)
>2010	-136.28	-136.73	-136.71	-131.61	-	-20.01	-41.52	-96.08
	(0.36)	(0.35)	(0.35)	(0.37)	-	(0.89)	(0.78)	(0.49)
NA	41.65	42.48	42.50	85.16	-	138.34	59.96	81.88
	(0.76)	(0.75)	(0.75)	(0.53)	-	(0.31)	(0.66)	(0.53)
Building condition								
New / under construction	179.29	178.92	178.92	190.25	41.17	-	193.18	211.64
	(0.12)	(0.12)	(0.12)	(0.10)	(0.70)	-	(0.09)	(0.06)
Good / habitable	-359.15 ***	-357.43 ***	-357.43 ***	-351.28 ***	-388.39 ***	-	-363.83 ***	-379.34 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.00)	(0.00)
To be restructured	-639.23 ***	-636.46 ***	-636.46 ***	-627.48 ***	-666.73 ***	-	-700.74 ***	-643.25 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.00)	(0.00)
NA	-1375.64 **	-1373.11 **	-1373.14 **	-1244.67 **	-1366.47 **	-	-1364.45 **	-1264.11 **
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.00)	(0.00)
Air conditioning								
Centralized system	506.85 ***	506.16 ***	506.16 ***	512.76 ***	547.09 ***	497.69 ***	-	592.23 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	-	(0.00)
System preparation	-297.73 *	-297.55 *	-297.54 *	-298.70 *	-329.19 **	-220.33	-	-310.36 **
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.06)	-	(0.01)
NA	-177.83 *	-178.31 *	-178.31 *	-178.84 *	-170.16 *	-349.75 ***	-	-174.19 *
	(0.02)	(0.02)	(0.02)	(0.02)	(0.03)	(0.00)	-	(0.02)
Heating system								
Centralized system	71.35	72.40	72.41	53.09	-19.81	48.44	191.58 **	-
	(0.35)	(0.35)	(0.35)	(0.49)	(0.78)	(0.53)	(0.01)	-
NA	-442.95	-444.57	-444.57	-438.12	-431.90	-712.55 *	-506.59	-
	(0.18)	(0.18)	(0.18)	(0.18)	(0.19)	(0.03)	(0.13)	-
Radiation of heating system								
By air	332.58 *	331.06 *	331.06 *	308.21 *	347.77 *	314.90 *	419.92 **	-
	(0.03)	(0.03)	(0.03)	(0.04)	(0.02)	(0.04)	(0.00)	-
On the floor	226.34 *	226.05 *	226.05 *	220.89 *	132.46	236.34 *	273.67 **	-
	(0.02)	(0.02)	(0.02)	(0.02)	(0.14)	(0.01)	(0.00)	-
NA	219.20	218.20	218.23	174.31	168.66	222.28	290.80	-
	(0.15)	(0.16)	(0.15)	(0.26)	(0.27)	(0.15)	(0.06)	-
Heating power of heating system								
Photovoltaic/solar powered	-68.96	-68.17	-68.19	-75.59	-174.14	-55.32	-69.37	-
	(0.82)	(0.82)	(0.82)	(0.80)	(0.55)	(0.85)	(0.82)	-
Heating pump	42.90	43.40	43.40	37.32	-9.99	68.07	136.70	-
	(0.73)	(0.72)	(0.72)	(0.76)	(0.93)	(0.58)	(0.26)	-
Others	88.06	89.21	89.24	119.27	41.80	123.47	145.41	-
	(0.70)	(0.69)	(0.69)	(0.60)	(0.85)	(0.59)	(0.52)	-
NA	226.06 *	227.57 *	227.55 *	219.75 *	217.43 *	241.56 *	193.34	-
	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.02)	(0.07)	-
Accessibility characteristic:								
Distance to city centre (Duomo) (in meters)	-0.40 ***	-0.40 ***	-0.40 ***	-0.40 ***	-0.41 ***	-0.40 ***	-0.41 ***	-0.41 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to Metro stop (in meters)	-0.38 ***	-0.38 ***	-0.38 ***	-0.39 ***	-0.37 ***	-0.39 ***	-0.38 ***	-0.37 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to kindergarden (in meters)	0.19 ***	0.19 ***	0.19 ***	0.19 ***	0.20 ***	0.20 ***	0.19 ***	0.18 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to primary school (in meters)	-0.26 *	-0.26 *	-0.26 *	-0.28 *	-0.20	-0.26 *	-0.29 **	-0.25 *
	(0.04)	(0.04)	(0.02)	(0.01)	(0.07)	(0.02)	(0.01)	(0.03)
Distance to secondary school (in meters)	0.00	0.00	-	-	-	-	-	-
	(0.99)	(1.00)	-	-	-	-	-	-
Distance to supermarket (in meters)	0.22 ***	0.22 ***	0.22 ***	0.22 ***	0.23 ***	0.21 ***	0.24 ***	0.20 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to hospital (in meters)	-0.29 ***	-0.29 ***	-0.29 ***	-0.28 ***	-0.28 ***	-0.29 ***	-0.29 ***	-0.28 ***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	1772	1772	1772	1772	1772	1772	1772	1772
R^2	0.68	0.68	0.68	0.68	0.68	0.67	0.68	0.68
Adj. R^2	0.67	0.67	0.68	0.67	0.67	0.67	0.67	0.67

Notes:
Dependent variable: house price per square meter.
Beneath each parameter estimate is given the p-value for the parameter in parentheses.
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

In summary, after selection and organization, the number of independent variables has been reduced from 49 to 19, as shown in Table 4-8. In order to make the interpretation of the dependent variable house price more intuitive, the unit of the accessibility independent variables is adjusted from "in meters" to "in kilometers". The adjustment in the unit of measurement does not have any effect on the models' goodness of fit and the interpretation and significance of the other variables. The simplified independent variables can be primarily categorized into three groups: variables representing building structural characteristics, variables reflecting building energy efficiency and occupant comfort, and variables representing social perspective characteristics of public transportation and public services.

Table 4-8: Processed data set with the filtered variables for the subsequent regression analysis;
Source: excel, author's ownership

Data	Variables
Dependent variable:	
House price per square metre	in euros
Structural characteristics:	
Number of bathrooms	discrete number
Total floor	discrete number
Floor level	discrete number
Presence of car parking	yes=1; no=0
Presnece of elevator	yes=1; no=0
Housing is an apartment	yes=1; otherwise=0
Year of built before 1979	yes=1; otherwise=0
Building in new / refurbished condition	yes=1; otherwise=0
Environment and comfort characteristics:	
EPC (Energy Performance Certificate) level	discrete number
Nearly zero energy buildings	yes=1; no=0
Autonomous AC	yes=1; otherwise=0
Centralized heating with radiators	yes=1; otherwise=0
Heat pump heating	yes=1; otherwise=0
Social characteristics:	
Public transport	
Distance to city centre (Duomo)	in kilometers
Distance to Metro stop	in kilometers
Public service	
Distance to kindergarden	in kilometers
Distance to primary school	in kilometers
Distance to supermarket	in kilometers
Distance to hospital	in kilometers

4.5.2 Regression analysis

The 19 filtered variables are put back in R to rerun the OLS linear regression analysis and the results obtained are shown in Model A of Table 4-9. As can be seen from the findings observed in Model A of Table 4-9, indicating the non-significance of certain independent variables such as "Presence of car parking," "Housing type_apartment," "Year of built before 1979," "Nearly zero energy buildings," "Autonomous AC," and "Heat pump heating." In order to enhance the interpretability of the key factors influencing house price, Model B is organized by eliminating these statistically non-significant independent variables, yielding the results present in Model B of Table 4-9.

The Figure 4-18 presents a more visual comparison between Model A and Model B. In Model A, a comprehensive set of predictors, encompassing structural, environmental, and social characteristics, is initially considered. Subsequently, in the creation of Model B, a more discerning approach is adopted, wherein statistically non-significant variables are purposefully omitted. This nuanced model refinement aligns with economic principles, as it seeks to distill the essential factors influencing house price while discarding variables that fail to contribute meaningfully to the predictive capacity of the model. The utilization of confidence intervals in the visual comparison is indicative of the robustness and precision of the estimated coefficients. For the coefficients of the important independent variables, there is no significant difference in the confidence intervals between Model B and Model A. From an economic standpoint, this instills confidence in the reliability of the regression findings, as it conveys the level of certainty associated with the estimated effects of the important independent variables on house price.

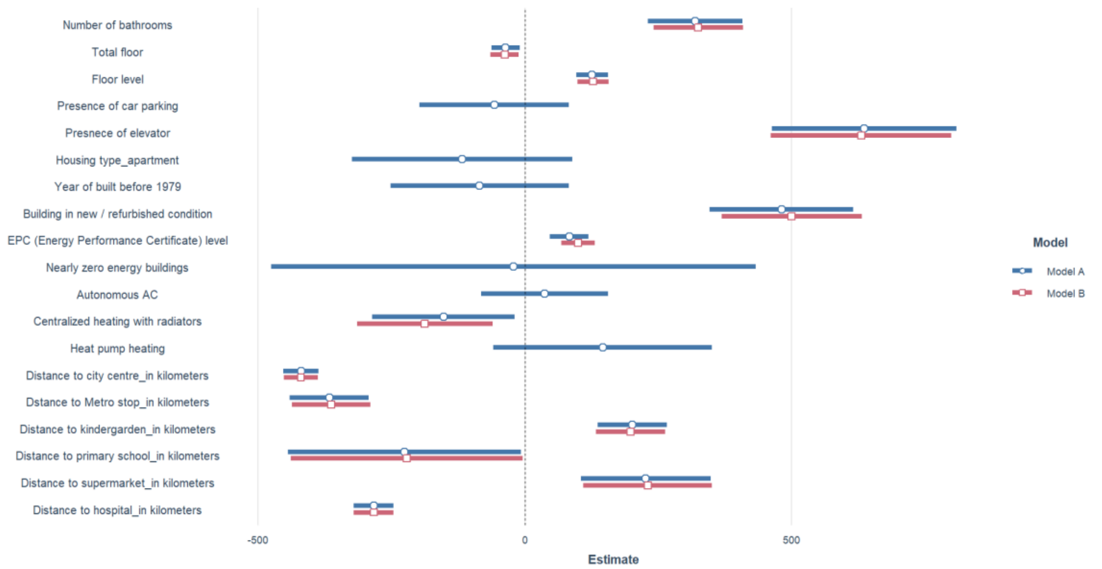


Figure 4-18: Comparison of the coefficients and their confidence intervals between the Model A and Model B,

Source: R

The estimated INTERCEPT value is 6,956.59, demonstrating statistical significance with a p-value below 0.001. it represents the estimated house price per square meter is 6,956.59 euros per square meter when all other predictors are zero. In other words, this is the baseline price. And based on data set prediction, there is a 95% probability that the true population value of the house price will fall within the [6,626.11, 7,287.07] range.

From the results of the impact of variables representing building structural characteristics on the dependent variable, house price, in Milan's residential real estate market, it appears that homebuyers tend to pay higher price for larger units with elevators, located on higher floor in newly constructed or renovated buildings. Conversely, ultra-high-rise buildings are less favored in the market and have a negative effect on house price. In contrast to the aforementioned building structural characteristics, features such as "presence of car parking," "housing type," and "year of built" do not play a decisive role in homebuyers' considerations when paying for house price. Specifically, the estimated coefficient for the house under the "new built or refurbished" building condition is 500. This house has, on average, the price per square meter is 500 euros higher compared to the house in other building condition categories.

Looking at the results of the impact of variables representing building environment and living comfort characteristics on the dependent variable, house price, the improvement in the Energy Performance Certificate level has a very positive effect on house price. The estimated coefficient for the EPC level is 99.43. For each increase in the EPC level, the house price per square meter increases by 99.43 euros, holding other independent variables constant. It's worth noting that although Milan's residential real estate market provides information about nearly zero-energy buildings, the air conditioning systems, and the energy sources for building heating, consumers' feedback suggests that these factors do not have a decisive impact on homebuyers' willingness to pay. Milan, as the economic center of Italy with well-developed urban infrastructure, receives negative feedback from homebuyers regarding the heating system, specifically the centralized heating system with radiators, which is energy-efficient but not well-received. The reasons behind this negative feedback need to be further explored.

The location of the house has a significant impact on house price. Homebuyers are more willing to reside in the city center or closer to public transportation stops. Specifically, based on the results reflected in Model B of Table 4-9, the estimated coefficient for the distance from the city center (Duomo) in kilometers is -419.3. For every one kilometer increase in the distance to the city center, the estimated house price per square meter decreases by 419.3 euros, holding other variables constant. The estimated coefficient for the distance from metro stops in kilometers is -362.57. The negative impact of these two variables on house price underscores the strong demand among citizens for convenient commuting options between their homes and workplaces. Regarding the surrounding public service facilities, the closer the distance to primary school and hospital, the more willing buyers are to pay higher price. Conversely, the distance to kindergarden and supermarket has a reverse effect on house price, with price being higher when these amenities are farther away. Specifically, the estimated coefficient for the distance from a primary school in kilometers is -220.98. The estimated coefficient for the distance from a hospital in meters is -283.12.

Table 4-9: OLS linear regression analysis;
Source: R

	Model A	Model B
(Intercept)	7139.91 *** (0.00)	6956.59 *** (0.00)
Structural characteristics:		
Number of rooms	319.59 *** (0.00)	324.70 *** (0.00)
Total floor	-35.92 ** (0.01)	-37.64 ** (0.00)
Floor level	126.08 *** (0.00)	128.09 *** (0.00)
Presence of car parking	-57.05 (0.42)	- -
Presnece of elevator	635.98 *** (0.00)	629.88 *** (0.00)
Housing type_apartment	-117.19 (0.27)	- -
Year of built before 1979	-84.44 (0.32)	- -
Building in new / refurbished condition	481.20 *** (0.00)	500.00 *** (0.00)
Environment and comfort characteristics:		
EPC (Energy Performance Certificate) level	83.26 *** (0.00)	99.43 *** (0.00)
Nearly zero energy buildings	-20.75 (0.93)	- -
Autonomous AC	37.06 (0.54)	- -
Centralized heating with radiators	-152.34 * (0.02)	-187.09 ** (0.00)
Heat pump heating	146.14 (0.16)	- -
Social characteristics:		
Public transport		
Distance to city centre_in kilometers	-418.88 *** (0.00)	-419.30 *** (0.00)
Dstance to Metro stop_in kilometers	-365.94 *** (0.00)	-362.57 *** (0.00)
Public service		
Distance to kindergarden_in kilometers	201.77 *** (0.00)	198.36 *** (0.00)
Distance to primary school_in kilometers	-225.31 * (0.04)	-220.98 * (0.05)
Distance to supermarket_in kilometers	226.83 *** (0.00)	230.10 *** (0.00)
Distance to hospital_in kilometers	-283.09 *** (0.00)	-283.12 *** (0.00)
Number of observations	1772	1772
R^2	0.66	0.66
Adj. R^2	0.66	0.66

Notes:
Dependent variable: house price per square meter.
Beneath each parameter estimate is given the p-value for the parameter in parentheses.
*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

5. The Further Promotion of Building Energy Efficiency Renovations

Building energy efficiency is a cornerstone of sustainable development, offering multifaceted benefits that extend beyond energy savings. In the context of Milan's residential real estate market analysis, a thorough examination of factors representing building structure, environmental and comfort, and social considerations has been conducted. Taking into account the results of the case study, the improvement of building Energy Performance Certificate indeed brings a premium effect to house price, the subsequent sections of this thesis will further delve into an economic perspective by comparing this premium benefit with the cost of building renovation to discuss the feasibility of building energy efficiency renovations. Furthermore, there will be additional discussions concerning the environmental and societal impacts stemming from building energy efficiency renovations.

5.1 Economic Perspective

When examining the challenges within the realm of building energy efficiency renovations, it's evident that significant disparities exist in the funding allocated by the European public sector compared to the extensive building stock. Furthermore, according to the 2016 statistics from BSO (Building Stock Observatory), the average cost of residential building energy renovation is 89.58 EUR/m2, with Italy reporting an average cost of 68.2 EUR/m2 (Table 1-8), slightly lower than the overall European average. Building upon the preceding case study of residential house price in Milan, it becomes apparent that the premium effect on house price resulting from upgrading the Energy Performance Certificate level, which is 99.43 EUR/m2, surpasses the renovation costs. Combining the premium effect on house undergoing renovation is 500 euros per square meter, Additionally, considering the premium effect of new constructed/ refurbished building condition, which is 500 euros per square meter, on house price, promoting the renovation of existing buildings with a focus on improving energy efficiency is economically feasible.

Solely from an economic standpoint, the gains from energy renovation activities themselves are sufficient to cover the costs, not to mention the added environmental and social benefits and the enhancement of living comfort. Therefore, to a certain extent, leveraging market-driven economic mechanisms to facilitate the sustainable progression of building energy efficiency renovations is feasible. However, it's worth noting that persistent barriers, including hidden costs, the advancement of energy efficiency renovation technologies, and the dissemination of pertinent knowledge, must still be addressed.

Moreover, building energy efficiency can reduce the energy bills. And the building energy renovation activities create jobs, driving economic activities. This is especially vital in times of economic downturns when job creation is a priority. The renewable energy sector, which often complements energy efficiency buildings, experiences substantial growth, fostering innovation and investment.

5.2 Environmental Perspective

From an environmental standpoint, building energy efficiency plays a pivotal role in mitigating climate change and reducing greenhouse gas emissions. It is well-acknowledged that high energy consumption in buildings contributes significantly to carbon dioxide emissions, making energy efficiency buildings crucial in reducing this environmental burden.

In Italy, the Integrated National Energy and Climate Plan (INECP) has set forth a commendable target - a saving of 0.33 Mtoe/year of final energy for the residential sector between 2021 and 2030. To precisely quantify the progress made in promoting energy efficiency renovations and the consequential impact on energy savings, Italy's Ministry for Ecological Transition joined forces with prominent institutions like ENEA, the Institute for Environmental Protection and Research (ISPRA), and the Electrical Systems Research program (RSE). Together, they established a concept known as the virtual deep renovation rate.

The virtual deep renovation rate of Italy’s building stock can be estimated with reference to different types of intervention and technological solutions, starting with the data relating to tax deductions for energy efficiency initiatives (the Ecobonus). Ecobonus estimates indicate that over 1.7 million energy efficiency measures were carried out in 2014-2018, of which over 334,000 took place in 2018. The annual virtual deep renovation rate of the national building stock, estimated using the average energy savings in kWh/m2 achieved in 2014-2018 through initiatives related to paragraph 344 of the Ecobonus provision (overall renovation), is about 0.26%. The estimate of the virtual deep renovation rate can be supplemented by also taking into account the efficiency measures promoted by way of tax deductions for building renovation (known as ‘Bonus Casa’), for which savings of 0.225 Mtoe/year were estimated in 2018. The virtual deep renovation rate linked to the Bonus Casa is 0.59%. Taking into account both existing incentives, Ecobonus and Bonus Casa, the virtual rate of deep renovation would therefore be 0.85%, with energy savings of 0.332 Mtoe/year.

This innovative approach to tracking and evaluating the efficacy of building energy efficiency renovations offers a promising framework for future endeavors. Nevertheless, it's important to emphasize that this method relies on virtual platforms for measurement. Thus, it still needs to be integrated with real-world building renovation activities to enhance its real-world applicability.

When it comes to achieving building energy efficiency renovations, the activities involved encompass a multitude of specific building systems and technologies. A significant portion of the energy currently consumed in buildings goes to waste due to outdated construction practices, inefficient systems or appliances, and a lack of effective technical control systems. However, there are well-established solutions that can mitigate this energy waste in buildings.

To illustrate, the demand for heating and cooling in buildings can be dramatically reduced through various means. This includes thermal insulation, efficient glazing solutions, eliminating thermal bridges and leaks, and installing efficient heating/cooling generation and distribution systems. Furthermore, other technical building systems such as air-conditioning, ventilation, hot water production, and lighting systems can be optimized for energy efficiency. Beyond these active solutions, passive design options like optimized spatial planning, building orientation, natural ventilation strategies, and the effective use of thermal mass, as well as passive solar systems for heating and cooling, all play a pivotal role in reducing energy consumption and enhancing thermal comfort. Additionally, the implementation of smart metering systems can enable better control of supplied services, inform occupants about their behavior, and encourage energy conservation measures. Many of these energy efficiency measures can yield substantial energy savings, thus reducing the overall contribution of the building sector to global warming.

By adopting energy-efficient technologies and practices, buildings can significantly reduce their carbon footprint. For instance, efficient insulation, advanced HVAC systems, and smart building technologies optimize energy use, thereby reducing reliance on fossil fuels. This not only results in lower greenhouse gas emissions but also eases the strain on natural resources.

It's worth noting that, from the perspective of Milan's residential real estate market, solutions such as "using heating pump as the heating source," "Nearly Zero Energy Buildings (NZEB)," and "automatic air-conditioning systems" – all of which have the potential to enhance energy efficiency – do not exert a decisive impact on house price. This could be attributed to insufficient understanding among homebuyers about the information, and further exploration is necessary. However, in the long run, such nearly zero energy buildings have significant benefits for energy efficiency and occupant comfort. Therefore, while there is a strong focus on promoting energy efficiency renovations in existing buildings, it's also important to pay attention to the development and maturation of building technologies for these new constructions, cost reduction, and raising public awareness of these nearly zero energy buildings.

The OECD (Organisation for Economic Co-operation and Development) and IPEEC (International Partnership for Energy Efficiency Cooperation) have articulated a comprehensive framework (Figure 5-1), as outlined in the 2018 reports of the Net Zero by 2050 report (IEA 2021b) and Zero Energy Building Definitions and Policy Activity. This framework delineates various levels of progress towards achieving net-zero-carbon [34] buildings. It encompasses aspects like energy efficiency, low-carbon energy sources, and even buildings that generate surplus renewable energy. This framework underscores the growing emphasis on sustainability and energy efficiency in the building sector, providing valuable guidance for navigating the complexities of energy efficiency buildings in Milan and beyond.

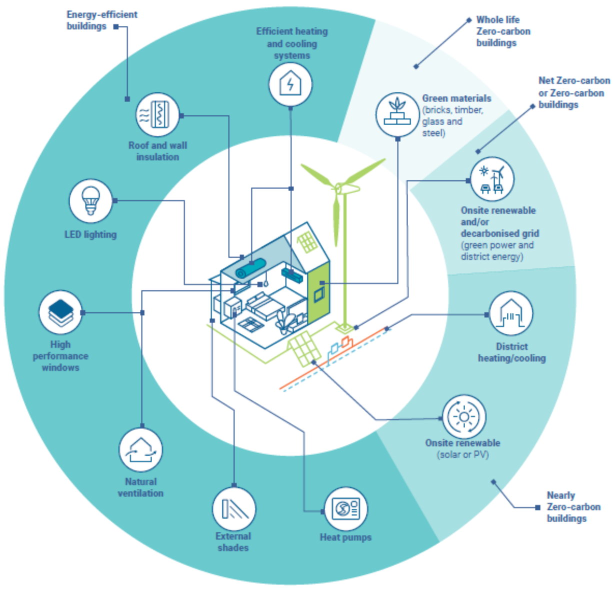


Figure 5-1: Different levels of zero-carbon buildings; Source: IEA 2021.

- Energy-efficient: a building with a high degree of energy efficiency in its fabric and building services that consume energy, e.g., heating, cooling, cooking, lighting, ventilation, hot water and appliances.

- Low-carbon: a building that is energy efficient (low energy) and is supplied by low-carbon energy. Some building services equipment may not be capable of decarbonizing without being replaced (e.g., fossil gas boilers).

- Nearly zero-carbon: a building that is energy-efficient and may have some available zero-emission energy supply (onsite or offsite), but that does not offset 100% of the building's energy demand.

[34] Net zero carbon buildings and net zero energy buildings are related concepts. Net zero carbon buildings consider both energy use and carbon emissions associated with that energy use, aiming to minimize the carbon footprint. Net zero energy buildings focus on achieving a balance between energy consumption and on-site energy generation, with less emphasis on carbon emissions specifically. However, in practice, these two goals often overlap, as reducing energy consumption often leads to lower carbon emissions, and vice versa. Both approaches contribute to sustainable and environmentally friendly building practices.

- Net zero-carbon: a building that is energy efficient and relies on zero-emission energy sources that meet the energy demand over the course of a year (or another established timeline, e.g., a month).

- Zero-carbon: a building that is energy efficient and has its energy demand completely met through zero-emission energy generated either onsite or offsite.

- Carbon-negative: an energy-efficient building that generates renewable energy onsite that not only fully covers the building's own energy demand, but also produces excess renewable energy which is fed back into a grid and can be used for other offsite purposes.

- Whole life cycle, net zero-carbon: A zero-carbon building with the additional requirement that the embodied emissions associated with the materials used for construction are themselves net zero, either through decarbonization or offsetting (IEA 2022e).

5.3 Social Perspective

Building energy efficiency positively influences people's lives and well-being. Building energy efficiency renovations enhance indoor environmental quality, fostering healthier living spaces. In addressing the social barriers often encountered in building energy efficiency renovation processes, particularly within renovation and sustainability contexts, a multifaceted and adaptive approach is essential. The approach should entail engaging diverse stakeholders from the outset, forming transdisciplinary teams to navigate complex interdependencies, and conducting comprehensive data analysis to understand socio-cultural and environmental factors. Scenario planning and flexible design principles accommodate uncertainties, while continuous monitoring and knowledge sharing ensure effective project management. Policy flexibility and strong community engagement further enhance the success and sustainability of renovation projects. Finally, the development of a clear sustainability framework and a commitment to regular review and adaptation are key to overcoming social obstacles and promoting building energy efficiency renovations.

In addition, energy-efficient buildings also promote social equity. Lower energy bills lead to more affordable housing for residents. Vulnerable communities, in particular, stand to gain from reduced energy costs, alleviating financial burdens.

6. Conclusion

Building energy efficiency renovations stand as a potent response to the urgent environmental, social, and economic challenges we face. They play a pivotal role in reducing greenhouse gas emissions, conserving resources, and addressing climate change from an environmental standpoint. Simultaneously, these renovations improve the quality of indoor living spaces, promote social equity, and create employment opportunities, fostering healthier, more equitable, and prosperous communities. As societies increasingly recognize the paramount significance of building energy efficiency, the pursuit of sustainable, energy-efficient buildings becomes a cornerstone for a brighter and more sustainable future.

This study focuses on residential house price in Milan, applying Hedonic Price Method and Econometrics, clearly demonstrates that the premium effect of building Energy Performance Certificates on house price is substantial enough to offset the costs of energy efficiency renovations in buildings. From an economic perspective, the sustainability of building energy efficiency renovations is indeed feasible.

However, there are some limitations to this thesis study. Firstly, the accessibility data is measured at the neighborhood center rather than at the specific location of each property, introducing a systematic error in the linear regression models. While the error distribution is uniform, and the impact on the results can be considered negligible, improving the accuracy of this data can enhance the model's precision in explaining house price.

Secondly, the dependent variable "house price" represents the list price on housing transaction websites, which may differ somewhat from the actual transacted house price and might not fully reflect the real and final willingness of homebuyers to pay. Thus, obtaining actual transacted house price could improve the research's accuracy and authenticity to reality.

Thirdly, due to considerations related to data accessibility, the maturity of the real estate market, and the stock of buildings, Milan was chosen as the subject of the case study in this thesis. However, due to the high segmentation of the real estate market and Milan's position at the forefront of European urban development, it may not strongly represent the overall average levels of European cities. This is also a limitation of the case study in this thesis.

In the realm of building energy renovations, it is indeed acknowledged that they can potentially yield a premium effect on property values. Nevertheless, it is imperative to note that when a property is owner-occupied, and the homeowner does not have immediate intentions to sell or lease the property, the premium effect on property values resulting from building energy renovations does not readily translate into tangible monetary benefits for the owner. This is because, in reality, no property transaction occurs. Conversely, the costs incurred by the owner for implementing building energy renovations are concrete and tangible.

Hence, there is a pressing need to delve deeper into the composition of the costs associated with building energy renovations. This encompasses not only the overt costs but also the latent costs arising from information asymmetry during the renovation process, along with expenses borne by homeowners when temporarily relocating during the renovation period, among other factors. Simultaneously, it is paramount to conduct further investigation into the less overt benefits of building energy renovations. These benefits accrue to homeowners irrespective of property transaction involvement. They encompass savings on energy expenses, improvement of the occupants' comfort, and environmental benefits, among others.

In addition to scrutinizing the benefits and costs associated with building renovation activities, it is also essential to conduct in-depth research into household income levels and expenditure structures. This, in turn, permits a more profound investigation into the influence of building energy renovations on housing affordability, environmental and social sustainability.

7. Bibliography

2022 NDC Synthesis Report | UNFCCC. (n.d.). Retrieved October 17, 2023, from https://unfccc.int/ndc-synthesis-report-2022#Means-of-implementation

Arcipowska, A., Anagnostopoulos, F., Mariottini, F., & Kunkel, S. (2014). *Energy performance certificates across the EU: a mapping of national approaches*. www.bpie.eu

Bassi, R. (1995). Concrete surface systems: European standards update. *Concrete (London)*, *29*(1).

Beerepoot, M., & Sunikka, M. (2005). The contribution of the EC energy certificate in improving sustainability of the housing stock. *Environment and Planning B: Planning and Design*, *32*(1). https://doi.org/10.1068/b3118

Behavioural Insights Team. (2011). Behaviour Change and Energy Use. In *Energy* (Vol. 1, Issue July).

Beillan, V., Goater, A., Huber, A., Battaglini, E., & Trotigon, R. (2011). Sustainable building : barriers and drivers to energy-efficient refurbishment in the residential sector. Empirical findings from five European countries. *European Council for an Energy-Efficient Economy Conference*.

Belussi, L., Barozzi, B., Bellazzi, A., Danza, L., Devitofrancesco, A., Fanciulli, C., Ghellere, M., Guazzi, G., Meroni, I., Salamone, F., Scamoni, F., & Scrosati, C. (2019). A review of performance of zero energy buildings and energy efficiency solutions. In *Journal of Building Engineering* (Vol. 25). https://doi.org/10.1016/j.jobe.2019.100772

Bertoldi, P., & Economidou, M. (2018). EU member states energy efficiency policies for the industrial sector based on the NEEAPs analysis. *Eceee Industrial Summer Study Proceedings*, *2018-June*.

Brown, M. A. (2001). Market failures and barriers as a basis for clean energy policies. *Energy Policy*, *29*(14). https://doi.org/10.1016/S0301-4215(01)00067-2

Caluwaerts, P., Sjöström, C., & Haagenrud, S. E. (2014). Service life standards: Background and relation to the european construction products directive. In *Durability of Building Materials and Components 7* (Vol. 9781315025018). https://doi.org/10.4324/9781315025018

Copenhagen Economics, & EMF-ECBC. (2020). *Literature review of the energy efficiency gap*. https://ec.europa.eu/clima/policies/eu-climate-action/2030_ctp_en

Costa, G., & Sabatinelli, S. (n.d.). *CITY REPORT: MILAN*. http://demo.istat.it/

D'Agostino, D., & Parker, D. (2018). A framework for the cost-optimal design of nearly zero energy buildings (NZEBs) in representative climates across Europe. *Energy*, *149*. https://doi.org/10.1016/j.energy.2018.02.020

Davis, P. T., McCord, J., McCord, M. J., & Haran, M. (2015). Modelling the effect of energy performance certificate rating on property value in the Belfast housing market. *International Journal of Housing Markets and Analysis*, *8*(3). https://doi.org/10.1108/IJHMA-09-2014-0035

de Alegría Mancisidor, I. M., Díaz de Basurto Uraga, P., Martínez de Alegría Mancisidor, I., & Ruiz de Arbulo López, P. (2009). European Union's renewable energy sources and energy efficiency policy review: The Spanish perspective. *Renewable and Sustainable Energy Reviews*, *13*(1). https://doi.org/10.1016/j.rser.2007.07.003

De Ayala, A., Galarraga, I., & Spadaro, J. V. (2016). The price of energy efficiency in the Spanish housing market. *Energy Policy*, *94*. https://doi.org/10.1016/j.enpol.2016.03.032

Economidou, M., Todeschi, V., Bertoldi, P., D'Agostino, D., Zangheri, P., & Castellazzi, L. (2020). Review of 50 years of EU energy efficiency policies for buildings. *Energy and Buildings*, *225*. https://doi.org/10.1016/j.enbuild.2020.110322

Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries. (2013).

European Commission. (2020). *Stakeholder consultation on the renovation wave initiative*.

Fischer, C. (2008). Feedback on household electricity consumption: A tool for saving energy? *Energy Efficiency*, *1*(1). https://doi.org/10.1007/s12053-008-9009-7

Gillingham, K., Newell, R. G., & Palmer, K. (2009). Energy Efficiency Economics and Policy. *Annual Review of Resource Economics*, *1*(1). https://doi.org/10.1146/annurev.resource.102308.124234

Golove, W. H., & Eto, J. H. (1996). Market Barriers to Energy Efficiency : A Critical Reappraisal of the Rationale for Public Policies to Promote Energy Efficiency. *Energy & Environment*, *March*.

Jakob, M. (2007). The drivers of and barriers to energy efficiency in renovation decisions of single-family home-owners. *CEPE Working Paper Series*, *18*(56).

Kamari, A., Jensen, S. R., Corrao, R., & Kirkegaard, P. H. (2019). A holistic multi-methodology for sustainable renovation. *International Journal of Strategic Property Management*, *23*(1), 50–64. https://doi.org/10.3846/ijspm.2019.6375

Karlin, B., Zinger, J. F., & Ford, R. (2015). The effects of feedback on energy conservation: A meta-analysis. *Psychological Bulletin*, *141*(6). https://doi.org/10.1037/a0039650

Linares, P., & Labandeira, X. (2010). Energy efficiency: Economics and policy. *Journal of Economic Surveys*, *24*(3). https://doi.org/10.1111/j.1467-6419.2009.00609.x

Loveday, C. (1992). Quality and the construction products directive. *Quarry Management*, *19*(1).

Ó Broin, E., Nässén, J., & Johnsson, F. (2015). Energy efficiency policies for space heating in EU countries: A panel data analysis for the period 1990-2010. *Applied Energy*, *150*. https://doi.org/10.1016/j.apenergy.2015.03.063

Palm, J., & Reindl, K. (2018). Understanding barriers to energy-efficiency renovations of multifamily dwellings. *Energy Efficiency*, *11*(1). https://doi.org/10.1007/s12053-017-9549-9

Phillips, Y. (2012). Landlords versus tenants: Information asymmetry and mismatched preferences for home energy efficiency. *Energy Policy*, *45*. https://doi.org/10.1016/j.enpol.2012.01.067

Richalet, V., Neirac, F. P., Tellez, F., Marco, J., & Bloem, J. J. (2001). HELP (house energy labeling procedure): Methodology and present results. *Energy and Buildings*, *33*(3). https://doi.org/10.1016/S0378-7788(00)00086-4

Ringel, M., & Knodt, M. (2018). The governance of the European Energy Union: Efficiency, effectiveness and acceptance of the Winter Package 2016. *Energy Policy*, *112*. https://doi.org/10.1016/j.enpol.2017.09.047

Sjöström, C., Caluwaerts, P. J. P., Haagenrud, S. K. S., & Chevalier, J. L. (2002). Implementation Of The European Construction Products Directive Via The Iso 15686 Standards. *Concrete*.

Thonipara, A., Runst, P., Ochsner, C., & Bizer, K. (2019). Energy efficiency of residential buildings in the European Union – An exploratory analysis of cross-country consumption patterns. *Energy Policy*, *129*. https://doi.org/10.1016/j.enpol.2019.03.003

Van Wees, M. T., Uyterlinde, M. A., & Maly, M. (2002). Energy efficiency and renewable energy policy in the Czech Republic within the framework of accession to the European Union. *Energy*, *27*(11). https://doi.org/10.1016/S0360-5442(02)00068-3

Weiss, J., Dunkelberg, E., & Vogelpohl, T. (2012). Improving policy instruments to better tap into homeowner refurbishment potential: Lessons learned from a case study in Germany. *Energy Policy*, *44*. https://doi.org/10.1016/j.enpol.2012.02.006

Wilson, C., Crane, L., & Chryssochoidis, G. (2015). Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research and Social Science*, *7*. https://doi.org/10.1016/j.erss.2015.03.002

Zangheri, P., Serrenho, T., & Bertoldi, P. (2019). Energy savings from feedback systems: A meta-studies' review. *Energies*, *12*(19). https://doi.org/10.3390/en12193788

Zvingilaite, E., & Togeby, M. (2015). *Impact of Feedback about energy consumption*. www.eaea.dk

International Energy Agency. (n.d.). *Energy Efficiency 2019*. Retrieved October 18, 2023, from www.oecd.org/about/publishing/

Caradonna, J. L. (2017). Routledge Handbook of the History of Sustainability. In *Routledge Handbook of the History of Sustainability*. https://doi.org/10.4324/9781315543017

Temperatures | Climate Action Tracker. (n.d.). Retrieved October 17, 2023, from https://climateactiontracker.org/global/temperatures/

ACEEE | American Council for an Energy Efficient Economy. (n.d.). Retrieved October 17, 2023, from https://www.aceee.org/

Nzeb: edifici ad energia quasi zero: che punto siamo in Italia | Camera di Commercio, Industria, Artigianato ed Agricoltura del Nord Sardegna, Sassari. (n.d.).

Retrieved October 17, 2023, from https://www.ss.camcom.it/sportello-energia/nzeb-edifici-ad-energia-quasi-zero-che-punto-siamo-in-italia/

Modelli APE - ARIA S.p.A. (n.d.). Retrieved October 17, 2023, from https://www.cened.it/modelli-ape

Progetto Dati Cened DIH - ARIA S.p.A. (n.d.). Retrieved October 17, 2023, from https://www.cened.it/cened_dataviz_certificazioni_energetiche_DIH

Monosilio, F., Altieri, G., Colopardi, E., Manni, F., Nurra, M. G., Riccardelli, E., Sabatini, A., & Ranieri, B. (n.d.). *L'Osservatorio congiunturale sull'industria delle costruzioni è curato dalla Direzione Affari Economici, Finanza e Centro Studi dell'Ance*. Retrieved October 17, 2023, from www.ance.it

Convert million tonnes of oil equivalent to kilowatt hours - energy converter. (n.d.). Retrieved October 17, 2023, from https://www.unitjuggler.com/convert-energy-from-Mtoe-to-kWh.html

Renovation wave. (n.d.). Retrieved October 17, 2023, from https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en#documents

Regione Lombardia - Certificazione energetica degli edifici. (n.d.). Retrieved October 17, 2023, from https://www.cti2000.eu/certificazione-energetica-regionale/lombardia/

Database - epbd-ca.eu. (n.d.). Retrieved October 17, 2023, from https://epbd-ca.eu/database-of-outputs

Home Energy Efficiency in Italy Explained. (n.d.). Retrieved October 17, 2023, from https://www.gate-away.com/blog/expert-building-energy-efficiency-rating-explained/

Municipality of MILANO: demographic balance, population trend, death rate, birth rate, migration rate. (n.d.). Retrieved October 17, 2023, from https://ugeo.urbistat.com/AdminStat/en/it/demografia/popolazione/milano/15146/4

Nearly zero-energy buildings. (n.d.). Retrieved October 17, 2023, from https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en

Mappa degli ospedali in Italia. (n.d.). Retrieved October 17, 2023, from http://www.datiopen.it/it/opendata/Mappa_degli_ospedali_in_Italia?

Servizi all'Infanzia (0-6 anni). (n.d.). Retrieved October 17, 2023, from https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=bab9faa8f95e4680a5bebb58305e9a9a

Scuole Aperte. (n.d.). Retrieved October 17, 2023, from https://geoportale.comune.milano.it/portal/apps/webappviewer/index.html?id=a7395207c19448dbb8ac16060842cad5&mobileBreakPoint=300

Mappe | Geoportale SIT. (n.d.). Retrieved October 17, 2023, from https://geoportale.comune.milano.it/sit/mappe/

Patrimonio Immobiliare del Comune di Milano. (n.d.). Retrieved October 17, 2023, from https://geoportale.comune.milano.it/MapViewerApplication/Map/App?config=%2FMapViewerApplication%2FMap%2FConfig4App%2F417&id=ags

Open data | Geoportale SIT. (n.d.). Retrieved October 17, 2023, from https://geoportale.comune.milano.it/sit/open-data/

Cened - Certificazione energetica - ARIA. (n.d.). Retrieved October 17, 2023, from https://www.ariaspa.it/wps/portal/Aria/Home/cosa-facciamo/energia/cened-certificazione-energetica

Dati CENED+1.2 - ARIA S.p.A. (n.d.). Retrieved October 17, 2023, from https://www.cened.it/dati-cened-1.2

TABULA WebTool. (n.d.). Retrieved October 17, 2023, from https://webtool.building-typology.eu/#bm

SIAPE - Sistema Informativo sugli Attestati di Prestazione Energetica. (n.d.). Retrieved October 17, 2023, from https://siape.enea.it/analisi-territoriali

RenOnBill. (n.d.). Retrieved October 17, 2023, from https://www.renonbill.eu/

Real estate market in the province of Milano - Immobiliare.it. (n.d.). Retrieved October 17, 2023, from https://www.immobiliare.it/en/mercato-immobiliare/lombardia/milano-provincia/

Schede - Osservatorio del Mercato Immobiliare - Compravendite immobili residenziali - Agenzia delle Entrate. (n.d.). Retrieved October 17, 2023, from https://www.agenziaentrate.gov.it/portale/web/guest/schede/fabbricatiterreni/omi/banche-dati/volumi-di-compravendita/archivio-volumi-di-compravendita/compravendite-immobili-residenziali

Schede - Osservatorio del Mercato Immobiliare - Volumi di compravendita - Agenzia delle Entrate. (n.d.). Retrieved October 17, 2023, from https://www.agenziaentrate.gov.it/portale/web/guest/schede/fabbricatiterreni/omi/banche-dati/volumi-di-compravendita

PNPE2. (n.d.). Retrieved October 17, 2023, from https://pnpe2.enea.it/statistiche

EU Building Stock Observatory. (n.d.). Retrieved October 17, 2023, from https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/eu-building-stock-observatory_en

CO2 emissions from buildings and construction hit new high, leaving sector off track to decarbonize by 2050: UN. (n.d.). Retrieved October 17, 2023, from https://www.unep.org/news-and-stories/press-release/co2-emissions-buildings-and-construction-hit-new-high-leaving-sector

BPIE is a leading independent centre of expertise on energy performance of buildings. > BPIE - Buildings Performance Institute Europe. (n.d.). Retrieved October 17, 2023, from https://www.bpie.eu/

Built-up area and built-up area change in countries and regions. (n.d.). Retrieved October 17, 2023, from https://stats.oecd.org/Index.aspx?DataSetCode=BUILT_UP

Climate Change 2022: Mitigation of Climate Change. (n.d.). Retrieved October 17,

2023, from https://www.ipcc.ch/report/ar6/wg3/
CO2 emissions - Our World in Data. (n.d.). Retrieved October 17, 2023, from https://ourworldindata.org/co2-emissions
CO_2 and Greenhouse Gas Emissions - Our World in Data. (n.d.). Retrieved October 17, 2023, from https://ourworldindata.org/co2-and-greenhouse-gas-emissions
Emissions by sector - Our World in Data. (n.d.). Retrieved October 17, 2023, from https://ourworldindata.org/emissions-by-sector
Sustainable Real Estate: Trends and Trajectories - Green Business Bureau. (n.d.). Retrieved October 17, 2023, from https://greenbusinessbureau.com/industries/real-estate/sustainable-real-estate-trends-and-trajectories/
How the conversation around green real estate is changing | World Economic Forum. (n.d.). Retrieved October 17, 2023, from https://www.weforum.org/agenda/2022/01/green-real-estate-sustainability-corporate-priority/
Climate Change Data | Climate Change Indicators Dashboard. (n.d.). Retrieved October 17, 2023, from https://climatedata.imf.org/pages/climatechange-data
Our World in Data. (n.d.). Retrieved October 17, 2023, from https://ourworldindata.org/
Database | Globalabc. (n.d.). Retrieved October 17, 2023, from https://globalabc.org/database
E3P | European Energy Efficiency Platform. (n.d.). Retrieved October 17, 2023, from https://e3p.jrc.ec.europa.eu/
Sustainable Buildings - Smart Specialisation Platform. (n.d.). Retrieved October 17, 2023, from https://s3platform.jrc.ec.europa.eu/sustainable-buildings#fragment-89005-rhoy
The EU Green Deal – a roadmap to sustainable economies. (n.d.). Retrieved October 17, 2023, from https://www.switchtogreen.eu/the-eu-green-deal-promoting-a-green-notable-circular-economy/
World Built Environment Forum. (n.d.). Retrieved October 17, 2023, from https://www.rics.org/news-insights/wbef
Sustainable investment in real estate. (n.d.). Retrieved October 17, 2023, from https://www.rics.org/news-insights/wbef/sustainable-investment-in-real-estate
Basic Information about the Built Environment | US EPA. (n.d.). Retrieved October 17, 2023, from https://www.epa.gov/smm/basic-information-about-built-environment
Urban Regeneration | UN-Habitat. (n.d.). Retrieved October 17, 2023, from https://unhabitat.org/topic/urban-regeneration
What is Built Environment | IGI Global. (n.d.). Retrieved October 17, 2023, from https://www.igi-global.com/dictionary/built-environment/46840
United Nations Department of Economic and Social Affairs. (2015). *World Population Prospects: Key findings and advance tables*.

Segatto, P. L. (n.d.). *Real estate analysis: buy/rent houses in Milan*. Retrieved October 17, 2023, from https://pierluigi-segatto.medium.com/real-estate-analysis-252739af7c2b

Zehra, K. (2022). *RICS sustainability report 2022*. www.rics.org

Handy, S. L., Boarnet, M. G., Ewing, R., & Killingsworth, R. E. (2002). *How the Built Environment Affects Physical Activity Views from Urban Planning*.

Chegut, A., Eichholtz, P., & Kok, N. (2014). Supply, Demand and the Value of Green Buildings. *Urban Studies*, *51*(1), 22–43. https://doi.org/10.1177/0042098013484526

Fuerst, F., & Haddad, M. F. C. (2020). Real estate data to analyse the relationship between property prices, sustainability levels and socio-economic indicators. *Journal of Cleaner Production*, *245*. https://doi.org/10.1016/j.jclepro.2019.118642

Taruttis, L., & Weber, C. (2022). Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter? *Energy Economics*, *105*. https://doi.org/10.1016/j.eneco.2021.105750

International Energy Agency. (2016). *Energy Technology Perspectives 2016: Towards Sustainable Urban Energy Systems*. www.iea.org

Zancanella, P., Bertoldi, P., & Bertoldi, P. (2018). *Energy efficiency, the value of buildings and the payment default risk*. https://doi.org/10.2760/267367

Carlander, J., & Thollander, P. (2023). Barriers to implementation of energy-efficient technologies in building construction projects — Results from a Swedish case study. *Resources, Environment and Sustainability*, *11*. https://doi.org/10.1016/j.resenv.2022.100097

PwC. (2021). *Real Estate Market Overview*. www.pwc.com/it

Berry, B. J. L., & Bednarz, R. S. (1975). *A Hedonic Model of Prices and Assessments for Single-Family Homes: Does the Assessor Follow the Market or the Market Follow the Assessor? 51*(1), 21–40. https://www.jstor.org/stable/3145138

Herath, S., & Maier, G. (2010). *The hedonic price method in real estate and housing market research: a review of the literature*. http://ro.uow.edu.au/buspapers/971

United Nations Human Settlements Programme (UN-Habitat). (2022). *World Cities Report 2022: Envisaging the Future of Cities*.

Bean, F., Fabbri, M., Kontonasiou, E., Geyer, F., Tzanev, D., Simeonov, K., Vlainic, M., Jurko, N., Stvarnik, L., Popovic, M. J., Csaszar, C., Mischler, F., Hoereth, K., & Botzler, S. (2017). *Barriers that hinder deep renovation in the building sector Project Title: EmBuild-Empower public authorities to establish a long-term strategy for mobilizing investment in the energy efficient renovation of the building stock*. www.embuild.eu

Gabriella Azzolini, Hugony, F., & Martino, A. (2020). *Implementation of the EPBD: Italy Status in 2020*. www.enea.it/it,

Stock, J. H., & Watson, M. W. (2019). *Introduction to econometrics* (4. ed). New York : Pearson, 2019.

Crawley, M. J. (2005). *Statistics : an introduction using R*. Chichester : Wiley, c2005.
Gelman, A., & Hill, J. (2007). *Data analysis using regression and multilevel/hierarchical models*. Cambridge [etc.] : Cambridge University press, 2007.
Greene, W. H. (2012). *Econometric analysis* (7. ed.). Boston [etc.] : Pearson, 2012.
Fuerst, F., & Warren-Myers, G. (2018). Does voluntary disclosure create a green lemon problem? Energy-efficiency ratings and house prices. *Energy Economics*, *74*, 1–12. https://doi.org/10.1016/j.eneco.2018.04.041
Gevorgian, A., Pezzutto, S., Zambotti, S., Croce, S., Filippi Oberegger, U., Lollini, R., Kranzl, K., & Müller, A. (2021). *European Building Stock Analysis: A country by country descriptive and comparative analysis of the energy performance of buildings*.
Ministry of Ecological Transition. (2021). *Strategy for energy retrofitting of national building stock in Italy*.
Krugten, van L. T. F., Hermans, L. M. C., Havinga, L. C., Pereira Roders, A. R., & Schellen, H. L. (2016). Raising the energy performance of historical dwellings. *Management of Environmental Quality: An International Journal*, *27*(6), 740–755. https://doi.org/10.1108/MEQ-09-2015-0180
Mei, Y., Gao, L., Zhang, J., & Wang, J. (2020). Valuing urban air quality: a hedonic price analysis in Beijing, China. *Environmental Science and Pollution Research*, *27*(2), 1373–1385. https://doi.org/10.1007/s11356-019-06874-5
Nairobi. (2022). *2022 Global status report for buildings and construction：Towards efficient and resilient buildings and construction sector*. www.globalabc.org.
Brian Dean and John Dulac (International Energy Agency), K. P. (Copenhagen C. on E. E. and P. G. (Global B. P. N. (2016). *2016 Global status report: Towards zero-emission efficient and resilient buildings*.
Bloem, J. J., Pignatelli, F., Martirano, G., Borzacchiello, M. T., Lodi, C., Mor, G., & Hernandez, G. (2018). *Building Energy Performance and Location-from building to urban area*. https://ec.europa.eu/jrc
Malpezzi, S. (2003). Hedonic pricing models: a selective and applied review. *Housing Economics and Public Policy*, *1*, 67–89.
Baranzini, A., Ramirez, J., Schaerer, C., & Thalmann, P. (2008). Hedonic methods in housing markets: Pricing environmental amenities and segregation. In *Hedonic Methods in Housing Markets: Pricing Environmental Amenities and Segregation*. Springer New York. https://doi.org/10.1007/978-0-387-76815-1
Camagni, R., & Capello, R. (2016). An ex-ante evaluation of an urban project through property value increases: An hedonic price approach. In *New Principles in Planning Evaluation*. https://doi.org/10.4324/9781315248004-16
Court, A. T. (1939). Hedonic Price Indexes with Automotive Examples. *The Dynamics of Automobile Demand*.
Kauškale, L., & Geipele, I. (2016). Economic and Social Sustainability of Real Estate Market and Problems of Economic Development – a Historical Overview. *Baltic*

Journal of Real Estate Economics and Construction Management, *4*(1), 6–31. https://doi.org/10.1515/bjreecm-2016-0002

Malpezzi, S., Gibb, K., & O'sullivan, A. (2002). *Hedonic Pricing Models: A Selective and Applied Review*. https://web.archive.org/web/20160221230431id_/http://down.cenet.org.cn:80/upfile/49/20072137445140.pdf