D2.8
User Centric Indicators and recommendation tool
- Consolidated version -

EPC RECAST

ENERGY PERFORMANCE CERTIFICATE RECAST

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4. Executive Summary

The EPC RECAST project is focused on developing a transparent, common, and explicit data model (i.e., input data to be collected for EPC assessments and calculations) which will support the characterization of existing buildings and dwellings during on-site inspections by professional certifiers and improve the comparability between Energy Performance Certificates.

These Energy Performance Certification (EPC) schemes have stood in the past as one of the most important sources of knowledge on the energy performance (EP) of the European building stock. However, there are still several barriers to overcome towards a widely supported and successful implementation of the EPCs as effective tools to support the revised EPBD [1].

By involving end-users in multiple steps throughout design phase of the next generation EPCs, the project aims to provide an easier understanding of the energy performance results and context-specific renovation roadmaps, introducing a next generation of user-centred EPCs to value buildings in a holistic and cost-effective manner.

This deliverable describes part of the activities of the WP2, titled “Technical development and integration”, in which, according to the Grant Agreement (GA), existing and proven technology components are going to be combined with the well-structured methodologies and protocols deriving from WP1 activities, based on the three phases of the EPC RECAST certification, which are as follows:

- building information capture and model input collection;
- energy performance evaluation based on real-world and reliable energy model;
- delivery of user-friendly EPC UCIs and renovation roadmap.

Task 2.4 aims in particular on developing the EPC recommendation layer in a user-friendly manner with user-centric UCIs identified throughout activities of state of the art, coupled with user investigation to identify requirements, mandatory rules and needs to be implemented in the EPC RECAST recommendation layer to advise users regarding energy performance renovation in relation also with the Renovation Roadmap and the Smart Readiness UCI in terms of timeline, costs and technology quality.

This document focuses on user centric UCIs and the EPC RECAST recommendations. All activities, actions and work done in this phase are meant to develop components and a recommendation module linked to the existing standards.

Starting from the technologies provided by the EPC RECAST partners, this task refers to the results of WP1 tasks to fulfil the requirements of T2.1 and identifying the user-centric UCIs and recommendations to be delivered to the user from Human Interaction point of view.

A feedback loop will be implemented to consider the impact assessment of the pilot tests which will be conducted later within the WP3 activities.

To support the strict synergies of the dataflow exchange, the T2.4 process has been divided in three main parts:

- state of the art analysis to identify user-centric UCIs on this topic;
- implementation of results from T1.5 together with knowledge from TC16 and TC17;
- EPC assessors and building owners testing to identify requirements, rules and needs to be implemented in the EPC RECAST recommendation layer.

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This, to reach the objective of providing results in a user-friendly manner and advising users regarding energy performance renovation in relation with the Renovation Roadmap and the Smart Readiness UCI, in terms of timeline, costs and technology quality.

Starting from existing technologies developed by the EPC RECAST Consortium partners, modules will be adapted to fulfil the requirements of T2.1 and build the design interface of the tool with user-centric UCIs and recommendations to be delivered to the user from a Human Interaction point of view.

To develop user friendly results, it is crucial to develop a user-friendly methodology.

WP1 has focused on the possibility of establishing a user centric design approach, following the ISO 9241-210 standards, and using certain concepts commonly in use in the scope of energy performance calculations. Terms and definitions of the UCIs presented mainly refer to the following standards:

- EN ISO 52000-1 section 3 [2],
- EN ISO 52016-1 section 3 [3],
- EN ISO 52018-1 section 3 [4].

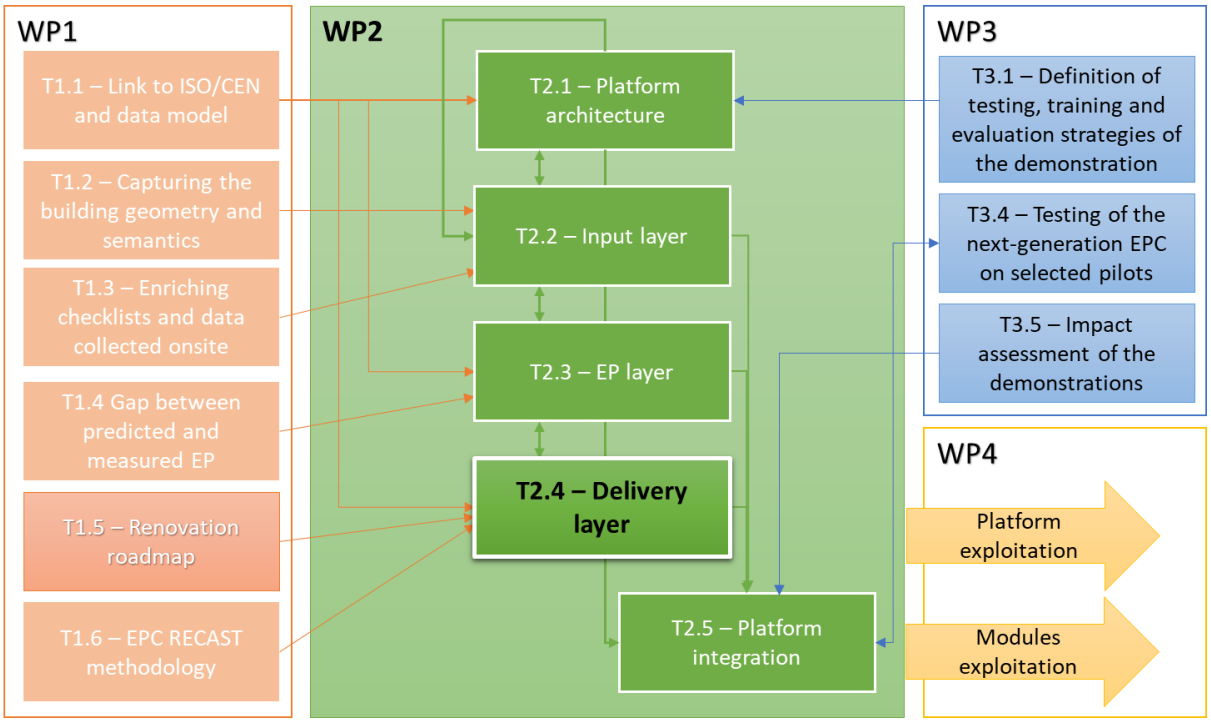

Figure 1. Links and connections between WP2 activities and the different tasks of EPC RECAST.

Figure 1 summarized the synergies between Work Packages within EPC Recast with the detailed of the tasks to underlying the data inputs-outputs flow in between them.

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5. Introduction

Next generation EPC schemes should base their buildings performance assessment on a holistic and complimentary dimension to support decision making by end-users on deep renovation. Thus, including Key Performance UCIs (KPIs) based on a holistic user-centred perspective.

Last decade studies identified in fact the strong influence of occupants on building performance and provided a sound framework for experimentally studying and modelling different behavioral actions, including the implementation of these models into simulation platforms. But real operation of buildings shows that many such models do not represent the manifold human interactions with a building appropriately enough, and that there is no guidance for designers and building managers on how to apply occupant behavior models in everyday practice. However, design and building operation practice shows that many of the models do not represent the manifold human interactions with a building appropriately enough, and that there is no guidance for designers and building managers on how to apply occupant behavior models in standard practice.

The main key discoveries, developments, and outcomes of the most interesting and recent research (e.g., resulting from IEA EBC Annex 66 (2014-2017 [6])) are summarized following.

• A detailed review of, and best practices guide, for data collection methods (sensors, research methods) using four main research methods in-situ, lab, survey, virtual reality. Development of building data ontology to structure and describe all building data (including occupant-related).

• Rigorous comparison of occupant modelling methods (e.g., Markov chains, Bernoulli) with theoretical explanations for all common occupant modelling forms. The issue of modelling inter-occupant diversity was explored with recommendations made and methods for evaluating occupant model performance were developed. Occupant model implementation into simulation tools was explored using various approaches such as occupant behavior functional mock-up unit).

• Investigation of relationship between model application and model complexity (“fit for purpose”). Surveys were performed to gain a better understanding of industry’s attitudes and practice about occupant modelling and 30 case study buildings were documented to understand the role of occupant behavior in buildings.

However, new research questions emerged out to address the path for further investigations such as:

• What are the relationships and interdependencies between different indoor environmental parameters (thermal, visual, olfactory, and aural comfort) and their impact on perception and behavior?

• How do building controls’ interfaces and their underlying logic affect behavior? How can and should interfaces be systematically tested in experimental, in situ, immersive environments, and simulation approaches?

• How should experimental and occupant modeling findings be used to influence building codes, standards, and policies?

• How much impact does occupant behavior have across building types, climates, and against other agents (e.g., building operators)?

• How can uncertainty and risks from occupants be managed and exploited in building design?

• Are current post-occupancy surveys adequate to study behavior?

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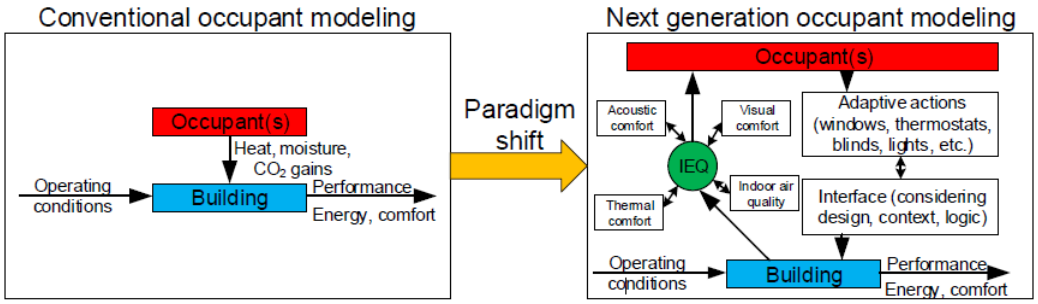

Figure 2 - Paradigm shift in the way occupants are modelled in buildings: from occupants as passive sources of heat, moisture, and emissions to active decision-making agents that respond to indoor environmental conditions.

Previous endeavors within EPC Recast, mainly Task 1.5 and Task 1.6 of WP1, provided relevant findings regarding EPC Recast new generation assessments, certification schemes and UCIs.

In addition, the experts of EPC Recast partner, have led the development of key EPB standards in the field of EPB UCIs:

- EN ISO 52018-1. Energy performance of buildings - UCIs for partial EPB requirements related to thermal energy balance and fabric features - Part 1: Overview of options [4];
- EN ISO 52003-1. Energy performance of buildings - UCIs, requirements, ratings, and certificates - Part 1: General aspects and application to the overall energy performance [5].

Lastly, EPC Recast consortium is aware of the key findings made by the most relevant and recent H2020 initiatives; namely, ALDREN, Triple A-reno, and the sister projects among others.

All these sources of information have been studied to develop a comprehensive state of the art and individuate a dataset of user centred KPIs. Additional UCIs will be included in the EPC template to complete the holistic, technical, and user-friendly soundness of the new generation, also with a view of allowing to leverage measured data.

This deliverable is only focused in selecting relevant UCIs for the user centric recommendation layer into the next-generation EPC. The specifics concerning the inputs, the calculation and evaluation methodology are the other layers of the EPC RECAST platform (Figure 3), out of the scope of this document. Refer to Deliverables of WP1 for further details.

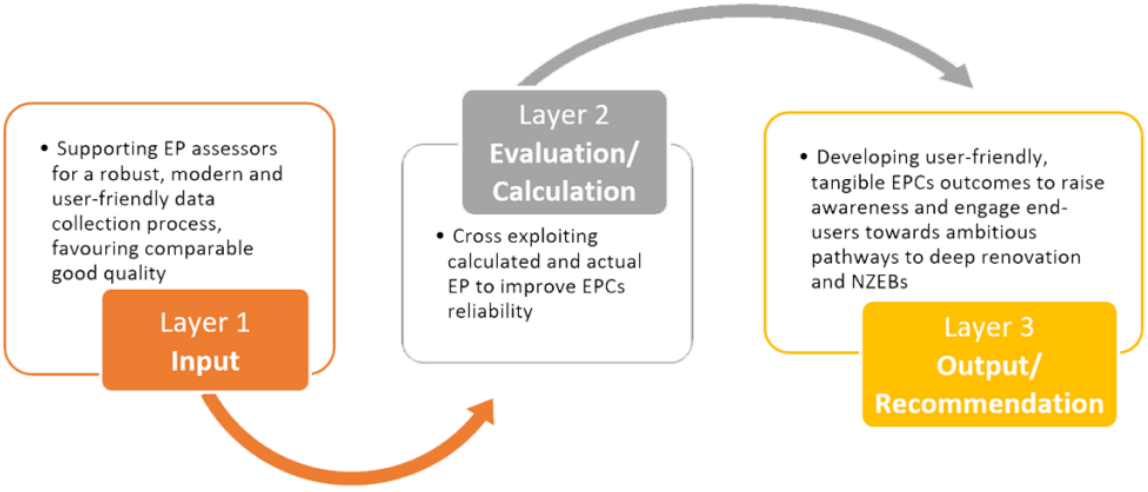

Figure 3 – EPC RECAST platform structure and data flow composed by the three main layers.

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6. Overview on building performance UCIs with a User Centric approach

Exhaustive literature is available to understand the concepts of building performance UCIs based on number of theories. From the review of the last decade research results, seven factors have been identified as Building Performance Attributes (BPAs) essential to be measured to assess building performance in relation to user requirements (internationally recognized and standardized by ISO 19208:2016 [9]) and satisfaction. This standard has been taken into consideration providing the framework for specifying the performance of a building as a whole or a part thereof to satisfy specified user requirements and societal expectations. Seven BPAs are grouped into built form and environmental factors directly related to building performance and three attributes though not directly related to building performance, has all likelihood of influencing user satisfaction. Hence, they are grouped under external factors. BPAs grouped under physical, environmental, and societal factors are listed as under in Table 1.

Table 1 - Building Performance Attributes (BPAs)

S No	Factor	Attributes	User requirement
1	Built Form	1.1 Spaces 1.2 Finishes, Fittings & Furniture	Suitability for spaces for specific use
		1.3 Physical Condition	Durability requirements Tactile requirements Dynamic requirements Tightness requirements Stability requirements
		1.4 safety	Fire safety requirements Safety in use requirements
2	Environmental	2.1 Lighting	Visual requirements
		2.2 Air, Noise and Water	Hygrothermal requirements Air Purity requirements Acoustical requirements
		2.3 Waste Disposal	Hygiene requirements
3	External	3.1 Societal	Community participation Congeniality of neighborhood
		3.2 Accessibility	Accessibility to public transport Location of building Proximity to shops, walkways etc
		3.3 Amenities	Parking, shops, recreational facilities etc

Besides the above listed standard, it has been considered also the ISO 9241-210 [10] which identified the User Centric UCIs on which the user-centric approach is structured, and it is defined as following:

"Human-centred design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs, and requirements, and by applying human factors / ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility, and sustainability; and counteracts possible adverse effects of use on human health, safety, and performance."

The User Centric UCIs (UCIs) may be developed in different ways. They can be general concepts which allow the involvement of the user at all levels, such as understandability, completeness and transparency of the information, or more specific elements implemented directly in the EPC certificate

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to include information useful to the owner, make the representation of data more understandable and/or enhance the awareness of the user on the function and possible usage/advantages of an EPC.

The state-of-the-art analysis on the UCIs has been conducted starting from results and lessons learned reached by the Next Generation EPC Horizon 2020 projects cluster and this section reports a review and comparison of their USIs. Table 2 summarizes the 8 macro categories in which the UCIs has been clustered and identified in the different colors to facilitate their comprehension and comparison, while Table 3 reports the UCIs analyzed per each topic with respective details.

Table 2 – List of the topics individuated by the H2020 projects on Next Generation Energy Performance Certificates cluster

1.	General concepts
2.	Dataset: definitions, structure, sources and uses
3.	Building data: current state and future scenarios for renovation
4.	Environmental impact
5.	Energy performance
6.	Smart Readiness
7.	Comfort
8.	Cost

Table 3. UCIs overview with details per each topic identified in Table 2.

1. General concepts				
UCI	**Definition**	**Use**	**Unit**	**Source**
Strengths and weaknesses	The EPC gives an overview of the strengths and weaknesses of the building's energy performance.	EPC certificate	-	QualDeEPC
Understandability	The information in the EPC is presented in understandable language and figures.	EPC certificate	-	QualDeEPC
	Visual representation of data and understandable language.	EPC certificate	-	U-CERT
	Improve the existing design of EPC products and services, relate energy performance ratings with aspects that specific users find meaningful (e.g., comfort, health, safety, financial benefits, etc.), provide relevant information at the appropriate time depending on the specific user profile (i.e., various level of complexity for different user profiles), digitalize EPCs and insert them in building passports.	Whole process	-	crossCert
Awareness	Promote EPCs in relation to building renovation/retrofitting and its potential benefits.	EPC procedure	-	crossCert
Clarity of objective	Simple definition of the objectives: reduced energy consumption, increase comfort, health and quality of life and generate savings that will be reinvested boosting the economy and preserving the environment.	EPC procedure	-	E-DYCE
Clarity of methods	Simple definition of the methods: to label the building utilizing the free-running potential.	EPC procedure	-	E-DYCE

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Clarity of benefits	Communication of expected savings and benefits in a user-friendly way.	EPC procedure	-	E-DYCE
Clarity of data usage and security	Data will only be used to conduct the certification and associated simulations in accordance with GDPR and will be processed anonymized.	Whole process	-	E-DYCE
Completeness	The EPC contains all the information expected.	EPC certificate	-	QualDeEPC
	Complexity and contextualization of data.	EPC certificate	-	U-CERT
Transparency	Public insight in the work of public bodies and excellent awareness of stakeholders in all levels of the procedure.	EPC procedure	-	QualDeEPC
	Provide transparent data and information about calculation methods and EPC databases.	EPC procedure	-	crossCert
Accessibility	Easy access via the national authority website.	EPC certificate	-	U-CERT
	Provide EPC products and services at an affordable cost; consider differences in accessibility for different social groups.	EPC procedure	-	crossCert
Cost-effectiveness	Optimization of the costs and resources for management, control, and implementation of the EPC schemes.	EPC procedure	€	QualDeEPC
	Investment costs are lower than energy cost savings.	Energy efficiency recommendations	€	QualDeEPC
	Cost-optimal target or combination of renovation measures which imply the minimum global cost.	EPC certificate	€	ePANACEA
Reliability	Data quality and identification of objectively verifiable UCIs (i.e., appropriate and measurable performance UCIs).	EPC procedure	-	QualDeEPC
	Quality of certification services (i.e., interaction with EPC issuers).	EPC procedure	-	U-CERT
	Ensure reliability of information through frequent updates to existing EPCs.	Whole process	-	crossCert
Comparability	Comparable results and recommendations for similar buildings both at country and EU level.	EPC results	-	QualDeEPC
	Comparable results and recommendations for similar buildings, different building systems and/or required standards.	EPC results	-	U-CERT
	Reference values for the main parameters.	EPC certificate	-	ePANACEA
Functionality	High level of accessibility for convenient, fast, and accurate servicing of the system at any level of implementation and high level of user-friendliness.	EPC procedure	-	QualDeEPC
	Availability of auxiliary services such as customer support.	EPC procedure	-	U-CERT

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Functionality	Provide quality information sources, provide support for all profiles of EPC users (including expert users), enable customer feedback, recognise regional and local socio-cultural specifics.	Whole process	-	crossCert
Usability	Extent of which the EPC can be used and implemented by all stakeholders to achieve certain goals with the required efficiency, productivity, and satisfaction under the specified conditions.	EPC certificate	-	QualDeEPC
Feasibility	Provide better financial and IEQ modelling for buildings, provide realistic and robust investment recommendations, address the wider systemic problems in the construction and renovation sector, build arguments on existing evidence and examples of good practices.	EPC process	-	crossCert
Neutrality	Equal conditions for all actors and lack of conflict of interest and non-discriminatory conditions.	Whole process	-	QualDeEPC
Normalisation	Specification of how the overall numerical UCIs are normalized for the size of the building.	EPC procedure and certificate	-	ePANACEA
Training	Provide guidance on how to read, understand and use the EPCs.	EPC certificate	-	U-CERT
	Provide support and/or education concerning the management of buildings for both owners and professionals, train and educate key players in the building renovation and retrofitting market, provide educational content for buyers and tenants, improve the certification user-experience also for EPC assessors, develop training and education modules on key aspects of EPCs.	EPC process	-	crossCert
Overall impact	Develop or enhance interactive features in the design of EPC products and services, target specific user-profiles and tailor EPC products and services to match their specific interests and purpose of use, leverage existing social networks, develop new EPC business models to scale up the rate of certification.	Whole process	-	crossCert
Promotion and marketing	Target profiles and channels of communication, diversify the national communication strategy, inform buyers about the implication of the EPC content, make EPC public and available.	Whole process	-	crossCert

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2. Dataset: definitions, structure, sources and uses				
UCI	**Definition**	**Use**	**Unit**	**Source**
EPC purpose and usage	Description of the EPC process and form in an easily understandable language.	EPC certificate	-	QualDeEPC
Glossary	Formulation of terms and definitions in an easily understandable language.	EPC certificate annex	-	QualDeEPC
Funding programs	Information on funding programs that can help building owners to implement energy-efficient measures.	EPC certificate	Link or QR-code	QualDeEPC
	Provide information on financial relations (cost of investments, public funding).	EPC certificate	-	U-CERT
	Information on financial support and its specific recommendations.	EPC certificate	-	X-tendo
EPC databases	Storage of all EPCs and underlying data with quality assurance processes and data verification.	EPC procedure	-	X-tendo
	Databases including a detailed description and investment cost estimation for the implementation of the main energy efficiency measures for new buildings and major renovations of existing buildings.	EPC procedure	-	ePANACEA
Building logbook	Building-related data repository that will be accessible to a wide audience.	EPC procedure	-	X-tendo
One-stop-shop	Transparent and integrated advisory tools/venues, which will accelerate energy renovations by informing, motivating, and assisting building owners throughout the renovation journey, from beginning to end.	EPC procedure	-	X-tendo
3. Building data: current state and future scenarios for renovation				
UCI	**Definition**	**Use**	**Unit**	**Source**
Real-time parameters	Include real-time building energy performance information about IEQ, power, CO_2 emissions, safety.	Interactive features	kW, kg/m^2 per year	U-CERT
Information on building components (e.g., envelope, HVAC system)	Details on current energy efficiency levels for building envelope and building HVAC system including renewable energy.	EPC certificate	Color-coded rating	QualDeEPC
	Details on the parameters which identify the energy performance of building envelope and HVAC system including renewable electricity production.	EPC certificate	Different unit for each parameter	U-CERT
Possible improved classifications	Display of improved classifications and energy performances for specific sets of renovation recommendations.	EPC certificate	Energy class	QualDeEPC
Energy savings	Difference between the value of energy performance before and after	EPC certificate	kWh/year	QualDeEPC

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	a set of renovation recommendations.			
Investment cost	Estimation of the cost of the investment divided by component and in relation to its influence on energy efficiency.	EPC certificate	€ - category of expense (from low to expensive)	QualDeEPC
Implementation of renovations	Information on useful renovation combinations or stepwise implementation.	EPC certificate	-	QualDeEPC
	Tailored recommendations which show how much the building's energy efficiency can be improved; tailored roadmap for each assessment object in order to meet energy efficiency targets through staged deep renovations.	EPC certificate	-	ePANACEA
Tailored recommendations	Type of recommended measure and consequent implication in terms of costs, emissions, energy demand and compliance with efficiency and decarbonising targets.	EPC certificate	Different unit for each parameter	X-tendo
Renovation Network Platform	Platform with updated and validated information to obtain detailed knowledge on building components, their renovation, and costs.	EPC certificate	Link or QR-code	QualDeEPC
Renovation potential	All the UCIs must be recalculated representing the foreseen status of the building after each proposed renovation scenario.	EPC certificate	Different unit for each parameter	U-CERT
4. Environmental impact				
UCI	**Definition**	**Use**	**Unit**	**Source**
Overall equivalent CO_2 emissions	Emissions calculated considering compensation between different energy carriers and the effect of exported energy.	EPC certificate	kg/m^2	U-CERT
Global warming potential	Potential global warming due to emissions of greenhouse gases to the air.	EPC certificate	kg CO_2 eq/kg	D^2EPC
Ozone depletion potential	Emissions to air that causes the destruction of the stratospheric ozone layer.	EPC certificate	kg CFC11 eq	D^2EPC
Acidification potential	Decrease in the pH-value of rainwater and fog measure.	EPC certificate	mol H+ eq, kg SO^2 eq/kg	D^2EPC
Eutrophication aquatic freshwater	Excessive growth measurement of aquatic plants or algal blooms due to high levels of nutrients in freshwater.	EPC certificate	kg P eq	D^2EPC
Eutrophication aquatic marine	Marine ecosystem reaction measurement to an excessive availability of a limiting nutrient.	EPC certificate	kg N eq	D^2EPC
Eutrophication terrestrial	Increased nutrient availability measurement in soil as a result of input of plants nutrients.	EPC certificates	mol N eq	D^2EPC
Photochemical ozone formation	Emissions of nitrogen oxides (NOx) and non-methane volatile organic compounds (NMVOC) measurement and consequent effects on the	EPC certificates	kg NMVOC eq	D^2EPC

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	Human Health and Terrestrial Ecosystem areas of protection.			
Depletion of abiotic resources (minerals and metals)	UCI of the depletion of natural non-fossil resources.	EPC certificates	kg Sb eq	D^2EPC
Depletion of abiotic resources (fossil fuel)	UCI of the depletion of natural fossil fuel resources.	EPC certificate	MJ	D^2EPC
Water use	UCI of the amount of water required to dilute toxic elements emitted into water or soil.	EPC certificate	m^3	D^2EPC
Use stage energy performance	Primary energy demand measurement of a building in the use stage, generation of low carbon or renewable energy.	EPC certificate	$kWh/m^2/yr$	D^2EPC
Life cycle Global Warming Potential	Building's contribution to greenhouse gas (GHG) emissions measurement associated with earth's global warming or climate change.	EPC certificate	kg CO_2 $eq/m^2/yr$	D^2EPC
Bill of quantities, materials, and lifespans	Quantities and mass of construction products and materials, as well as estimation of the lifespans measurement necessary to complete defined parts of the building.	EPC certificate	Unit quantities, mass, and years	D^2EPC
Construction & demolition waste and materials	Overall quantity of waste and materials generated by construction, renovation, and demolition activities; used to calculate the diversion rate to reuse and recycling, in line with the waste hierarchy.	EPC certificate	kg/m^2	D^2EPC
Design for adaptability and renovation	Building design extent assessment of facilitation future adaptation to changing occupier needs and property market conditions; a building proxy capacity to continue to fulfil its function and for the possibility to extend its useful service life into the future.	EPC certificate	Score	D^2EPC
Design for deconstruction, reuse, and recycling	Building design extent assessment of facilitation future recovery of materials for reuse of recycling, including assessment of the disassembly for a minimum extent of building parts ease, followed by the reuse and recycling for these parts and their associated sub-assemblies and materials ease.	EPC certificate	Score	D^2EPC
Use stage water consumption	Total water consumption for an average building inhabitant, with the choice of splitting this value under potable and non-potable, supplied water, as well as support measurement of the water-scarce locations identification.	EPC certificate	m^3/yr per occupant	D^2EPC

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Water consumption	Parameter related to the energy consumption for DHW and important environmental factor.	EPC certificate	m^3/month, m^3/day	ePANACEA
Urban Heat Island Degree Hours and Urban Cool Island Degree Hours	Area of diurnal temperature between the lower urban and higher rural air temperature; area of diurnal temperature between the higher urban and lower rural air temperature.	EPC certificate	°C	E-DYCE
Impact of building on external spaces	Ratio between the overall surface area of the lot capable of reducing the heat island effect to the total intervention area of the lot.	EPC certificate	-	E-DYCE
District energy UCIs	Efficiency and climate effect of the nearby district heating/cooling network, possibility to connect the building to a low-temperature district heating grid or to use low-temperature heat supply systems.	EPC certificate	-	X-tendo
Outdoor air pollution	Potential building influence on local smog development and efficiency of air filtration in the ventilation system of a building.	EPC certificate	Scale from very low to hazardous and color-coded score	X-tendo
5. Energy Performance				
UCI	**Definition**	**Use**	**Unit**	**Source**
Energy performance services + appliances	Include in the energy performance evaluation all the services and residential appliances and/or office equipment.	EPC procedure	-	ePANACEA
eMobility	Vehicle batteries considered as an energy backup, allowing the optimization of renewable energy use in buildings.	EPC procedure	-	ePANACEA
Overall primary energy and CO_2 emissions	Provide dynamic assessment of energy parameters.	EPC certificate	kWh/m^2 year, kg CO_2 eq	ePANACEA
Partial energy UCIs	Energy use for one specific purpose, energy need for space heating and cooling, characteristics of the fabric or of the technical building system.	EPC certificate	-	ePANACEA
EP	Energy needs (e.g., primary/specific energy) and energy performance for heating, DHW, cooling, lighting, transportation, and global index.	EPC certificate	kWh/m^2 year or month, kWh/m^3	E-DYCE
Overall non-renewable primary energy use	Final global impact of the building's energy performance.	EPC certificate	kWh/m^2, kWh	U-CERT
	Non-renewable global energy performance index.	EPC certificate	kWh/m^2 year	E-DYCE
Overall renewable primary energy production	Whole onsite renewable primary energy production.	EPC certificate	kWh/m^2, kWh	U-CERT
Overall total primary energy use	Total primary energy the building requires to operate according to the energy needs, technical building system efficiency and renewable contribution to the onsite energy use.	EPC certificate	kWh/m^2, kWh	U-CERT

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	Total primary energy.	EPC certificate	kWh/m² year	E-DYCE
ISO weighted energy use	Energy use calculated through harmonized primary energy factors.	EPC certificate	kWh/m² year	E-DYCE
Energy performance coefficient	Ratio between the yearly energy use of the building and the sum of ground surface and thermal transmission surface.	EPC certificate	-	E-DYCE
Overall renewable primary energy use	Onsite renewable primary energy production compensating the energy demanded by the uses of the building.	EPC certificate	kWh/m², kWh	U-CERT
Renewable energy ratio	Ratio between renewable primary energy and total primary energy.	EPC certificate	-	E-DYCE
Renewable electricity generation, self-use, and exportation	Renewable electricity produced onsite, quantity of it used onsite and quantity of it exported.	EPC certificate	kWh/m², kWh	U-CERT
	Quantification of the fraction from onsite electricity production which is consumed inside the building and fraction that is exported to the grid.	EPC certificate	-	ePANACEA
Energy needs/use per service and energy vector	Quantity of energy needed/used for heating, cooling, DHW, humidification and dehumidification, mechanical ventilation, and lighting.	EPC certificate	kWh/m², kWh	U-CERT
Energy performance scale	Overall energy performance of the building.	EPC certificate	Class	U-CERT
	Energy class.	EPC certificate	Label	ePANACEA
nZEB standard	Checkmark that indicates if the building's energy performance meets the nZEB standard.	EPC certificate	Yes/No	QualDeEPC
	nZEB target or minimum consumption of non-renewable primary energy consumption.	EPC certificate	kWh/m² per year	ePANACEA
Plus Energy Building target	When a building generates more energy than it consumes within the annual energy balance.	EPC certificate	-	ePANACEA
Typical energy usage	Energy usage of typical buildings for reference.	EPC certificate	kWh/m² per year	QualDeEPC
Annual energy consumption	Past metered and/or calculated total annual energy consumption.	EPC certificate	kWh	QualDeEPC
	Energy performance of a building based on measured energy use expressing the total annual primary energy consumption and the renewable energy ratio of the building at standard conditions of climate and use.	EPC certificate	-	X-tendo
Power consumption of the building	Ratio of the total power consumption of the building in kWh over: the total number of occupants, the total number of hours that occupants spend in the building, the total surface area of the building, the total volume of the building.	EPC certificate	kWh/occupants, kWh/h per occupants, kWh/m², kWh/m³	D^2EPC
Heating consumption	Ratio of the heating power consumption per energy carrier of the building in kWh over: the total number of occupants, the total number of hours that occupants	EPC certificate	kWh/occupants, kWh/h per occupants,	D^2EPC

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	spend in the building, the total surface area of the building, the total volume of the building.		kWh/m², kWh/m³	
	Thermal performance index for winter heating of the building.	EPC certificate	kWh/m² year	E-DYCE
Cooling consumption	Ratio of the cooling power consumption per energy carrier of the building in kWh over: the total number of occupants, the total number of hours that occupants spend in the building, the total surface area of the building, the total volume of the building.	EPC certificate	kWh/occupants, kWh/h per occupants, kWh/m², kWh/m³	D^2EPC
	Thermal performance index for summer cooling of the building.	EPC certificate	kWh/m² year	E-DYCE
Average seasonal efficiency of plant systems	Average seasonal efficiency of heating system, cooling system and DHW system.	EPC certificate	-	E-DYCE
Weather-Normalized Heating & Cooling Energy Consumption	Parameter based on Heating Degree Days and Cooling Degree Days which indicates if the consumptions are more than expected (positive number) or less than expected (negative number), in relation to the specific climate.	EPC certificate	Positive or negative number	D^2EPC
Lighting consumption	Ratio of the total lighting power consumption of the building in kWh over: the total number of occupants, the total number of hours that occupants spend in the building, the total surface area of the building, the total volume of the building.	EPC certificate	kWh/occupants, kWh/h per occupants, kWh/m², kWh/m³	D^2EPC
Electrical appliances energy	Ratio of the total energy consumption of the electrical appliances in the building in kWh over: the total number of occupants, the total number of hours that occupants spend in the building, the total surface area of the building, the total volume of the building.	EPC certificate	kWh/occupants, kWh/h per occupants, kWh/m², kWh/m³	D^2EPC
DHW consumption	Ratio of the DHW power consumption per energy carrier of the building in kWh over: the total number of occupants, the total number of hours that occupants spend in the building, the total surface area of the building, the total volume of the building.	EPC certificate	kWh/occupants, kWh/h per occupants, kWh/m², kWh/m³	D^2EPC
Fictitious Energy Needs	Translation of residual discomfort intensities into virtual energy needs.	EPC certificate	-	E-DYCE
Coefficient of Performance	Ratio of rate of heat production to the electrical power.	EPC certificate	-	E-DYCE
Energy Efficiency Ratio	Ratio of rate of heat removal to the electrical power.	EPC certificate	-	E-DYCE
Seasonal Energy Efficiency Ratio	Ratio between the reference annual cooling demand and annual electricity consumption considering the varied outdoor temperature.	EPC certificate	-	E-DYCE

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Seasonal Coefficient of Performance	Ratio between the reference annual heating demand and annual electricity consumption.	EPC certificate	-	E-DYCE
European Seasonal Energy Efficiency Ratio	Weighed parameter that enables to consider the variation od EER with the load rate and the variation of air or water inlet condenser temperature.	EPC certificate	-	E-DYCE
Ventilative Cooling Seasonal Energy Efficiency Ratio	Ratio between the cooling/heating need and the electricity energy need for activating the ventilative system.	EPC certificate	-	E-DYCE
Advantage of Ventilative Cooling	Ratio between the electrical energy need for cooling and the electrical energy need of ventilation system.	EPC certificate	-	E-DYCE
Energy Requirement Reduction	Ratio between the energy need in the standard reference scenario and the energy need for the analysed case.	EPC certificate	-	E-DYCE
Energy signature	Correlation between heating and cooling needs and climatic data.	EPC certificate	-	E-DYCE
Operational passive solar building	Adaptation of the energy signature for passive solar buildings.	EPC certificate	-	E-DYCE
Energy cost	UCI of the expense that is easily understandable by an inexperienced end user.	EPC certificate	€/m^2 per year or month	ePANACEA
Overall energy cost per energy carrier	Expense of every different energy carrier.	EPC certificate	€	U-CERT
Free running hours	Number of hours in which the building is operating in free running.	EPC certificate	-	E-DYCE
Mechanical system activation hours	Number of hours in which the building is operated mechanically to reach thermal comfort.	EPC certificate	-	E-DYCE
Passive air-conditioning efficiency ratio	Number of hours in which the building is in free running mode and air-conditioning is not required, divided by the total number of hours of the simulation period.	EPC certificate	-	E-DYCE
Frequency distribution of degree-hour of stack-effect	Indication of the applicability of buoyancy driven natural ventilation.	EPC certificate	-	E-DYCE
Overheating indices	Percentage of occupied hours above/below a reference temperature.	EPC certificate	-	E-DYCE
Percentage of occupied hours with natural ventilation within a temperature range	Occupied hours in which there is a specific passive/low energy technique maintaining indoor comfort temperature ranges.	EPC certificate	%	E-DYCE
Climate cooling potential	Sum of products between building/external air temperature-difference and time interval.	EPC certificate	-	E-DYCE
Residual Heating/Cooling Degree Days or Degree Hours	Building or system resilience to climate changes or different events.	EPC certificate	-	E-DYCE

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Heating/Cooling Internal Degree Hours	Discomfort intensity in a building.	EPC certificate	-	E-DYCE
Temperature difference ratio	Heat removal effectiveness in night cooling.	EPC certificate	-	E-DYCE
Decrement factor	Ratio of indoor air temperature variations to the environmental air temperature fluctuations.	EPC certificate	-	E-DYCE
Time lag for thermal inertia effect of envelope	Time difference between the peak temperatures of outdoor and indoor surfaces.	EPC certificate	-	E-DYCE
Summer/winter thermal performance	Maximum/minimum daily indoor temperature must be lower/higher than the maximum daily outdoor values in shade.	EPC certificate	Yes/No	E-DYCE
6. Smart Readiness				
UCI	**Definition**	**Use**	**Unit**	**Source**
Smart Readiness UCIs (SRI)	Capability of buildings or building units to adapt their operation to the needs of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid.	EPC certificate and annex	Score and detailed assessment	U-CERT
	Capacity of buildings to use information and communication technologies and electronic systems to better suits the needs of occupants and the grid and improve energy efficiency and overall building performance.	EPC certificate	Score	X-tendo
	Measure of the intelligence of a building by evaluating the extent to which a building can adapt its operation to the needs of its occupants and the energy grid while maintaining energy efficiency and operation.	EPC certificate	%	D^2EPC
	Capability of buildings or building units to adapt their operation to the needs of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid.	EPC certificate	Score	E-DYCE
	Capacity of buildings to use information and communication technologies and electronic systems to adapt the operation of buildings to the needs of the occupants and the grid, snd to improve the energy efficiency and overall performance of buildings.	EPC certificate	Score	ePANACEA
7. Comfort				
UCI	**Definition**	**Use**	**Unit**	**Source**
Thermal comfort	Dry-bulb temperature index.	EPC certificate	-	U-CERT
	Deviation from the temperature range, Thermal Degree Hours,	EPC certificate	% and number	D^2EPC

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	deviation from the humidity range, deviation from the acceptable WBGT levels, humidex levels.			
Thermal comfort scale	Thermal comfort score based on the percentage of occupancy hours in each IEQ category.	EPC certificate	Color-coded score	U-CERT
Summer/winter thermal comfort	Amount of weighted occupation hours the temperature is above/below a certain reference temperature.	EPC certificate	Kh	U-CERT
Domestic Hot Water thermal comfort	UCI to check that sanitary hot water is provided, when there is demand, at a certain minimum reference temperature.	EPC certificate	Kh	U-CERT
Predicted Mean Vote	Average thermal sensation response of a large set of people in given thermal conditions for a sufficient long time.	EPC certificate	Scale	E-DYCE
Adapted comfort model	Optimal operative temperature based on running mean outdoor temperature adapted to different climatic conditions, cultural background, and contextual factors.	EPC certificate	-	E-DYCE
Adaptive model discomfort	Number/percentage of hours in assumed upper/lower comfort boundary.	EPC certificate	%	E-DYCE
Bioclimatic charts	Distribution of occupied hours on psychometric bioclimatic charts to analyse thermal comfort and verify potential passive strategies to increase comfort boundaries.	EPC certificate	-	E-DYCE
Accumulated PPD, PPD-weighted criterion, average PPD	Global thermal comfort over long periods.	EPC certificate	-	E-DYCE
Exceeding PMV	Number/percentage of hours in the chosen interval in which the PMV or the operative temperature is not in the defined comfort interval.	EPC certificate	%	E-DYCE
Weighing index	Time in which the operative temperature is in the given domain weighted by adopting a coefficient that is function of how much this domain was overpassed.	EPC certificate	Number of hours	E-DYCE
Degree Hours criterion	Time during which the actual operative temperature exceeds the specified range during the occupied time weighted by a factor which is a function depending on by how many degrees the range has been exceeded.	EPC certificate	-	E-DYCE
Exceedance	Percentage of occupied hours with conditions over the 20% dissatisfied threshold on warm side, weighted by the time varying occupancy.	EPC certificate	%	E-DYCE
Long-term percentage of dissatisfied	Overheating and overcooling in buildings normalised over the number of occupants, over all zones, and over all calculation periods.	EPC certificate	-	E-DYCE

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Percentage outside range	Percentage of occupancy hours when the PMV or indoor operative temperature is outside the comfort range.	EPC certificate	%	E-DYCE
Operative temperature	Mean temperature between dry-bulb air temperature and mean radiant temperature.	EPC certificate	°C	E-DYCE
Wet Bulb Globe Temperature	Heat stress in hot conditions along with metabolic rate.	EPC certificate	°C	E-DYCE
Tropical summer index	Air temperature of still air with an RH of 50% generating the same thermal sensation as the considered environment.	EPC certificate	°C	E-DYCE
Humidex	Level of discomfort associated with conditions of high humidity and temperature based on the dew point.	EPC certificate	-	E-DYCE
Index of Thermal Stress	Overall thermal exchange between the human body and its surroundings.	EPC certificate	-	E-DYCE
Thom's discomfort index	Outdoor thermal comfort based on dry bulb and wet bulb temperatures.	EPC certificate	-	E-DYCE
Mediterranean Outdoor Comfort Index	Mediterranean people's mean vote values judging the thermal qualities of an outdoor environment.	EPC certificate	Scale	E-DYCE
Universal Thermal Climate Index	Outdoor heat stress based on air temperature, mean radiant temperature, wind speed, and humidity expressed as water vapour pressure.	EPC certificate	Scale	E-DYCE
Wind chill index	Cooling power of subfreezing atmosphere in absence of shade and evaporation.	EPC certificate	-	E-DYCE
Wind chill equivalent temperature	Equivalent colder air temperature without wind when the same skin heat loss happens as in the actual windy conditions.	EPC certificate	°C	E-DYCE
Weighted discomfort temperature index	Distance of discomfort from upper operative limit.	EPC certificate	-	E-DYCE
Discomfort over-temperature Time Percentage	Percentage of occupied hours where indoor temperature is higher than a fixed upper temperature limit.	EPC certificate	%	E-DYCE
Percentage of discomfort hours turned to comfort by passive or bioclimatic technologies	Number of environmental or internal discomfort occupied hours translated to comfort by the activation/usage of passive and bioclimatic technologies.	EPC certificate	%	E-DYCE
Acoustic comfort	Noise level index.	EPC certificate	-	U-CERT
Indoor Environmental Quality	CO_2 level TAIL index, ventilation TAIL index, relative humidity TAIL index, mould TAIL index, benzene TAIL index, formaldehyde TAIL index, radon TAIL index, PM2.5 TAIL index.	EPC certificate	-	U-CERT
	Ventilation rate, Total Volatile Organic Compounds, benzene, CO_2 indoors, formaldehyde, radon, PM2.5, PM10.	EPC certificate	%, $\mu g/m^3$ and Bq/m^3	D^2EPC

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Air Quality Index	Measurements of different outdoor pollutants (e.g., VOC, CO, O_3, NO_2, SO_2, PM2.5, PM10, Cl_2, NH_x, H_2, etc.).	EPC certificate	Color-coded scale	E-DYCE
Indoor Air Quality Index	Measurements of different indoor pollutants (e.g., VOC, CO, CO_2 O_3, NO_2, PM10, H_2, etc.).	EPC certificate	Color-coded scale	E-DYCE
	Information about concentration of main indoor air pollutants (e.g., CO, NO_2, asbestos, radon formaldehyde, etc.).	EPC certificate	-	ePANACEA
CO_2 risk	Number/percentage of hours maximum healthy CO_2 concentration limits.	EPC certificate	%	E-DYCE
Percentage of days at or above a given CO_2 level	Amount of time during the occupied period that the CO_2 level exceeds the predefined levels.	EPC certificate	-	E-DYCE
Hours with bad air quality	Percentage of occupied hours with CO_2 concentrations above a certain limit.	EPC certificate	%	E-DYCE
CO_2 index of air quality	Average value of CO_2 level indexes in the monitored ventilated space at an instant of time.	EPC certificate	-	E-DYCE
Air change rate	Calculated using the average CO_2 generation rates per person, number of occupants, volume of the space, steady state indoor/outdoor CO_2 concentrations.	EPC certificate	-	E-DYCE
Stale air UCI	Ratio between the occupied hours with CO_2 concentrations above a certain value and total occupied hours.	EPC certificate	-	E-DYCE
Visual comfort	Illuminance index.	EPC certificate	-	U-CERT
	Deviation from the set illuminance boundary, deviation from the standard illuminance levels, Set Visual Degree Days, Standard Visual Degree Days.	EPC certificate	%	D^2EPC
	Number of hours per year with sufficient daylighting to reach the set point of mean luminance appropriate for the space use.	EPC certificate	h per year	ePANACEA
Lighting Energy Numeric UCI	Normalized annual energy demand for lighting.	EPC certificate	kWh/m^2 year	E-DYCE
Daylight Autonomy	Percentage of annual hours that a given point in a space receives daylight above a specified illumination level.	EPC certificate	%	E-DYCE
Spatial daylight autonomy	Sufficiency of daylight illuminance for a given floor area at a specified illuminance level for a specified number of annual hours.	EPC certificate	-	E-DYCE
Annual sunlight exposure	Percentage of floor area that exceeds a specified direct sunlight illuminance level for a specified number of hours, with any blinds or shades left in the fully retracted position.	EPC certificate	%	E-DYCE

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Useful daylight illuminance, Daylight saturation percentage	Percentage of annual hours that a given point falls in the specific range of illuminance.	EPC certificate	%	E-DYCE
Annual light exposure	Amount of annual visible light incident on a point.	EPC certificate	Lux*h per year	E-DYCE
Frequency of visual comfort	Percentage of the time during which daylight's average illuminance level stays in the range between two thresholds values to guarantee the visual.	EPC certificate	%	E-DYCE
Intensity of visual discomfort	Time integral of the difference between the spatial-average daylight illuminance and the upper and lower limits of visual comfort.	EPC certificate	-	E-DYCE
Discomfort glare index	Predicted glare from large sources.	EPC certificate	-	E-DYCE
Daylight glare probability	Fraction of dissatisfied people regarding illuminance at eye level.	EPC certificate	Scale	E-DYCE
Daylight factor	Ratio of the illuminance at a point on a given plane due to the light received directly and indirectly from a sky of assumed or known illuminance distribution, to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky, without the contribution of direct sunlight.	EPC certificate	%	E-DYCE
Comfort UCI	Levels of thermal comfort, indoor air quality, visual comfort, and acoustic comfort.	EPC certificate	Color-coded score from very bad to excellent	X-tendo
	Thermal comfort associated with operative temperature, humidity ratio and air speed, information about IEQ.	EPC certificate	-	ePANACEA

8. Cost

UCI	Definition	Use	Unit	Source
Global Cost	Total amount of investment cost and relevant cost items during the building's life cycle.	EPC certificate	€	E-DYCE
As-operated costs	Cost per month per energy use, cost per month per energy carrier, total cost per month, total cost per year, total cost per square meter.	EPC certificate	€	D^2EPC
As-designed costs	Total cost per month, total cost per year, total cost per square meter.	EPC certificate	€	D^2EPC
Total cost comparison	Comparison of the as-designed and as-operated cost, namely the total costs per each month and the total costs for the whole year.	EPC certificate	€	D^2EPC
Predicted costs	Real cost, nominal cost, and Net Present Value for the next 10 years.	EPC certificate	€	D^2EPC
Expected costs for building systems	Estimation of the costs that the user can expect for the replacement and maintenance of building systems.	EPC certificate	€	D^2EPC

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The collection and analysis of those UCIs permits to highlight that some H2020 project introduced some UCIs only in relation to selected topics in line with their respective objectives and scope.

For example, referring to Figure 4, it is clear to see that some projects establish to integrate in their EPC UCIs only to frame the general concepts and EPC data structure with user-friendly current state information of the building, instead others focus more on the use of UCIs to report the Energy Performances of the building with an high number of indicators only on that topic.

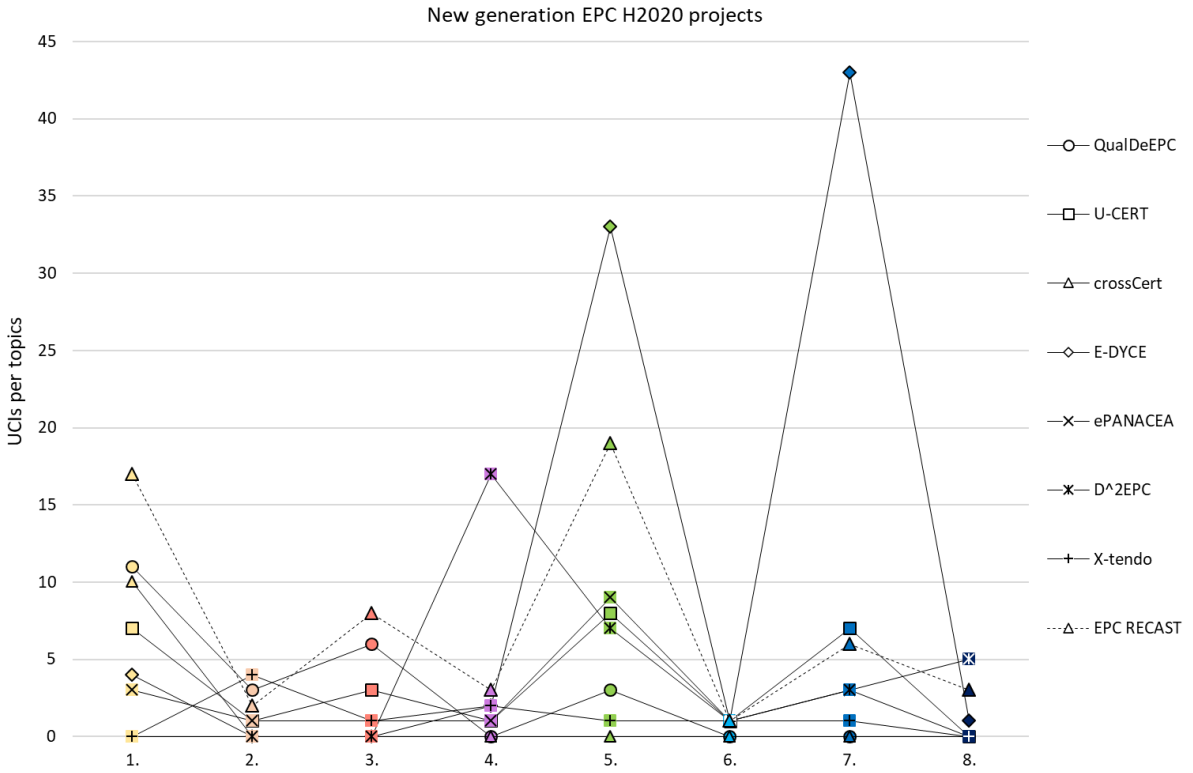

Figure 4 – Comparison of UCIs number per topic implemented in the different H2020 New generation EPC projects

The EPC RECAST approach embraces the use of UCIs for all the topics because, beyond user-friendliness and awareness, the project aims to develop and consolidate methodologies and tools to support professionals and building certifiers performing EPCs as a decisive decision-supporting tool for tenants and potential buyers and providing guidance on cost-optimal building renovation for building owners. Moreover, house owners' considerations about usefulness of the EPC are central as owners decide whether to implement energy conservation opportunities provided by the EPC.

Table 4 – Overview of the topics and the respective UCIs per the Next Generation EPC H2020 project

H2020 project on	Number of UCIs	UCIs per topics							
		1.	2.	3.	4.	5.	6.	7.	8.
QualDeEPC	23	11	3	6	-	3	-	-	-
U-CERT	28	7	1	3	1	8	1	7	-
crossCert	10	10	-	-	-	-	-	-	-
E-DYCE	84	4	-	-	2	33	1	43	1
ePANACEA	19	3	1	1	1	9	1	3	-
D^2EPC	33	-	-	-	17	7	1	3	5
X-tendo	10	-	4	1	2	1	1	1	-
EPC RECAST	**59**	**17**	**2**	**8**	**3**	**19**	**1**	**6**	**3**

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7. EPC RECAST Methodology for user-friendly results

7.1. The overall approach of the EPC RECAST

The overall EPC RECAST approach from data collection to Energy Performance Certificate and Renovation Roadmap is under definition within Task 1.6. EPC RECAST is an innovative process and digital toolbox to develop and validate a new generation of EPCs for residential buildings. The project aims at facilitating and improving the working practices of EPC assessors through quality and reliability of EPC and at tailoring the renovation recommendations and highlighting the benefits for building owners through a user-centric approach.

The main steps of EPC RECAST methodology are data collection and inspection process, energy performance assessment and certification and renovation roadmap, respectively represented by input layer, EP evaluation layer and output and recommendation layer.

As presented in Figure 5, the first phase of the approach is organized in six following steps:

1. Capturing building geometry and semantic;
2. Data enrichment and quick measurement;
3. Energy-related measured data acquisition;
4. Data model (IFC)
5. Self checking procedures;
6. Energy simulation model generation.

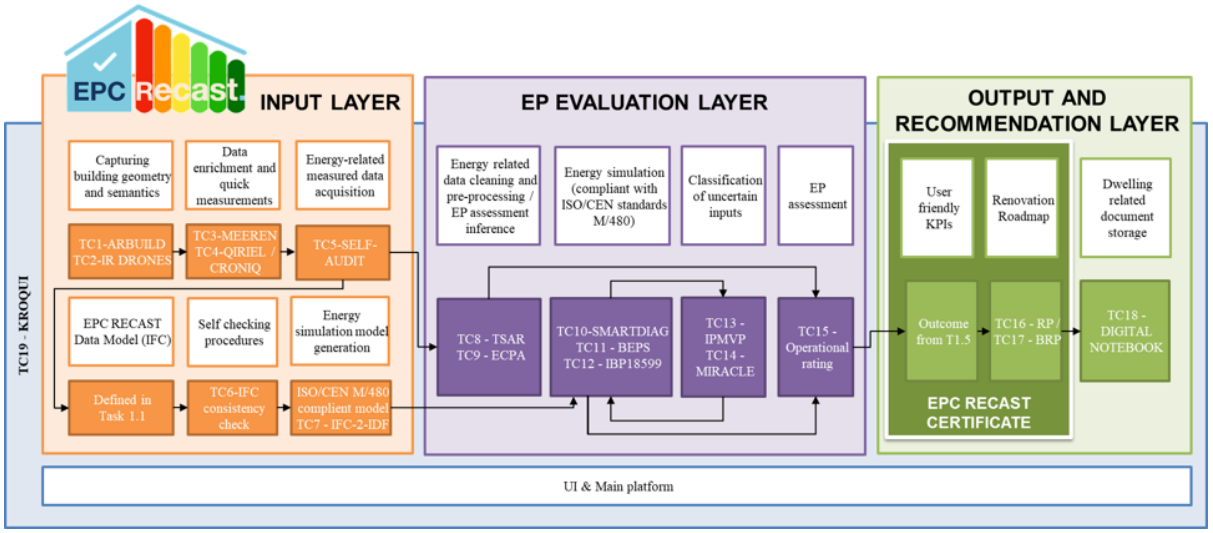

Figure 5. Initial architecture of EPC RECAST cloud-system toolbox.

Energy performance evaluation, instead, regards four different actions that interact each other:

1. Energy-related data cleaning and pre-processing / EP assessment inference;
2. Energy simulation (compliant with ISO/CEN standdards);
3. Classification of uncertain inputs;
4. Energy performance assessment.

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Finally, the outputs of the whole process are the EPC RECAST certificate, which includes the user friendly KPIs and the Renovation Roadmap core of this document.

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7.2. The overall scheme and function of the EPC RECAST

WP2 of EPC RECAST project develops a cloud-based software and data architecture, called the Common Data Environment (CDE), which provides a common and standardized access point for different solution developers to capture, reuse, analyse and display the information of the building energy assessment process, having as a tangible objective to be linked to the normative calculation tools existing in Member States as well as to generate an EPC compatible with each of them.

In particular, Task 2.1 develops the main principles and architecture design of the platform focusing on two main pillars: a common data environment as a mechanism to interlink heterogeneous data and models and a standardised Application Programming Interface (API) to provide transparent and common access to any external tool in collaborative workflows.

To reach the objective of WP2, the CDE follows these principles:

- Avoid duplicating the information in several places by providing a centralised data model compatible with BIM/IFC formats and by providing means to link and cross-reference different sources and formats (BIM models, images, certificates, monitoring data, etc.) through a commonly agreed vocabulary;
- Provide distributed information repositories managed by different actors/entities thanks to the reference system;
- Provide a single or centralised access point with a public API which will internally handle the data interconnections in a transparent way;
- Allow an iterative process to simplify the collection of information from a workflow perspective.

The core idea behind a Common Data Environment is to set up the principles for a collaborative environment for efficient data management in BIM related projects. The most relevant principles are the following:

- Accesibility of data from the cloud;
- Information management (possibility to connect data of different origin and nature by a proper naming convention and possibility to keep track of changes, versioning, control data ownership and access control);
- Functionalities for data querying and filtering;
- Integration of systems (possibility of implementing „software workflows“ with low human interaction through APIs and connectors based on open standards for software developers);
- User interfaces (online BIM viewers for visualizing the model and annotating information and issues and adaptable interfaces, accessible from every kind of device).

Considering the general principles of a CDE, the EPC RECAST Common Data Environment follows the following specific principles:

- Allow the management and proper interlinking of heterogeneous files and data models that are involved in current audit and certification processes through a master schema which acts as a meta-model from where other data sources, files, BIM models, etc. will be referenced. The master schema will be based on XML (eXtensible Markup Language);

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- Allow the once-only insertion of data and the reuse of them any time through the automated extraction of information from the BIM model or the calculation of a parameter from related data (avoid errors and inconsistencies due to manual inputs);
- Define precise naming convention to avoid misunderstanding in different countries, domain or software tool;
- Develop a XML schema flexible enough to cope with different levels of detail (spatial and temporal) to accommodate to the requirements to each country or each calculation method;
- Associate to each piece of data (or at least the most critical ones) metadata about its origin, ownership, acquisition method, etc. for better knowing its reliability or uncertainty;
- Made all the information available online (with proper access rights) in a single central platform or in a distributed ecosystem, uniquely identifying each resource by its public address.

A key aspect of the EPC RECAST CDE is to provide a homogeneous framework and information model EU-wide, with the aim to foster standardisation and comparability of results across Europe. However, each Member State implements its own calculation standards with its own formats and tools. Additionally, each country could have its own naming conventions and categorisation of typologies and some data could be considered with greater detail in some country rather than in others.

For this reason, EPC RECAST considers the possibility for software developers of implementing services for the automatic translation of the EPC RECAST schema to national ones and vice versa. With this approach it is possible to drastically reduce the manual input requirements and to pave the way for homogenisation.

During the recent years, digitalization and automation are one of the most relevant trends that are affecting society and almost all industrial sectors, including the construction one. In addition, the use of BIM/IFC in the EPC processes can have enormous benefits:

- Possibility to automatically import from BIM building and zones dimensions and thermal properties, reducing drastically the manual data input requirements in dedicated interfaces and incrementing the accuracy of information;
- Possibility to reuse the BIM model for other purposes, such as building operation and maintenance, design of renovation alternatives and rendering, etc.

Thus, for defining the EPC RECAST CDE schema, the definitions and naming conventions already used in IFC have been considered, when existing, because they are already based on international consensus, well documented and publicly available. The concept at the base of IFC classification system has been mimicked by EPC RECAST by allowing any object to assign a variable number of properties, especially the ones involving quantities or measurements.

The main layers of the CDE are the following:

- Data Layer, that is the core layer where all the information is stored and managed, ideally through internal data management services which validate the consistency of the internal information or implement routines for generating aggregated or synthetic data from detailed data;
- API Layer, which decouples and provides independence between the data and the services by providing standard data access mechanism, usually in the form of web services. In this

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part of the CDE CRUD functionalities (Create, Read, Update, Delate) are provided with the appropriate permissions;

- Services Layer, in which all the logical components that produce or consume the information stored in the CDE are deployed. This layer is in turn split into three main sequential layers: input, evaluatio and output (or delivery), with an additional component focused on data postprocessing.

Figure 6 shows the overall view of the EPC RECAST CDE developed by Task 2.1.

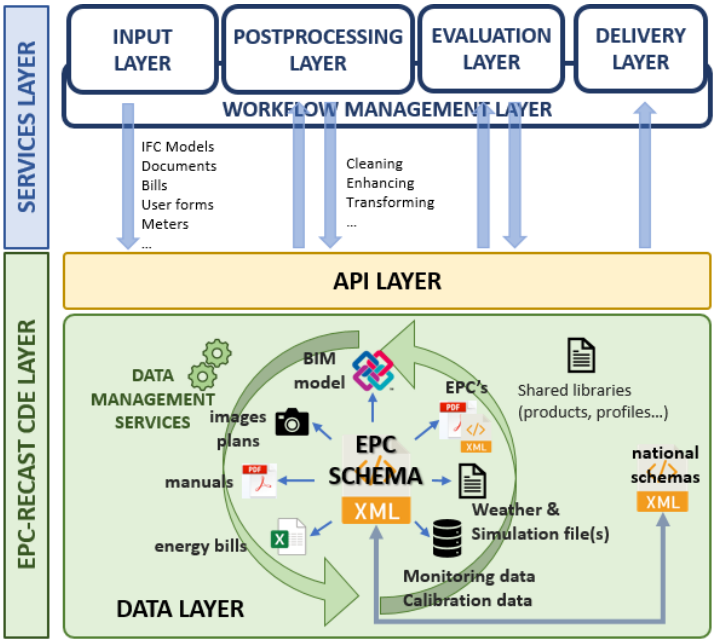

Figure 6. Conceptual architecture of the EPC RECAST CDE.

The additional postprocessing layer has been included in the architecture of the CDE to distinguish between tools that provide plain input information to the platform (with no prior requirements) and tools which provide inputs by enhancing or adding new information to previous inputs. These tools could eventually be automatically invoked by the platform with no need of user requests and could include:

- Services for validating the correctness of an IFC or other files in terms of data;
- Srvices for generating aggregated data based on detailed data;
- Services for estimating/guess missing data based on other values or based on AI;
- Interoperability services to convert/map data to/from specific countries' standards.

The postprocessing tool could be an integral part of the CDE platform or an external tool invoked by the CDE as web services. To ensure access of external tools and interoperability, the platform architecture is provided with a REST (Representational State Transfer) Application Programming Interface (API), which is already supported in a huge variety of tools, including several technical components considered within the project. Each web service is associated with an HTTP method, according to the type of action it performs. The convention followed by EPC RECAST is the most adopted one:

- GET for reading information;

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- POST for creating new information;
- PUT for updating existing information;
- DELETE for deleting information.

Considering how the common data model is defined, the API can be structured in several sub-components: projects, BIM models, resources, libraries, and simulation. The last one takes place in a future scenario with more digitalized workflows in which the software tools that are normative in each country for simulation and certification could be connected to the platform and directly invoked using web services.

7.3. EPC development from the assessors' point of view

User testing is associated with usability and user experience questionnaire, based on scales which allow to measure the user experience and/or the perceived usability of the prototype. In the EPC RECAST project, this approach will be adopted as feedback from owners/tenants involved in the demonstration activities of WP3, in particular Task 3.5 - *Impact assessment of the demonstrations according to pre-defined KPIs* will assess the evaluation strategy of the whole EPC RECAST approach.

As the main users directly interacting with EPC are building owners and EPC assessors, the involvement of those selected users for the whole process is necessary to fulfill the user-centric objective.

Within the frame of Task 1.5 - *Improving the impact of EPCs through the certificate and user-centric building-specific renovation roadmap, articulated with building renovation passport*, a methodology has been elaborated to collect data from user needs and specifications with the aim of improving the impact of future EPC by better understanding the strength and weaknesses of current certificates. This approach is user-centric because data is directly taken from EPC assessors through a face-to-face interview that implies strong interaction and sincerity. In particular, the user journey map tool, which takes place in the consultation process, is a visual representation of the customer journey that helps capturing the assessors needs and specifications by using a dynamic, modern, and graphical methodology.

The process of testing assessors has started in 2021 in Luxembourg and has been planned in four steps:

- draft of user journey map tool based on researcher's experience;
- meeting with federation of assessors to describe the process and validate the journey map;
- workshop with 6-8 EPC assessors to discuss opportunities of new developments and adjust the draft of the map;
- workshop to test the EPC RECAST Templates & Tools.

Even though the EPC assessor testing is in an early phase, some practical inputs useful to the EPC and Renovation Roadmap planning are already available:

- an automated process for computing the "energy reference surface";
- tools to have a better control of EPC and contruction works to avoid lack of control by the authorities;
- an all-in-one tool instead of compared outputs from different softwares.

In addition, Table 5 reports the thoughts and opportunities highlighted by the assessors.

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Table 5. Assessors' thoughts and opportunities.

USER THOUGH	OPPORTUNITIES
In-use information on energy consumption rarely shown in the EPC (i.e., the energy consumption could be larger than expected)	Standardized monitoring protocol at the end of the EPC process for energy fault detection
No integration of the aging of building in the EPC	Blower door tests and/or thermography after a few years to check building energy performance
Use of different software for EPC generation at European level	Software development or use of standardized file format
Information not complete/precise enough at the first EPC draft (e.g., reference surface, size of windows, etc.)	Automatic extraction from BIM model of a standardized list of data and parameters
Feasibility study not useful (too late)	Other tool to be used in early design
Many documents to handle, a lot of administrative work	All-in-one tool also for exchanging with authorities through electronic signature
Thermal bridges selection and computation not yet well harmonized	Clear rules
No/very few controls on site	Tools to have quick and cheap control of works
Lack of site workers knowledge about new construction methods	Training sessions
No integration of some building's processes in the EPC (e.g., building physics)	Standardized structuration of EPC assessors' tasks and responsibilities

The EPC assessor testing process allowed the testing and modification of tools according to user needs to have better acceptance and easy implementation. In conclusion, from the experience of assessors, the next generation of EPC should be more readable, more auditable, and more efficiently documented so that it could be possible to speed up the whole process and avoid failures at design phase and on building site. The opportunities highlighted by the EPC assessors can be addressed in EPC RECAST, as shown in Table 6.

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Table 6. EPC RECAST features to tackle assessors' opportunities.

OPPORTUNITIES	EPC RECAST FEATURES
Standardized documents framework for some phases (e.g., offer, design, EPC, as built)	Standardized KPIs, content of EPC, data for EU comparability (WP1 – Task 1.5)
Mandatory on-site control	Input data checklist (WP1 – Task 1.1)
Automatic information extraction from BIM	TC 7 IFC2IDF converter (WP2)
Interoperability between tools (EPC + Environmental assessment + SRI) for automatic generation of EPC	TC6 IFC consistency check, TC20 4DCollab (WP2)
Legal checklist for municipality quality control	-
Electronic signature in EPC tool and/or link with electronic permit	TC12 Printing tool for a standardized documentation (WP2)
EPC viewer to view EPC related data onsite	-
Mobile app for BIM annotation onsite and document exchange	TC1 AR2BUILT (WP2)
Better definition/communication of EPC assessor's tasks and responsibilities	-
EPC in-use protocol for energy fault	Comparison with measured energy, operational rating (WP1 - Task 1.4)
EPC in-use determination of the aging of building/materials	-

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7.4. Key Performance – User Centric Indicators (KP-UCIs)

As remarked in the introduction, one of the main objectives of EPC RECAST in this field is to provide recommendations for comparability at the EU level and better understanding of Energy Performance Certificates (EPCs) and the Key Performance throughout UCIs clear to different target groups such as stakeholders, assessors, tenants, owners etc. in this context the template of new generation Energy Performance Certificate, outcome of the project, wants to fill the gap in national EPCs.

The EPC RECAST certificate template reports in detail the set of building information and data. New Key Performance User Centric Indicators (KP-UCIs) have been introduced to cover not only the most common areas of interest, but also the most relevant and efficient for user such as thermal comfort score for calculated energy, Smart Readiness and financial evaluation costs for renovation.

The analysis developed within Task 1.5 with the User-Centric approach led to the decision of implementing two levels of complexity for EPC template: one for professionals and one version for owner and tenants. The second one has the aim of motivating the direct user of the building towards the improvement of energy performances through renovation and its focus is on the operational costs-global costs ratio with respect to the influence of energy consumption on the behavior of building users.

The template developed in Task 1.5 is the main inputs source for Task 2.4 in terms of requirements, mandatory rules and needs to be implemented in the EPC RECAST Roadmap Tool.

The core findings and core topics which Task 1.5 point out as mandatory to be implemented in the Renovation Roadmap are:

- Energy Performance User Centric Indicators with rating scale with the NZEB rating;
- Climate change impact on thermal comfort;
- Smart Readiness;
- Indoor Environmental Quality risks;
- Complementary visions for both the tenant and the owner on UCIs costs taking into account yearly energy cost, energy signature and global cost;
- Predicted and actual energy consumption expressed by asset and measured energy rating;
- Non-renewable primary energy self-used (without export counted) and non-renewable primary energy balance (with export counted).

In line with the proposal for the EPBD revision, KP-UCI risk related to sustainability, economy and the value generated by the renovation investments have been included in EPC RECAST template, considering also the externalities (IEQ and health influencing renting rate and vacancy, etc.).

An important new KP-UCI introduced in EPC RECAST template and developed in a previous H2020 project ALDREN [13][14] is the Thermal Comfort Score for simulated energy performance reported with energy class and displayed in the Renovation Roadmap.

The EPC template for professionals (based on ALDREN template developed for non-residential buildings and adapted to residential ones - Figure 7 a) contains the KP-UCIs listed following:

- Modular design enabling tailor-made solutions to reach needs and purpose, based on UCIs compliant with CEN standards and Level(s);

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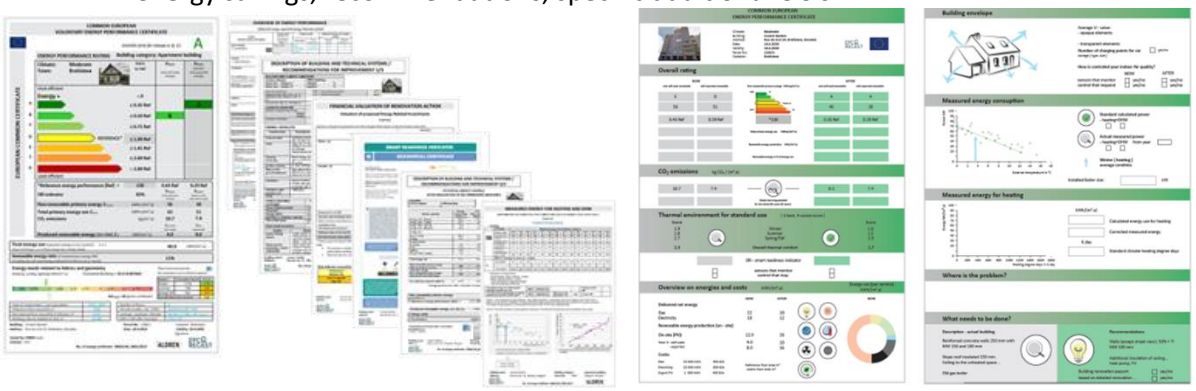
- Additional UCIs: GWP, SRI, financial UCIs, valuation of energy related investment, measured energy;
- Specific pages with additional information for different purposes: delivered energy, energy savings, recommendations, specific additional UCIs.



a) b)

Figure 7. EPC RECAST templates: a) for professionals, b) for owners and tenants.

Instead, the EPC template for owner/tenant (2 pages, new design- Figure 7 b) contains the following information and KP-UCIs, reported for both current state and after renovation state:

- Non-renewable primary energy;
- CO_2 emissions;
- Total primary energy;
- PV production (total, self-used and exported);
- Energy use per service (heating, cooling, DHW, lighting);
- Delivered energy per energy vector;
- EPC RECAST thermal comfort score;
- Financial UCIs (operational costs, global costs);
- Recommendations for improvement towards NZEB and links to Renovation Roadmap;
- Actual operation (measured actual energy, normalised energy and calculated one, energy signature for heating and DHW for monitoring operation).

The information about SRI displayed in the EPC will be also tested in two different ways:

- The BIM-based approach based on BIMtoSRI TC will be tested in one pilot in Luxembourg;
- The official SRI testing pack will be tested on all EPC RECAST pilots to allow an easier comparison with other ongoing testing activities and to focus on the applicability and added value of the SRI to residential buildings, highlighting the expected costs of this specific assessment.

In conclusion of the section 7 of the present document, Table 7 reports the main important KP-UCIs of the EPC RECAST toolkit for the core topic of the energy building performance evaluation, specifying which are reported in the EPC RECAST template and/or in the EPC RECAST Renovation Roadmap tool.

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Table 7. UCIs and information reported in the EPC.

UCIs of the EPC RECAST platform toolkit	UCIs' EPC RECAST template	UCIs' EPC RECAST Renovation Roadmap tool
Energy		
Energy class A-G for primary energy	✓	✓
% of renewable energy in kWh	✓	
Primary energy (total and per different use)	✓	✓
Final energy (for heating, cooling, and lighting;..)	✓	
Emissions		
Annual CO_2 emissions	✓	✓
Renovation recommendations		
Energy classes after renovation	✓	✓
Detailed information for each recommendation (description, timing, specific UICs per energy, emissions, comfort, costs)		✓
Measured energy		
Reported as measured	✓	
Normalised at least for weather	✓	
Comparison, verification of calculated energy performance	✓	
Energy signature (predicted power)	✓	
Comfort		
Overall thermal comfort score in relation to occupied hours	✓	✓
Winter thermal comfort score in relation to occupied hours	✓	
Summer thermal comfort score in relation to occupied hours	✓	
SRI		
Global SRI score	✓	
Costs		
Annual energy costs		✓
Energy costs after renovation, cost savings	✓	
Investment costs for each renovation interventions		✓
Global costs (e.g., for 30 years)	✓	

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8. Roadmap Tool Visualization

8.1. Overview of existing roadmap initiatives

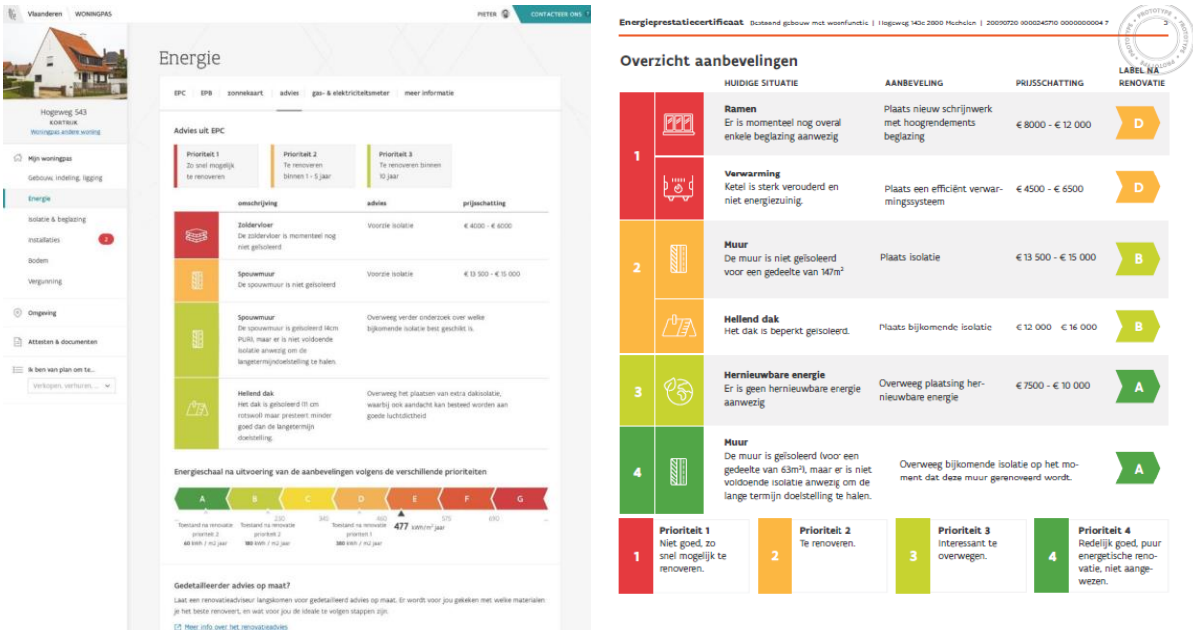
After the state of the art on the UCIs and the definition of the KP-UCIs to be implemented in the new generation of the EPC RECAST template, the activities of the T2.4 foreseen the development of the Renovation Roadmap visualization (TC17), for this reason a deep analysis on the already existing roadmap initiatives has been conducted to individuate suggestions and barrier from those examples. In particular, the review focuses on the architecture of the platform/certifications, the different UCIs and the level of detail of the data to be visualized.

The main initiatives analyzed and summarized are: WONINGPAS, developed in the Flemish area; Passeport Efficacité Energétique (P2E), developed in France, and Individueller Sanierunsfahrplan, developed in Germany.

8.1.1. WONINGPAS (Flemish area)

The WONINGPAS (building pass) is developed by the Flemish Agency for energy and climate in collaboration with the environment Department, Housing Flanders and the public Flemish Agency for waste. It consists of a web interface with an overview of different information about the building, such as insulation, energy, certifications, installations, history and environment [15].

As reported in Figure 8 (a), the front page presents a left bar in which the main topics can be selected, such as building's classification and location, energy, insulation and glazing, installations. In particular, the energy tab in has different sub-tabs related to EPC, EPB, solar maps, recommendations, gas and electricity meters and more information. The aim of the analysis is to compare different displays of Renovation Roadmap; thus the "recommendations" sub-tab has been considered more in detail.



(a) *(b)*

Figure 8. Example of visualization of the WONINGPAS, respectively: (a) front page and organization in different sections, and (b) roadmap with details on the different renovation actions foreseen. Source: VEA.

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In fact, it is a synthetic representation of Renovation Roadmap that includes an order of priority of the renovation actions, the description of the "problems" that must be solved with renovation (i.e., missing insulation), the related renovation action and its cost. At the bottom of the page there is also an energy classification with the actual level and the ones that can be reached after implementing the recommended renovation actions in order of priority.

Figure 8b) shows the page of WONINGPAS related to the detailed Renovation Roadmap. It presents the renovation actions in order of priority, from what must be renovated as soon as possible (Priority 1 in red) to what is not strictly necessary at the moment (Priority 4 in dark green). Every recommended renovation action is listed in a table with the associated priority level and color and is described in terms of current situation of the construction element that must be renovated, recommended actions on that element, costs and energy class that can be reached through that renovation action.

8.1.2. Passeport Efficacité Energétique – P2E (France)

The Passeport Efficacité Energétique is a tool developed by The Shift Project in collaboration with the main players in the sector and territories. It proposes an engineering and energy meditation approach aimed at making it a relevant first step in the household renovation process. In fact, P2E must allow the systematization of support for the renovation of buildings and the improvement of the quality of renovations through a planning of the works in global vision, maintaining low costs. In addition, the Passeport Efficacité Energétique represents the renovation step of the Digital Notebook for monitoring and maintaining houses. The main objective of the project is to improve renovation in stages thanks to a global vision planned over the long term able that ensures the compatibility of the work with the achievement of the Low Consumption Building level and the national Energy and Carbon objectives [16].

The P2E tool is dedicated to single family houses and implements the roadmap in an easy way to be completely clear for owner/tenant [17]. The P2E BETA version platform consisted of different tabs, including a dashboard, general information, energy performances, choices, and actions. In particular, the dashboard, presented in Figure 9**Erreur ! Source du renvoi introuvable.**(a), was divides in six sections:

1. energy (from audit), with energy and GHG emissions performances and annual costs;
2. comfort (from questionnaires), with winter and summer thermal comfort, acoustic comfort and air quality level;
3. current state and renovation actions divided by constructive and technological components, with a qualitative indication of the priority of intervention on each one;
4. valorisation, which indicates the estimated value of the property;
5. founding, with intervention cost, subsidies and other founding;
6. documents, from which the user can download all the documents related to the building.

In the lower part of the dashboard there is the planning of renovation actions divided by constructive and technological components, with the indication of the year inside the total renovation period in which the works should be done.

Figure 10 reports the actual display of P2E certificate with the Renovation Roadmap.

In the upper part the user can find all the general information of the building, such as surface, year of construction, location, type of project and general description.

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The central part presents the actual roadmap in order of priority of intervention and with the total amount of each priority step. For every action there is the description of the current state's problem accompanied by the project of the solution to implement.
The bottom of the roadmap gives indications about the levels of energy and GHG emissions performances that can be reach after each step of renovation and about the risks that may be encountered during the renovation process. At the end of the certificate, some recommendations to motivate the owner/tenant towards renovation are presented, such as higher value of the property, higher quality of life and lower climate impact.

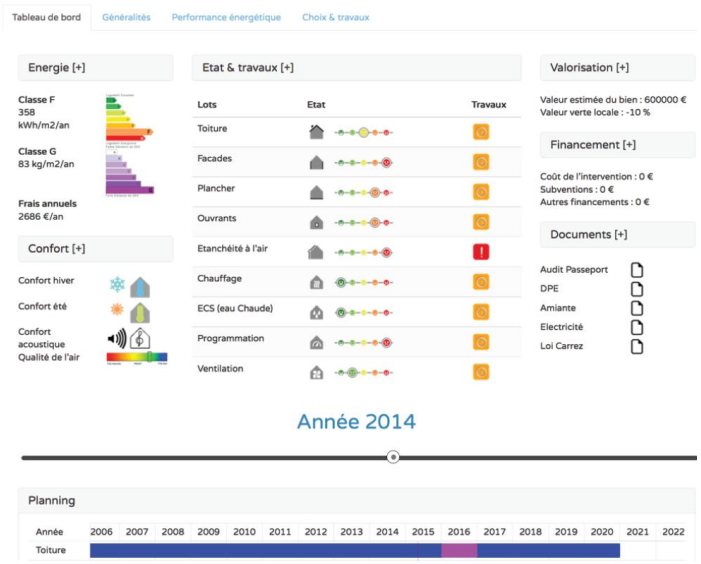

Figure 9. P2E example with energy evaluation from audits and comfort evaluation from questionnaires (on the left), and performance of the building (in the middle) year of data reference (on the bottom).

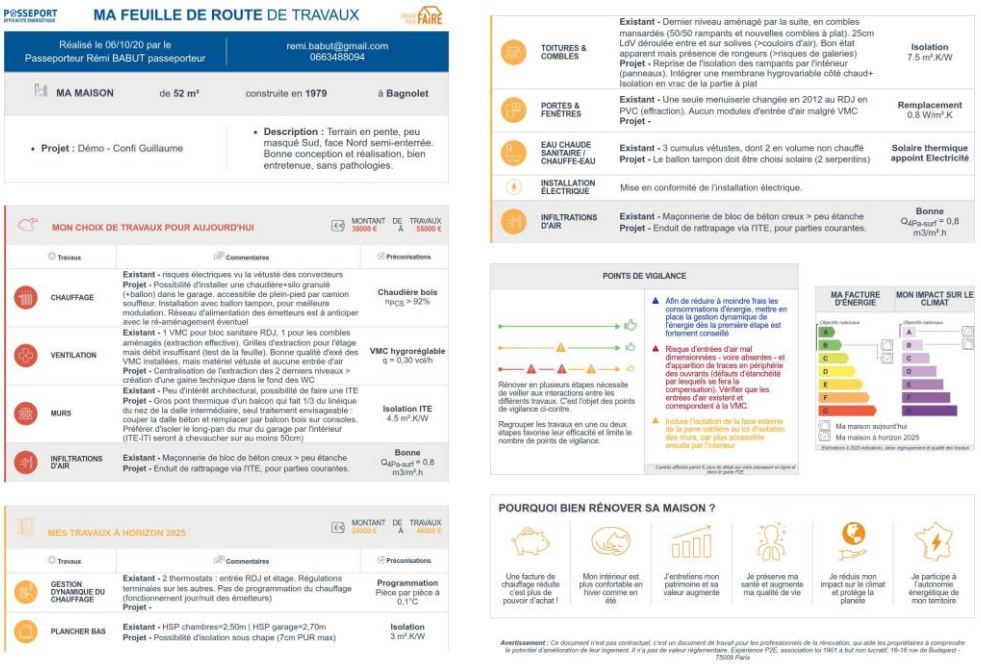

Figure 10. P2E example of the Renovation Roadmap sheet and renovation measures descriptions and details

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8.1.3. Sanierungsfahrplan and Individueller Sanierungsfahrplan (Germany)

Sanierungsfahrplan of the Baden-Württemberg region is a renovation program developed by the Baden-Württemberg Ministry of the Environment, Climate and Energy and intended to summarize and clearly present the most important information for building owners. In particular, it presents the initial state of the building, the saving potential and the recommended measures. The model of the Renovation Roadmap consists of six pages with the following information:

- introduction to energy efficiency and climate protection;
- energetic evaluation of the building in its current state;
- overview of packages of measures and condition after renovation;
- renovation steps in detail;
- explanation of the rehabilitation roadmap.

The roadmap can include up to five packages of measures, which can be made of one or more measures each. In addition, every measure is described in terms of costs, subsidies, and recommended period for long-term planning. The model also includes the evaluation of various building parameters, such as the quality of the envelope and the system technology [19].

As presented in Figure 11(a), the summary view of the Renovation Roadmap consist of the actual status of the building (with indication of energy consumption and CO_2 emissions), the roadmap step-by-step (which indicates what measures should be implemented and the related costs) and future status of the building after renovation (with indication of energy consumption and CO_2 emissions). In addition, for every renovation step, there is the indication of the energy performance class that can be reached after the implementation of the relative measures.

Figure 11(b) shows the visualization of the detailed steps in order of priority. For each of them there is a left bar with the total energy class and the ones for the building envelope and the plant systems. In the right side of the page, instead, there is the description of all the actions necessary to implement the renovation step, with the related period, energy performance (quantity), costs, founding, indication of why the action is needed, observations and comments to prepare the building for future related actions and description of the benefits in terms of internal comfort improvement.

Individueller Sanierungsfahrplan (iSFP) is an individual renovation program for residential building developed by dena (Deutsche Energie-Agentur) in collaboration with the Institute for Energy and Ambiental research (ifeu) and the Institute for Passive House (PHI). The aim of the iSFP is to present the renovation action in a simple way to guarantee the comprehension by the user (also without technical expertise). The individual renovation program offers also the opportunity to integrate the actions in a general concept of the building, thus reaching a high-quality result. The program gives information about comfort, energy performance of the building and economic aspects, both in in a practical way and in a future prospective. [18]

Figure 12(a) represents the planning page of iSFP's output document, which contains all the actions to be implemented for a step-by-step renovation. In particular, the roadmap divided the renovation actions in different steps and give to each of them a temporal indication for its implementation. The first and last steps correspond respectively to the current state and the after-renovation state. For these two situations there is an indication of the energy consumptions and CO_2 emissions. The renovation steps, instead, are characterized by the list of actions required and their costs.

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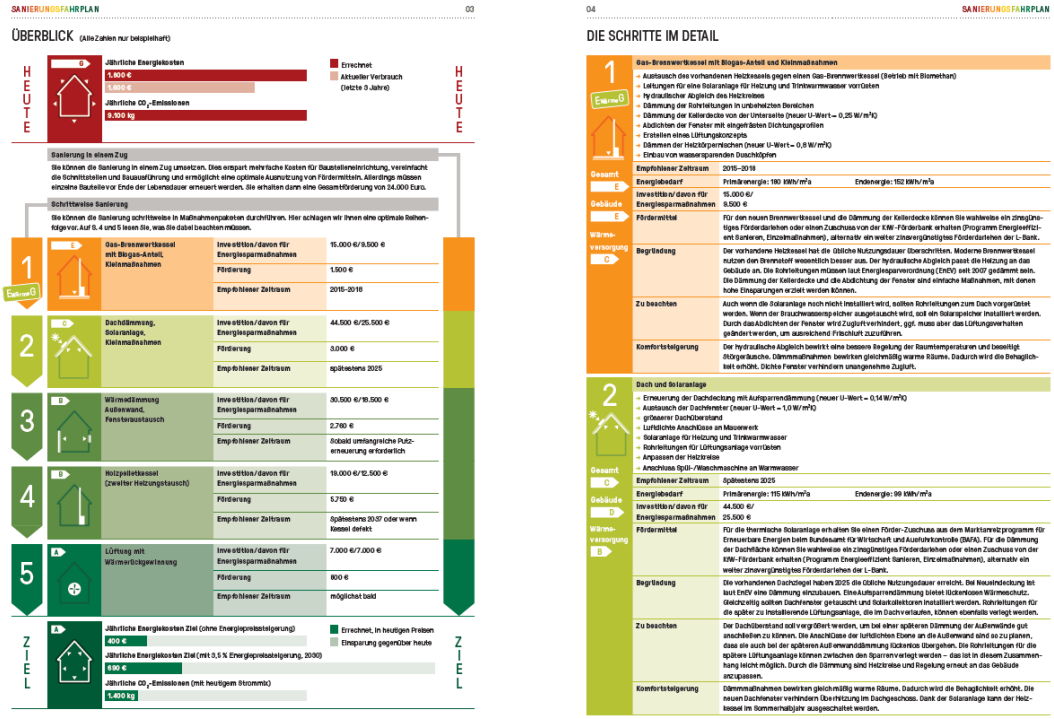

(a) (b)

Figure 11. Sanierungsfahrplan – Baden-Württemberg roadmap visualization: (a) summary view, and (b) detailed actions. Source: Baden-Württemberg Ministry of the Environment, Climate and Energy.

As presented in Figure 12(b), there are also detailed descriptions of each step with information about the benefits provided by the intervention, when and why the actions should be implemented and the detailed description of the renovation measures. The last one includes the type of intervention, how it must be implemented (practical indication), energy performance of the building before and after the action (class), performance of the envelope in terms of air tightness and thermal bridges (yes or no), energy consumption (kWh/m^{2}a) and CO_2 emissions (kg/m^{2}a) and costs.

(a) (b)

Figure 12. Individueller Sanierungsfahrplan: (a) roadmap, and (b) dedicated section for the detailed view of each step.

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8.2. The EPC RECAST Roadmap Tool

8.2.1. Needs and barriers collections among consortium partners

As introduced at the beginning of this document, there are different point of view to be taken into consideration when you refer to the development of an EPC with a user centric approach. Besides the literature review on the UCI definition, the Roadmap initiatives currently ongoing in Europe and the development of the EPC RECAST methodology for EP assessment, for the definition of the EPC RECAST Roadmap Tool, it has been crucial the brainstorming and the technical meeting exchange with the partners involved in the EPC RECAST Toolkit development.

In particular the expertise on Digital Logbook of EDF partner for the France territory and their review support on the Roadmap proposals, led to the current definition of the tool in term of structure, inputs and outputs necessary for the execution of the roadmap. The main highlights used as milestone to reach in the development of the Roadmap tool are summarized as follows and graphically represented in Figure 13 and Figure 14:

- develop a Roadmap in line with EU, national and regional targets and UCIs indicated in EPB and most recent directive and regulations in term of energy efficiency and savings;
- refer to the roadmap reccomandations since the initial stage of the renovation path;
- provide information about the main and usual doubts of owners/tenants:
  « Can I afford the refurbishement of my building? Which which technological solutions and in how many months – years? »;
- to enable an informed and optimal choice with the Renovation reccomandation
  « What is the most efficient way to reach a specific energy target? »;
- use a scientific but comprehensible language to develop a user friendly roadmap, as a useful tool for different target groups: from stakeholdersto owner, tenant, to the final user in the building.

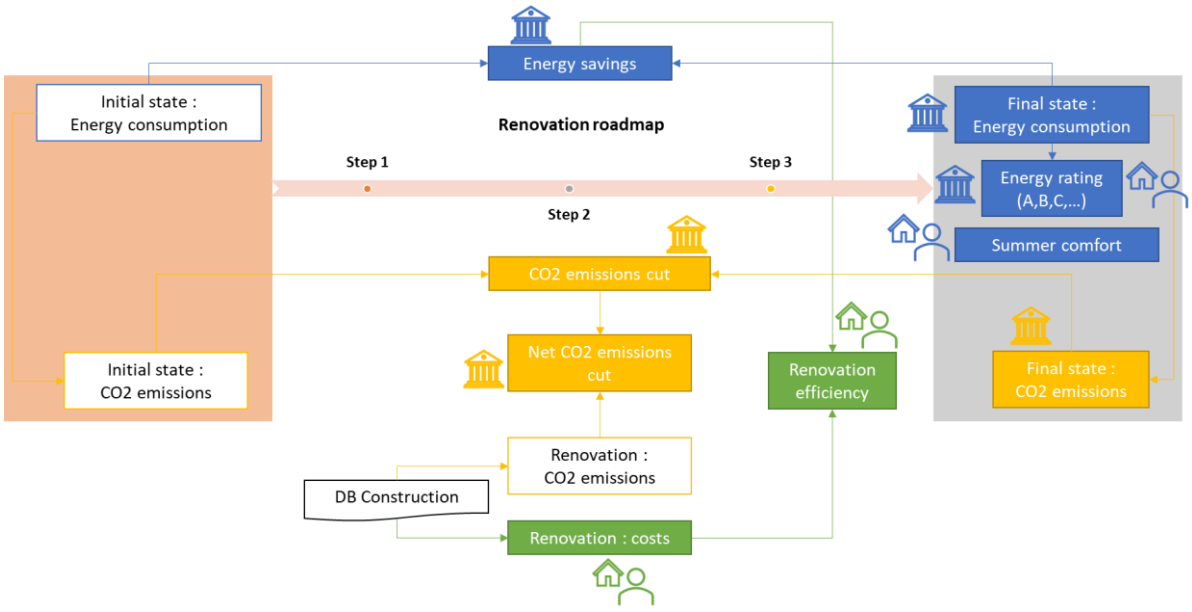

Figure 13. Selected topics- along the building renovation process -relevant for the evaluation of the optimal choices for the renovation interventions in comparison with the initial state of the building

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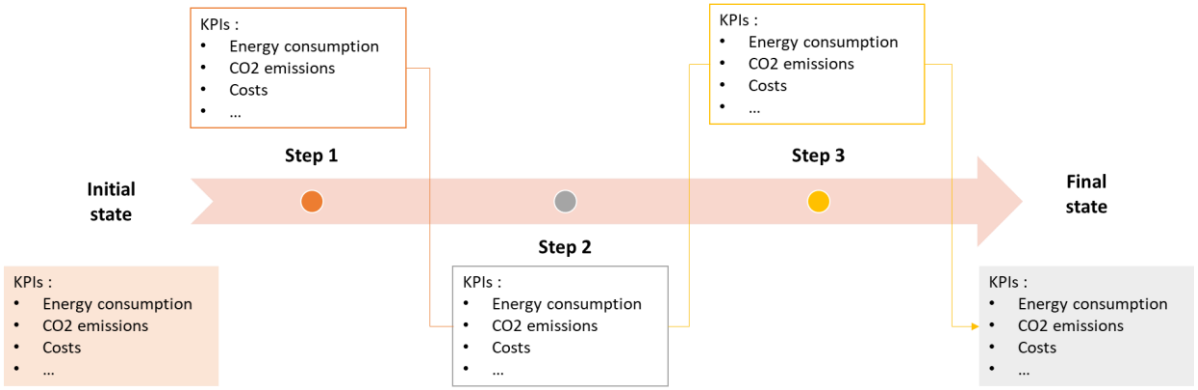

Figure 14. identification of the main renovation roadmap step to be considered for the EPC RECAST Roadmap Tool

Finally, the different inputs and indications from consortium partners has been summarized in the Table 8.

Table 8. Key Performance UCIs and associated warning points.

KP - UCIs	AIM	UNIT	DESCRIPTION	WARNING POINTS
Primary energy consumption / reduction	Reduce energy consumption on a global scale	kWh/m²y	Energy consumption in final state / Difference between the energy consumption in initial and final state	
CO2 emissions / (net) reduction	Reduce CO_2 emission on a global scale	CO2/m²y	CO_2 emissions in final state / Difference between the CO_2 emissions in initial and final state (minus the CO_2 emissions of the renovation operation)	
Costs	Do the renovation	€	Cost of the overall renovation operation	Equipment's oversizing
Energy rating	Improve the building stock Unlock financial aid Meet institutional rules	-	Energy Performance Certificate in final state	Selling and renting ban Financial aids
Summer comfort	Improve the quality of housing	h	Degree hours of discomfort	Exceeding acceptable threshold
Renovation efficiency	Make the most efficient choice in terms of financial effort and energy savings	€/kWh/m²y	Costs by energy consumption reduction	

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8.2.2. The EPC RECAST Roadmap Tool visualization development

In this section, the proposal for the EPC RECAST roadmap visualization is described and shown in the following figures.

Figure 15 is the front page of the EPC RECAST Renovation Roadmap Tool which summarized all the main KP-UCIs of the renovation process from the current state to each single renovation intervention proposed by the roadmap.

In the upper section of the visualization, the user can read the overall performance rating and the value of energy consumption, CO_2 emissions, investment cost and the thermal comfort score regarding the current state.

The lower section, instead, reports the chronological order (from left to right) of renovation interventions, represented by the year, and the overall performance rating that can be reached through the suggested measures, represented by the icons.

Finally, in the middle section the user can compare the value of energy consumption, CO_2 emissions, investment cost and thermal comfort score of each renovation step.

This visualization of the EPC RECAST Renovation Roadmap Tool can be read in two different ways:

- horizontally, comparing the values of each parameter in the different renovation steps, the achieved overall performance rating and the chronological order of the renovation actions;
- vertically, analysing the performances of each renovation step regarding energy consumption, CO_2 emissions, investment costs and comfort score and the overall performance rating.

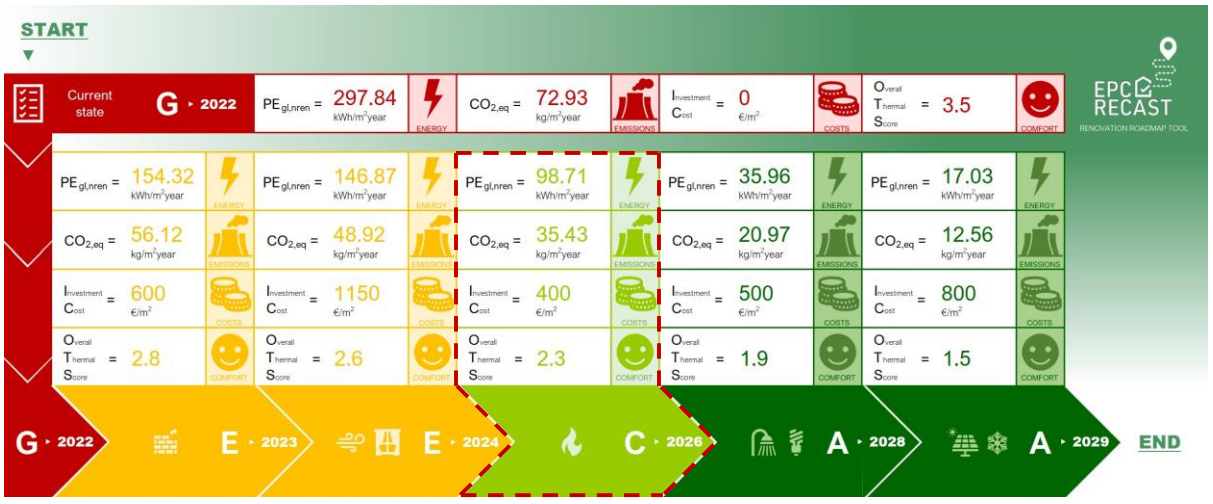

Figure 15. Proposal for the EPC RECAST roadmap visualization, front page highlighting for example the step number 3 that will be furtherly detailed below.

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Figure 16 reports an example of a renovation step with its detailed – in this case it corresponds to the Step 3 and the image provide an overview on it starting from the renovation action foreseen by the step, followed by the previous renovation steps foreseen that can all refer to the time line at the bottom of the picture and finally provide the actual level of energy efficiency rating score in the diagram of the predicted energy rating.

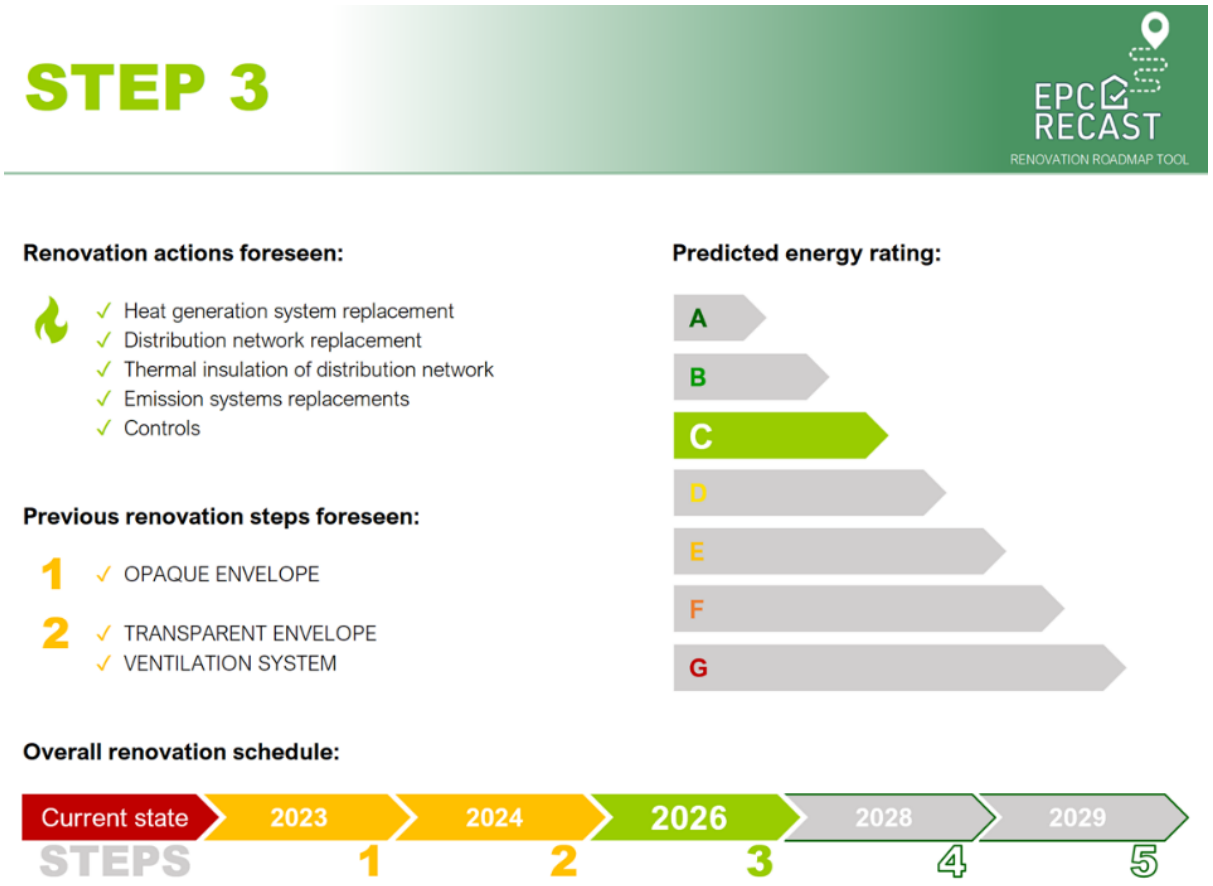

Figure 16. Proposal for the EPC RECAST roadmap visualization, example of detailed view of the step number 3.

From Figure 17 to Figure 20 an in-depth assessment examples are presented for each of the four main topics considered:

- Energy
- Emissions
- Costs
- Comfort

On the left side of each visualization, the summary of the results per topic of the specific step is represented, while on the right side a graphical representation of the results is reported, comparing the values obtained by each step of the renovation roadmap.

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Figure 17 describes the energy performance reporting the primary energy for heating, cooling and from renewable sources in kWh/m²year.

The graph on the right side of the visualization represents the energy savings achieved through the renovation actions of each step are also represented by means of percentage reduction of the primary energy from current state to each specific step.

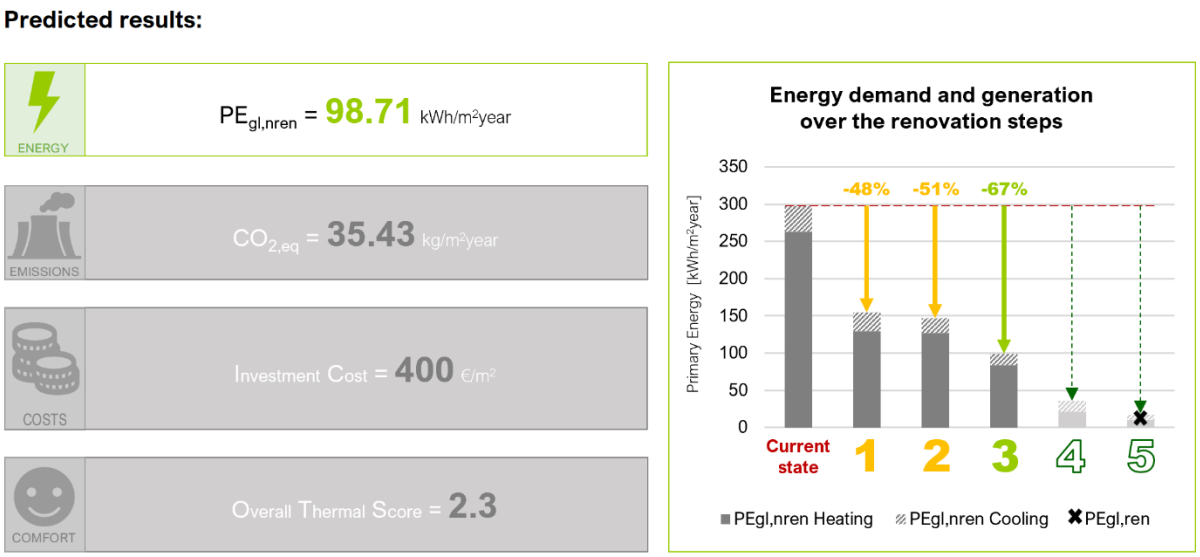

Figure 17. Proposal for the EPC RECAST roadmap visualization, energy in-depth assessment.

The graph of CO_2 emissions (Figure 18Figure 17) reports both the CO_2 equivalent emissions value of each step-in kg/m²year and the percentage reduction achieved through the renovation actions from current state to each specific step.

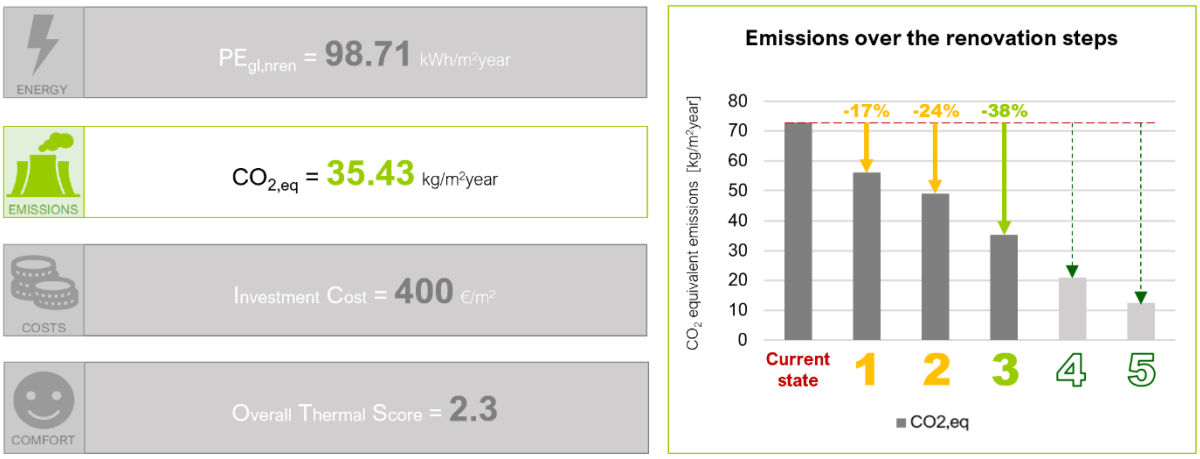

Figure 18. Proposal for the EPC RECAST roadmap visualization, emissions in-depth assessment.

The graph of costs (Figure 19Figure 17) reports both the investment cost and the annual operational cost of the building for each renovation step. In addition, the savings in operational cost are represented by means of percentage reduction achieved through the renovation actions from current state to each specific step.

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Predicted results:

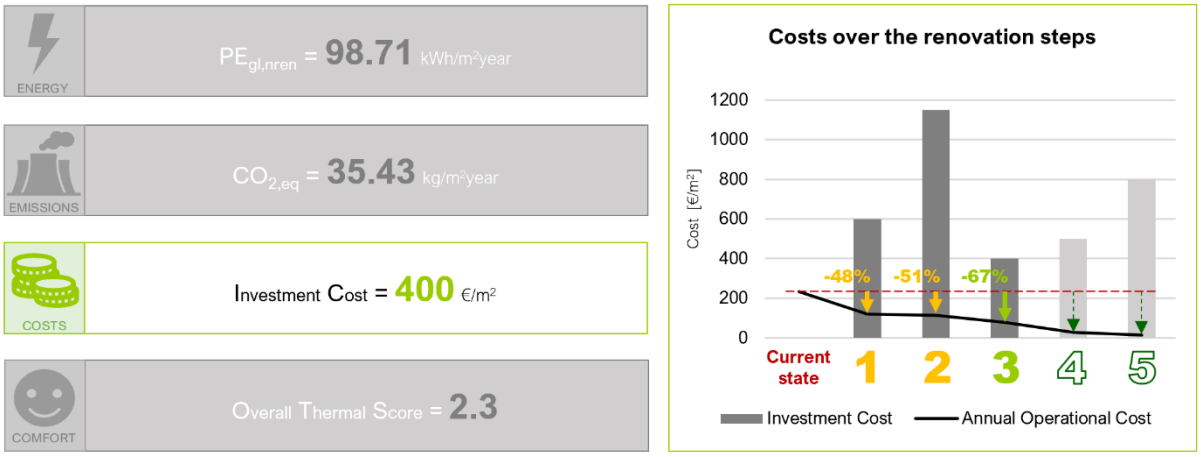

Figure 19. Proposal for the EPC RECAST roadmap visualization, costs in-depth assessment.

In accordance with U-CERT sister project, the comfort representation (Figure 20Figure 17) reports the ALDREN Thermal score. It is a parameter evaluated under the same standard conditions assumed in the calculation model for energy performance assessment and divided in three seasonal periods of the year based on the outdoor running mean temperature (i.e., heating, cooling, and intermediate season). The thermal comfort score for each season is based on the percentage of occupancy hours outside the intervals for the IEQ categories according to EN ISO 16798-1:2019. Then, the overall thermal comfort score is calculated as a weighted average using the occupancy hours for each season period as a weighting factor.

The graph of comfort reports both the occupied hours and the Thermal score of the specific renovation step for each seasonal period and the overall value of Thermal score.

Predicted results:

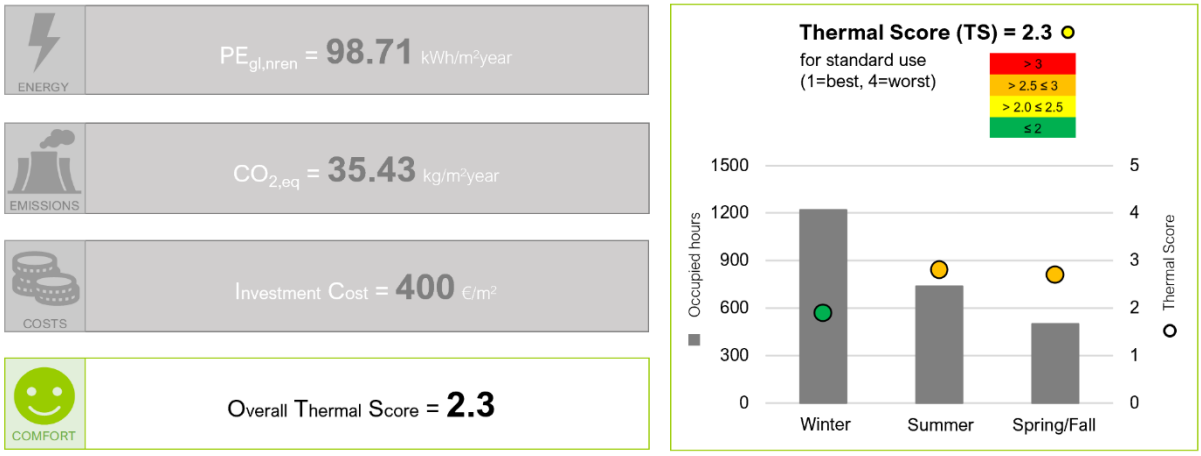

Figure 20. Proposal for the EPC RECAST roadmap visualization, comfort in-depth assessment.

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8.2.3. Navigating the RoadMap Interface

This section describes the step-by-step user experience of interacting with the "RoadMap" tool.

Figure 21. RoadMap User Interface Navigation Flow

Existing State (1/6):

The user journey within the "RoadMap" begins with an assessment of the building's existing state. This initial step involves a set of questions aimed at capturing the current status of the building, providing essential data that complements the Energy Performance Certificate information.

Renovation Plan:

Definition (2/6): Users enter their intended renovation measures in the 'Definition' part of the Renovation Plan. This section is designed for users to specify the work they plan to carry out to transition the building to its targeted post-renovation state.

Results (3/6): Following the input stage, the 'Results' section processes the user-defined parameters to simulate and display projections of energy consumption, carbon emissions, comfort levels, and cost analysis for the renovated state. It also includes alerts for potential technical issues and highlights additional improvement opportunities, providing a basis for users to refine their plans.

Steps Definition:

Organisation (4/6): In the 'Organisation' phase, users are guided to plan the sequencing and timing of the renovation works. This stage allows for the distribution of tasks across different phases of the project timeline.

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Results (5/6): Similar to the Renovation Plan, the 'Results' here offer a detailed breakdown of the implications of the scheduled works, including validation checks and warnings regarding the practicality and coherence of the renovation steps.

Synthesis (6/6):

The final phase is the 'Synthesis', which compiles all the information into a coherent presentation format. This screen generates visuals and summaries that articulate the full scope and impact of the renovation roadmap for presentation to the building owners (see 8.2.2).

8.2.4. RoadMap Results and Improvement Suggestions

Results Interface Composition:

The "RoadMap" tool's results interface provides a dual-tabbed comprehensive evaluation of the renovation plan. It is meticulously structured to offer actionable insights and foresight into the renovation's implications through 'Possible Improvements' and 'Results' tabs.

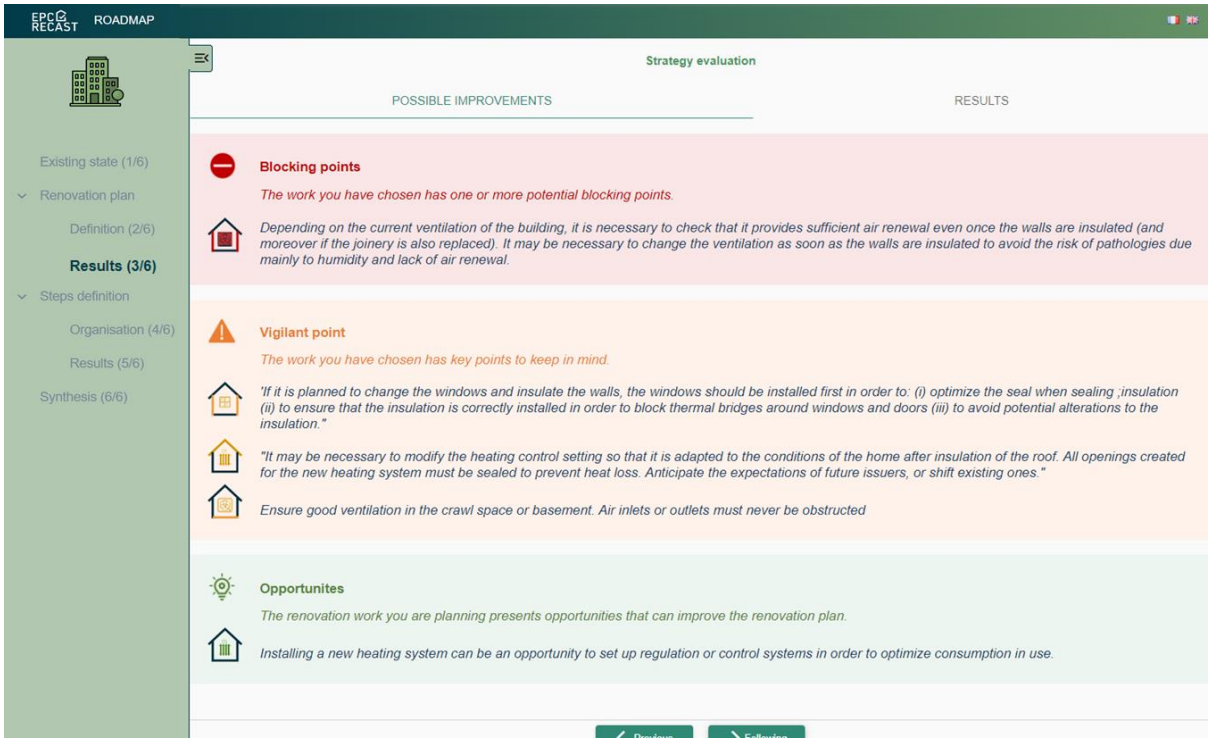

Figure 22. Tab of "Possible Improvements" at the "Renovation plan" stage

Tab of Possible Improvements:

Blocking Points: This segment surfaces crucial impediments that could halt the renovation progress, like technical issues or health hazards stemming from inadequate ventilation post-insulation.

Vigilant Points: Details here remind users of significant factors that may not be immediate blockers but are essential for the roadmap's success, such as the interplay between renovation tasks and subsequent system adjustments.

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Opportunities: This proactive section recommends additional enhancements to the current renovation plan that could lead to further benefits, leveraging the synergy between various improvement measures.

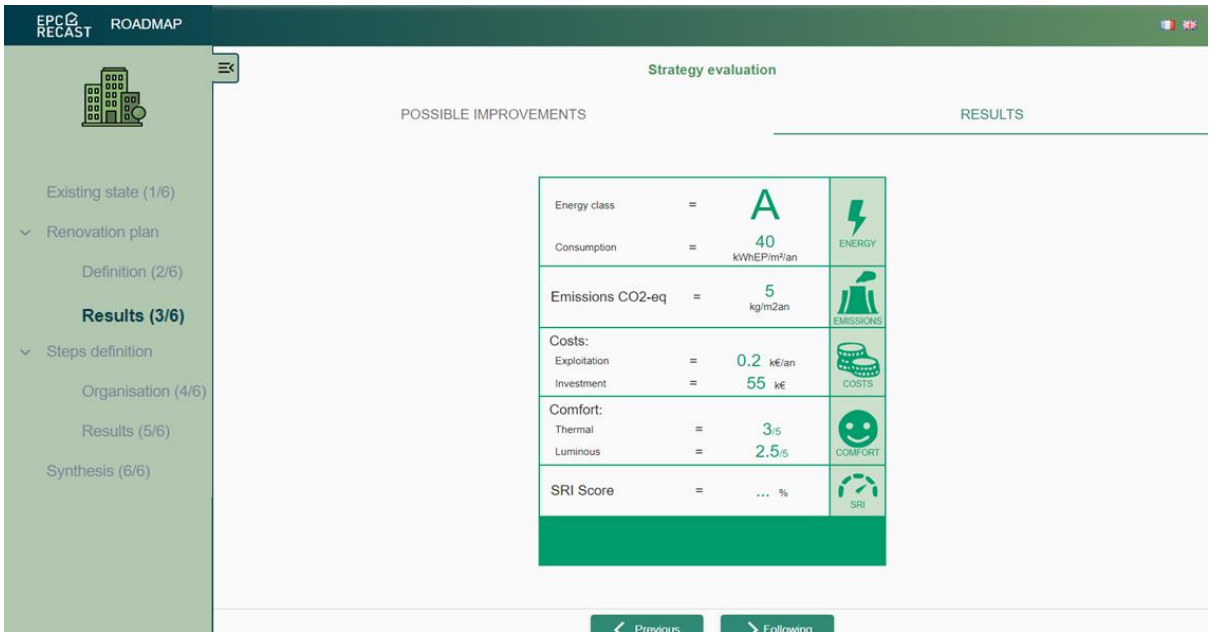

Figure 23. Tab of "Results" at the "Renovation plan" stage

Results Tab Explanation:

The 'Results' tab displays a compilation of five key performance indicators with their respective units:

Energy: Showcases the building's energy class and presents the primary energy use in kilowatt-hours per square meter per year (kWh/m²/year).

CO2 Emissions: Displays the carbon footprint as kilograms of CO2 equivalent per square meter per year (kg CO2-eq/m²/year).

Costs: Operational costs are shown as annual energy expenses (€/year), while investment costs reflect the financial outlay for renovations (thousands of euros, k€).

Comfort: Comfort is evaluated with scores from one to five for thermal and luminous comfort, indicating the quality of the indoor environment.

SRI (Smart Readiness Indicator): The SRI is shown as a percentage, denoting the building's capacity to integrate smart technologies.

Supported by the EPC RECAST calculation chain and enhanced by a comprehensive database of energy costs and comfort evaluations, provide users with a clear picture of the renovation's outcomes.

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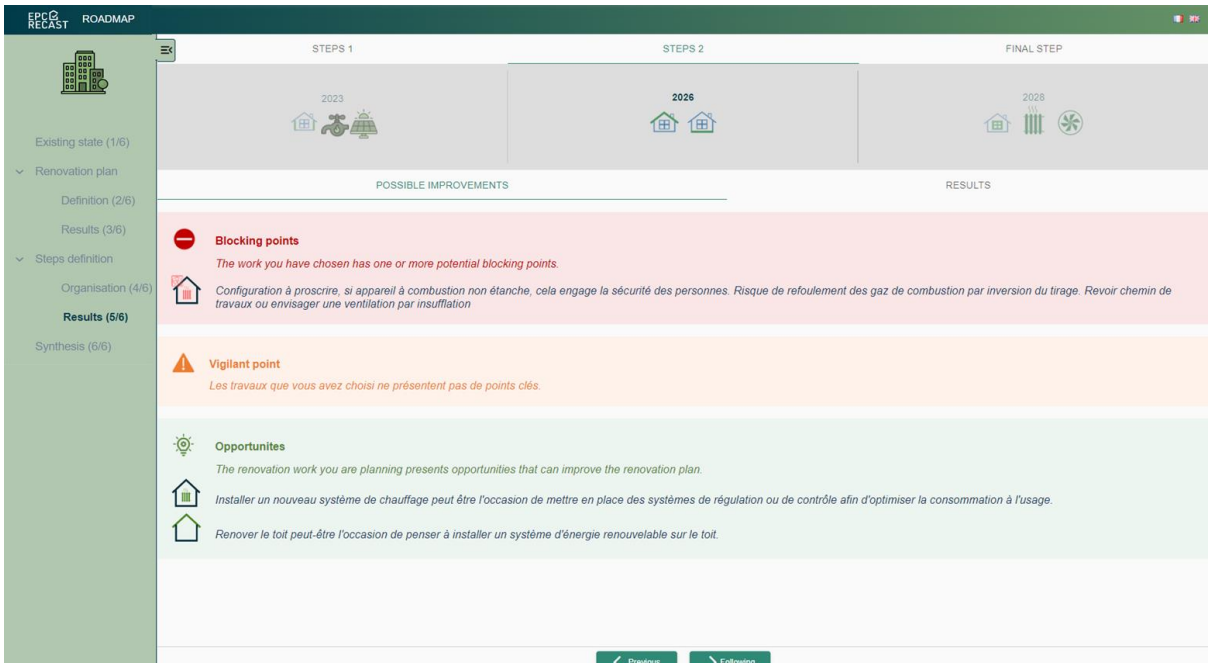

Figure 24. Tab of "Results" at the "Steps definition" stage

Results Tab at the "Steps definition" stage:
For the 'Step Definition', as shown in Figure 24, the results for each roadmap phase are accessible through an intuitive tab system at the screen's top. The work collections are visually represented, allowing users to see the distribution of tasks over time easily. Notably, the alerts for Step 2 identify critical issues, such as a blocking point related to gas backflow risks, with ventilation solutions scheduled for subsequent stages, illustrating the tool's capability to flag potential sequencing concerns.

8.2.5. User Feedback and Improvements for MVP

This section compiles user feedback and suggests improvements that were taken into account for the MVP (Minimum Viable Product) version of "RoadMap". It includes recommendations for enhancements based on actual user experiences and needs.

On the renovation roadmap global display:

- Add the consumption in primary energy, in addition to the energy class.

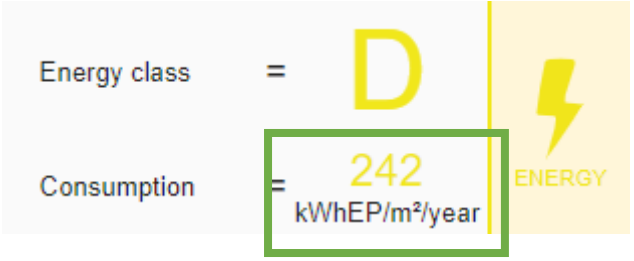

Figure 255. Zoom on the new display with the consumption in primary energy

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- Display the operation costs in k€ per year.

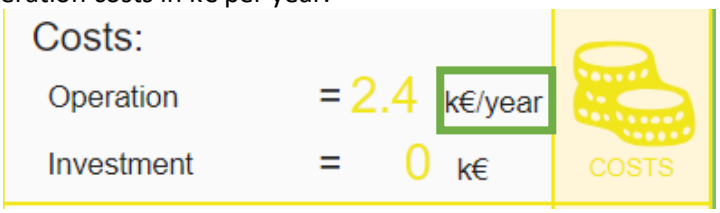

Figure 266. Zoom on the display with the updated unit for operational costs

- Align the existing state results with the other steps, to facilitate reading.

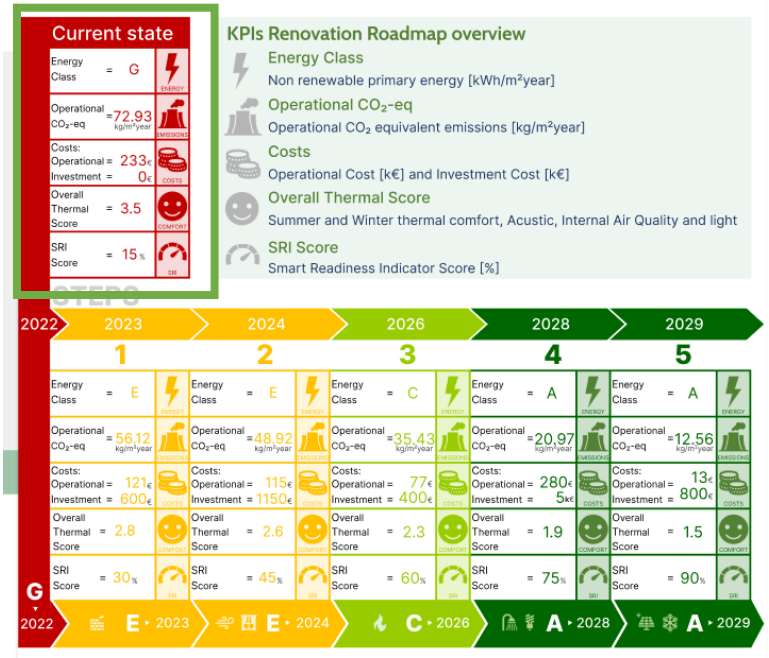

Figure 277. Overall original renovation roadmap display, with the initial state not aligned

Figure 288. New overall renovation roadmap display, with the initial state aligned

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On the comfort section:

- Add the word “potential” for the assessment of Acoustic and Air quality comfort (due to the lack of data to evaluate them accurately): “potential improvement”, “potential deterioration”

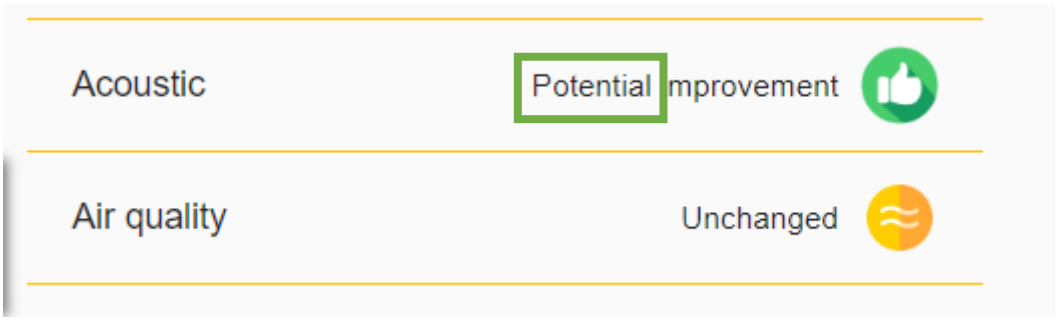

Figure 299. Zoom on the acoustic and air quality comfort display

On the renovation works definition:

- Needs to clarify the hypothesis behind the insulation levels: “average”, “efficient”, “very efficient”.
  1) Add a range of thermal resistance.
  2) Add an information popup window with an example to illustrate.

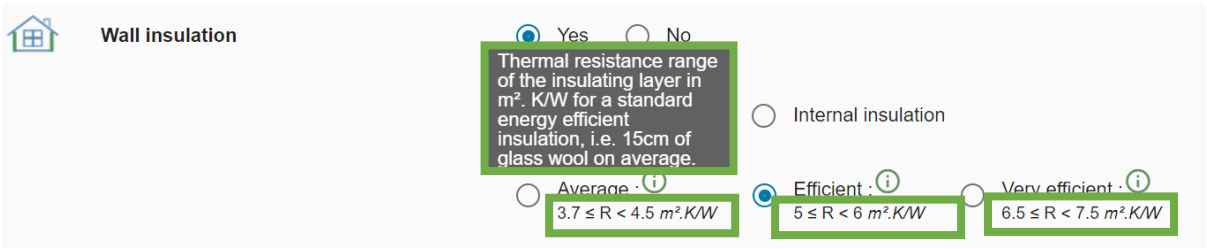

Figure 30. Updated wall insulation level display

This applies to wall, roof, and floor insulation screens.

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8.2.6. The EPC RECAST Roadmap Tool visualization: main evolutions

Section 8.2.6 outlines updates to the visualization of the EPC RECAST Roadmap tool, detailing enhancements since our initial design featured in section 8.2.2. It succinctly identifies the few but impactful changes made, underscoring their significance in the tool's practical application.

1) The Renovation Roadmap overview

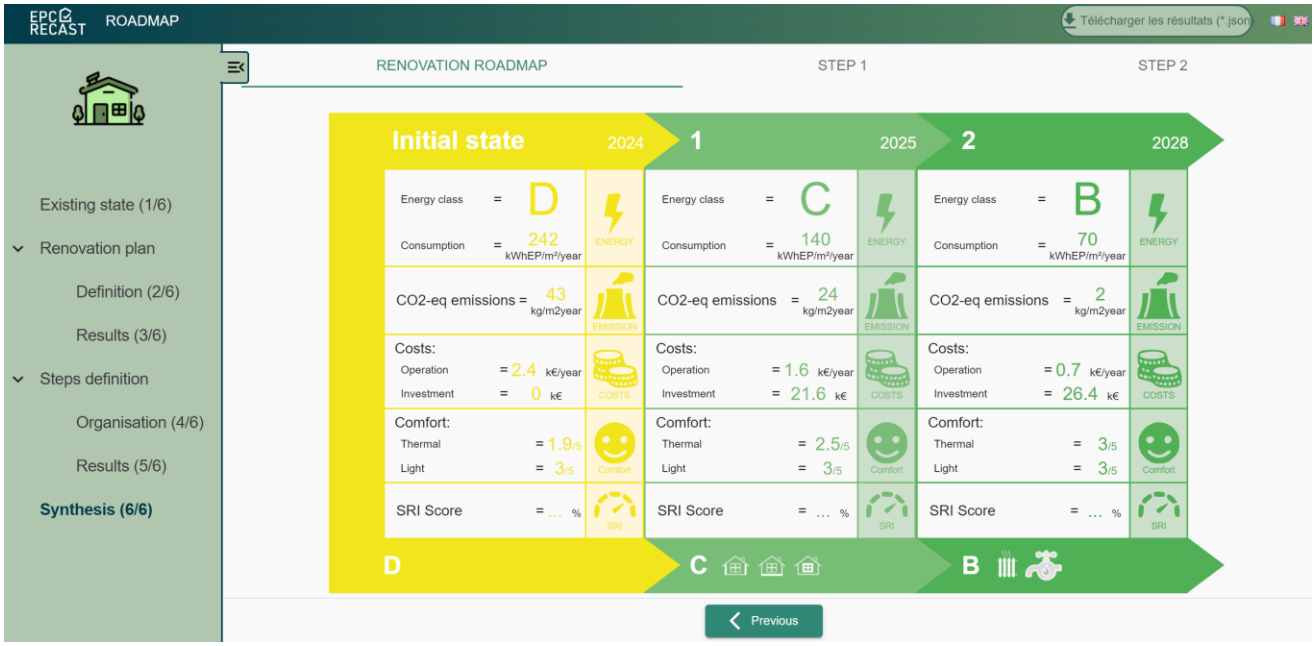

Figure 31. Full screen of the Renovation Roadmap "synthesis"

The initial state is aligned with the other steps, to facilitate the reading and to compare the KPIs between the steps.

The section with the definition of KPIs was removed so the roadmap overall display could take all the screen. The KPIs are now defined in the detailed screens for each step.

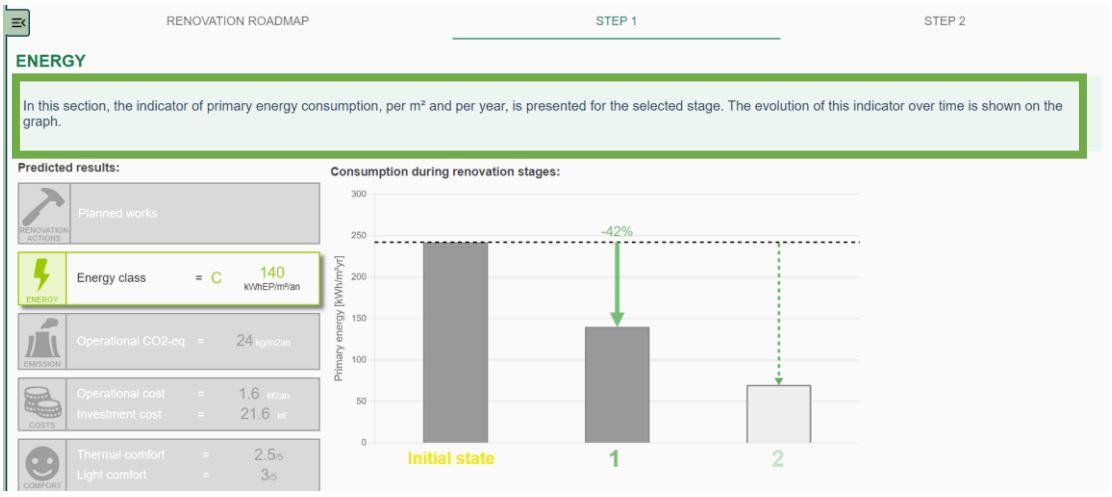

Figure 32. Description section for the KPI energy consumption

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2) A new “planned work” section

A new “planned work” section was added to the existing KPIs sections. This section serves to display the previous (in earlier steps) and the current renovation actions (for the selected step).

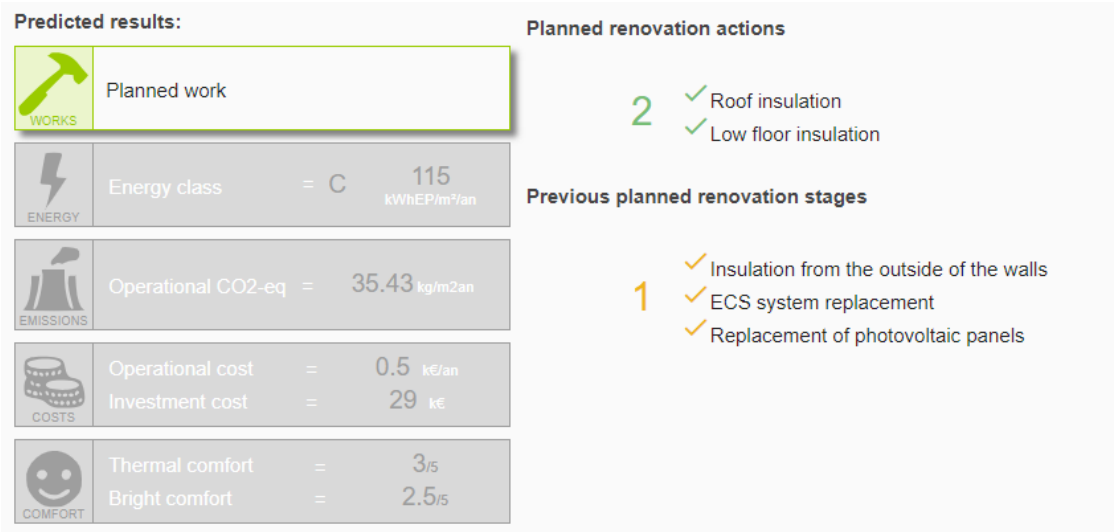

Figure 33. The “planned work” section screen

3) Comfort scores displayed with stars

In order to make the comfort score as intuitive as possible for owners, it was decided to use a scale over 5 to represent all comfort scores. This scale facilitates the score comparisons between steps.

In the comfort section, the scores are displayed using 5 stars : 0 being the worst, and 5 being the best.

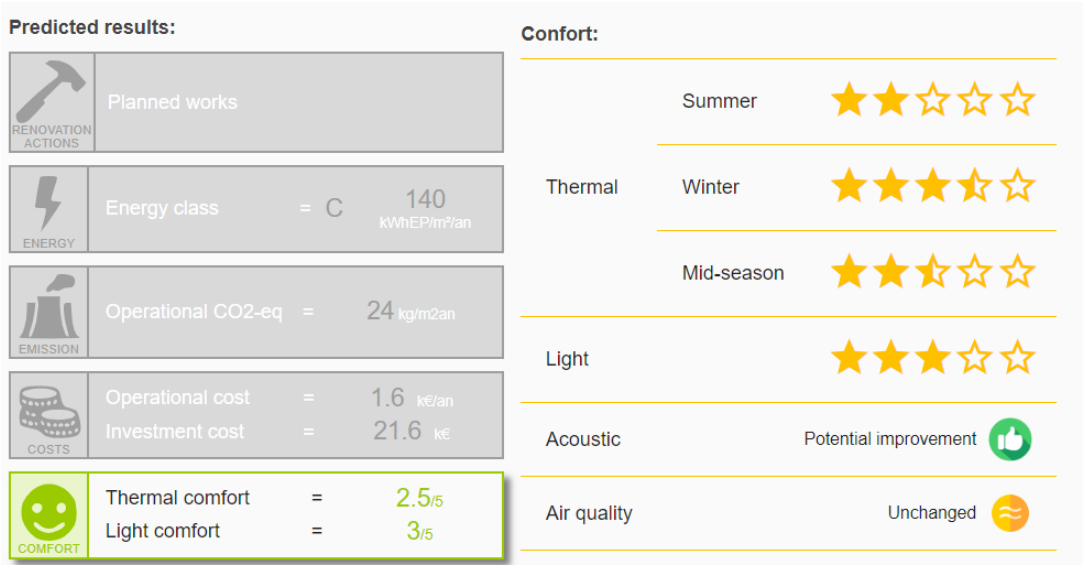

Figure 33. The comfort screen, with scores displayed using stars

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9. Conclusions

This deliverable reports the developed Key Performance - User Centric Indicators (KP-UCIs) identified for the EPC RECAST Renovation Roadmap tool in order to provide more user-friendly EPCs, by involving end-users in multiple steps throughout the design phase of the next-generation EPCs.

The proposed method incorporated social, environmental, economic, and resiliency dimensions and will be then implemented in the EPC RECAST Toolkit platform as a user-friendly design-aid tool.

The Renovation Roadmap visualization tool is an advanced proposal based on the inputs from the previous WP1 and WP2 as specified in detail in the document. According to the further implementation and development of the EPC RECAST toolkit, the Roadmap visualization has been improved and changed accordingly to ICT needs and barriers to visualization and database creation.

Moreover, the core KP-UCIs selected to be visualized in the roadmap were mostly maintained. Only the comfort indicators needed to be displayed differently (score over 5 - stars), to facilitate the reading for the owner and the comparisons between steps. The thermal comfort calculation method however is still based on the ALDREN Thermal score.

The major outcomes are the following:

- KP-UCIs definition and list in reference of core topics in line with the sister projects of the Next Generation EPC cluster;
- the concept for the online visualization of the Renovation Roadmap tool development;
- a universal, enhanced user-friendly EPC form template and background on the proposed content;
- a general proposal for advertisement guidelines and for actions to improve the user-friendly use of EPCs both for assessors and owners/tenants with KP-UCIs;
- The MVP (Minimum Viable Product) of the Renovation Roadmap tool, which includes updates from the assessors's feedback, has been released.

These enhancements were the basis for both a discussion with stakeholders and public entities of the SMG and PAB members of the projects during workshops and for their testing in pilots of the WP3. In fact, for all the selected pilots on which the roadmap was applied, the latest version of the Renovation Roadmap tool was used, which includes updates from the assessors's feedback.

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