Deliverable D2.1

Report on Building Renovation Financing Typologies

April 2023

Project Data	
Project Acronym	ENERGATE
Project Name	Energy Efficiency Aggregation Platform for Sustainable Investments
Grant Agreement Nr.	101076349
Project Coordinator	National Technical University of Athens
Project Duration	1 January 2023 – 30 June 2025
Website	www.energate-project.eu

Deliverable Data	
Deliverable No	D2.1
Dissemination Level	Public
Work Package	2
Lead Beneficiary	NTUA
Author(s)	Aikaterini Papapostolou (NTUA), Konstantinos Touloumis (NTUA), Panagiotis Kapsalis (NTUA)
Reviewers	Stella Ntaouti (Greenesco), Vassilis Iliadis (Greenesco), Ioannis Vlachos (FWT)
Due Date	30 April 2023
Release Date	30 April 2023

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Published in April, 2023 by ENERGATE.

Acknowledgments:

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

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List of Abbreviations

BEMS	Building Energy Management Systems
EE	Energy Efficiency
EeaaS	Energy Efficiency as a Service
EEFIG	Energy Efficiency Financial Institution Group
EE-FiTs	Energy Efficiency Feed-in Tariffs
EEM	Energy Efficiency Mortgages
EFSI	European Fund for Strategic Investments
ELENA	European Local Energy Assistance
EPBD	Energy Performance of Building Directive
EPC	Energy Performance Certificate/Contract
ESCO	Energy Service Company
ESIF	European Structural and Investment Fund
HVAC	Heating, Ventilation & Air Conditioning
ICT	Information & Communication Technologies
KPI	Key Performance Indicator
NPV	Net Present Value
NZEB	Nearly Zero Energy Building
OBF	On Bill Finance
OBF	On Bill Finance
P4P	Pay for Performance
PACE	Property Assessed Clean Energy
RRF	Recovery and Resilience Facility
SAREF	Smart Application Reference

Executive Summary

The present report aims to set the basis for the upcoming ENERGATE activities concerning the platform's conceptual design parameters, information entries (Fetch stage - project entry module) and aggregation and matchmaking processes (Process stage). This deliverable holds the analysis and outcomes of ENERGATE's Task 2.1: Identification of building renovation financing typologies.

The aim of the report is to review previous work done on the subject and identify the common patterns in relation to the current practices and the likelihood of certain building types to be renovated. The research seeks to identify common factors and thereby define renovation categories using diversified set of key aspects which affect the definition of building renovation typologies such as: i) barriers and risks, ii) technical aspects e.g., technologies or technology indicators and architectural/town planning characteristics or even iii) the type of finance that has proven suitable or appears attractive for large scale renovation.

The research conducted and presented in this deliverable may assist in understanding the interplay (also taking stock of previous relevant initiatives) of different combinations of building ownership status, technology, financing methods and their effect on accelerated building renovation rates. It will support the development of specifications for standardised data entry forms for building EE projects and will contribute to the identification and calculation of the relevant energy, financing and risk KPIs that will be used to develop large, standardised, financeable project packages.

In brief, the report presents the following:

A. Proposed buildings typologies and an overview of energy efficiency measures in the building sector.
B. A review and analysis of financial mechanisms for building renovations.
C. Risks for the implementation of energy efficiency investments.
D. KPIs to evaluate various aspects of retrofitting interventions.
E. An analysis of data regarding large scale building renovations.

1. Introduction

Energy Efficiency in the EU

Energy efficiency (EE) plays a crucial role in building a sustainable and resilient energy system that can meet the modern society's energy needs, minimising the environmental impact, while promoting economic growth, and improving public health [1]. While the total final energy consumption of the global buildings sector remained at the same level in 2019 compared to the previous year, CO_2 emissions from the operation of buildings have increased to their highest level yet at around 10 $GtCO_2$, or 28% of the total global energy-related CO_2 emissions[2]. To face the challenge of carbon reduction, a number of global organisations are working towards an energy revolution to tackle greenhouse gas emissions by deploying low-carbon technologies and adopting renewable energy measures to increase energy sustainability and economic development [3]. EE is a key component of any 21st century energy policy and is crucial for meeting climate change targets. Thus, the enhancement of energy performance of buildings has become a pillar of energy policies [4]. In order to prioritise EE in Europe, the European Commission (EC) has initiated in July 2021 a proposal for a recast of the previous directives on EE [5]. The Energy Efficiency Directive is an important element for progressing towards climate neutrality by 2050 [5], under which EE is to be treated as an energy source in its own right [6].The renewed Directive consists part of the package "Delivering on the European Green Deal" [7], which aims to make Europe the first climate neutral continent in the world by reducing its emissions by at least 55% by 2030, compared to the 90's levels. Moreover, a key component of the EU energy policy is the "Energy Efficiency First" principle [8], which empasises the importance of ensuring sustainable energy supply, as well as climate neutrality, in European countries.

Energy Efficiency in buildings

Collectively, buildings in the EU are responsible for 40% of energy consumption and 36% of greenhouse gas emissions [9]. More than 220 million buildings, representing approximately 85% of the building stock, need to be renovated by 2050. This translates to approximately €275 billion of additional investments in building renovation needed every year [10]. EE investment in buildings is picking up again but the speed of change lags behind overall building construction investment [9]. Improving the EE of buildings is an often-overlooked strategy that can help alleviate many of the challenges cities face - from climate change and public health problems to unemployment and poverty [11].

However, the building sector, which has the largest potential for major gains in energy efficiency, suffers from some perverse incentives: landlords have no interest in investing for the sake of tenants, and tenants do not want to invest when they will not get long-term benefits [12]. The building sector encompasses a diverse set of end use activities, which have different energy use implications. Space heating, space cooling and lighting, which together account for the majority of building energy use in industrialized countries, depend not only on the EE of temperature control and lighting systems, but also on the efficiency of the buildings where they operate [13].

In other words, EE in buildings is considered of crucial importance, as it accounts for a considerable amount of global energy consumption and carbon emissions. However, the rate of building renovation in Europe remains too low, due to the lack of effective tools to support decision making procedures regarding funding options for retrofitting projects, considering the buildings' type, use, ownership status etc.

The ENERGATE scope

ENERGATE aims to facilitate upstream energy efficiency in buildings, by focusing on the development of an ICT (Information and Communication Technology) enabled marketplace. The ENERGATE platform pursues to enable aggregation of EE projects while supporting EE investment by providing services for sustainable financing of building renovation.

The ENERGATE marketplace on the one hand will aim to mobilise and accelerate the creation of NECP-compatible credible project pipeline and on the other, it will aim to facilitate the financial closure and project implementation by offering standardisation, risk mitigation and appropriate "packaging" of investments.

The added value of ENERGATE is the effective aggregation of EE projects in the marketplace, also taking stock of the knowledge and tools developed by the EU backed projects. Such a liquidity (i.e., concentration of candidate investments) combined with the provision of the necessary standardised instruments are believed to be necessary conditions to effectively support investors and financiers in a) assessing the financial viability of the EE measures, b) creating investment "funnels" and c) evaluating the performance already from the first steps of such investments' elaboration.

The ENERGATE pilots

The ENERGATE pilots and their pilot projects cumulatively cover a different set of private and public buildings and users which are adequately represented in the team i.e. asset managers, ESCOs, technical consultants, EE financing partners etc. so as to bring together different perspectives and needs in the table. ENERGATE and its marketplace follows the 3W model (who, what, how) via the 5 ENERGATE pilots and their 2 respective pylons. For that reason, they will include relevant indicators and cost-optimal aggregates that will be derived in the form of optimised large, standardised, financeable project packages of EE measures.

To this end, the deployment and validation phase of the platform will focus on enabling the reflection of the Supply and Demand side in the actual flow of the ENERGATE platform. Each side will present their contribution to the ENERGATE platform value workflow and to the EE project cycle in general. Therefore, five ENERGATE pilots (COMMUTY RPR, Greenesco, EB, LDK) have been carefully selected in order to bring value in the whole ICT platform umbrella. The 5 ENERGATE pilots are grouped in a form of 2 Pylons (Pylon A & Pylon B) with the scope to bring together targeted stakeholders and their requirements respectively. It should be also noted that the practice-proven support via the pilot projects deployment with active engagement of stakeholders and validation offers trustworthy opportunities ready for uptake.

The expected outputs from pilots' deployment and validation will include relevant indicators and cost-optimal aggregates that will be derived in the form of optimised large, standardised, financeable project packages of EE measures. Finally, within the assessment phase, the performance of each pilot will be validated through internal analysis (encompassing both intra-project KPIs benchmarking and extra-project validation) as well as stakeholders' assessment to receive effective feedback from the project partners.

Scope of the report

The present report aims to set the basis for the upcoming ENERGATE activities concerning the platform's conceptual design parameters, information entries (Fetch stage - project entry module) and aggregation[1] and matchmaking[2] processes (Process stage). This deliverable holds the analysis and outcomes of ENERGATE's Task 2.1: Identification of building renovation financing typologies.

The aim of the report is to review previous work done on the subject and identify the common patterns in relation to the current practices and the likelihood of certain building types to be renovated. The research seeked to identify common factors and thereby define renovation categories using, at first, the broad typologies of household vs non-household and public vs private buildings. However, it is recognised that these broad categories can only serve as the starting point. So, a diversified set of key aspects which affect the definition of building renovation typologies were analysed such as: i) barriers, ii) technical aspects e.g. technologies or technology indicators and architectural/town planning characteristics or even iii) the type of finance that has proven suitable or appears attractive for large scale renovation. Moreover, since risk identification & mitigation comprises a key aspect in financial decision-making the also made use of the rich experience in this area by the partners from Triple-A, DEEP database, LAUNCH and QualitEE and/or other relevant work within this area. As a preparatory step to the aggregation and matchmaking process (Task 3.2), building renovation typologies will aim to identify large aggregates of buildings that can be characterised by certain common characteristics in terms of, non-exhaustively: use, ownership, technologies, typical measures, risks and financing methods.

To reflect the supply side, it is necessary to create an appropriate ontology to be modelled within the platform, in which several variables representing the characteristics of the building will be integrated in order to generate a building profile. To this end, a Common Data Model which could incorporate the necessary variables should be designed and developed. As far as the demand side is concerned, a filtering process will be applied by potential investors so that they can find attractive products (i. e. buildings and respective retrofitting measures) for financing. Thus, the available financing mechanisms enabling funding of EE projects in buildings should be detected, and the type of buildings and retrofitting measures that are more likely to be funded using these financial tools should be specified.

Within the respective task's activities, research of available open-source data regarding the European building stock has been conducted, focusing on EE renovation measures. Standardised data schemas, as well as data models and the relationships between the various entities, have been analysed and presented, to assist the next actions of the ENERGATE project. The results are thoroughly presented throughout the document, substantiated by literature review, including official reports, scientific publications and results obtained by other relevant projects. These data have been assessed, focusing on identifying the most frequent and important variables, to outline their typology and structure, and extract meaningful results for the creation of an integrated Common Data Model for the ENERGATE platform.

The research conducted and presented in this deliverable may assist in understanding the interplay (also taking stock of previous relevant initiatives) of different combinations of building ownership status, technology, financing methods and their effect on accelerated building renovation rates. It will support the development of specifications for standardised data entry forms for building EE projects and will contribute to the identification and calculation of the

[1] The **aggregation process** will be based on identifying the similarities between the different products to create the different bundles. The similarities may refer to the same typology of the building, the use of the building (public or private), the location, the building services (heating, cooling or ventilation systems) or the type of energy efficiency measures identified as necessary to improve the energy efficiency.

[2] The **matchmaking process** aims to bring together the buy-side and the sell-side inside the ENERGATE platform. It will select the best combination of products and product financing by using a multi-criteria approach to prioritize for each side the most attractive products based on the listed properties, KPIs and financial indicators for each project.

relevant energy, financing and risk KPIs that will be used to develop large, standardised, financeable project packages.

Deliverable structure

The remaining report is structured as follows:

- Section 2 examines existing building typologies to create ENERGATE methodological principles, in order to generate a Common Data Model for the ENERGATE platform
- Section 3 presents financing typologies and their correlation with building characteristics through an examination of specific case studies.
- Section 4 presents barriers and risks of EE measures implementation and proposed KPIs that could be used in the ENERGATE platform for the matchmaking process.
- Section 5 presents a brief overview of EE in buildings, retrofitting measures and their impact on energy consumption based on statistical data from previous initiatives.
- Section 6 summarizes the main conclusions of the research conducted.

2. Buildings Typologies

One of the scopes of the ENERGATE project is to provide standardised project entry forms allowing for the aggregation, enhancement of financial performance and matching with suitable financing tools. The aggregation process aims to select, bundle, split, and generally rearrange a project with the ultimate purpose of increasing its attractiveness for financing. More specifically, the aggregation process will be based on identifying the similarities between the different products[3] to create the different bundles. The similarities may refer to the same typology of the building, the use of the building (public or private), the location, the building services (heating, cooling or ventilation systems) or the type of EE measures identified as necessary to improve the energy efficiency. For example, a bundle of products may be projects referring to the energy renovation of public-school buildings which may focus on improving heating systems using geothermal energy. In addition, a set of “products" can be the improvement of thermal insulation of a particular building typology, in order to achieve energy savings.

In order to proceed with this process, it is obvious that a variety of factors (e. g. building type, use, year of construction, number of floors, heated area) should be taken into account and, thus, they need to be modelled within the ENERGATE platform. Subsequently, the main goal of this section is to identify all the various aspects, variables and metrics that characterise a building, so that the Common Data Model which could be used during the early efforts of designing and developing the ENERGATE platform is proposed. As a starting point, research of existing typologies has been conducted. Several typologies have been identified, although, in general, the approaches are limited, primarily following a conceptual perceptive of building aggregation. It is worth mentioning that the research reveals that limited approaches focus on energy efficiency, but the majority focuses on typologies under the civil engineering and seismic research scope. In contrast, ENERGATE follows a different approach compared to the previous related work, focusing on data-oriented results, giving special focus to EE financing.

The results of this section could assist also in identifying the data that will be asked from the pilot leaders in order to construct an analytical database that includes all the necessary data/ elements that will be needed for the several stages of the projects, for the calculation of the energy, financing and risk indicators, the user rankings, etc.

2.1 Existing typologies and proposed Common Data Model for the ENERGATE ontology

Building typology is a classification system used to categorise buildings based on their function, form, and construction [14]. Building typologies can be used for an in-depth understanding of the energy performance of a building stock [15]. Although building typologies facilitate the identification of patterns and set the basis for the creation of databases and ICT enabled technologies, there is no respective official standardisation, while there is a scarcity of available resources as well.

Since the ENERGATE platform will be an ICT based tool, it is necessary to not only analyse and identify typologies of buildings, but also explore ways of modelling them so that they can

[3] A product can be considered as an investment package that consists of the project (building) entry information along with the energy efficiency measures from the project entry module of the platorm, the energy savings that can be achieved and all the financial indicators necessary for financing the project.

be integrated within the platform. Therefore, it is necessary to thoroughly examine previous endeavours to model building typologies using Common Data Models.

A European collaborative effort exists, under the name TABULA, focused on the creation and applicability of European building typologies with an emphasis on the residential sector [15]. TABULA is part of a greater initiative, the IEE Project EPISCOPE [16]. Moreover, a European Building Classification has been presented by the Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (NERA) initiative [17]. In addition, GEM Building Taxonomy is mainly focused on characterising assets according to attributes that can influence the likelihood of damage due to the effects of natural hazards [18].

It is noteworthy that the categories of buildings from previous projects are very broad, and some building information could be lost when using these classification methodologies [18]. In addition to theoretical approaches on building typologies, ICT approaches also exist, which aim to create frameworks to store buildings' data into standardised databases. The following paragraphs analyse the most common standards in ICT and database modeling for buildings. The majority of these are protocols, frameworks and guidelines that also form the basis of creating a standardized method for creation of Common Data Models (See also Section 2.2.3).

FIWARE

FIWARE is an open-source initiative contributing towards building a set of standards to develop smart applications for different domains such as Smart Cities, Smart Ports, Smart Logistics and Smart Factories. FIWARE promotes a standard, which describes how to collect, manage and publish context information, while adding certain elements that allow exploiting collected data [19]. FIWARE is an inclusive entity specialised in buildings, with its entities containing a harmonised description of a building. It is also associated with the vertical segments of smart homes, smart cities, industry and related IoT applications [20].

Haystack

Project Haystack provides a standardised approach for data modeling on building automation systems, facilitating the integration of data from different systems and devices, enabling more efficient management and analysis of building data. The organization has developed a set of labels and classifications that can be used to describe the data provided by different building systems [21]. Project Haystack encompasses the entire value chain of building systems and related intelligent devices. Haystack is more than just a set of tag definitions; it is also a protocol. The process of integrating multiple systems can be simplified since the Haystack protocol is more enhanced than the BACnet standard [22].

BRICK

The BRICK data model's function is based on defining a set of classes and properties that can be used to represent different aspects of a building, such as its physical structure, mechanical and electrical systems, and environmental conditions. These classes and properties are organized into a hierarchy, that is to say, specific classes and properties inherited from the more generalized ones. One of the key features of BRICK is its modular architecture, which allows only the classes and properties associated with a particular application to be used. A set of ontologies, which are collections of classes and properties used to represent specific domains, are also defined [23].

SAREF

The SAREF (Smart Application Reference) data model for buildings defines a set of classes and properties that can be used to represent data provided by smart devices and systems in a consistent and interoperable manner. The SAREF data model defines a number of classes that are specific to building automation and control. Classes are further divided into subcategories representing more specific types of devices or systems; Each class and subcategory in the SAREF Data Model has a set of properties that represent the different characteristics of the devices or systems [24].

2.2 Identification of building variables: Methodology

Creating the ENERGATE ontology is of vital importance, since the users of the platform on the supply side will have to provide information regarding buildings which will need to be renovated. Thus, an appropriate Common Data Model will allow them to create profiles for their buildings, highlighting important characteristics that could determine which retrofitting measures and financing options apply to them. Furthermore, since potential investors might be interested in financing the renovation of multiple buildings, this procedure could enable the match-making process of projects and products with potential investors, according to the filters they will choose to apply.

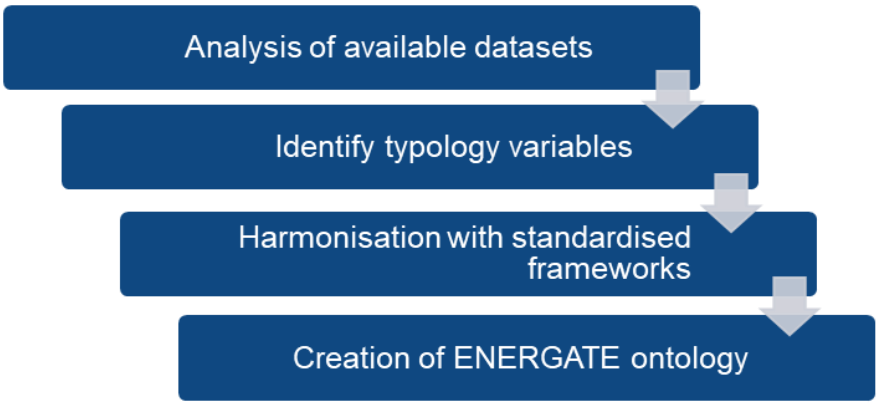


Figure 1 Identification of building variables: Methodology

As shown in Figure 1, the first stage of the methodology is the examination of available datasets. More specifically, open-source databases as well as data retrieved from previous projects relevant to EE in buildings, have been examined so that the most common variables used within the datasets are identified. In the second step of the methodology, a classification of the identified variables in two broad categories (“identification variables” and “measured elements”) has been proposed. During the third stage of our methodology, we have examined the compatibility of the detected variables and the proposed classification with existing, established frameworks of building representation in ICT based environments, by matching those variables with entities and properties utilised within the FIWARE, Haystack, BRICK and SAREF frameworks. The matching procedure proves that the variables are in fact harmonised with the standardised frameworks and can be modelled and integrated in the ENERGATE platform. Thus, the final step of our methodology is the creation of the ENERGATE ontology, inspired by the detected variables in the examined databases and the information provided by the ENERGATE pilots. The choice of variables has been justified, by explaining why each variable plays an important role in building renovation projects. Lastly, different Common Data Model Schemas are proposed.

2.2.1 Analysis of available datasets

Databases of Buildings

The analysis made use of open-source data, available from official sources and relevant initiatives, data from previous projects (anonymised, to ensure compliance with regulation due to confidentiality issues), as well as data available to ENERGATE partners through the pilots of the project. The sources used for the identification are presented in Table 1:

Table 1 Examined Databases

Database	Data
BuiltHub [25]	Data relevant to EU buildings
Eurostat [26]	Final energy consumption, cooling and heating degree days, GPD per capita, U-Values
EU Building Stock Observatory (BSO) [27]	Building stock, energy consumption, energy mix, energy performance and technical building systems, energy certifications
MATRYCS H2020 project [28]	Information of renovation projects (building types, base energy consumption, annual energy consumption after renovation, retrofitting measures)
Triple-A H2020 project [29]	EE financing of project fiches
EEFIG DEEP Database [30]	Building type, ownership
iNSPiRe EU FP7 project [31]	Average consumption for different uses (heating, cooling, lighting etc.)

BuiltHub Data

Builthub is an EU funded Horizon 2020 project. Its purpose is the development of a data exchange platform enabling both insertion and extraction of information relevant to EU buildings. By providing access to such information, Builthub allows relevant actors interested in achieving EE through renovation measures to collect accurate data, while creating a community of stakeholders aiming to enhance sustainability in EU buildings through efficient policies [25].

Eurostat

Eurostat is the official statistical authority of the European Union. Data from Eurostat relevant to EE in buildings include the energy consumption in residential building sector (per building), the energy consumption of non-residential and residential buildings (by fuel) and the energy consumption of residential per m² [26].

Eu Building Stock Observatory (BSO)

BSO is a web tool, which supports monitoring of buildings' energy performance across Europe. More specifically, it provides reliable data regarding building stock, energy consumption, energy mix, energy performance and technical buildings systems, energy certification, financing, energy poverty and social aspects [27].

MATRYCS H2020 project

The MATRYCS project aims at addressing the emerging challenges in big data management for buildings, enabling the handling of heterogeneous types of data (open data, sensor/IoT, historical data, etc.) from multiple domains and sources [28].

Triple-A H2020 project

Triple-A aims at identifying and mainstreaming EE investments in various sectors, including the building sector, focusing on the pre-screening process, where no standardisation exists. This project pursues to support the identification of attractive project ideas, as well as the creation standardised tools and benchmarks [29].

EEFIG DEEP Database

The DEEP 2.0 database results from the work of the Energy Efficiency Financial Institutions Group (EEFIG). The DEEP platform is an open-source initiative aiming to up-scale European EE projects and enable transparent sharing of data related to building renovation. The project's vision is increased EE financing through improved understanding of the real risks and benefits of EE investments [30].

iNSPiRe

The project iNSPiRe aims at conceiving, developing and demonstrating Systemic Renovation Packages, through the innovative integration of envelope technologies, energy generation (including RES integration), energy distribution, lighting and comfort management systems into deep energy renovation of buildings, both in the residential and tertiary sectors [31].

Initial Data from the ENERGATE pilots

Although the collection of data is still in early stages, the first drafts provided by the ENERGATE pilots have highlighted broad guidelines indicating which variables are important in building renovation projects and should be modelled within the platform. Through the examination of the above-mentioned databases, we have detected a plethora of additional variables, which are presented and analysed in the following sections. These variables do not only contribute to the creation of the ENERGATE ontology, but will also designate further information to be requested from the pilots.

2.2.2 Identify typology variables

After detecting the variables that are widely used to identify building renovation patterns, a matching process has been carried out. The goal of this process is to match the variables, as they appear in various datasets, to the indicated standardised forms, as defined from the FIWARE [20], Haystack [21], SAREF [24] and BRICK [23] frameworks. This will assist to create a standardised Common Data Model, which will set the ground of the ENERGATE data gathering process form the pilots and the type of data that will be asked from the users to be inserted in the platform in the project entry module.

The data that will be gathered based on the typology aim to assist in the matchmaking process and the calculation of the energy related KPIs within the ENERGATE platform. The KPIs and variables of the typology will be used to identify which of the project bundles are attractive to be financed and be proposed to the demand side. In addition, the supply side will be able to see as output the energy performance of their buildings, which indicates whether deep renovation or single retrofitting measures are needed to improve the building's EE.

The variables (Figure 2) are separated into two distinct types:

- **The identification variables:** These include variables such as identifiers of the entities represented in the datasets, data set names, total appearances of specific elements, timestamps indicating creation and modification of data. The geographical area, location and construction year of buildings are variables which determine the identity of the building and, therefore, are included in this category.
- **The measured elements:** In this category, values regarding the building's characteristics, as well as data regarding the energy consumption are registered. To be more specific, U-values of walls, floors, roofs and windows are represented by appropriate entities. Naturally, the evaluation of U-values for a particular building depends on weather and climate conditions, which is why temperature values are also included as variables in the "measures elements" category. As far as energy consumption is concerned, values are classified according to the energy use (space heating and cooling, domestic hot water, cooking, lighting etc.) and to the type of fuel consumed (natural gas, oil and petroleum, solid fuels, electricity etc.). Registered CO_2 emissions are also included in this category. Finally, to assess a building's energy performance, energy consumption data must be accompanied by information regarding the heated, cooled and total floor area, thus, these variables are also included in the "measured elements" category.

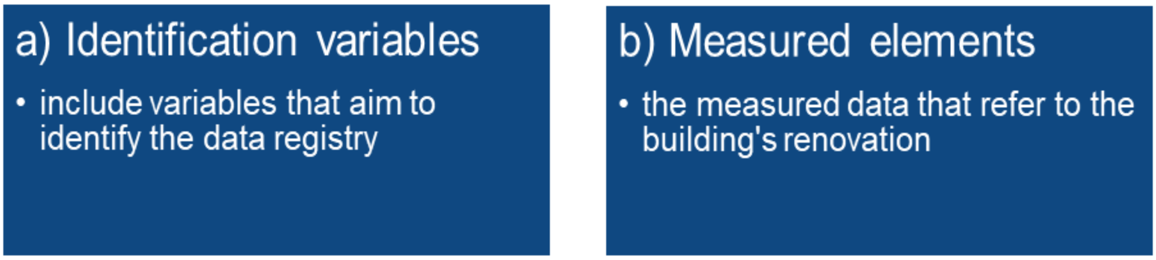


Figure 2 Variables typology

2.2.3 Harmonisation with standardised frameworks

As demonstrated in the paragraphs above, several frameworks and standards exist. These standards have been analysed and reviewed to identify similarities, differentiations, and outline the strong and weak points of each one. The results of the analysis are presented in the following paragraphs, which will assist the decision-making process for the technical implementation of the ENERGATE platform.

To begin with, it must be highlighted that a semantic data model is a data model that represents data in a structured and machine-readable format [32]. The data elements are defined using a set of concepts, relationships, and rules. Data are presented in a way that is both human-readable and machine-readable [33]. SAREF and Brick use the semantic modeling approach, and although Project Haystack is also considered as a semantic data model, it uses a more flexible approach based on a combination of labels and relationships. While all three models use this combination, labels and relationships utilised by each model are different. For example, Project Haystack uses a standardised set of tags and relationships to represent various parts of a building's functions, while Brick and SAREF provide a broader set of entities and relationships to model more complex systems and environments.

SAREF focuses more on describing the behavior and functionality of smart devices, while Brick provides a more detailed representation of building systems, focusing on the physical characteristics of control systems. Project Haystack, in turn, focuses more on describing the data generated by building systems. SAREF uses a top-down approach to model the building sector, starting with high-level concepts and gradually improving them to more detailed levels. Brick uses a bottom-up approach to model the building sector, starting with low-level concepts and gradually moving up to higher levels.

Brick and SAREF are two Common Data Models that can represent various elements and systems associated with a building. However, despite their extensive coverage, there may be cases where certain elements or systems are not represented. In such cases, both in Brick and SAREF, it is possible to use already existing entities to represent elements that do not have their own exclusive entity. This can be done either by using a more general entity, or by using a combination of existing entities to represent the desired asset. For example, in SAREF, if there is no entity for a particular type of power consumption, it can be represented using the more general "EnergyConsumption" entity and adding existing properties to determine the specific type of consumption.

An alternative approach could be the creation of new properties, while taking advantage of existing ones. Brick can take advantage of its scalability and create new classes from existing ones, properties and relationships, in order to expand the ontology to meet any user need. Similarly, SAREF offers a flexible way of expanding its ontology by creating new entities and properties. For example, if a user wants to represent a specific type of power consumption that is not available in SAREF, a new entity or property can be created by specifying its attributes and relationships with existing entities.

In the first column of the following tables, certain variables used in the examined datasets (see Section 2.2.1) are presented. A brief description of the contents of the variables is provided in the second columns, and in the following columns, the corresponding tags or entity/property names for each of the examined frameworks are presented. Since these frameworks function in different manners, not all of the variables match all of the frameworks.

Identification variables

As mentioned in section 2.2.2, the identification variables include variables that aim to identify the data registry. Table 2 presents several identification variables used within standardised frameworks.

Table 2 Matching identification variables with standardised frameworks

Variable	Description	FIWARE TAG	HAYSTACK TAG	SAREF	BRICK
Identifier	Unique identifier of the entity	Id	id		
startDate -endDate	The timestamps	dataCreated-dataModified	date - dateTime	Has timestamp	TimeShape
nutsName	The geographic area where a	AreaServed	geoCountry	location	Location

	service or offered item is provided				
location	The location of the building	location	geoPlace	location	Location
Year Built	The year in which the building was made			hasBuiltYear	YearBuilt
topic	The sector of the building in which measuredElemenet is referred		feature		
feature	The feature of the topic in which the measuredElement is referred		feature		
measuredElement	Data value type		val		
Value	Integer or floating point numbers annotated with an optional unit		number	hasvalue	
Unit	Unit identifier from standard unit database		unit	Is measured in	
Sources	A sequence of characters identifying the provider of the harmonised data entity	dataProvider-source	uri	Value source	

Measured elements

Measured variables, on the other hand, refer to measured data relevant to the building. The information provided by the data is important for the renovation process. In Table 3 several measured elements used within standardized frameworks are presented.

Table 3 Matching measured elements with standardised frameworks

Variable	Description	FIWARE TAG	HAYSTACK TAG	SAREF	BRICK
TotalFloorArea	Area of a shape or floor space		area	FloorArea	Space
HeatedFloorArea	Heated area of building			Heating_Zone	Heated_Area_Fraction
CooledFloorArea	Cooled area of building			Cooling_Zone	Cooled_Area_Fraction
Floor U-Value	The rate of transfer of heat through a structure			Thermal Transmittance (entity) uValue (property)	Variety of tags like Thermal_Transmittance
Wall U-Value	The rate of transfer of heat				

Variable	Description	FIWARE TAG	HAYSTACK TAG	SAREF	BRICK
	through a structure				U_Value Thermal_Resistance
Roof U-Value	The rate of transfer of heat through a structure				
Windows U-Value	The rate of transfer of heat through a structure				
share of ownership	Owner of the building/type of ownership	owner		hasOwnership	Ownership_Percentage
ShareofPeopleOccupancy	People present at the building	peopleOccupancy	occupancy	Occupancy	OccupancyPercentageShape
Temperature	The external temperature in the location of building			Temperature rating	Temperature_Sensor
SpaceHeatingConsumption	Associated with a heating process		heat	Energy_Consumption	Heating
SpaceCoolingConsumption	Cooling mode or process		cooling	Energy_Consumption	Cooling
DHWConsumption	Domestic water flows from the referent to this entity		domesticWaterRef	Energy_Consumption	
LightingConsumption	Systems associated with illumination in the built environment		lighting	Energy_Consumption	Electric_Energy
CookingConsumption	Energy consumed in cooking			Energy_Consumption	
TotalEnergyConsumption	Energy consumed per unit time		power	Energy_Consumption	Energy_Meter
NaturalGas	Fossil fuel energy source consisting largely of methane and other hydrocarbons		naturalGas	Fuel (the type of energy that is used), Energy_Consumed (the quantity of fuel that is used)	NaturalGas
OilandPetroleum	Petroleum based oil burned for energy		fuelOil		FuelOil

Variable	Description	FIWARE TAG	HAYSTACK TAG	SAREF	BRICK
SolidFuels	Solid Fuels used to energy production				(Different tags for solid fuels like pellets, biomass, etc)
Electricity	Electrical energy consumed per unit time		elec-power		Electricity
Renewables	Energy that produced by renewable fuels				(Different tags for renewable energy sources like solar, wind)
CO_2	Greenhouse gas emission of carbon dioxide (CO_2) into the air		co2-emission		Carbon_Dioxide_Emissions

2.2.4 Creation of ENERGATE ontology

A Common Data Model is a standardised way of representing data designed for different applications or systems. It provides a coherent structure for the elements of the data, which facilitates the exchange of information between different systems and ensures that data is understood in the same way by different users and applications [34].

Common Data Models are designed to be sector-specific, which means they aim to represent data in a specific industry or field. By using a Common Data Model, organisations can reduce data inconsistencies and errors, increase efficiency, and facilitate the integration of different systems. Common data models can take various forms, from conceptual models that describe the relationships between data elements to physical models that define the specific database schema. They can be developed by industry consortia, standards organizations or individual companies or groups [35], [36].

After extensive review of all the available datasets, the most common variables are identified and divided into 3 main classes (Figure 3). The classes describe the main types of variables of an EE building renovation project:

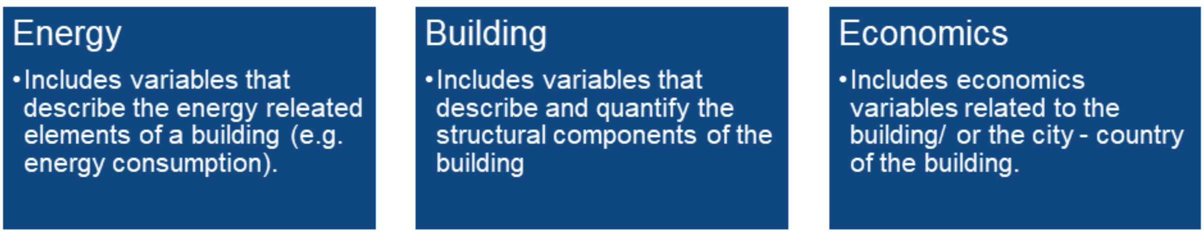


Figure 3 Classification of variables

The approach of creation of the Common Data Model

The main steps for the creation of a Common Data Model for building analysis is presented in Figure 4:

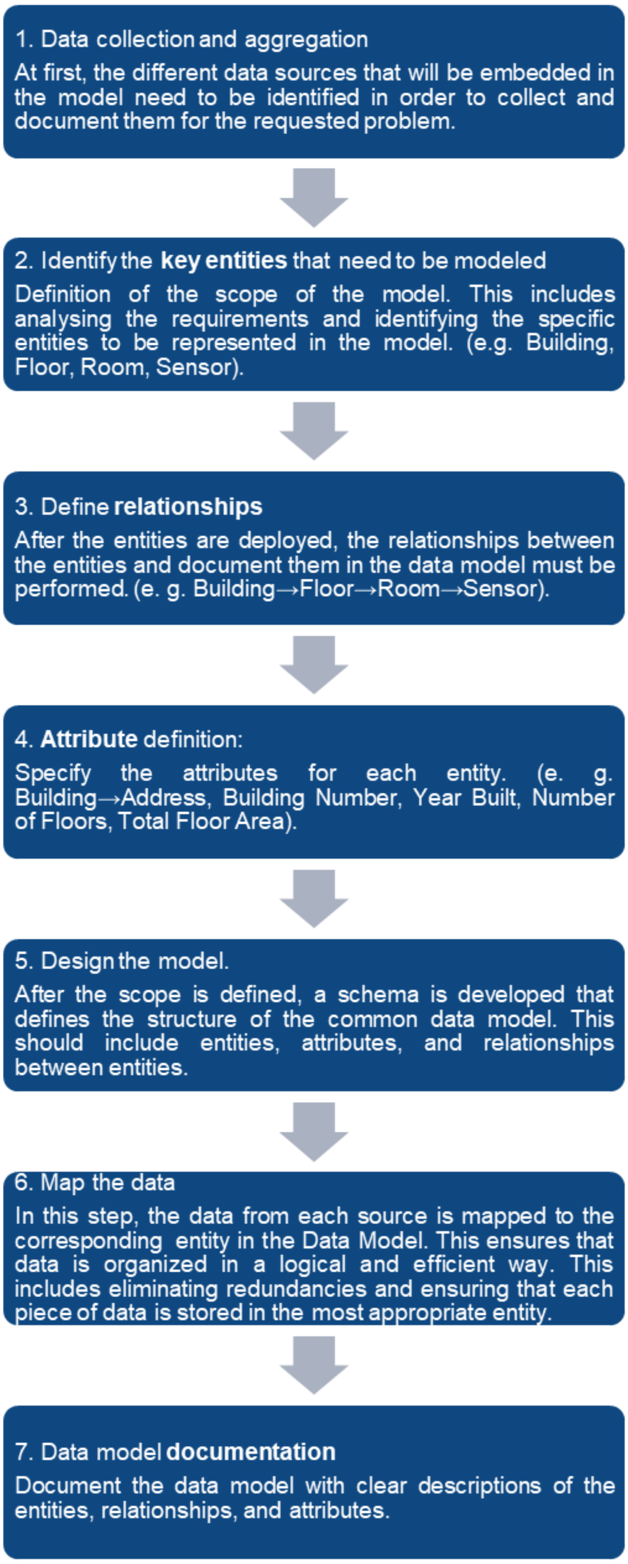


Figure 4 Common Data Model creation steps

It must be highlighted that the identification of the relations between the entities is of great importance for the proper definition and design of the Common Data Model, since these relations will define the model's final schema.

Some examples that make the possible relations of the attributes are:

1. A building could have several floors / levels.

2. One floor / level could have several rooms / spaces with different uses.

3. A room / space could have several sensors from which measurements are derived.

4. A sensor gives various kinds of measurements and is utilised to implement different control strategies.

After creation of the model, model validation is performed, i. e. the data model is tested by applying scenarios and data to make sure it can effectively support the requirements. The main steps of model evaluation are presented in Figure 5:

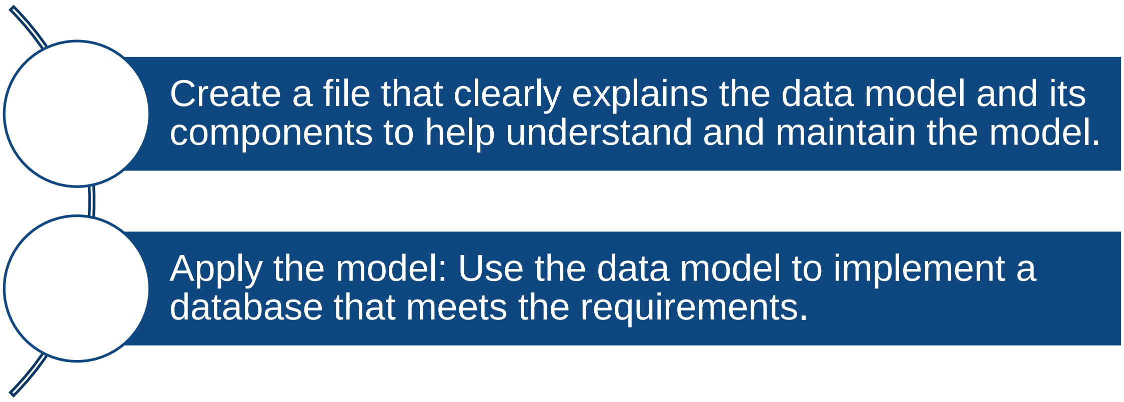


Figure 5 Common Data Model evaluation steps

In the following paragraphs, we analyse possible parameters of building analysis, explaining why each one of these elements is an important factor that should be considered when renovation measures are examined, so as to extract a general Common Data Model. Our building analysis was based on the databases mentioned in Section 2.2.1.

Building analysis

1. *Building characteristics (*Figure 6*)*

The location of the building significantly impacts its energy efficiency, since heating and cooling needs are directly influenced by climate zones [37]. Moreover, space limitations may complicate EE systems' implementation in urban buildings. EE can also be enhanced by taking advantage of sunlight to reduce energy used for lightning, which can be achieved by careful design and proper choice of building orientation [38].

Construction year is also a crucial factor determining whether an EE renovation would be truly beneficial. Older buildings are usually less energy efficient, due to their outdated systems, equipment and construction material. Depending on their construction year, buildings can be divided in five categories:

- **Listed buildings:** These buildings are usually considered of great importance due to historical or architectural reasons. Buildings may be categorized as listed because of their oldness, rarity, and exceptional construction method [39].

- **Over 80 years:** The end of a building's life cycle is 80 years on average.
- **50-80 years:** Buildings are usually heading towards the end of their life cycle, therefore, reinforcement of their structural strength and stability might be necessary. However, interventions may be challenging due to the oldness of the building [40].
- **20-50 years:** Renovations usually start during this period of a building's life cycle.
- **10-20 years:** This is considered the most suitable period to turn a building into a Nearly Zero Energy Building by taking appropriate actions.

Technical characteristics, such as U-values and floor area, also determine the energy performance of a building. U-values highlight the effectiveness of insulation [41]. Lower values indicate better performance, while in buildings with high U-values more energy is consumed to maintain the desired temperature. The floor area and the number of floors also have a significant impact on energy consumption.

Moreover, the number of people in a building affects energy efficiency, as high occupancy requires more energy for lighting, heating and cooling. The behavior of the occupants also affects the effectiveness. Therefore, high occupancy must be considered when designing the building, in order to achieve higher efficiency, through factors such as natural ventilation and efficient lighting.

Ownership of buildings is an important feature to be considered when assessing energy performance and renovation prospects. A building that is privately owned may have more resources available for renovation than a public building, where funding may be limited. In addition, private owners may have more flexibility in deciding on energy-efficient upgrades or renovations, whereas stricter regulations and procedures need to be followed in public buildings. Subsequently, the ownership status of a building can be distinguished in the following cases:

- Public buildings
- Private buildings, such as houses or small businesses
- Commercial buildings, referring to buildings used for commercial purposes, including office buildings, warehouses and retail buildings.

In addition, one building could belong to one or more owners and each property could have a different use (e.g., a multistore apartment building with stores on the ground floors and parking in the basement). Finally, the function of a building affects its energy needs. Different types of buildings have different energy requirements, thus, the type of energy-efficient upgrades that may be feasible or desirable may differ according to the building's function. The operation of the building also affects the potential benefits and purposes of energy-efficient upgrades, such as improved indoor air quality or operational savings. For this reason, based on the Energy Performance of Buildings Directive (EPBD) [42], buildings are divided into the following categories:

- single-family houses of different types
- apartment blocks
- offices
- educational buildings
- hospitals
- hotels and restaurants
- sports facilities
- wholesale and retail trade service buildings

- other types of energy-consuming buildings

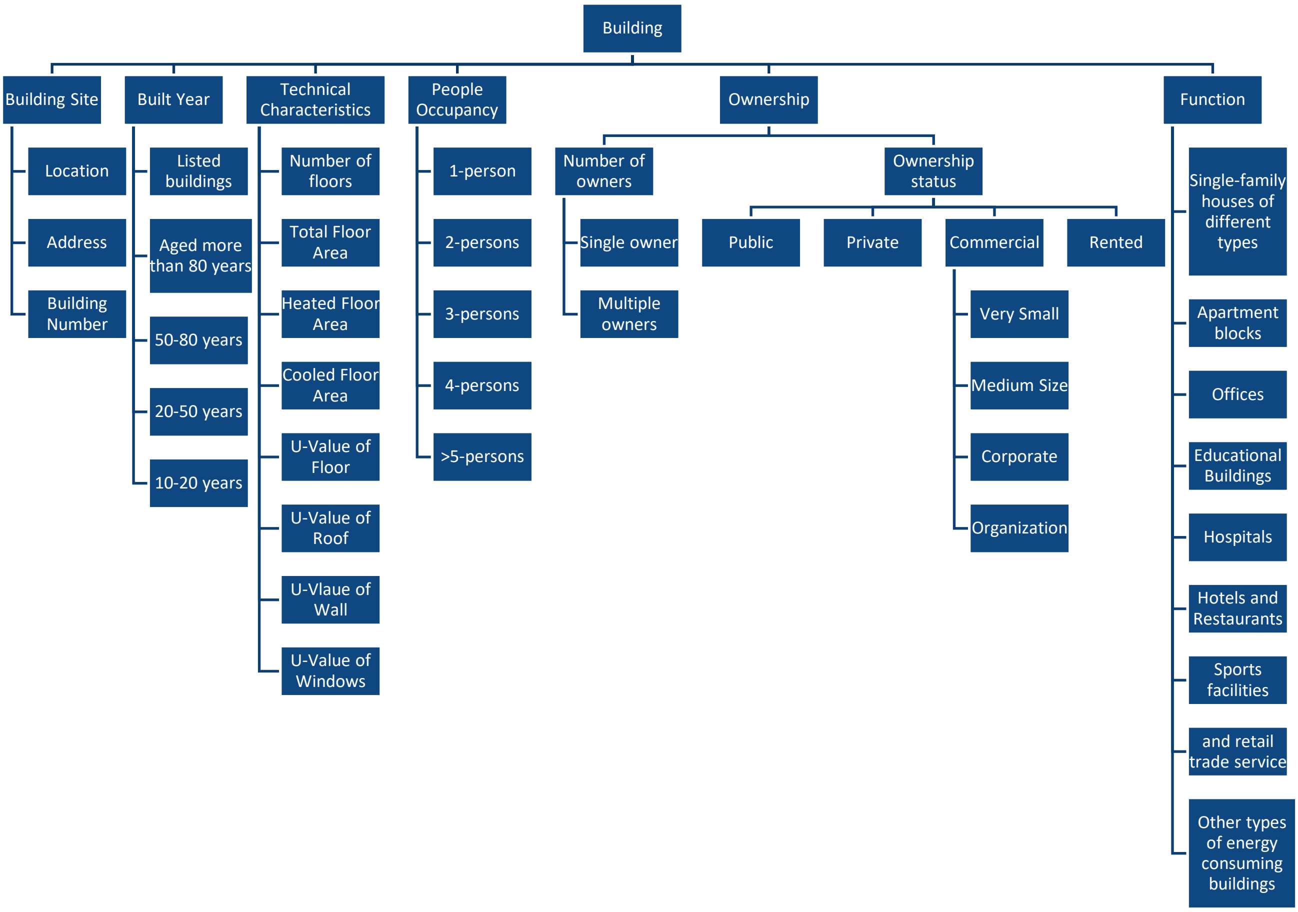


Figure 6 Building characteristics

2. *Energy usage in buildings (*Figure 7)

The evaluation of energy consumption per sector is a very important part of a building's analysis, as it provides the necessary information on how energy is used in a building and where energy overuse can occur. By examining energy consumption in various sectors (heating, cooling, lighting, domestic hot water, cooking and any other end-use) building managers can identify areas of improvement and make informed decisions about the necessary interventions-upgrades.

Besides the energy consumption per sector, the observation and evaluation of buildings considering the total energy consumption is of vital importance. By examining the energy use of a building as a whole, stakeholders can detect the areas where energy is used inefficiently or where energy-saving measures could be implemented. Such an analysis can help engaged parties set improvement targets and benchmarks for energy efficiency. In addition, it is important to note that total energy consumption is analysed both cumulatively (Total Energy Consumption), and proportionally based on the total area of the building (Total Energy Consumption per m^2), but also individually for a building as a unit (Total Energy Consumption per building), if we refer to consumption of a wider area.

Fuel consumption must also be taken into account. When analysing fuel consumption, the type of fuel, as well as the amount used must be considered. The main categories whose consumption must be considered are natural gas, oil, fossil fuels, electricity, heat fuel and renewable energy.

Similarly, the energy usage in a building can be examined through the share of fuel consumption in relation to the total consumption. By analysing fuel consumption, building owners can identify opportunities to reduce energy wastage and, simultaneously, prepare for the transition to renewable energy sources. It is noteworthy that evaluating fuel consumption is also important for compliance with energy and environmental regulations.

Additionally, linking energy consumption to fuel prices can be useful, if relevant data are available (natural gas, electricity). Prices play an important role in the analysis of buildings, as they can have a significant impact on overall energy costs, since fluctuations in fuel prices can affect the economic viability of EE measures.

Furthermore, evaluation of the building's energy performance through its gas emissions should not be omitted. To be more specific, gas emissions refer to the release of greenhouse gases, such as carbon dioxide (CO_2), into the atmosphere as a result of burning fossil fuels for energy [43]. It is necessary to reduce the carbon footprint of buildings in order to mitigate climate change.

Another feature that was studied for the analysis of buildings is the nearly zero energy building (NZEB). NZEBs are defined as buildings that have a very high level of energy efficiency, with the near-zero or very low amount of energy needed to meet heating, cooling and ventilation needs, coming mainly from renewable sources [44]. Analyzing them in a building project can provide valuable information with the potential to achieve high levels of EE and sustainability.

Energy Performance Certificates (EPC) are the last feature considered in the "energy" branch of the building analysis. They are documents that provide information regarding the energy performance of a building, as well as recommendations for performance improvement [45]. As expected, better performance is recorded in buildings with such certificates.

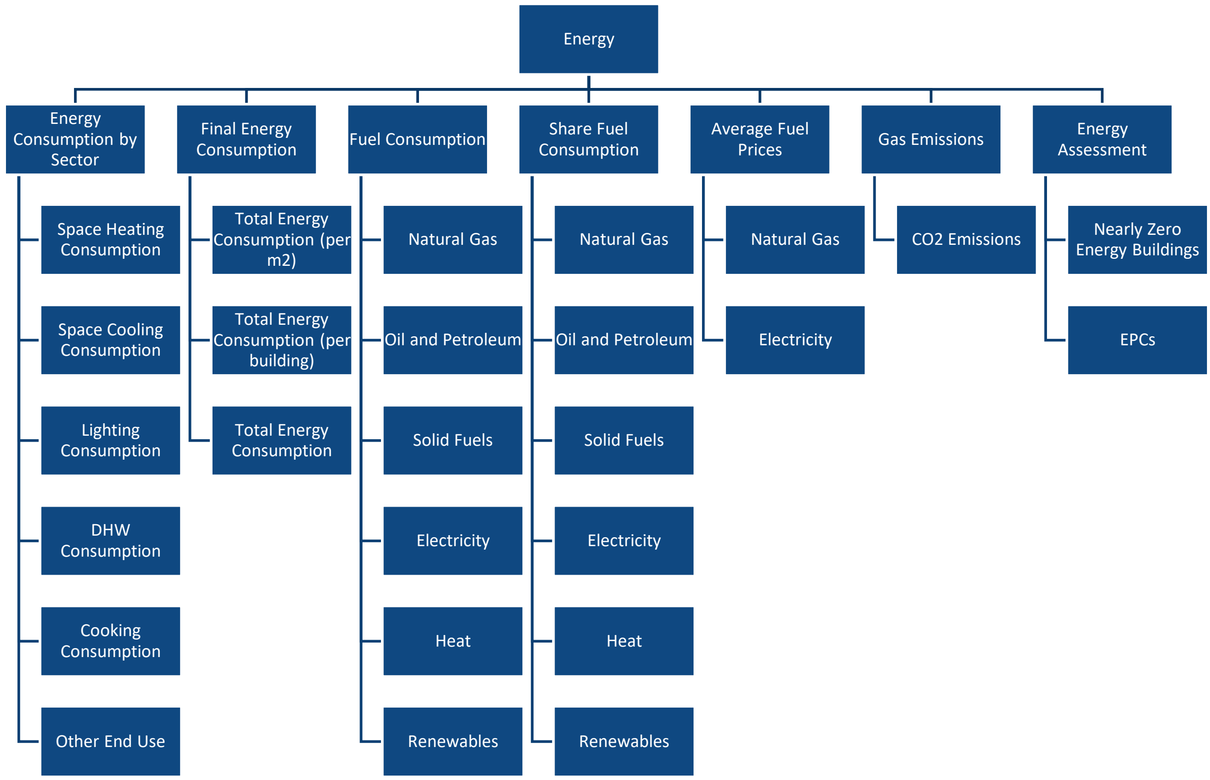


Figure 7 Analysis of elements regarding energy usage in buildings

3. *Economic factor (*Figure 8*)*

GDP per capita, which refers to the value of all goods and services produced in a region divided by its total population [46], is an important aspect of building analysis, because it can help building managers assess the economic viability of different building projects and upgrades. At the same time, through the examined data, it was concluded that in countries with higher GDP per capita there is a relatively higher energy consumption.

However, GPD per capita might be considered too general and may not be indicative of a specific building, which is why a further classification of low, medium and high income could be added in the ENERGATE ontology.

Investments in building renovation operations and, in general, energy-related investments are a key part of the building analysis, as far as the economic sector is concerned. Through the research of relevant data, trends in the implementation of energy upgrades are recorded. The goal is to increase movement in renovation and energy upgrade works, since it is expected that the upgrades will lead to a corresponding enhancement of building's energy efficiency.

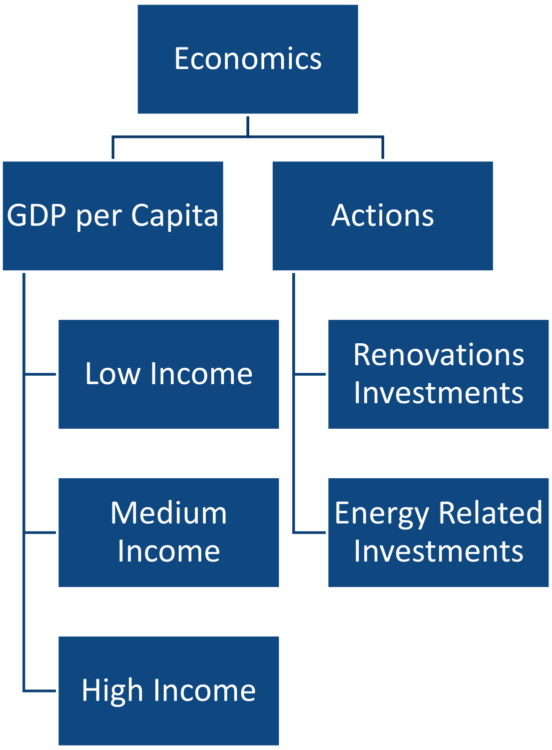


Figure 8 Analysis of elements regarding economic aspects in building

The final proposed Common Data Model for the ENERGATE platform is illustrated in Figure 9.

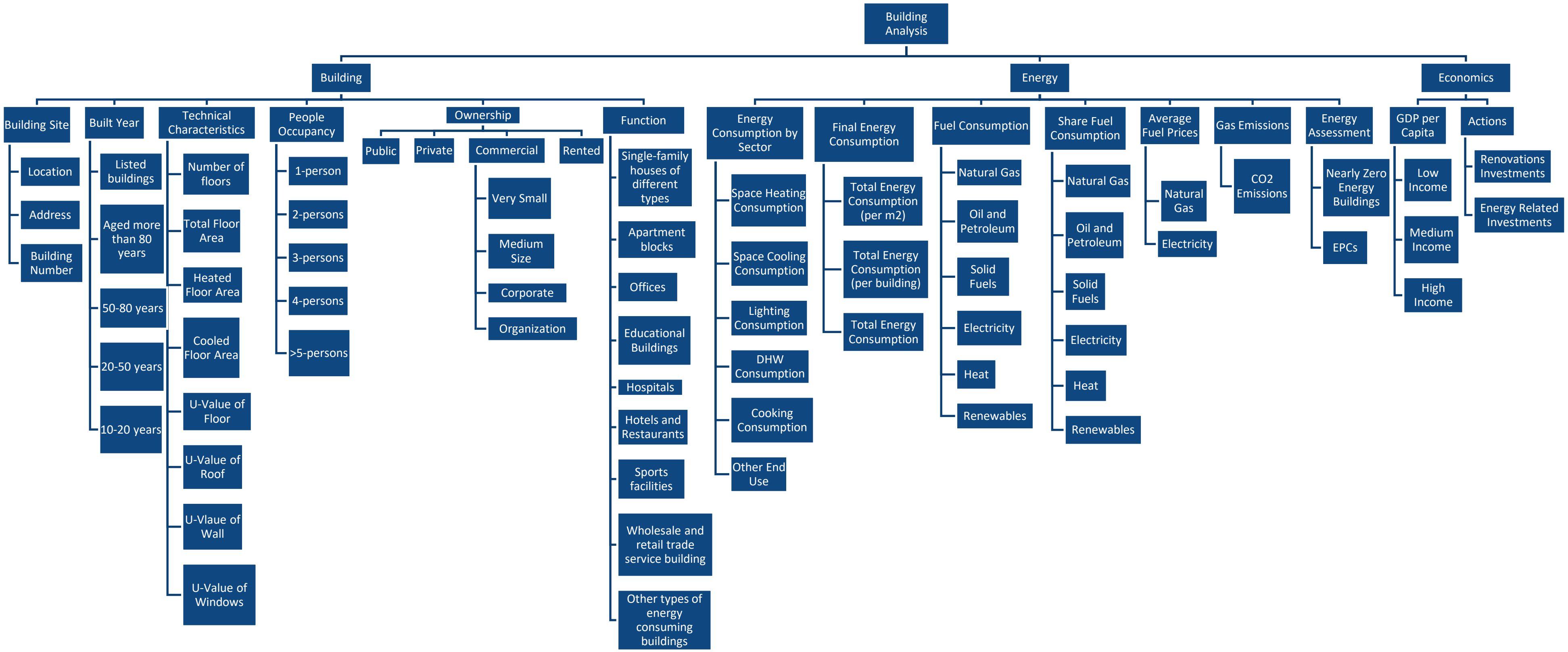


Figure 9 Proposed Common Data Model

2.3 Retrofitting actions: Types and measures

One of the key services provided by the ENERGATE platform could be the proposition and prioritisation of different retrofitting measures, according to the typology of the building. Thus, in this section, the most prominent EE interventions in the building sector have been reviewed and presented. To achieve EE goals, renovations should go beyond improvements in insulation or innovative heating technology. Retrofitted building automation should be considered as well, to increase energy performance in existing buildings [47]. Common retrofitting types and measures are presented in Table 4. The main broad categories are the following:

Building envelope: Insulation of walls, floors and roofs can prevent heat losses during cold weather and preserve low temperature in the building during hot weather [48]. Doors and windows with high thermal efficiency can also reduce energy needs and result in energy savings [37], [49].

HVAC (Heating, Ventilation and Air-Conditioning): Large amounts of energy are consumed for heating and cooling in buildings. Besides enhancing façade, floor, roof, fenestration and doors, energy can be saved thanks to efficient HVAC systems. Efficiency of heating, cooling and ventilation can be achieved by renovating existing infrastructure (e. g. air conditioning units, boilers, mechanical ventilation), or by installing new systems (new air handling units, heat pumps, heat recovery systems). EE can also be improved through simpler measures, such as installation of solar shading systems and improvement of natural ventilation techniques [50], [51].

Lighting: Lighting retrofit usually includes replacement of current lamps with more efficient, less energy consuming lamps. Furthermore, energy consumption can be regulated through daylight systems, which redirect natural light so that it can be optimally exploited throughout the day [38].

Renewable installations: The most common renewable energy installation used in building is photovoltaic panels [52]. Small wind turbines, geothermal heat pumps and biomass-empowered technologies can also contribute to sustainable energy usage [53].

Automation: Building automation systems include devices such as sensors, counters, timers and smart appliances which can significantly contribute to efficient energy use [54].

Table 4 Identification of retrofitting measures

Category		Retrofitting Measures		
Building design	Building Envelope	***Façade & Floor***	***Roof***	***Fenestration & Doors***
		Insulation of external walls	Flat roof external insulation	Door replacement
		Insulation of internal walls	Pitched roof internal insulation	Glazing replacement
		Insulation of floor		Installation of solar shading systems
		Insulation of basement ceiling	Top slab external insulation	
			Slab internal insulation	Airtightness
	Lighting	***Lamp Replacement***	***Daylight strategies***	
		Replacement of current infrastructure with less energy consuming equipment, e. g. LED lamps	Daylight-controlled artificial lights	
			Redirection of natural light (e. g. with reflection panels)	

Category	Retrofitting Measures		
HVAC	***Cooling***	***Heating***	***Ventilation & hot water preparation***
	Economizer cycle	Water, ground and air source heat pumps	Improvement of mechanical ventilation
	Chiller plant retrofit	Replacement of inefficient boilers with condensing gas boilers	Ceiling fans
	Air-conditioning improvement		Installation of heat recovery system
		Boiler economizer	Improvement of natural ventilation techniques
	New air handling unit	Thermal solar systems	
	Roof top unit	Roof top unit	Roof top unit
	Evaporative cooler	Radiant heating system	Hot water accumulator
Renewable installations	***Solar***	***Wind***	***Other***
	Photovoltaic systems	Micro wind generation	Geothermal, biomass technology
Other measures	***Automation***		
	Smart appliances, sensors, counters, timers, Building Energy Management Systems		

Within the ENERGATE platform, the above-mentioned retrofitting actions could be classified in broad typologies of renovation upgrades, as shown in Table 4, in order to serve as initial suggestions for the users of the platform and further, more distinct suggestions could be made according to the typology of the building and the preferences of the supply side.

3. Financing Typologies

The section focuses on the available financing mechanisms for building renovations, in order to identify the most promising financing typologies for different building types. The feasibility of incorporation of these financing schemes in the ENERGATE platform will be examined, as the supply side could be provided with suggestions of financing solutions automatically, based on the input they have given to the platform, that is to say, their buildings profiles based on final typology that will be developed.

The matchmaking and aggregation process needs to be driven by the appropriateness of the financing method. The latter should determine the size and composition of the project by means of aggregating different measures or dealing with homogeneous project pipelines involving a single or several project owners/sponsors. Based on the research conducted the broad categories of financing methods that a product may be tied to shall comprise Private and Public/ PPP finance, whereas larger pipelines (30- 50 Meuro and above) may be implemented as under a project finance method (involving a dedicated cycle of due diligence, project management and organization, etc.) and small pipelines may be implemented via corporate finance, P4P, EeaaS, on-bill, EPC, etc.

As a starting point, the JRC report [55] on financing building energy renovations has been examined. The financial instruments identified in the report are still valid, as demonstrated by our literature review, which is presented below. However, new financing tools for EE in the building sector have been adopted as well [56]. Additional funding mechanisms and programs to promote sustainability and renovation in buildings have been developed by the European Union [57]. The research is based on 83 scientific publications in order to identify and categorise the financing schemes.

3.1 Common financing instruments for building renovations

The most prominent financial instruments for building renovation, EE upgrades and retrofitting actions are:

Grants/Subsidies: Grants, perhaps the most wide-spread financial mechanism, are non-repayable funds for renovation projects [57]. Grants are typically provided by government agencies, private foundations or non-profit organizations and may cover a wide range of costs related to renovation projects, including design and engineering fees, construction costs and EE upgrades [58]. Grants can be combined with other financing tools, so as to help overcome barriers such as long payback periods and limited financial returns [56], [59].

Subsidies are provided by government agencies and may include tax credits, deductions or low-interest loans, which aim to encourage renovation projects that have public benefits, such as reducing greenhouse gas emissions [56], [60], [61], [62].

Several funding mechanisms to support building renovation and other EE actions have been developed and implemented by the European Union. Such mechanisms are:

Recovery and Resilience Facility (RRF): The RRF is a financial mechanism established by the European Union (EU) to support the recovery and resilience of the economies and societies of the EU Member States from the effects of the COVID-19 pandemic. Its funding can be used for a wide range of purposes, including renovation to make buildings more energy efficient and sustainable. The funding can be used to support various aspects of retrofitting projects, such as the installation of energy-efficient heating and cooling systems, insulation and other energy-saving measures. In order to receive funding, Member States must submit a national recovery and resilience plan outlining their reform and investment priorities. The plan should include details on how the funding will be used to support the transition to a sustainable and climate-neutral economy, including investments in energy efficiency, renewable energy and building renovation [63], [64].

European Structural and Investment Funds (ESIF): European Structural and Investment Funds are a group of funds that are available to EU Member States and are aimed at supporting economic and social cohesion across the EU [65]. These funds can be used to support a range of activities related to building renovation, including energy audits, insulation upgrades, and the installation of renewable energy systems. In order to access ESIF funding, building renovation projects must be in line with the EU's environmental and energy policy goals, which are set out in the Europe 2020 strategy and the Energy Union. Projects must also meet certain eligibility criteria, which can vary depending on the specific fund being used. The funding is often provided in the form of grants or low-interest loans, which can help to reduce the financial burden of building renovation projects. In addition, ESIF funding is accompanied by technical assistance and support, which can be valuable for project planning and implementation [66].

Horizon 2020: Horizon 2020 is a modern research and innovation funding program, created by the European Union to support scientific and technological research in a wide range of fields[67] . While not specifically designed to finance building renovation, it offers opportunities to fund research and development activities that can be applied to retrofitting projects. Horizon 2020 funding is available to a wide range of organizations, including universities, research institutes and private companies. However, access to program funding can be competitive and proposals must demonstrate their potential for scientific and technological excellence and social impact in order to be considered for funding [66].

European Local Energy Assistance (ELENA): The European Local Energy Assistance-ELENA is a technical assistance instrument that provides funding and support to local and regional authorities across Europe to help develop and implement sustainable energy and climate action plans [57], [68]. ELENA provides funding for technical assistance and feasibility studies related to sustainable energy projects, including building renovation projects. It can support a range of activities related to the renovation of buildings, such as energy audits, the development of EE plans and the preparation of project proposals for funding [66].

LIFE programme: The LIFE program is another EU funding instrument for environmental and climate action projects. It provides funding to support the development and implementation of innovative environmental and climate projects across Europe, including building renovation projects, focusing on improving EE and reducing greenhouse gas emissions. The program offers several funding opportunities for building renovation projects. An example of this is the LIFE Climate Change Mitigation sub-program which supports projects aimed at reducing greenhouse gas emissions. The LIFE Energy Transition sub-program also supports projects aiming to promote efficient use of energy through building renovation projects. To access LIFE funding, applicants must submit a project proposal demonstrating their ability to deliver environmental and climate benefits, as well as their technical and financial capacity to implement the proposed project. Besides funding, the LIFE program also offers technical support and guidance to project developers [69].

European Fund for Strategic Investments (EFSI): The European Fund for Strategic Investments is another financial mechanism that can be used to support building renovation projects. It was set up in 2015 as part of the Investment Plan for Europe, which aims to boost investment in the EU and support job creation and economic growth [70]. EFSI uses a guarantee facility to exploit private sector investments, which can help increase the amount of funding available for building renovation projects. In addition to providing funding, it also offers technical support to project promoters, as well as assistance in preparing projects and advice on funding options [66].

Cohesion Policy Funds: Cohesion policy funds are financial instruments established by the European Union to reduce disparities and promote economic, social and territorial cohesion between EU regions. These funds are mainly intended to support less developed regions but are also allocated to more developed regions facing economic challenges. They can be used for a variety of purposes, including supporting the renovation of buildings. The main funds for building renovation projects under Cohesion Policy are the European Regional Development Fund (ERDF) and the European Social Fund (ESF) [60].

The ERDF is the main financial instrument for supporting regional development in the EU. It provides funding for projects that contribute to economic growth and job creation in less developed regions. One of the priorities of the ERDF is to support the transition to a low-carbon economy, including the renovation of buildings to improve EE [60], [71].

The ESF, on the other hand, provides funding for projects that promote employment, social inclusion, and human capital development. It can be used to support training and education programs for workers in the construction industry, as well as to promote energy efficiency and sustainable building practices [60], [72].

In addition to these funds, there are also other Cohesion Policy instruments, such as the Cohesion Fund, which can be used to support building renovation projects in specific contexts[73].

Tax incentives: Tax incentives are usually provided by governments as a way to encourage building owners to invest in energy-efficient building upgrades and renovations, because they provide a direct financial benefit to the building owner. Incentives may include tax credits, tax deductions and accelerated depreciation [58]. Certain researchers consider tax credits more effective than grants and subsidies [74]. Tax credits reduce the amount of tax owed by the building owner by a percentage of the cost of the renovation project [75]. Tax deductions allow building owners to deduct a portion of the renovation costs from their taxable income, thereby reducing the amount of tax due. Rapid depreciation allows building owners to recoup the cost of the renovation project in a shorter period of time, thereby reducing their taxable income [56], [76].

Energy efficiency obligations (EEOs): Energy efficiency obligations require energy companies to meet specific EE targets and certain levels of energy savings by incentivizing energy-efficient building renovations [77]. Obligations can be implemented through various tools, such as energy saving certificates, which in turn, are granted to energy companies that achieve energy savings beyond a desired threshold. Certificates can then be traded in a market, incentivizing energy companies to invest in EE measures [78]. They are an important source of funding for building renovation projects, especially when it comes to commercial and industrial buildings, with a limited impact on the residential buildings sector. Nevertheless, EE obligations can be complex to implement and may require significant coordination between energy companies, building owners and government agencies [56].

Energy Performance Contracting (EPC): Energy service companies finance energy efficiency-focused building renovation projects, providing a wide range of energy-related services to building owners, including energy audits, EE upgrades and energy management systems. The cost of EE upgrades is covered through the savings resulting from the improvements [58]. In an energy performance contract, ESCO covers the initial costs of the renovation project and is reimbursed through part of the energy savings achieved by the building owner for a certain period of time. The contract usually includes an energy savings guarantee, which provides assurance to the building owner that the investment will pay off [56], [79].

Energy Performance Contracting is an increasingly used financial mechanism for building renovation projects. The EPC is a contractual arrangement between the building owner and an energy services company (ESCO), which provides financing for EE measures in buildings. Under the EPC contract, ESCO assumes responsibility for the identification, design and implementation of energy saving measures in the building [80]. ESCO finances the project in advance and is compensated through energy savings achieved over a predetermined period of time, which can range from 5 to 15 years or more. The owner of the building benefits from the energy savings achieved without having to make any initial investment. This financing mechanism can be particularly attractive for public buildings, such as schools, hospitals and government buildings, which often have limited budgets for capital investment [81]. Another similar contractual scheme enabling EE measures implementation in buildings is the ESA financing mechanism (Energy Services Agreements). Project developers are responsible for operation and maintenance of retrofitted infrastructure, and building owners repay implemented interventions based on achieved energy savings. Therefore, performance guarantees are required to certify that savings will occur [56], [82].

On-bill finance (OBF): On-bill finance allows building owners to fund EE upgrades through utility bills. The owner of the building borrows money from a lender to finance the renovation project, and the repayment of the loan is added to the building's utility bill, usually at a lower interest rate than a traditional loan [58]. OBF can offer a number of benefits to building owners, including reduced financial risk, lower interest rates and simplified repayment terms [56].

Property Assessed Clean Energy (PACE): Property Assessed Clean Energy is a financing mechanism that allows building owners to finance EE and renewable energy improvements through a special estimate in their property tax account [83]. PACE funding is typically available for commercial, industrial, and residential real estate. The building owner borrows money from a lender to finance EE or renewable energy improvements, and the loan is repaid through a special appraisal in the property tax account. The valuation is spread over a period of 10 to 25 years, and the loan remains on the property even if the property is sold. This means that the owner of the building does not need to provide personal guarantees or collateral for the loan [56], [58].

Loans/ Energy-efficient mortgages (EEM): Loans can be used to cover the costs of building renovation projects, including materials, labor and design services, and are obtained from a variety of sources, including banks, credit unions and private lenders. Loans can be structured in different ways, such as secured and unsecured loans, fixed and variable interest rates, and short- and long-term repayment periods. Secured loans require collateral, while unsecured loans do not require collateral, but have higher interest rates and stricter lending standards. Fixed interest rates provide stability in loan payments, while floating interest rates may fluctuate over time [56], [62].

Energy-efficient mortgages are a type of mortgage that allows homebuyers to finance the cost of energy-efficient upgrades to their homes [58]. EEMs are available for both new and existing homes, and they can be used to finance a wide range of energy-efficient improvements, such as insulation, windows, and high-efficiency heating and cooling systems. Under an EEM, homeowners can qualify for a larger mortgage or a lower interest rate based on the anticipated energy savings from the energy-efficient upgrades. The energy savings are typically calculated using an energy audit or a home energy rating system, and the savings are factored into the borrower's debt-to-income ratio [56], [60], [85].

Energy Efficiency Feed-in Tariffs (EE-FiTs): An additional incentive mechanism for EE improvements in buildings is Energy Efficiency Feed-in Tariffs. Similar to feed-in tariffs for renewable energy, EE-FiTs offer a financial reward for building owners who invest in EE measures. Under an EE-FiT, building owners are remunerated at a fixed rate for each unit of energy saved through EE improvements. Payments are made by the local utility or government agency and are intended to cover the cost of improvements and provide a return on investment for the building owner [56], [64].

Incremental property taxation: In the context of incremental property taxation, property taxes are gradually increased based on the estimated value of the building after the improvement of energy efficiency, thus this financing mechanism aims to incentivize property owners to invest in EE improvements in their buildings. The incremental increase in property taxes is based on the estimated energy savings resulting from the improvements, and the tax increase is gradually implemented over a period of several years. The idea behind this mechanism is to provide a financial incentive for property owners to invest in EE improvements that will lead to long-term cost savings while generating revenue for local governments [56], [86].

Crowdfunding: Crowdfunding has the potential to play an important role in promoting EEand sustainability in the built environment, especially when it comes to small-scale projects, since building owners may find it difficult to access traditional sources of finance. By providing a medium to raise funds from a large number of people, crowdfunding platforms can help finance EE improvements and promote sustainable and resilient communities [74].

Equity: Equity refers to ownership in a company or project, and equity financing involves raising capital by selling ownership shares to investors [58]. In the context of building renovation, equity can be raised through various mechanisms, such as private investment and public-private partnerships. Private investors can provide funds in exchange for ownership of the project and can potentially earn a return on their investment through project revenues or the valuation of their ownership share [74].

One-stop shops: One-stop shops provide comprehensive support and guidance to building owners interested in improving the energy performance of their buildings. Their primary function is the provision of a range of services, including energy audits, financing options, contractor referrals, and technical assistance. One-stop shops can provide several kinds of financing options. Usually, they offer financing plans combining different funding schemes, nonetheless, they sometimes provide their own resources to finance EE projects and could therefore be regarded as a financing tool for building renovation. They aim to simplify the process of implementing EE improvements by giving building owners access to all the resources they need. By facilitating the process and building owners' access to support and information, one-stop shops help overcome some of the obstacles that can hinder the implementation of EE improvements [56], [87], [88].

Each financing mechanism analysed above has been classified in one of the seven categories presented in Table 6. Based on the keywords in Table 5, a literature review has been conducted focusing on papers and research articles published after 2015. In Figure 10, the percentages of publications in different categories of financial schemes are illustrated in a pie chart.

Table 5 Keywords for the literature review of financing schemes

Keywords
Financing, funds, funding, investments, financial tools, mechanisms, schemes
Buildings, green buildings, nZEB, residential, commercial, historical, private, public, households

Renovation, retrofitting, energy efficiency measures, actions, interventions, upgrades
Grants, subsidies, loans, mortgages, energy efficiency obligations, ESCOs, EPC, energy efficiency feed in tariffs, tax incentives, investment property taxation, PACE, cohesion policy funds, EU programs, equity, crowdfunding, one-stop shops, on-bill financing

Table 6 Categories of financing schemes and sources

Categories	Sources
Non-repayable funds (Grants, Subsidies)	[59], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100], [101], [102], [103], [104]
EU programs and financing mechanisms (Cohesion Policy Funds, RRF, ESIF, ESFI, Horizon 2020, ELENA, LIFE program)	[105], [106], [107], [108], [109], [110], [111], [112], [113], [114]
Debt financing (Loans, Mortgages)	[104], [115], [116], [117], [118], [119], [120]
Funds based on achieved energy savings (EEOs, ESCOs, EPCs, EE-FiTs)	[80], [81], [121], [122], [123], [124], [125], [126], [127], [128], [129], [130], [131], [132], [133], [134], [135], [136]
Tax-related financing instruments (Tax Incentives, Investment Property Taxation, PACE)	[75], [76], [86], [137], [138], [139], [140], [141], [142], [143], [144]
Equity financing (Equity, Crowdfunding)	[116], [145], [146], [147], [148]
Other investment schemes (One-stop Shops, On-bill Financing)	[87], [88], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164]

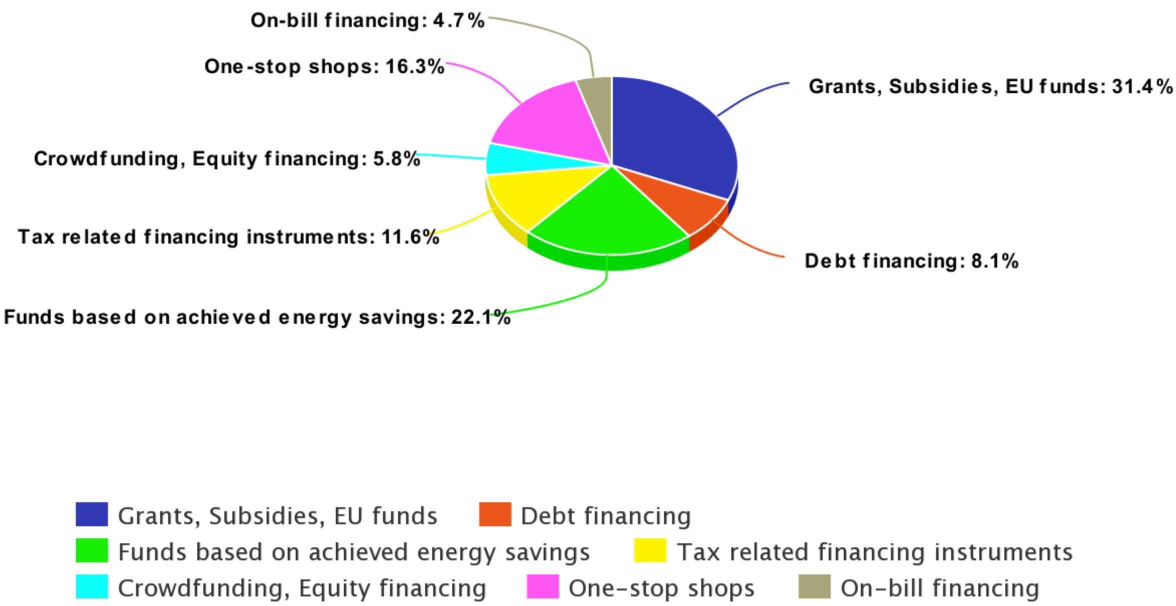


Figure 10 Categories of financing schemes

As observed in Figure 10, grants and subsidies, including funding mechanisms established by the European Union, are the most common funding tools discussed in relevant literature. More than 20% of the reviewed publications concerned funds based on achieved energy savings, such as EEOs, EPCs and EE-FiTs. About 16% of the examined sample of papers considered one-stop shops, although it must be highlighted that this category is not exclusively a financing mechanism, because one-stop shops provide comprehensive services supporting EE projects and do not always provide their own resources. Crowdfunding and on-bill financing, which could be considered as relatively innovative ways of funding retrofitting actions represent only a small amount of the reviewed publication. Therefore, it is observed that traditional mechanisms (grants and subsidies, debt financing, tax related financing instruments) are still discussed in relevant literature, more than revolving funds based on achieved energy efficiency, whereas newer mechanisms have not yet attracted the attention.

3.2 Correlation between financing and building typologies

Based on the reviewed articles, we have associated each financial mechanism used for building renovation with the most common building status (ownership and type). Furthermore, risks and most prominent barriers for each funding scheme have been identified, mainly based on [56] and [165]. The results are presented in Table 7.

Table 7 Building status and financial mechanism

Financial Mechanism	Building Ownership	Building Type	Risks	Barriers
Grants & Subsidies	Public & Private	All	Attraction of free riders & Limitation of private sources of finance [165]	Complexity of application process, budget restriction [56]
Recovery and Resilience Facility (RRF)	Public & Private	All	Grant schemes relying on EU funds often include considerable delays. This may result in uncertainties which could have a negative impact on market players. Follow-up financing schemes may be needed, since resources are limited [165]	European initiatives aim to overcome barriers of building renovation (high initial costs, long payback periods, perceived credit risk) but there is still a lack of awareness regarding current available financial mechanisms [66]
European Structural and Investment Funds (ESIF)	Public	All Public		
European Funds for Strategic Investment (EFSI)	Public & Private	All		
HORIZON 2020	Public & Private	All		
European Local Energy Assistance	Public & Private	All		
LIFE program	Public & Private	All		
Cohesion Policy Funds	Public	Commercial, Public		
Tax incentives	Public & Private	All	Tax collection rate determines the	Low-income households may

			success of potential tax incentives [56]	not be significantly benefited [56], Lack of awareness [144]
Loans & Energy Efficient Mortgages	Public & Private	All	Complication/ reluctance and perceived risk of acquiring additional mortgage on top of existing debt [56], [165]	Limited eligibility for vulnerable groups [165], Limited availability of loans for energy investments in certain European countries [166]
Energy Efficiency Obligations	Public & Private	Residential, Commercial	Lack of motivation to deliver more than the mandated savings [56]	Difficulty in measuring savings [78]
Energy Service Companies/ Energy Performance Contracting (ESCOs, ECPs)	Public & Private	Mainly non-residential	ESCOs could become very indebted and, thus, unable to access finance [165]	Lack of awareness, market immaturity [137]
On-bill Financing (OBF)	Public & Private	Residential, Commercial	Risk of no payment or partial payment by costumers [165]	Challenging credit risk evaluation [165], Regulatory issues [164]
Property Assessed Clean Energy (PACE)	Private	Residential, Commercial	Incompatibility of property tax collection procedures and PACE schemes in certain countries [165]	Limited availability (property owners only) [167]
Energy Efficiency feed-in tariffs	Public & Private	All	Risk of favoring cheap EE interventions in a fixed price system [56], [165]	Complex design issues and budget restrictions [56]
One-Stop Shops	Public & Private	All	Perceived complexity and uncertainty [87]	Inadequate experience due to the novelty of this mechanism [87]
Crowdfunding	Private	Residential, Commercial	Possible online fraud [168]	Insufficient funds [168], Weak regulatory framework [56], [165]

Based on the information provided in Table 7, it becomes apparent that there is a plethora of available financing mechanisms for building renovation. To overcome the most prominent barriers, a combination of different funding schemes may be preferable. Moreover, it has been observed that certain financial tools are more suitable for specific building types. In Table 7, a broad typology for buildings (private, public, residential, non-residential, commercial etc.) has been selected. In the following paragraphs, a more detailed view on different building uses, ownership status and retrofitting measures is provided through the examination of case studies. To be more specific, data from several European retrofitting projects, both completed and ongoing, have been examined. The statistical analysis was based on case studies (see Appendix) in various European Countries. To conduct a more informed statistical analysis and extract reliable conclusions, additional data have been retrieved from the Triple-A project from real project fiches in the project case study countries. Due to confidentiality issues, Triple A data are not open-source. However, with the aim of extracting valuable information to identify patterns regarding building use and ownership status, common retrofitting measures and types, as well as financing methods, data from the Triple-A project have been accessed by authorised partners (NTUA is the coordinator of the Triple-A project) and anonymised so that they can be utilised in the contexts of the present deliverable.

Although the selected case studies consider various building uses, the residential sector is the most prominent in the literature, as shown in Figure 11. Numerous business cases considered tertiary buildings, that is to say, administrative buildings, hotels or commercial buildings (supermarkets, retail centers etc.). Educational institutions, including schools, preschool buildings, as well as day care centers, have also been renovated in quite a high percentage of the considered case studies.

It has been observed that in case studies considering residential buildings, the retrofitting actions did not take place in single apartments or houses. On the contrary, large aggregates of dwellings have been grouped together. Quite a few case studies in this category concerned social housing establishments, which are often more likely to need deep renovation. In some cases, entire neighborhoods have been retrofitted, including both residential and non-residential buildings. The massive renovation of buildings situated in the same geographical area allows the employment of additional retrofitting actions, such as installation of heating networks or upgrade of outdoor lighting infrastructure.

On the contrary, larger non-residential public buildings providing various services, such as educational institutions, medical or sports facilities, administrative buildings etc. do not need to be grouped together with other buildings in order to be financed and retrofitted.

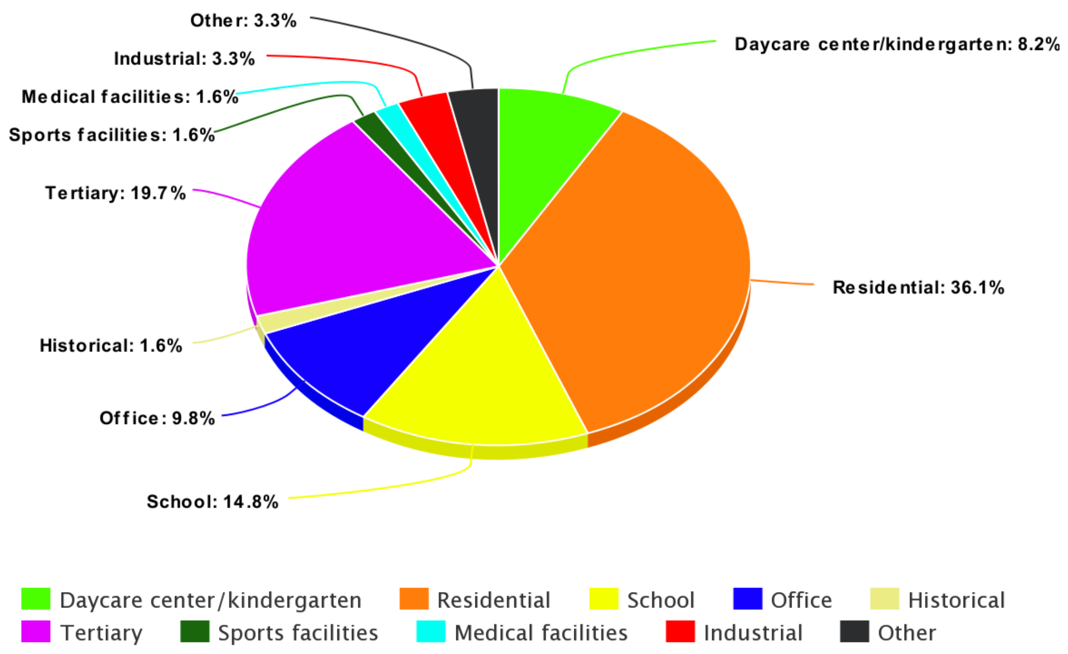


Figure 11 Case studies: building use

In addition, more case studies concerned private buildings than public buildings (Figure 12). In some case studies of private buildings, the owners covered part of the investment using their own resources, or the already established maintenance budget of the building. In rented properties there have also been cases where both the owners and the tenants covered part of the investment.

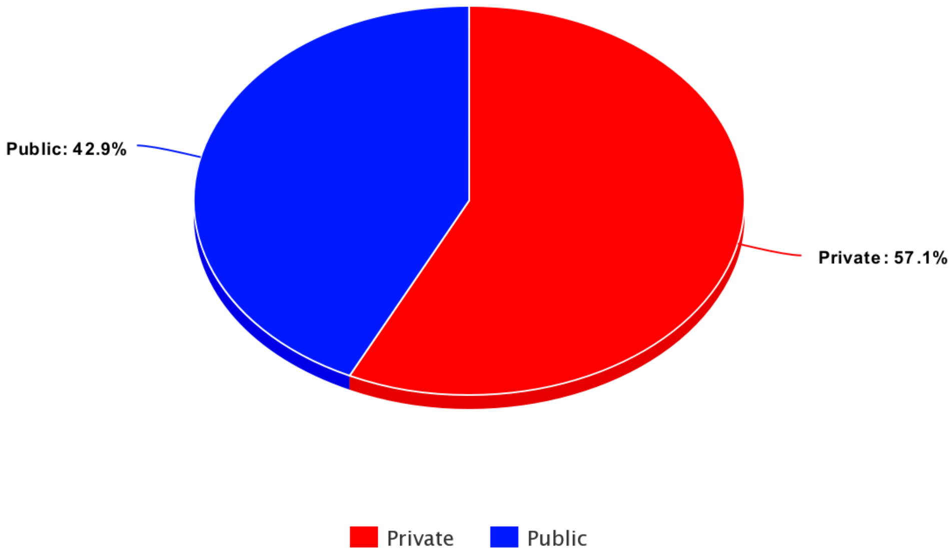


Figure 12 Case studies: building ownership

As far as financing methods are concerned, half of the case studies have been financed by non-repayable funds offered by the European Union or local government/municipality. Fewer projects have been financed exclusively by private investors, whereas in some cases a combination of both private and public financing has been utilized, as illustrated in Figure 13. The most common financing schemes were grants, subsidies, loans and EPCs.

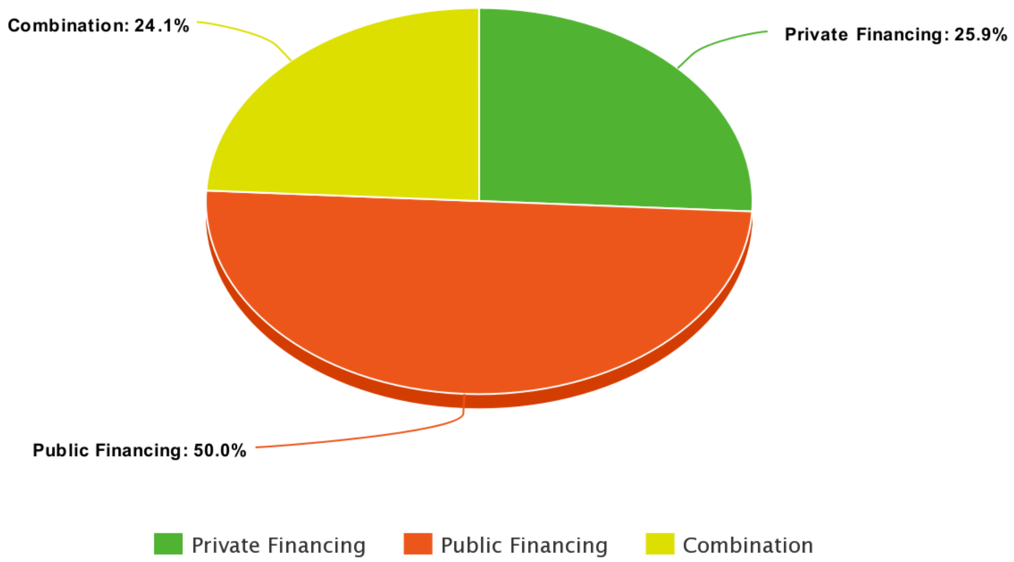


Figure 13 Case studies: financing

As shown in Figure 14 and Figure 15, according to the considered cases studies, renovations in residential buildings are more likely to be financed by public funds, whereas private and public financing schemes are almost equally applied when it comes to non-residential buildings.

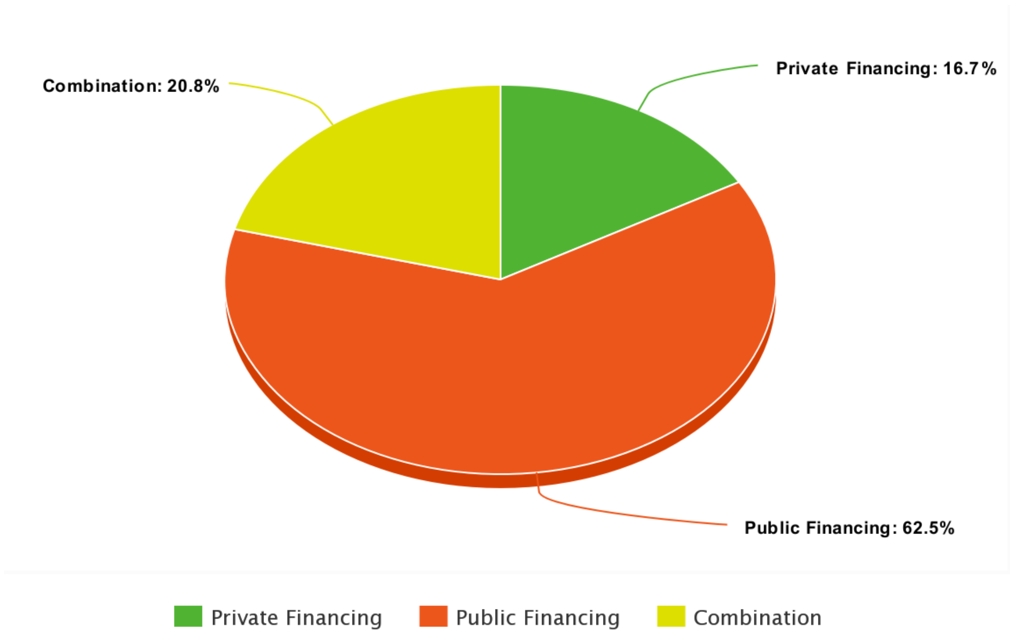


Figure 14 Case studies: financing of residential buildings

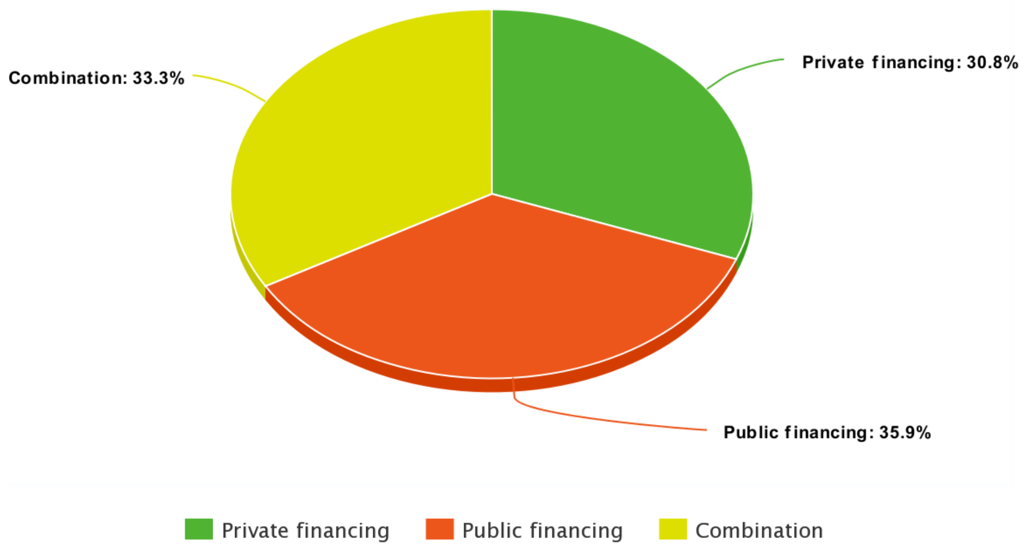


Figure 15 Case studies: financing of non-residential buildings

As far as retrofitting measures are concerned, building envelope improvements (wall, roof, floor insulation, replacement of windows and doors) and HVAC upgrades have been funded and implemented in most of the case studies. Lighting infrastructure has also been retrofitted in several case studies, whereas installations of renewable sources (mainly solar panels and biomass enabled technologies) were not implemented as much as the previously mentioned measures. Only few of the case studies applied automated devices such as sensors, as well as energy management systems. More specifically:

- **Building envelope:** 87.7% of the case studies include enhancement of the building envelope.
- **HVAC:** In 78.5% of the case studies HVAC systems have been upgraded.
- **Lighting equipment:** Lighting has been retrofitted in 52% of the case studies.
- **Renewable installations:** Renewable energy generation systems have been installed in 38.5% of the case studies.
- **Automation and energy management systems:** 18.5% of the case studies included automated devices and BEMS (Building Energy Management System).

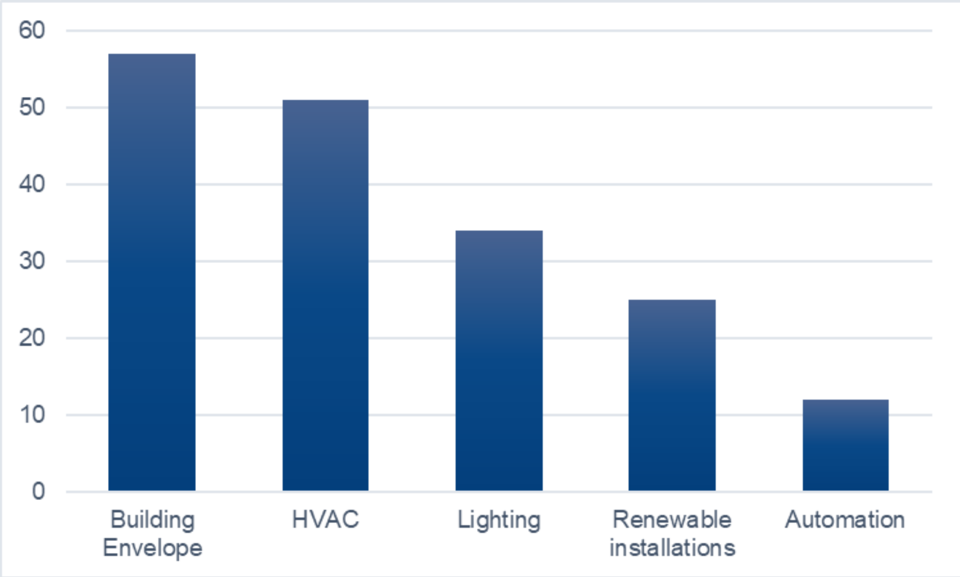


Figure 16 Case studies: retrofitting measures financed

It has been observed that renewable sources and automated systems are more likely to be financed and installed in non-residential public buildings. More specifically, PV panels were mainly installed in offices, commercial and industrial buildings. In addition, the installation of energy management systems and devices, especially sensors for lighting control, are often financed in medical buildings.

Through the analysis of the available data, it has been observed that renovation projects which implement only one type of retrofitting measures (e. g., only lighting replacement) are more likely to be financed by one single funding source. However, most of the examined case studies combine different types of measures (in some cases all categories illustrated in Figure 16 are included), and therefore a combination of different funding sources is necessary.

4. Assessing EE investments in buildings: Risks and KPIs

The center of the concept of ENERGATE (aggregation and match-making process), is to develop large, standardised, financeable project packages, the so-called “products”, that seek to get financed and could be attractive for the financing community. A product can be considered as an investment package that consists of the project (building) entry information along with the EE measures (that will be derived from the project entry module of the platform), the energy savings that can be achieved and all the financial indicators necessary for financing the project. Since ENERGATE is essentially destined to be an electronic platform enabling EE and smart energy services marketplace, the “product” properties need to be mutually recognised by the buy-side and the sell-side. The identification of risks is a necessary preparatory task which will set the basis for potential risk assessment approaches carried out within the offered services of the ENERGATE platform. Furthermore, the determination of KPIs is required, to assist the matchmaking process which will be supported by a multi-criteria approach, so that the ranking of products can be realised and the interests of multiple and different stakeholders are optimally attended.

4.1 Main barriers and risks of energy efficiency projects

Risk is inherent to all financial transactions, and its assessment occupies whole departments at large financial institutions. EE finance is no exception, but along with an overall lack of standardised terms and contractual agreements, there’s is also no generally accepted way of discussing, analysing and potentially mitigating specific risk types in this sector.

The lack of an agreed methodological structure of risk assessment causes many projects to fail, as it leads to very time-consuming discussions and increases due diligence costs and process time unnecessarily. Moreover, getting a common understanding right from the start on all of the key risk areas would help to avoid even to discuss project opportunities further, should the risk profile not match the investors’ expectations.

Although, as emphasised in the previous chapters, there is a plethora of financing options for building renovation projects, investments in retrofitting actions might be perceived as highly risky. Besides financial risks, additional barriers hindering EE projects in the building sector, which should be considered, are presented in this section.

Despite the variety of potential retrofitting measures and their positive impact on energy efficiency, many factors are hindering the implementation of EE measures in buildings **Error! Reference source not found.**. The identification of barriers and risks is of great importance for the ENERGATE activities, as they will define key aspects that need to be modelled and analysed in the ENERGATE platform. To be more specific, the word “risks” can be interpreted in various ways within the building renovation sector. A general interpretation could define risk as any factor or event that threatens the successful completion of a project in terms of time, cost and quality **Error! Reference source not found.**.

In the context of EE building renovations stakeholders are interested in de-risking investments to secure their capital, their future expenditure in energy bills and their comfort levels in indoor spaces. However, stakeholders are not always willing to take the responsibility of de-risking and choose light energy renovation approaches instead. The EC has highlighted the importance of de-risking EE for investors and this is revealed by projects that have been funded by the EU to support de-risking investments, such as EEnvest [171], Triple-A [29], LAUNCH, QUEST [4], U-CERT[5] project, among others. According to the International Standard Organization (ISO), and ISO 31,000 [172] standard in particular, risk management is based on the following steps: context definition, risk identification, analysis process and mitigation measured identification.

It is worth mentioning that a risk assessment process is being explored currently in order to facilitate risk profiling and appropriate packaging of investments. Towards this direction, the Triple-A risk assessment methodology **Error! Reference source not found.** and LAUNCH r isk assessment protocols **Error! Reference source not found.** are being thoroughly examined.

For the ENERGATE project the following categories of risks and barriers have been identified according to the project needs, literature and similar related projects:

- **Technical risks and barriers:** They can negatively affect the economic trend of the investment, producing some deviations from the expected business plan. These differences depend on several factors (errors or technical failures) and occur in different phases of the renovation project (design, installation, or operation phase) [175]. Technical risks might include:
    - **The energy performance gap:** In the building renovation process it is highly possible that there is going to be a difference between the planned building energy performance, as calculated during the design phase and the actual energy consumption after the completion of the renovation and the actual building's operation phase [176].
    - **Inadequate technical skills:** Professionals in the building sector are often insufficiently informed about energy efficiency, energy saving measures, as well as renovation projects [177], [178].
    - **Installation, operation and maintenance risk:** Proper installation, operation and maintenance of building systems is essential for ensuring energy efficiency. Neglecting maintenance can lead to energy wastage and higher energy bills [179], [180].
    - **Inaccurate prediction of energy savings:** Lack of capacity to predict energy savings accurately due to a lack of proper measurements or simulations at an early stage of the renovation project is a considerable risk in building renovation projects [180].
- **Energy market risks**: These may be related to prices and taxes volatility associated with the price risk in EE investments. More specifically:
    - **Energy prices:** The uncertainty of energy prices influences the decision to undertake an EE investment as it may lead to unexpected monetary savings and therefore the return of the EE investment may fluctuate from the initial estimation [181].

[4] Project quest (project-quest.eu)
[5] U-Cert Project - User-centred Energy Performance Assessment and Certification

- **Taxes volatility:** Energy taxes are considered important as they affect the end-use price and thus the monetary savings of the EE investments.

- **Financial and economic risks:** Financial risks describe the possibility of losing money on an investment, or not achieving the expected return of an investment for EE renovation of a building. As far as retrofitting projects are concerned, financial and economic risks and barriers may include:
  - **High upfront costs:** High initial costs might impede renovation, especially if recovery cost of investment primarily relies on income issued from rent [182]. In addition, consumers tend to make decisions based on initial costs rather than operational costs, thus they often select inefficient systems [177].
  - **Limited access to finance:** Willingness to engage in renovation activities largely depends on available financing schemes. For instance, it has been shown that financing mechanisms that reduce upfront cost, such as on-bill financing, may somewhat increase willingness to retrofit. Moreover, willingness rises significantly if the proposed financing tools transfer the risks to the contractor (e. g. Revolving Loan Funds combined with Energy Performance Contracts). Therefore, lack of access to finance could substantially reduce willingness to renovate buildings [183].
  - **Unavailability of private capital:** Capital investment requires clear evidence of cost effectiveness based on estimation of expenditure, benefits, and uncertainties. Lack of such evidence may result in unavailability of private capital [177].
  - **Credit risk:** Credit risk refers to the possibility of financial losses due to repayment inability. Repayment uncertainties may discourage both asset owners and potential investors from engaging in renovation projects **Error! Reference source not found.**.
  - **Weak economic environment:** Economic risks are generally connected to the "weak economic environment" [184]. The weak economic environment is related to poor economic conditions that may exist in the country that the EE investment takes place. It is connected to, among other indicators, interest rates, inflation, availability of finance, etc. Weak economic environment can negatively influence the investment in many ways, such as affecting the investment's profitability through inflation or KPIs through interest rates. It should be noted that the economic category is also connected to other more specific risk factors (e.g., interest rates volatility) that are part of the weak economic environment, as reported by literature. To that end, the risk factor 'weak economic environment' was selected as a means of evaluating this risk category, as well as to take into consideration all the relevant risks for the calculation of the risk of this category.

- **Behavioural risks and knowledge deficiencies:**
  - **The rebound effect:** The rebound effect is generally expressed as a proportion of the lost benefit compared to the expected environmental benefit when consumption remains constant [180]. This effect is due to behavioral bias

[185], which affects stakeholders and emerges when the implementation of a renovation leads to lower costs for energy services combined with an increase in the demand for such services. Therefore, the renovation results in higher final consumption and lower energy savings than initially anticipated.

- **Split incentives:** Distributing costs and ensued benefits amongst owners and tenants might be difficult**,** since owners usually make decisions regarding EE interventions, even though energy consumption is up to tenants. Thus, conflicting priorities of owners and tenants might impede renovation projects [186]**,** [177].
- **Insufficient knowledge regarding cost and financing instruments:** Researchers have identified lack of reliable information on renovation costs as a notable barrier. Naturally, lack of knowledge leads to risk aversion, thus renovation opportunities may be neglected. Moreover, because of inadequate knowledge, choosing between different financing mechanisms can be challenging [177].
- **Lack of awareness regarding potential benefits:** The positive impact of renovations on EE can be hard to realize, due to rises in energy prices, long payback periods or behavioural factors (e. g. different consumption patterns before and after the renovation) [187], [188]. Thus, owners might neglect efficiency measures, and prioritize other investments instead [178]**.** Furthermore, as far as residential buildings are concerned, certain researchers argue that energy performance and efficiency are often neglected by potential buyers and tenants, as they do not substantially influence the dwelling's price and are not considered important selection criteria [187], [182]. However, studies have reported rises in market values of retrofitted, green, or highly energy efficient buildings [177], [189], [190].
- **Risk avoidance:** Renovation projects might be perceived as too risky due to a plethora of reasons. Firstly, investors are more familiar and, subsequently, more comfortable with large-scale projects because they are considered less risky [178]. Secondly, return on investment might be uncertain and payback periods are often too long. Thirdly, when it comes to novel renovation practices and transition towards nZEB, stakeholders might be hesitant because they believe that not enough projects have been implemented and, therefore, new retrofitting methods have not reached maturity yet [177].
- **Disturbance of occupants' daily life:** Whether occupants will be willing to consent to large-scale renovation projects is doubtful, because their daily life will most likely be disturbed during renovation procedures [177].

- **Institutional barriers:**
  - **Lack of governmental support:** Transition towards energy efficient buildings might require governmental support, since renovations involve large investments. However, specific use cases have shown that those investments do not always comply with the institutional financial agenda, as previous maintenance plans for buildings did not focus on applying additional

functionalities, which are now considered necessary to improve EE and promote sustainability [182].

- **Legal issues:** Regulatory barriers refer to legal deficiencies, such as offering the same incentives and benefits for diverse renovation projects, regardless of achieved efficiency [177].
- **Extensive interior procedures:** Strict requirements for and bureaucratic procedures might delay and hinder renovation projects [177]. To be more specific, the request for issuing project permits signifies the legislative complexity for the completion of a project (e.g., construction permits/licenses, protocols or other approvals under the provisions of law), which could lead to administrative risks in a specific country. The administrative risk could be a decisive factor for the selection of a country to implement a project [192]. Some instances of this risk factor are the request for issuing project permits/licenses for renovations of existing buildings, the installation of geothermal heat pumps, the change of the electromechanical equipment, etc.
- **Absence of standardization:** Lack of standards and concrete guidelines that various stakeholders should follow during retrofitting actions should also be considered as a notable barrier [177].

Evidently, possible risks might significantly influence the attitude of potential investors, occupants and other engaged parties, towards building renovation. Thus, identification and thorough analysis of risks and barriers is of vital importance. A brief summary of the examined risks and barriers is illustrated in Figure 17:

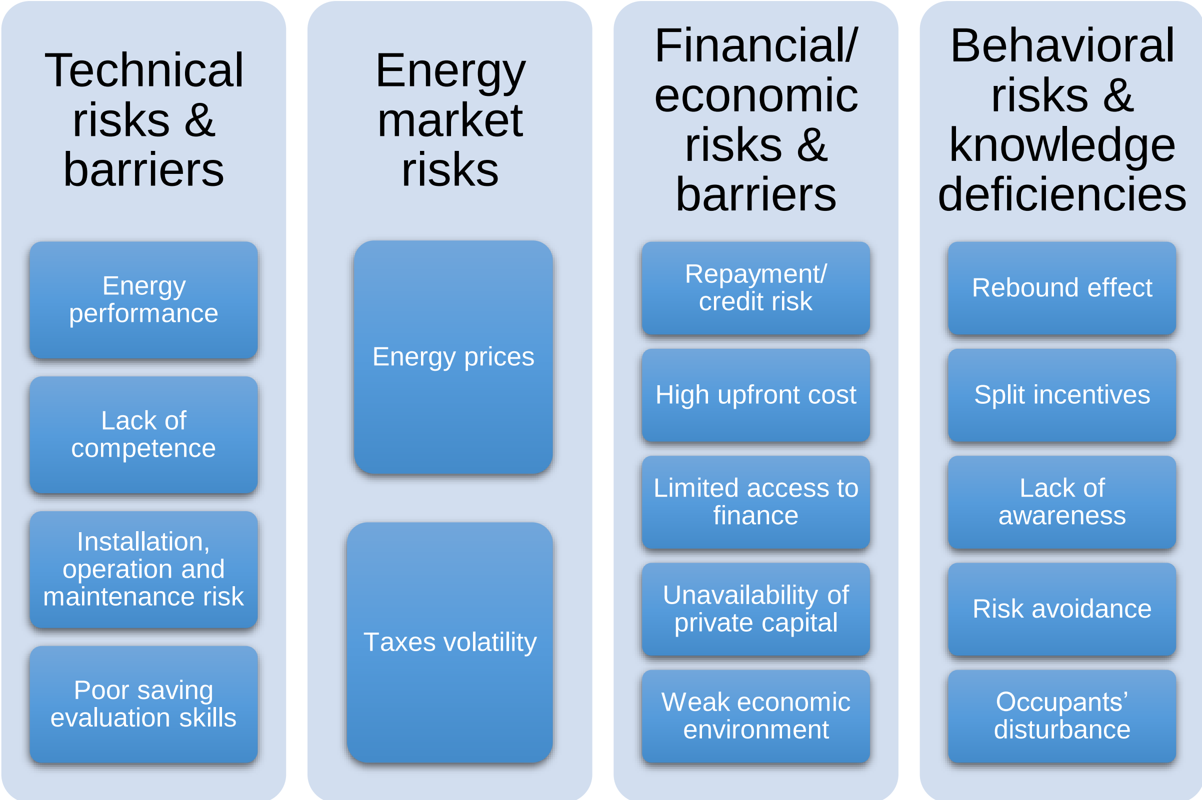


Figure 17 Risks and barrier of building renovation

Having identified the renovation activities and funding options that apply to buildings, as well as the barriers and risks associated with retrofitting actions, the research moves forward with the examination of important evaluation criteria and indicators for building renovation projects. These propositions could be used so as to facilitate the MCDA approach of project prioritisation and filtering suggested in Task 3.2 (Aggregation and match-making process), while setting the base for the KPIs definition for the pilot projects within Task 4.1 (Pilot planning, requirements, M&V and KPIs).

4.2 Evaluation of renovation viability: Proposed KPIs

As mentioned, during the matchmaking process a multi-criteria approach will be examined to be used in order to prioritize for each side the most attractive products based on the listed properties, KPIs and financial indicators for each project. The multicriteria approach will consider the weights defined by the different sides for the bundle of products. Towards this direction this section aims to review related KPIs that could assist in the assessment of the ENRGATE platform projects. The pilot projects will also test the input and output indicators and KPIs.

Defining KPIs is one of the most popular tools for assessing the sustainability of building renovation projects, since a multidimensional approach reflects on different aspects of the proposed renovations. For assessing the sustainability of building renovation actions many indicators have been proposed that reflect the project's objectives and define means for measuring the progress towards these goals. As regards to the ENERGATE project, to assist the determination of KPIs a set of indicators have been identified, which try to evaluate the potential building renovation actions from different perspectives. The ENERGATE methodology mostly focuses on the following indicators/KPIs:

Asset and related KPIs may be comprised of the location, climate zone, type/use, size, number of levels, occupancy range, year and type of construction of the building. Such indicators have been considered as variables of the proposed Common Data Model in the present deliverable (section 2.2.4).

Energy related KPIs may include information such as project type (i. e. chosen retrofitting measures, see section 2.3), type of heating and cooling and Measurement and Verification (M&V) protocols. Besides these qualitative KPIs, metrics capturing energy consumption and generation are also considered [193]. Energy performance of buildings can also be evaluated by indicators such as "Energy Class" **Error! Reference source not found.**.

Economic KPIs try to capture the economic feasibility of projects and play a fundamental role for reflecting on the costs of the renovation along with the economic performance of buildings from the stakeholders' point of view. These KPIs could include the capital investment (also referred to as capital expenditure, CAPEX) in terms of funding and the initial total cost [195]. In [196] a five-point Likert scale is used to measure the direct costs, that is to say "initial cost" and "life-cycle cost", and indirect costs including "Resettling cost of people", "Rehabilitating cost of ecosystem' are also considered. In **Error! Reference source not found.** a 10-point L ikert scale was employed to measure the "Flexibility and Adaptivity" and "Economic performance and affordability", where 1–3 translated to "ow priority", 4–6 "Medium priority" and 7–10 "High priority".

Financing KPIs try to track, measure, and analyze the financial efficiency of proposed building retrofitting actions. Those metrics reflect how the retrofitting action is performing from a financial perspective [177].

- **The Net Present Value (NPV)** reflects the risk and cashflows discount by quantising it through the discount rate the profitability of the investment by involving the yearly income calculations. It also reflects the operational costs and the initial investment.
- **The Discounted Payback Period** is the number of years necessary to recover the project cost of an investment while accounting for the time value of money. It is recommended since it allows for a quick assessment of the duration during which an investor's capital is at risk.
- **Internal Rate of Return (IRR)** is a rate of return used in capital budgeting to measure and compare the profitability of investments. IRR provides a straightforward means to compare different benefits and risks of projects.
- **Cost Effectiveness** is a measure of whether an investment's benefits exceed its costs. In the proposed methodology, the Cost Effectiveness is calculated based on the project cost per kWh saved during the average lifetime of measures.

Another indicator which could be included in the financial KPIs could be the O&M (Operation and Maintenance) cost reduction, which might be caused because of the upgrades of inefficient equipment and infrastructure in the contexts of the renovation project.

Environmental KPIs try to assess the environmental impact of building renovations. The KPIs included in this category can be structured in many subcategories that try to capture different aspects of environmental impact of the proposed renovations actions. In [180] to better describe the energy and environmental performances of retrofitting actions and make the results of the case studies comparable, qualitative environmental KPIs including "Energy Payback Time" and "Emissions Payback" Time were used. Dunphy et al. **Error! Reference source not found.** have used the 'Energy savings per annum' KPI that was expressed in a percentage [%] format. In **Error! Reference source not found.** the 'Energy and Natural Resources' and 'Materials used, Durability and Waste' KPIs were used and evaluated on a 10-point Likert scale. In **Error! Reference source not found.** more KPIs were used to evaluate building renovations including the net present index, describing how likely the building will reach net zero values, and the energy intensity data describing the total energy consumed per floor are [195].

Based on the review (Table 8) conducted a list of KPIs is displayed in Table 9 that are being examined to be used in the ENERGATE methodology for evaluating the building renovation projects.

Table 8 Literature Review: KPIs for renovation projects

Literature Review	
Keywords	Key Performance Indicators, Financial, Energy, Environmental KPIs, Energy Performance, Buildings, Retrofitting, Renovation Projects
Sources	[195], [196], **Error! Reference source not found.**, **Error! Reference source not found.**, [199], [200], **Error! Reference source not found.**, [202], [203], [204], [205], [206], [207], [208], [209], [210], [211], [212], [213]

Table 9 Identified KPIs for building renovation projects

Financing KPIs
• **Net Present Value (NPV):** reflects the risk, cashflows discount and initial investment [Quantitative] [€] • **Discounted Payback Period (DPP):** number of years to recover the project cost of an investment [Quantitative] [years] • **Internal Rate of Return (IRR):** rate of return in used capital budgeting to measure the profitability of investments [Quantitative] [%] • **Cost Effectiveness:** measurement of whether a project's benefits exceed its costs [Quantitative] [€/kWh] • **O&M cost reduction:** measurement of operational and maintenance cost reduction as a result of retrofitting actions [Quantitative] [%]
Economic KPIs
• **Capital Investment:** flow of money needed regarding funding, grants and subsidies [Quantitative] [€] • **Total Cost (Life Cycle Cost):** total amount of budget spent upon completion [Quantitative] [€] • **Initial Cost:** initial budget spent for starting project [Quantitative] [€] • **Variation costs:** rate reflecting on how much the actual costs varied from the predicted ones [Quantitative] [%]

Environmental KPIs
• **Annual carbon emission: total CO_2 emissions per year** [Quantitative] **[kg $CO_{2\ eq}$]** • **Emissions Payback Time:** the amount of time needed to save the emissions spent during the project [Quantitative] [years] • **Energy savings per year:** estimation of energy savings (compared to baseline energy consumption) [Quantitative] [kWh/year]
Energy related KPIs
• **Baseline energy consumption:** energy consumption before renovation [Quantitative] [kWh] • **Total energy consumption:** the total amount of energy needed [Quantitative] [kWh] • **Energy use intensity**: the total amount of energy needed divided by the floor area [Quantitative] [kWh/m2] • **Energy Performance Index (EPI):** measurement of the building's energy efficiency [Quantitative] • **Energy Generation Index (EGI):** measurement of energy generation [Quantitative] [kWh/m^2/years] • **Performance Coefficient:** Considers the yearly consumption and on-site renewable power generation [Qualitative] • **Energy Payback Time:** the initial cost of energy savings investment divided by the annual energy savings [Quantitative] • **Smart Readiness Indicator:** a score indicating the readiness of a building to adapt operations to the needs of occupants by minimizing energy [Rating scale] • **Net zero performance index:** rating score indicating how likely the building is to become net zero [Rating scale] • **Peak Energy Demand Reduction for building operations:** Indicates the reduction of peak load thanks to EE measures [Quantitative] • **Total life cycle primary from renewable energy:** To predict renewable primary energy used for building operations [Rating scale] • **Total life cycle primary non-renewable energy:** To predict non-renewable primary energy used for building operations and greenhouse gas emissions [Rating scale] • **Qualitative indicators:** project type, type of heating and cooling, M&V protocols • **Energy class:** indicator for energy performance of building [Rating Scale] [A-G]

5. Analysis of data from previous initiatives

This section aims to demonstrate the impact of renovation on energy consumption and the correlation between energy usage patterns, building characteristics and retrofitting measures. The aim is to review previous work done on the subject and identify the common patterns in relation to the current practices and likelihood of certain building types to be renovated. The identification procedure can be realised, by using statistical figures of data collected of more than 400 renovation projects, from datasets related to the MATRYCS project with which ENERGATE has a strong synergy and a cooperation agreement between MATRYCS and ENERGATE has been prepared and will be signed by July 2023. The input given to ENERGATE for the needs of this preliminary analysis were the type of variables recorded in the datasets, and anonymised data that have been processed to extract statistical results and figures. The process included data of renovation projects implemented in buildings of various types, such as residential, educational, office, industrial and tertiary buildings.

The positive impact of renovation measures on EE has been proven thanks to the collection of data regarding energy consumption before and after renovations. In the following section, a statistical analysis of energy usage patterns before and after the implementation of EE measures based on available datasets is presented. The aim of this analysis is the assessment of the effects of various retrofitting actions on energy performance, considering building characteristics such as the building type, the year of construction etc. The results of this assessment could set the basis for the evaluation of the suitability of different retrofitting measures for certain building profiles.

The results are discussed and commented in the following paragraphs of the present deliverable. The aim of the discussion is to identify patterns regarding the success of the implemented EE measures. At the same time, the analysis assists the steps of the ENERGATE project, by pointing out potential dataset variables and aspects of buildings that are the most influential for EE measures. Therefore, the following analysis could also provide insights regarding the specific information entries and data from the ENERGATE pilots which will be required.

The implementation of EE measures decisively affects the amount of energy consumed. As shown in Figure 18, the reduction of energy consumption from the very first year of implementation of the EE projects is remarkable. In addition, throughout the years the overall energy consumption tends to decrease and the normalised energy use by m^2 is eventually stabilised, presenting minor fluctuations which could be due to the differences in the amount of heating days per year. The available dataset considered 445 renovation projects implemented in buildings of various types, such as residential, educational, office, industrial and tertiary buildings.

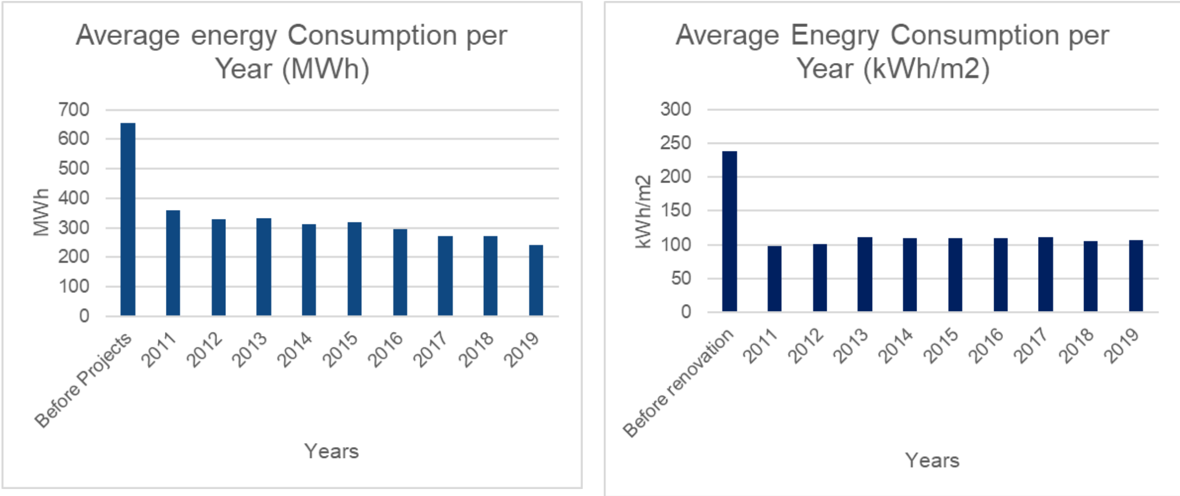
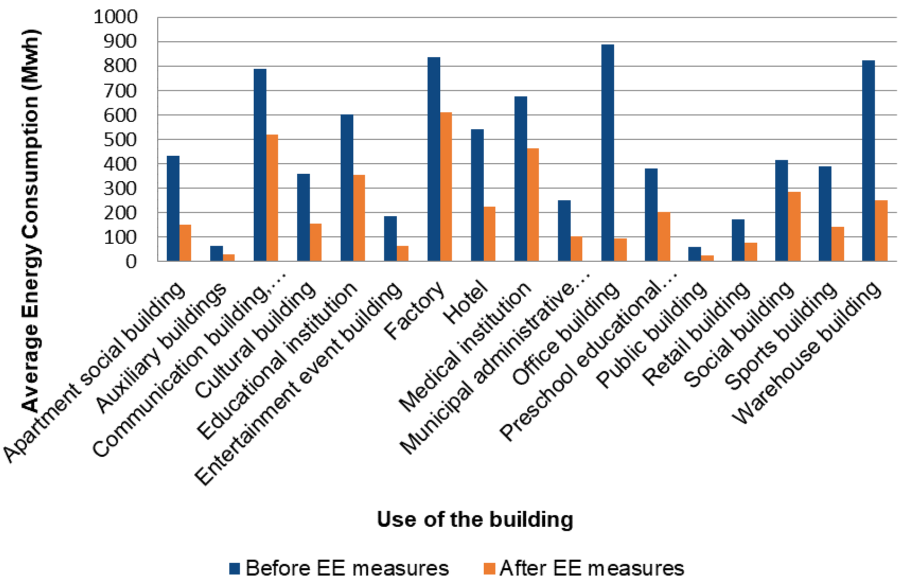


Figure 18 Average energy consumption per year

The type and use of buildings has an impact on the space heating energy performance, since different insulation characteristics imply different specific space heating consumption (due to different wall area in contact with the outdoors environment) [214]. Thus, the classification of building types is crucial for understanding how energy is used and for developing sound energy policies [53]. In Figure 19, the energy consumption before and after EE intervention for different building types is illustrated.

According to the graph, the greatest decrease in energy consumption after the implementation of EE measures was observed in office buildings. Retrofitting actions had a substantial impact (energy usage was reduced more than 50%) on residential, public, cultural, administrative and commercial buildings as well. The effect of renovation on educational and medical institutions was less intense but still considerable. The smallest reduction in energy consumption was recorded in industrial facilities.



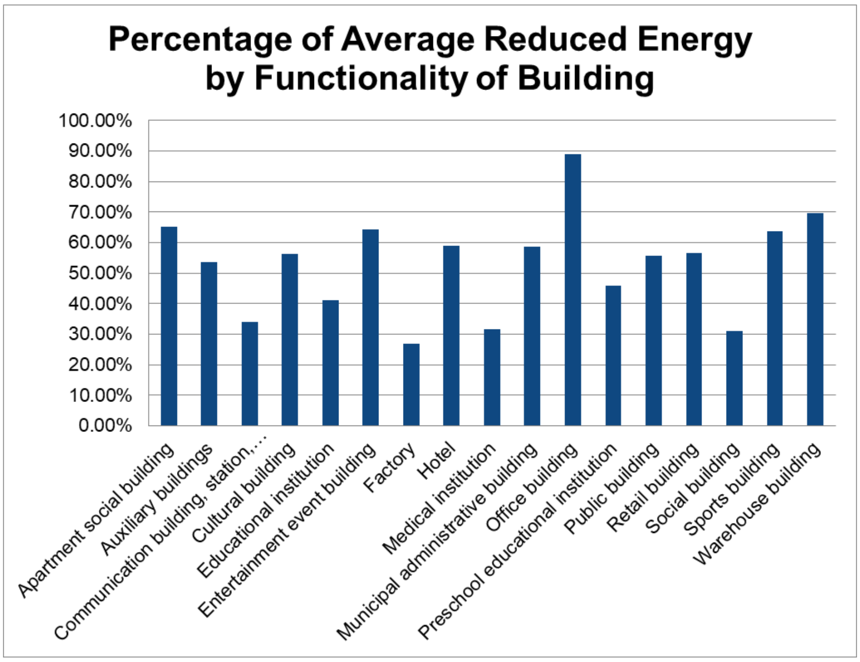


Figure 19 Average energy consumption and building type

As observed in Figure 20 the total heating area of a building greatly affects the energy consumption. As the building area (m^2) increases, so does the energy consumption. With the implementation of the renovation projects, there is a significant reduction in the consumed energy. Nevertheless, considering the normalised consumption by m^2, it is observed that energy usage drops while heating floor area increases in retail buildings, which highlights the importance of considering the building type when examining energy consumption and EE measures. However, the sample size was relatively small and subsequently a safe conclusion cannot be extracted.

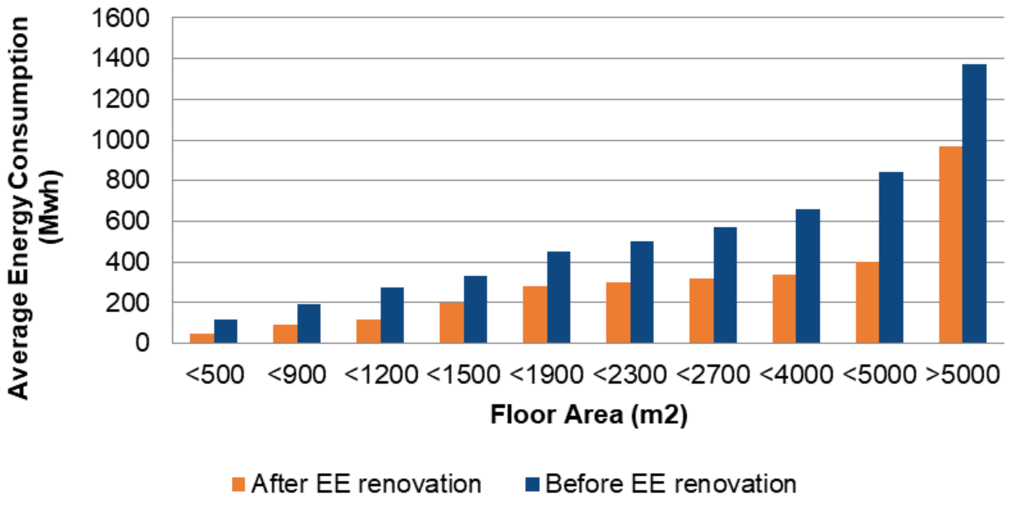


Figure 20 Average energy consumption and floor area

Furthermore, as expected, greater energy consumption is recorded in buildings with more floors. However, after the implementation of the EE measures, consumption is significantly reduced. The reduction can reach up to 60%, but the correlation between the reduction and the number of floors is not linear. As demonstrated in Figure 21, increasing the number of floors results in higher initial energy consumption, but as far as the energy reduction is concerned, a safe conclusion cannot be extracted.

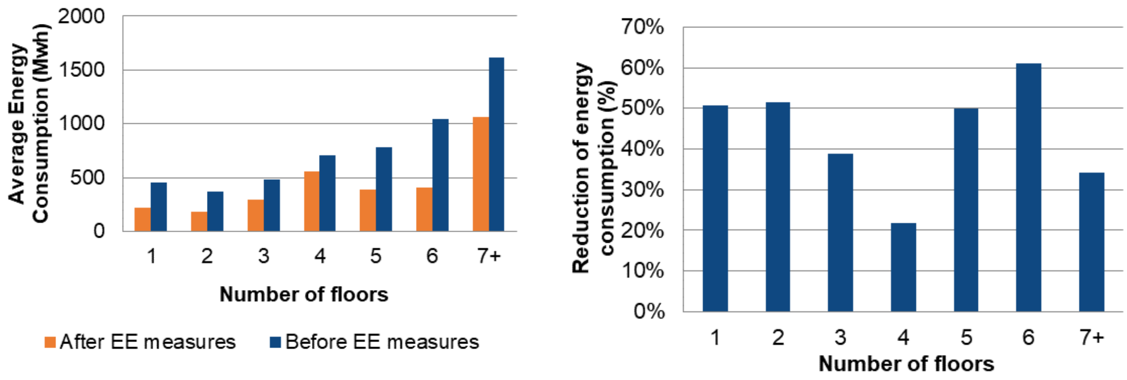


Figure 21 Average energy consumption and number of floors

Although the EE measures play a crucial role in lowering the energy needs of the buildings, it should be noted that large variation can be owed to differences in location and weather conditions, operational characteristics and electromechanical installations, along with deviations from the desirable indoor environmental quality (i.e. comfort conditions may be sacrificed to maintain lower energy consumption) [15]. Space heating and domestic hot water are more challenging in cold climate, where electrification would require the use of ground or water source heat pumps since low outdoor temperatures inflict the performance of air-to-water equipment [214].

Figure 22 demonstrates that the EE measures contribute to the reduction of the final energy consumption regardless of the construction year. Despite all the different years of construction appearing in the dataset, the recorded reduction of energy consumption is significant after the implementation of the EE measures. Nevertheless, as expected, the largest reduction is recorded in older buildings, since they were obviously subject to greater energy upgrades. As it is highlighted from EPISCOPE Final Report, even within comparable climate zones, U-values vary to a considerable extend [215]. U-Values of the building envelope, windows and doors, play a crucial role in the final building energy consumption, and they are closely related to the building's year of construction. Generally, the higher the share of new dwellings (built with higher efficient standards) the higher the overall energy performance of the building stock will be. For newer buildings, architectural design can be altered to improve the efficiency of the building, such as strategically designing window placement to better accommodate heating or cooling needs [216].

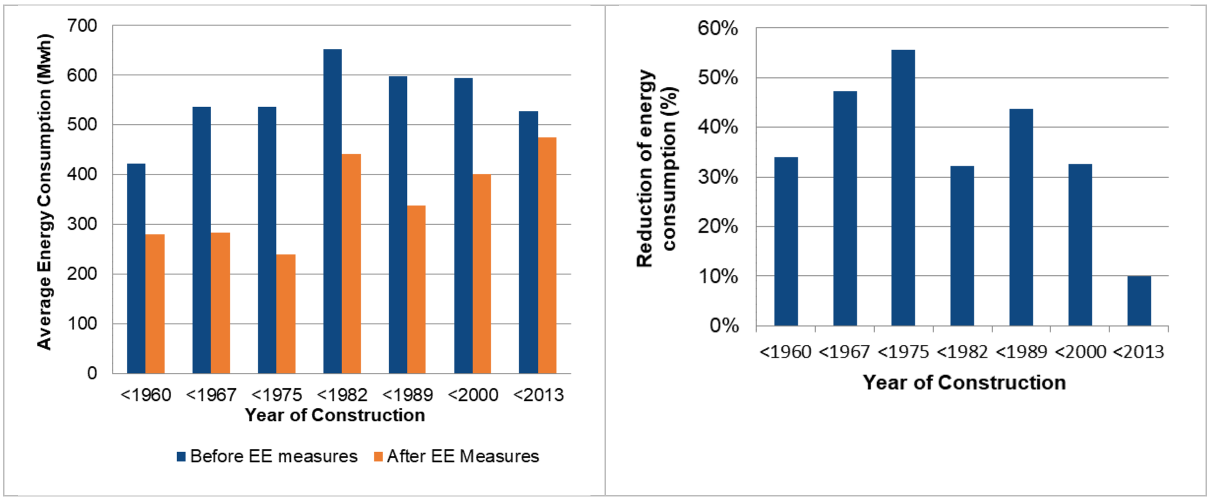


Figure 22 Average energy consumption and year of construction

Buildings use two main types of energy sources: electricity and fossil fuels (natural gas or oil for heating, cooling, or cooking purposes) [217]. Monitoring energy consumption per type of fuel is of vital importance, especially following Russian's invasion of Ukraine, since Europe must diversify energy supplies to be less dependent on fossil fuels [218]. As shown in Figure 23, in most cases, the implementation of EE measures lowers the average energy usage of all energy sources/ types of fuel, with the exception of natural gas, for which there is no significant reduction between the values before and after the implementation of EE measures. This could be substantiated, as in many cases, the EE measures do not primarily reduce the overall energy consumption of a building, but transfer the consumption to other type of fuels, which are considered greener. Electricity is virtually used in all homes, and retail electricity purchases accounted for 43% of total residential sector end-use energy consumption in 2021 [219]. Electric end-uses are more efficient, so they could reduce energy consumption, while lessening CO_2 emissions if electricity were produced from non-emitting sources (renewable and nuclear) [214]. Buildings with high EE use conventional and renewable energy sources more effectively due to lower energy demand [220].

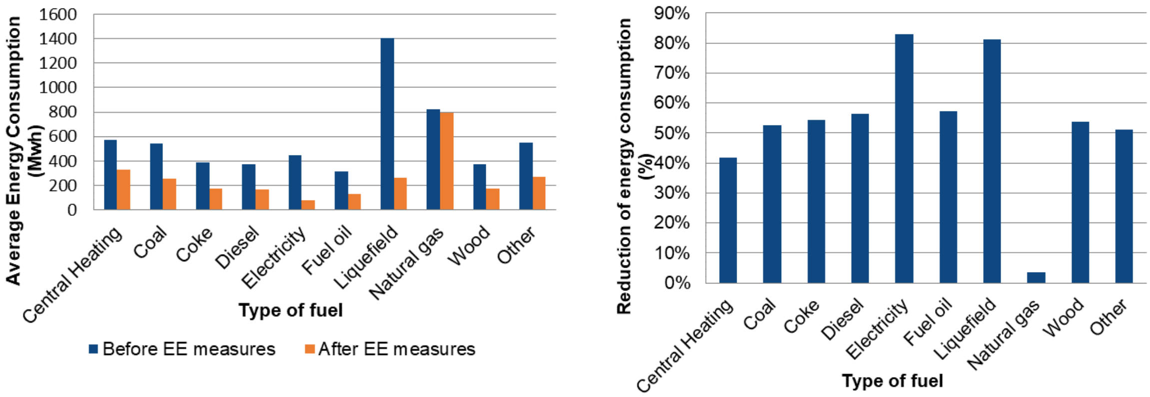


Figure 23 Average energy consumption and type of fuel

As observed in Figure 24, the results of the implementation of the EE measures have a great impact on the energy needed for heating. The first 4 years after the implementation of the measures, the energy demand for heating decreases exponentially, while after that period the energy consumption stabilizes to 25% of the consumption before the implementation of the EE measures.

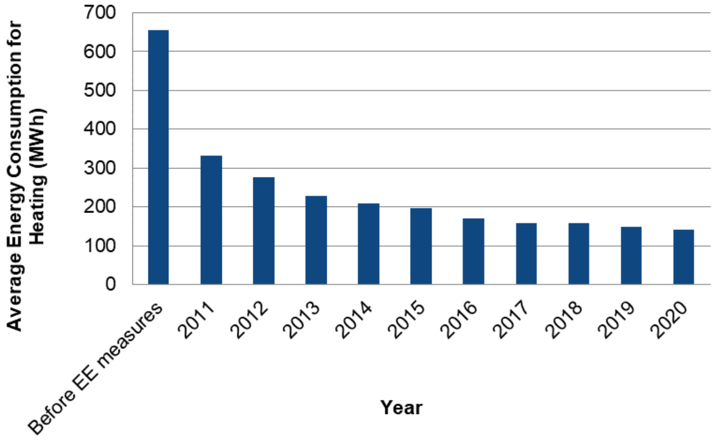


Figure 24 Average energy consumption for heating per year

Comparing energy consumption before and after renovation in already implemented projects would be useful for our research and reveal important conclusions and partners, because this comparison can contribute to the detection of certain building characteristics which are the most influential to the ensued energy savings. The statistical analysis proves that the variables of the proposed Common Data Model for the ENERGATE platform (see section 2.2.4) such as year of construction, building type, number of floors, total heated area and energy sources are truly important elements which should be considered and modelled to form the profiles of buildings within the platform.

As mentioned in the previous section, another important service provided by the ENERGATE platform will be the recommendation of different retrofitting measures according to the building's characteristics. Therefore, in the following figures, the applicability of various retrofitting actions in certain types of buildings, according to the data from the MATRYCS project, are presented.

Renovation of the building's enclosing structure is the most popular renovation strategy in all building categories, ranging from 66.4% to 85.1% of the implemented retrofitting actions. excluding building envelope improvement, the most widely applied interventions are heat supply renovation, ventilation system renovation and energy efficient lighting.

As shown in Figure 25, residential buildings from the examined data were only subject to heat supply renovation and upgrades in their enclosing structure. However, the sample size of the available data concerns mainly non-residential buildings. A greater variety of retrofitting measures can be applied to residential buildings, as revealed from the conducted review on specific case studies of renovation projects across Europe (Appendix), as well as the examination of data from the Triple A project, presented in section 4.2.

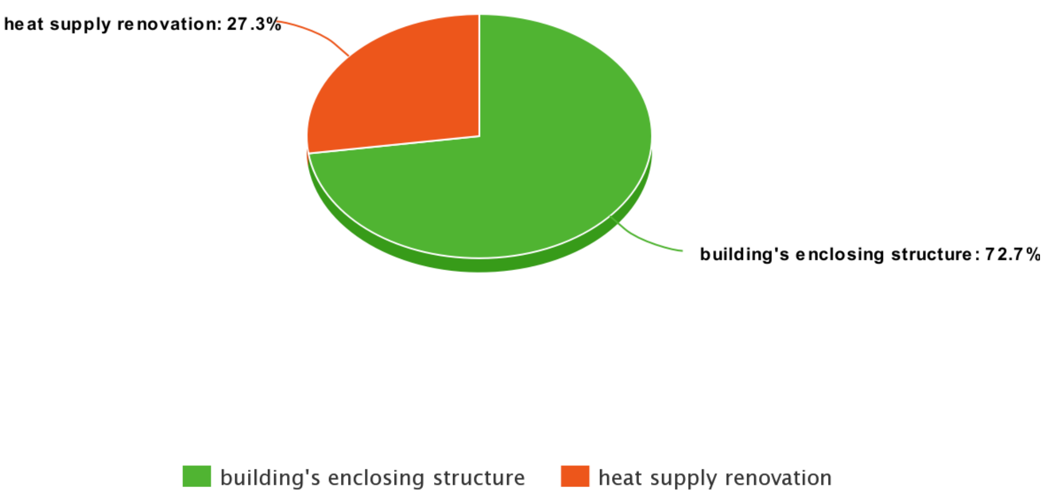


Figure 25 Retrofitting measures in residential buildings

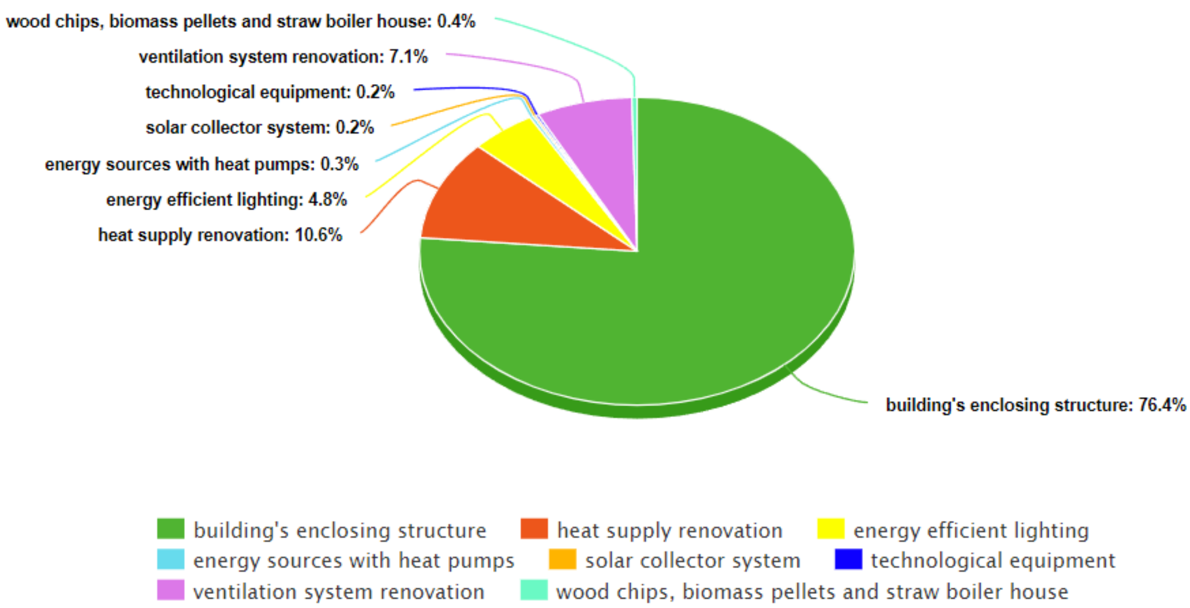


Figure 26 Retrofitting measures in educational institutions

As far as educational buildings are concerned, data from colleges and other high educational institutions, schools and preschool facilities were analysed. heat supply and ventilation renovation, following enhancement of the building's enclosing structure, were quite popular in this category, as illustrated in Figure 26.

Unlike most building categories, the third most common retrofitting measures in companies and offices in the examined dataset concerned wood chips, biomass pellets and straw boiler house. Apart from the most common renovation strategies (renovation of building's enclosing structure, heat supply and ventilation renovation, energy efficient lighting), technological equipment upgrades were conducted, and solar collector systems were installed, as shown in Figure 27.

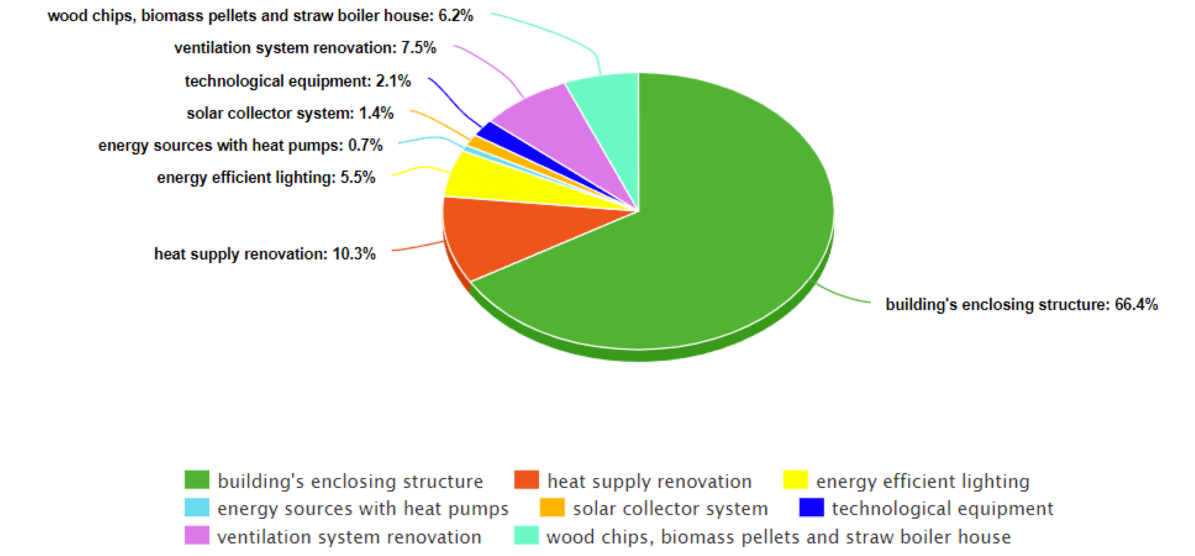


Figure 27 Retrofitting measures in offices and companies

The higher percentage of interventions in the buildings' enclosing structure was recorded in administrative buildings (Figure 28). As far as medical facilities are concerned, in Figure 29 a slightly higher percentage of heat supply renovation is observed compared to other categories (with the exception of residential buildings and hotels).

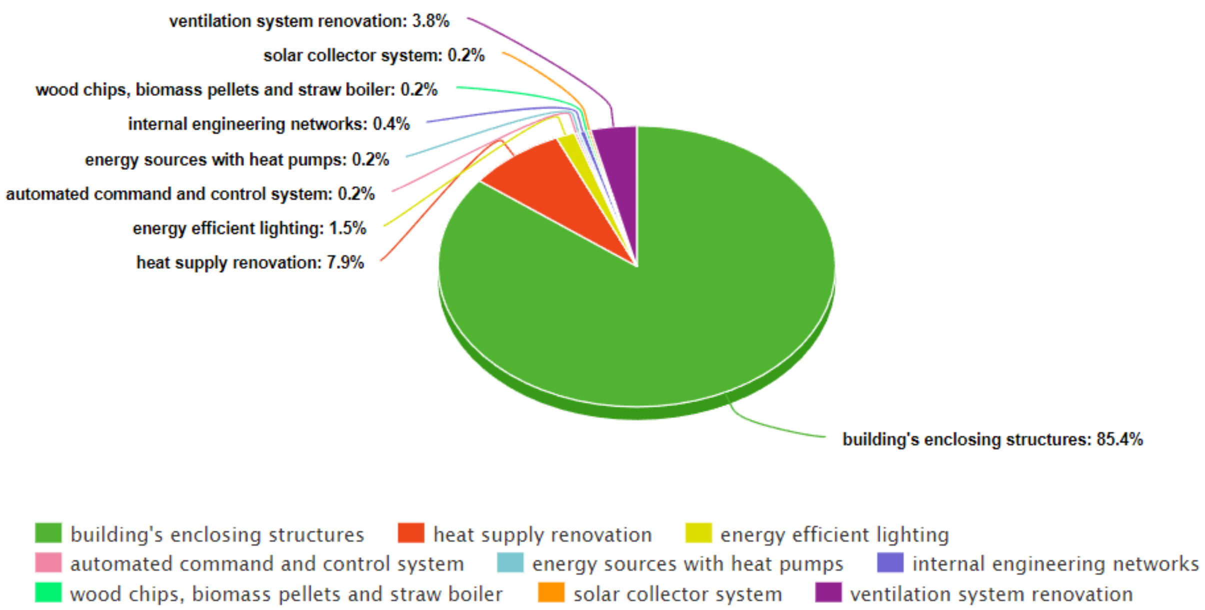


Figure 28 Retrofitting measures in administrative buildings

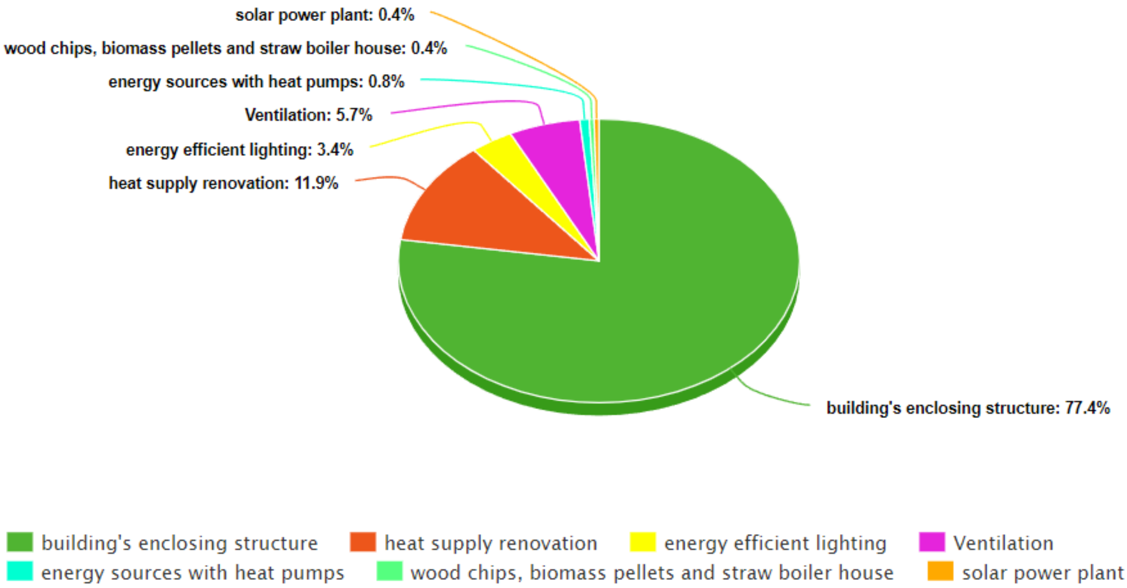


Figure 29 Retrofitting measures in medical facilities

In industrial buildings (Figure 30) the most well established renovation strategies (renovation of building's enclosing structure, heat supply and ventilation renovation, energy efficient lighting) recorded in all building categories are also popular, however, a non-negligible percentage of upgrades in technological equipment has also been recorded.

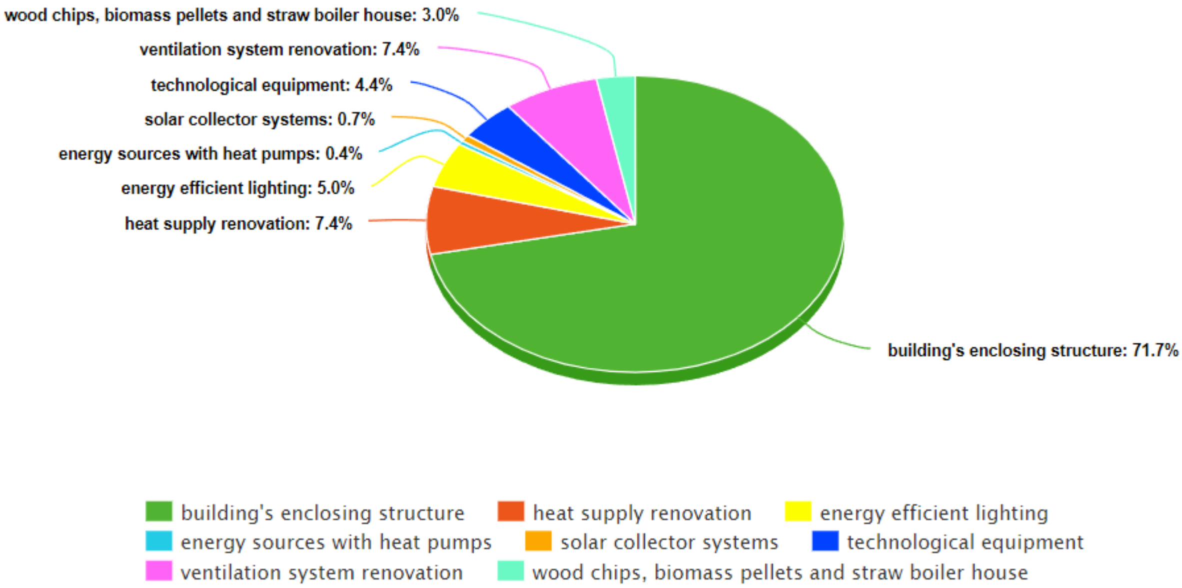


Figure 30 Retrofitting measures in industrial buildings

In hotels (Figure 31), the percentage of renovation of building's enclosing structure is not as high as in other categories. The highest percentage of energy efficient lighting amongst different building types is recorded, and the heat supply renovation percentage is the highest considering non-residential buildings.

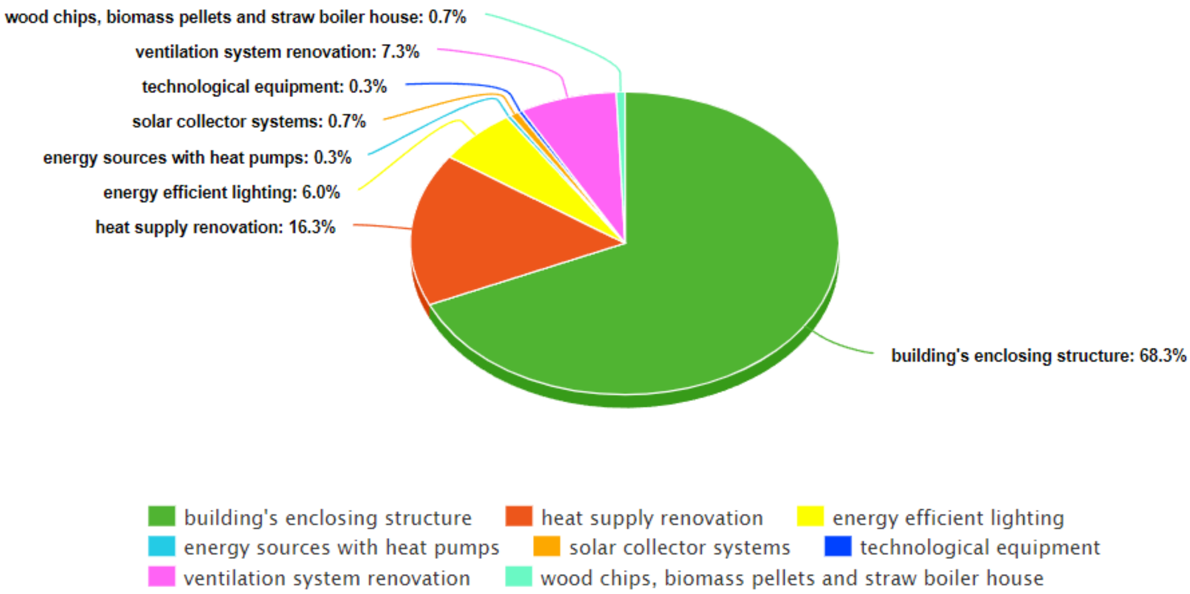


Figure 31 Retrofitting measures in hotels

Finally, as far as cultural buildings are concerned, the diversity of retrofitting measures is limited, as shown in Figure 32. Apart from the most prominent renovation measures (building's enclosing structure improvement, HVAC upgrades and light retrofitting), a small amount of internal engineering network has been recorded.

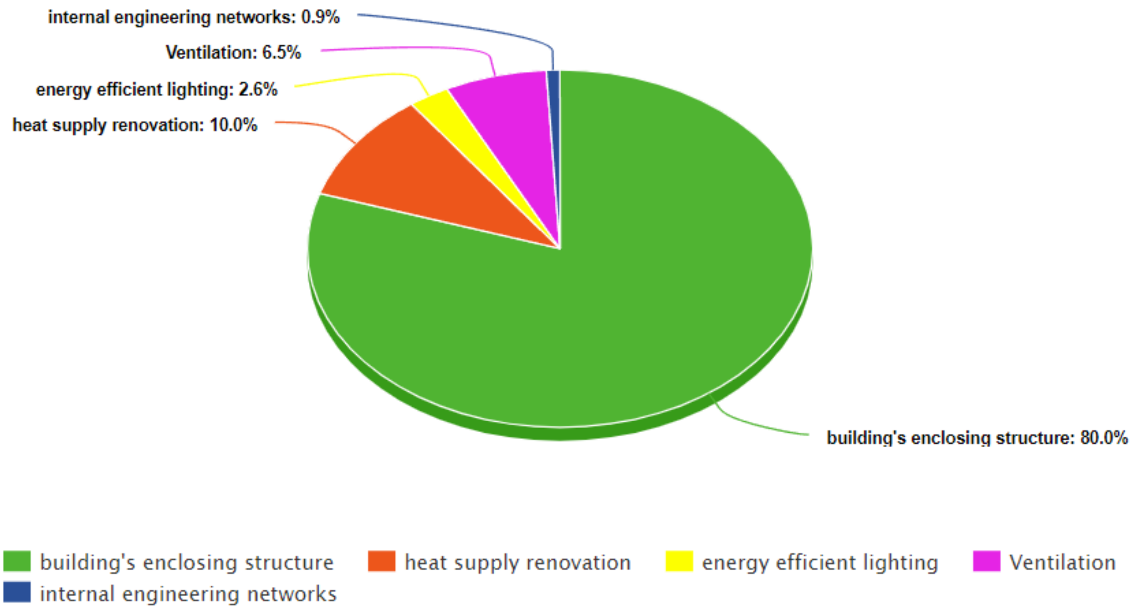


Figure 32 Retrofitting measures in cultural buildings

Besides energy consumption patterns and retrofitting measures, data regarding payback periods of retrofitting actions across Europe are also analysed, because estimated payback time might significantly influence the decisions made by asset managers or building owners when it comes to renovation projects. To this end, information has been retrieved from the DEEP platform [30].

As observed in Figure 33, lighting retrofitting measures and HVAC upgrades do not involve long payback periods (below 5 years on average). However, building fabric measures require longer payback periods, more than ten years on average. As expected, the longest payback periods are recorded in integrated renovation projects.

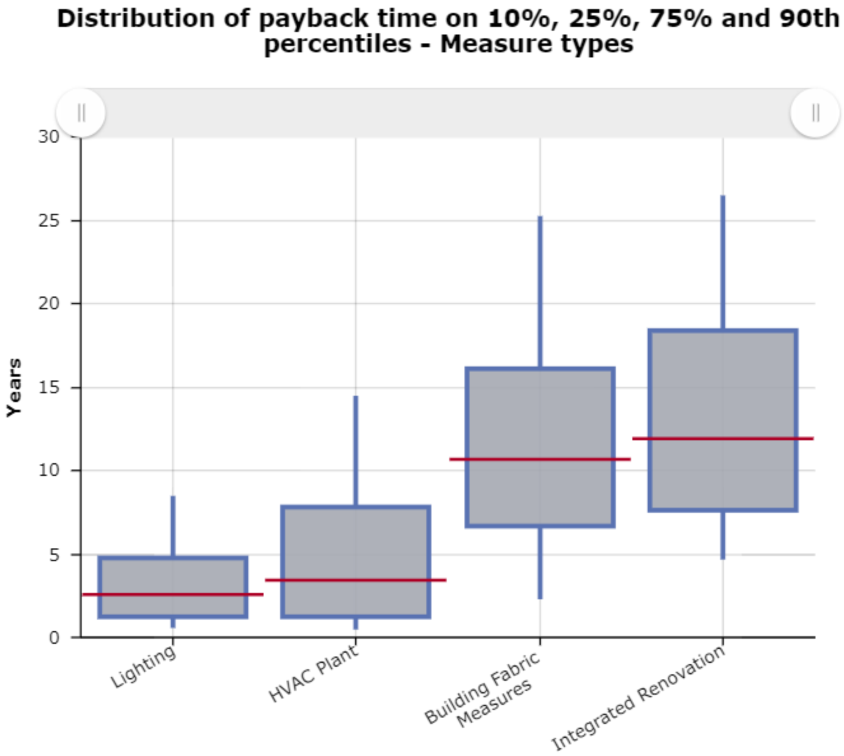


Figure 33 Payback times of retrofitting measures in Europe[6]

As far as different building types are concerned (Figure 34), longer payback periods are recorded in residential (multi-family) buildings compared to educational and health care establishments. The shortest payback periods are observed in commercial buildings (wholesale and retail trade, hotels and restaurants).

[6] De-risking Energy Efficiency Platform -Factsheet (eefig.eu)

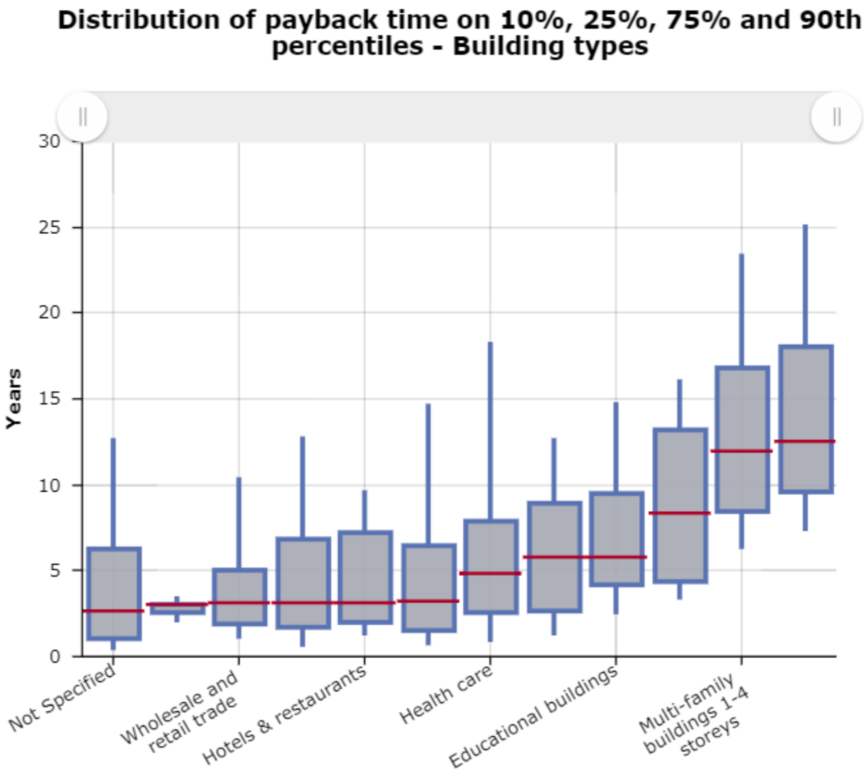


Figure 34 Payback times for renovation of different building types in Europe[7]

[7] [De-risking Energy Efficiency Platform -Factsheet (eefig.eu)](#)

6. Conclusions

Summing up the present deliverable serves its purpose of reviewing previous work done on the subject of building renovation and financing schemes, with the aim of conducting preliminary analyses that could support various activities and upcoming tasks which will lead to the designing and development of the ENERGATE marketplace.

As a first step, building typologies have been defined and a Common Data Model has been proposed. Secondly, various renovation measures which could be proposed to the supply side within the platform's function have been identified and categorised. Thirdly, a review of available financing options for retrofitting projects has been conducted and, based on available data, the correlation between building typologies, implemented retrofitting measures and financing tools has been examined. Moreover, risks and barriers of building renovation projects have been analysed and KPIs have been proposed. Finally, a statistical analysis based on data from the MATRYCS project has been conducted.

More specifically, to generate the Common Data Model, established frameworks for the storage of building data have been studied. Furthermore, databases including information regarding building renovation and EE have been examined, including initial data provided by ENERGATE pilots, so that the most important variables influencing energy performance and renovation strategies in the building sector could be identified. The selected variables included building characteristics (location of the building, ownership status, year of construction, technical characteristics, people occupancy and building type) energy variables (energy consumption by sector and fuel, energy prices and gas emissions) and economic factors (GPD per capita, income and previous energy investments). Since the identified variables were compatible with the existing frameworks, we proceeded to the presentation of the Common Data Model. This proposition could be utilised as a guide for the creation of the ENERGATE ontology, which will be used in the platform to model the information provided by the supply side, generate the building profile, and enable the matching process with the demand side. Furthermore, retrofitting measures could be suggested to building owners and asset managers, according to the building's type and needs. The identified potential measures were classified in the categories of building design interventions, including building envelope improvements and light retrofitting actions, HVAC upgrades which include enhancement of existing infrastructure or installation of new equipment for heating, cooling and ventilation, renewable sources installation and, finally, automated systems (Building Energy Management Systems and devices such as timers and sensors).

Moreover, the most popular financing typologies for building renovation have been examined and analyzed. Identifying potential risks and barriers linked to various financing tools could assist project partners, so that they can focus on addressing potential problems and issues linked to certain financing schemes. Moreover, data from specific case studies have been analysed, with the purpose of revealing possible patterns relevant to building usages and types, retrofitting measures and financing methods. Our review and analysis of financing tools for building renovation reveals that most projects, primarily in the residential sector, rely on grants and funds provided by the European Union, local governments and municipalities. Thus, there is a need to upscale private investment, since overly relying on non-repayable funds is not considered as sustainable policy. Therefore, business models and financing schemes which rely on revolving funds and are linked to achieved energy savings should be promoted and applied, since they encourage EE and have the potential to overcome several market barriers. However, the implementation of such mechanisms requires careful designing, reliable projection of energy savings and, in certain cases, effective measurement of energy consumption.

Naturally, risk is an inherent part of investments, and EE investments are no exception. Thus, risk assessment of renovation projects is necessary, which is why key barriers and risks of the implementation of retrofitting actions have been identified in the present deliverable. Risks and barriers have been classified as technical, energy market, financial/economic and behavioral. Moreover, a set of KPIs for the assessment of retrofitting projects has been presented. These indicators include asset and energy related, economic financing and environmental KPIs, and could support the assessment of projects and products in the ENRGATE platform, so that they can be ranked and matched with investors, based on the applied filters by the demand side and a multi-criteria approach.

Last but not least, a statistical analysis of large-scale building renovations has been conducted, by exploiting anonymised data from implemented projects that have been made available thanks to the collaboration of ENERGATE with MATRYCS. The aim of this analysis is to highlight the patterns and relations between the chosen variables considered in the Common Data Model, with the energy consumption. It has been observed that the positive effects of renovation on energy savings is significant in all building types, however, the impact is greater in office buildings, whereas the energy consumption in residential, public, cultural, administrative and commercial buildings has also remarkably decreased after the implementation of retrofitting measures. Finally, it has been observed that a greater variety of renovation strategies are applied in non-residential buildings, with the exception of cultural institutions. The majority of interventions are applied in the building's enclosing structure. Building envelope and HVAC interventions are the most commonly financed retrofitting actions. Improvements in lighting systems are also common, however, renewable installations and automation have not yet attracted enough attention by investors and other stakeholders and could substantially enhance EE in buildings. Based on the conducted review and analysis, financing mechanisms could be proposed to the supply side of the ENERGATE platform's users, based on the type and ownership status of the building, as well as the retrofitting measures that apply to it.

The research conducted and presented in this deliverable may assist in understanding the interplay (also taking stock of previous relevant initiatives) of different combinations of building ownership status, technology, financing methods and their effect on accelerated building renovation rates. It will support the development of specifications for standardised data entry forms for building EE projects and will contribute to the identification and calculation of the relevant energy, financing and risk KPIs that will be used to develop large, standardised, financeable project packages.

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Appendix: European Case Studies

Location	Buildings Use	Buildings Ownership	Considered Retrofitting Measures	Financing Methods
Aarhus, Denmark [221]	Daycare Centers	Public	Scenario 1: LED lights, efficient equipment, heating circulation pump replacement and ventilation system upgrade (Energy savings: 27.7%)	“Aa Plus” Project Aarhus Municipality (Estimated payback period: 4 years)
			Scenario 2: Improving energy supply systems efficiency and upgrading the buildings envelope (Energy savings: 50%)	“Aa Plus” Project Aarhus Municipality (Estimated payback period: 11 years)
Copenhagen, Denmark [222]	School	Public	Wall insulation, New windows, Building energy management system, efficient lighting HVAC upgrade, PV panels	Municipality of Egendal of Copenhagen funds, Loan, EU concerto
Copenhagen, Denmark [222]	Office building	Private	Wall insulation, New windows, New ventilation systems, Installation of rainwater harvesting system, Solar thermal system, Daylight controlled LED lighting	Partially financed by general maintenance budget provided by the company, Investment by owner (Danish Building & Property Agency) and tenants
Aalborg, Denmark [223]	Residential	Private	Insulation of building envelope, Window replacement, Heating network refurbished	Private investment
Salzburg, Austria [224]	Residential	Private	Thermal renovation: façade insulation, new windows, insulation of the basement and attic ceiling, District heating connection to the existing network of the Salzburg AG	EU CONCERTO initiative [225], [226] (One-stop shop business model)
Kapfenberg, Austria [222]	Residential (Social multi-family building)	Private (social housing company)	Wall, roof, floor insulation, New window/door, HVAC upgrade, solar thermal system, PV panels	“Maintenance and improvement fee” provided by tenants (Austrian Social Housing Law), “Comprehensive Renovation” funding model, additional subsidy, contracting model for PV installation
Varese, Italy [227]	Residential	Private	Buildings envelope thermal insulation (walls, floors), Building systems (replacement of the individual electric boilers with DHW tanks, installation of air-to-water heat pumps, installation of grid-connected PV systems)	Local public body “Regione Lombardia” (one third), ESCO (two thirds)

Lombardy, Italy [228]	Residential	Private	Building envelope (outer façade, cavity walls and interior envelope)	European Union Seventh Framework Programme (EASEE project)
Southern Italy [229]	Residential (Housing district)	Private	Wall, roof, floor insulation, External solar screens, Electric heat pump, Solar thermal system, PV	EPC
Italy [230]	kindergarten	Public	Ventilation upgrade, New windows, Solar screens, Roof Insulation	EU-GUGLE project funded by Seventh Framework Programme
Milan, Italy [231]	Day care center	Public	Hybrid ventilation, automated solar shading, lighting controls and renewable energy generation systems	EU-GUGLE project funded by Seventh Framework Programme
Porto, Portugal [232]	Residential (Social Housing)	Public	Walls and roof insulation, Double glazing windows	Private investors, who retained part of the neighborhood's land to develop new real estate
V. N. Gaia, Potugal [233]	Residential	Private	Installation of walls and roofs, Replacement of windows, Installation of shading elements	Financed by the municipality and through EU structural funds
Lisbon, Portugal [234]	Neighborhood, mainly residential	Private and Public	External Thermal Insulation Composite System, Window replacement, Solar thermal panels for hot water, Light retrofitting	QREN – Quadro de Referência Estratégico Nacional – (National Strategic Reference Framework)
Vitoria-Gasteiz, Spain [235]	Residential and Tertiary	Private and Public	Heating system of biomass boilers	Horizon 2020, Spanish Government (One-stop shop business model)
Tudela, Spain [236]	Residential	Private	Upgrade of building envelopes, Heating systems and network improvement, Solar collectors for domestic hot water, Biomass boilers	Public grants, Private loans
Latvia [131]	Residential (15 Buildings)	Private	Building Envelope, Heating system, Domestic hot water system, Ventilation system (with heat recovery), Heat pumps, Energy monitoring systems	ESCOs
Riga, Latvia [222]	Residential	Private	Building envelope improvement, HVAC upgrade, Lighting retrofitting	ERDF, Loan, EPC (RENESCO)
Athens, Greece [237]	Residential	Private	Improvement of U-values for walls, windows and roof, Heat recovery efficiency on the ventilation system, Heat pump, PV, Reduction of lighting load	Horizon 2020

Miribel, France [238]	Residential	Private	Total envelope insulation (walls, floor, roof), New ventilation system, Optimization of heating and hot water preparation	Horizon 2020, one-stop shop
London, UK [239]	Historical	Public	Roof and floor insulation, New windows, Daylight exploitation, Efficient lighting, New ventilation system, Heat pump, Solar thermal system, PV panels	Funded by the Department of Business Innovation and Skills
Portsmouth, UK [240]	Residential (Social Housing)	Public	Insulation, Window replacement, Mechanical ventilation and heat recovery system	Fully funded by Portsmouth City Council
Darmstadt, Germany [222]	Office	Private	Wall, roof, floor insulation, New windows, Efficient lighting, New ventilation system	Private investor (building owner)
Baden-Württemberg, Germany [222]	School	Private	Façade, Windows, Lighting, Heating System	Self-financing, Stimulus package II, bank loan, Heating through EPC
Bavaria, Germany [222]	Residential	Private	Building envelope improvement, New ventilation system, Solar panels for hot water preparation	ERDF, Funding by the Bavarian Ministry of Economics
Ostfildern, Germany [222]	Sports facility	Public	Building envelope improvement, HVAC upgrade, New lighting system	Self-financing, Kfw credit
Osnabrueck, Germany [222]	School	Private	Building envelope improvement, efficient lighting, HVAC upgrade, ground coupled heat pump	Federal Ministry of Environment, Owner
Olbersdorf, Germany [222]	School	Public	Building envelope, HVAC upgrade, New lighting, Daylight exploitation	Federal Ministry of Environment
Bavaria, Germany [222]	Office	Private	Building Envelope improvement, Roof lights, Efficient lighting, Heating recovery ventilation system	Public-private partnership

Nordrhein-Westfalen, Germany [222]	School	Public	Building envelope, HVAC upgrade, New lighting, PV panels, Sun protection control	Subsidy of the German Environment Foundation
Valga, Estonia [222]	Kindergarten	Public	Wall, roof, floor insulation, Solar thermal system, Efficient lighting	Financed by EU and local government
Dun Laoghaire Rathdown, Ireland [222]	Residential (Social Housing)	Public	Building Envelope, HVAC upgrade	Publicly funded by local and central government
Plevlja, Montenegro [222]	School	Public	Insulation of walls, replacement of windows, New boiler, New lights	KfW, Ministry of Economy, Montenegro
Kotor, Montenegro [222]	Student Dormitory	Private	Building envelope improvement, (roof, wall, ceilings, windows, doors), heating water upgrade, new lighting system	KfW grant and loan
Leeuwarden, the Netherlands [222]	Shelter home	Welfare organization	Building envelope improvement, New HVAC systems, LED lights with occupancy sensors, Automated solar protection	Investment cost covered by both owner and tenant
Lund, Sweden [241]	Residential	Public (LKF Public Housing Company)	Improvement of building envelopes, Lighting replacement (LED), Presence lighting control, Heating upgrade, Temperature sensors, Hot water metering, Ventilation renovation	Public funding (EU and LKF)
Tampere, Finland [242]	Residential	Private	Insulation, Replacement of Windows and Doors, Heat pumps, Heat recovery ventilation, Building Energy Management System	ERDF