Deliverable 4.1

Definition of active and passive measures for energy-efficiency refurbishment and climate adaptation

Responsible partner: POLITO (DENERG)

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Executive summary

1. Purpose and scope

Work Package 4 aims to accelerate the transition towards Positive Energy Districts through a holistic identification of active and passive refurbishment strategies that integrate urban form, energy consumption patterns, energy-efficiency measures, renewable energy sources, and climate-adaptation needs. The WP is structured into two complementary tasks: Task 4.1, which defines the full set of active and passive measures for energy-efficient refurbishment and climate adaptation; and Task 4.2, which identifies the most suitable refurbishment and adaptation solutions for buildings, public spaces, and district-level energy systems within the living labs.

Building on the morphological parameters developed in WP2, particularly the identification of active and passive strategies relevant for PED-oriented urban regeneration, Task 4.1 provides a comprehensive and operational definition of refurbishment measures that can drive PED transitions:

- Passive measures will focus on reducing energy demand through envelope retrofitting and other interventions that enhance the intrinsic performance of buildings.
- Active measures will address the upgrading of building- and district-scale energy and utility systems, explicitly considering the potential for local renewable energy generation and flexibility services explored in WP6.
- Passive climate-adaptation measures will respond to region-specific climate impacts identified in WP5, prioritising solutions that mitigate additional cooling and heating demand and strengthen the climate resilience of future PEDs.

Task 4.1 is coordinated by the Politecnico di Torino (POLITO), ensuring methodological alignment with the morphological analysis in WP2. The Universitat Politècnica de Catalunya (UPC) contributed with expertise on passive measures and passive climate-adaptation strategies in coherence with WP5. The Technical University of Cluj-Napoca (UTCN) and The Hague University of Applied Sciences (THUAS) investigated active measures in relation to building and district-level energy potential defined in WP6. The Romania Green Building Council supported the integration of international guidelines and standardisation frameworks.

The deliverable is structured to guide the reader through the context, methodology, and results of the work carried out to define retrofit measures relevant to the transition toward Positive Energy Districts. It opens with an introduction that situates the topic within the

broader project framework, clarifying the objectives, scope, and operational role of Deliverable 4.1. The conceptual and methodological framework in Section 2 outlines the approach adopted for the literature review, the criteria used to classify the measures, and their alignment with the morphological parameters of WP2 and with the analytical activities of WP5 and WP6. The central part of the deliverable presents the results in Section 3: the taxonomy of measures (section 3.1), the structure of the Catalogue (section 3.2), and the description of passive (section 3.3) and active (section 3.4) measures, highlighting their contribution both to energy-demand reduction and to climate resilience. In section 3.5, the document also refers to the main international standards and guidelines that informed the classification. The conclusions summarise the key outcomes, underline their relevance for the project, and describe how the Catalogue will be used in the following tasks. The deliverable closes with a section of Annexes containing the full Catalogue of Measures.

2. Conceptual framework and Methodology

Section 2 provides an overview of the conceptual foundations and methodological approach guiding the work. Given the extensive and heterogeneous nature of the existing literature, the consortium selected a scoping review methodology to ensure a structured and inclusive examination of relevant contributions. The review was conducted collectively by project partners under the coordination of Politecnico di Torino (POLITO). The Universitat Politècnica de Catalunya (UPC) contributed with expertise on passive measures and passive climate-adaptation strategies in coherence with WP5. The Technical University of Cluj-Napoca (UTCN) and The Hague University of Applied Sciences (THUAS) investigated active measures in relation to building and district-level energy potential defined in WP6. The Romania Green Building Council supported the integration of international guidelines and standardisation frameworks. Regarding the collection of Key Performance Indicators (KPIs), potential impacts across climate zones (Köppen–Geiger classification), the information collected from the various studies was aggregated in order to provide a harmonized set of KPIs used to assess the effectiveness of each measure. Where possible, particular attention was given to distinguishing impacts in heating-dominated climates (HDD) and cooling-dominated climates (CDD). The harmonised set of KPIs utilised for the evaluation of impacts vary between active and passive measures, as illustrated in Table **Error! Reference source not found.**1.

Table 1. Set of harmonised KPIs for passive and active measures.

KPI	Description	Unit of measure	Passive/Active
CAPEX	Investment cost	[€/m^2]	Passive/Active

OPEX	Operational cost	[€/m²y]	Passive/Active
$\Delta Q_{C,nd}$	Variation in energy needs for cooling	[kWh/m²y]	Passive (for HDC and CDC)
$\Delta Q_{H,nd}$	Variation in energy needs for heating	[kWh/m²y]	Passive (for HDC and CDC)
$\Delta Q_{p,use}$	Variation in total primary energy uses	[kWh/m²y]	Active (for HDC and CDC)
$\Delta Q_{C,use}$	Variation in primary energy use for cooling service	[kWh/m²y]	Active (for HDC and CDC)
$\Delta Q_{H,use}$	Variation in primary energy use for heating service	[kWh/m²y]	Active (for HDC and CDC)
ΔCO_{2eq}	Variation in CO_2 equivalent emissions	[$kgCO_{2eq}$ /m²y]	Active (for HDC and CDC)

3. Results and Discussion

Section 3 outlines the framework used to map mitigation and adaptation measures. In detail, section 3.1 provides the corresponding taxonomy of measures, offering a structured classification to support consistent analysis and comparison. This taxonomy offers a clear framework for understanding how different design strategies, technologies, and operational actions contribute to energy efficiency and climate objectives. By classifying measures according to their nature and intended impact, taxonomy helps distinguish between passive and active measures, clarifying their role in climate change mitigation and adaptation. To support this classification, the deliverable includes a table that visually summarizes taxonomy, organizing the measures along two dimensions: the type of intervention (passive or active) and the primary contribution of the measure (mitigation or adaptation). Table 2 groups passive measures under categories such as Neighbourhood and Building Site, Building Shape, and Layout and Interior Design, highlighting strategies that reduce energy demand or enhance resilience through design and morphological choices without relying on mechanical systems. Active measures, instead, include technological and system-based solutions such as Envelope, HVAC, DHW, Lighting, Appliances, BACS, Electric Vehicles, and Renewables, which improve energy performance by increasing efficiency and reducing final energy uses. Beyond distinguishing between passive and active approaches, the taxonomy also identifies the mitigation and adaptation potential of each measure. In detail, climate change mitigation refers to actions that reduce GHG emissions or enhance carbon sinks. While climate change adaptation refers to actions that reduce vulnerability to current or expected climate impacts, strengthening the resilience of buildings and districts. By combining these two dimensions, taxonomy provides a coherent structure for interpreting the role of each measure within the broader PED transition framework. Table 2 presents the taxonomy of measures, summarising the classification of passive and active measures and their contribution to climate change mitigation and adaptation.

Table 2. Taxonomy of Measures.

Measure type	Main Classification	
	Climate Change Mitigation	Climate Change Adaptation
Passive Measures	Neighbourhood and Building Site	
	Building Orientation and Shape	
	Layout and Interior design	
	Envelope	
Active Measures	HVAC	
	DHW	
	Lighting	
	Appliances	
	BACS	
	PtV - Electric Vehicles	
	Renewable Energy Sources (RES)	

Then, section 3.2 presents the structure of the Catalogue of Measures, designed as a decision-support framework for the systematic classification and assessment of passive and active measures contributing to climate change mitigation and adaptation (Table 3). Measures are first distinguished by measure type (passive or active) highlighting the difference between measures that reduce demand through passive design and those that rely on active technical systems. They are further categorized by scale, enabling a clear distinction between interventions at the neighborhood or building levels. Each measure is assigned a unique code, ensuring traceability and consistency across the catalogue and its application within the project. Measures are then described through a sub-classification (technology) field, which specifies the concrete technological solution or design intervention, alongside a description of the energy efficiency strategy, clarifying its performance contribution. This allows grouping measures by technological families, which is useful for identifying synergies, overlaps, and redundancies or benchmarking performance. The energy efficiency strategy field explains the underlying thermodynamic principle through which the measure improves performance.

The catalogue also integrates KPIs to support the quantitative and qualitative assessment of measures and decision making. Economic dimensions are addressed through the inclusion of CAPEX (capital expenditure) and OPEX (operational expenditure), allowing for a comparative assessment of upfront and operational costs.

To address climatic variability, each measure is evaluated in terms of its effectiveness across different climate contexts, specifically Heating-Dominated (HD) and Cooling-Dominated (CD) climates, as well as its climate change adaptation potential, capturing its capacity to enhance building resilience under future climate scenarios.

Overall, this structured approach enables a consistent comparison of measures while supporting informed decision-making processes. It also ensures alignment with the

broader PED framework of the project, providing a shared reference for integration with the analytical and implementation activities developed within WP2, WP5, and WP6.

Table 3. Catalogue structure.

Measure Type	Scale	Code	Sub-classification (technology)	Description of energy efficiency strategy	CAPEX	OPEX	Effectiveness in HD climates	Effectiveness in CD climates	Climate change adaptation potential
Passive Measures	…	…	…	…	…	…	…	…	…
Active Measures	…	…	…	…	…	…	…	…	…

Table 4 presents a comprehensive the taxonomy of energy efficiency measures divided into passive and active measures, organized by their scale of application and technological function. Together, these categories establish the holistic framework for enhancing building performance.

Passive measures (Categories 1P–4P) prioritize solutions to reduce energy demand, ranging from urban-scale green and blue infrastructure to building-level strategies such as optimized solar orientation, thermal zoning, and high-performance envelope components like Phase Change Materials (PCM) and green roofs.

Conversely, active measures (Categories 5A–11A) focus on the efficiency of mechanical systems, including advanced HVAC technologies (e.g., heat pumps and heat recovery), smart Building Automation and Control Systems (BACS), and the integration of renewable energy sources and electric vehicle infrastructure.

Table 4. Summary List of Measures.

Measure Type	Main classification	Sub-classification (technology)	CODE
	1P - Neighbourhood and Building Site		
Passive	Neighbourhood and Building Site	Urban shading	P_NS_URB-SHD
Passive	Neighbourhood and Building Site	Green infrastructure (urban vegetation, parks)	P_NS_GREEN
Passive	Neighbourhood and Building Site	Water bodies / blue infrastructure	P_NS_BLUE
	2P - Building Orientation and Shape		
Passive	Building Orientation and Shape	Optimized solar orientation	P_BOS_ORI
Passive	Building Orientation and Shape	Compact building form	P_BOS_FORM

Passive	Building Orientation and Shape	Winter garden	P_BOS_WG
	3P - Layout and Interior Design		
Passive	Layout and Interior Design	Natural ventilation technologies (stack ventilation, windcatcher, solar chimney, etc.)	P_LID_NAT-VENT
Passive	Layout and Interior Design	Daylighting optimization	P_LID_DLT
Passive	Layout and Interior Design	Thermal zoning	P_LID_ZONE
	4P - Envelope		
Passive	Envelope	Wall insulation	P_ENV_WALL-INS
Passive	Envelope	Thermal mass integration	P_ENV_TH-MASS
Passive	Envelope	Solar walls (trombe walls, etc.)	P_ENV_SOL-WALL
Passive	Envelope	Double-skin façades	P_ENV_DSF
Passive	Envelope	Roof insulation	P_ENV_ROOF-INS
Passive	Envelope	Ventilated roof	P_ENV_V-ROOF
Passive	Envelope	Opaque Ventilated facade	P_ENV_V-FAC
Passive	Envelope	Airtightness (increase/reduction)	P_ENV_AIR-TIGHT
Passive	Envelope	High-performance glazing (transmittance, electrochromic (EC), low-e, etc.)	P_ENV_GLAZ
Passive	Envelope	Window to Wall Ratio	P_ENV_WWR
Passive	Envelope	Shading systems (overhangs, shutters, blinds, etc.)	P_ENV_SHAD
Passive	Envelope	Green roof	P_ENV_GR-ROOF
Passive	Envelope	Green façade / Living wall	P_ENV_GR-FAC
Passive	Envelope	Cool roof / Reflective materials	P_ENV_COOL
Passive	Envelope	Phase Change Materials (PCM) (envelope, ceiling panels, etc.)	P_ENV_PCM
	5A - HVAC		
Active	HVAC	Heat pump systems	A_HVAC_HP
Active	HVAC	Phase Change Materials (PCM) (PV panels, solar thermal panels, ducts, etc.)	A_HVAC_PCM
Active	HVAC	Biofuel and biogas (micro-CHP)	A_HVAC_BIOF
Active	HVAC	Hybrid ventilation system	A_HVAC_HYB-VENT
Active	HVAC	Deep lake water cooling	A_HVAC_DLWC
Active	HVAC	Absorption refrigeration systems	A_HVAC_ABS
Active	HVAC	New refrigerants	A_HVAC_REFR
Active	HVAC	Desiccant cooling	A_HVAC_DES-C
Active	HVAC	Earth-to-air heat exchangers	A_HVAC_EAHX
Active	HVAC	Heat recovery systems	A_HVAC_HRS
Active	HVAC	Hydronic heating and cooling system	A_HVAC_HYDRO
Active	HVAC	Radiative sky cooling	A_HVAC_RSC
	6A - DHW		
Active	DHW	Greywater / Rainwater reuse	A_DHW_W-REUSE

	7A - Lighting		
Active	Lighting	Efficient lighting systems (LED, etc,)	A_LGT_EFF
	8A - Appliances		
Active	Appliances	High-efficiency appliances	A_APP_EFF
	9A - BACS		
Active	BACS	Smart energy management systems	A_BACS_SEM
Active	BACS	Demand Limiting Controller (DLC)	A_BACS_DLC
Active	BACS	Peak Load Warning Technology	A_BACS_PLW
Active	BACS	Smart lighting sensors and controls (sensors, dimming)	A_BACS_S-LIGHT
	10A - PtV		
Active	PtV - Electric Vehicles	Building-integrated EV charging	A_PTV_EV
	11A - Renewable Energy Sources (RES)		
Active	Renewable Energy Sources (RES)	Photovoltaic systems (PV, BIPV)	A_RES_PV
Active	Renewable Energy Sources (RES)	Solar thermal systems	A_RES_ST

Sections 3.3 and 3.4 detail passive and active measures, respectively. Both types of measures contribute to reducing building energy demand and enhancing climate resilience, thereby supporting climate change mitigation and adaptation.

Finally, in section 3.5, the deliverable reviews relevant international standards and protocols. These references support alignment with European and international sustainability objectives and provide additional guidance for the evaluation of retrofit and adaptation strategies. In detail, this part of the analysis accounts for the minimal requirements posed by national standards to be followed in the renovation interventions (e.g., maximum U-values, systems efficiencies, limits for energy needs and uses), together with the exception allowed for specific condition of the building stock (e.g., in case of listed buildings, or partial interventions proposed).

4. Conclusions

PEDs aim to enhance energy efficiency and flexibility of urban areas, enabling them to achieve a positive annual energy balance and net-zero greenhouse gas emissions. However, transitioning to PEDs presents a variety of complex, interrelated challenges. In addition to integrating societal and technological perspectives — requiring alignment among citizen engagement, governance innovation, scientific expertise and viable

business models — implementing PEDs demands deep renovation interventions and greater reliance on locally generated renewable energy to significantly reduce heating and cooling demand, overall energy consumption and dependence on fossil fuels.

Furthermore, it is crucial to comprehend and predict the effects of climate change on infrastructure and community well-being, and to devise effective strategies to mitigate these impacts by adapting the built environment to climate change.

Another key challenge is the rapid transfer of knowledge and scaling up of solutions. European reports emphasise the importance of accelerating evidence-based dissemination to enable cities to replicate successful PED models and spread innovations across regions. Collaborative platforms and cross-project learning are therefore vital for overcoming fragmentation and accelerating the transition process.

To address these challenges, the EDUPED project aims to deliver scalable solutions by co-creating PED strategies based on the ongoing refurbishment of public buildings, district energy regeneration and the revitalisation of historic areas.

Among its other goals, the EDUPED project seeks to accelerate the transition towards Positive Energy Districts by holistically identifying active and passive refurbishment strategies. These strategies integrate urban form, energy efficiency measures, renewable energy generation and climate adaptation requirements. This effort aligns with the project broader objective of promoting deep renovation of the urban fabric by fully leveraging the mitigation and adaptation potential of urban transformation processes.

This document presents a comprehensive and operational definition of refurbishment measures that can support the transition towards PEDs. Starting with a clear conceptual distinction between passive and active measures, a literature review was conducted to identify retrofit solutions at building and district scales. The aim was to assess their potential contributions to climate change mitigation and adaptation.

Building on the morphological measures identified in Work Package 2, a catalogue comprising passive and active measures has been developed. The potential impact of these measures has been evaluated in heating- and cooling-dominated climates to provide an overview of their effectiveness in supporting mitigation strategies and documenting their potential for adaptation. Additionally, a set of detailed fact sheets has been produced to describe each measure, incorporating key insights and evidence from the literature.

The taxonomy of measures provides a clear, structured framework for understanding the contribution of different design strategies, technologies and operational actions to energy efficiency and broader climate objectives. The proposed classification organises measures into subcategories, mapping interventions in a way that makes the catalogue

easier to use for both experts and non-experts. Furthermore, by identifying the mitigation and adaptation potential of each measure, taxonomy provides a consistent foundation for interpreting their role within the broader PED transition framework.

Passive and active measures can be combined to reduce energy consumption. The effectiveness of such combinations depends on the specific building and urban context and should therefore be assessed through case-specific evaluations and simulations. Figure 1 provides an illustrative example of the different Energy Efficiency Measures (EEMs) - related to the building envelope, building systems and renewable energy sources – and how they can be combined into effectiveness packages.

Within the passive main category, measures are grouped into "Neighbourhood and Building Site"," Building Orientation and Shape", "Layout and Interior Design", and "Building Envelope". The active category includes "HVAC", "DHW", "Lighting", "Appliances", "RES".

Despite this structured approach, several gaps remain. There is a general lack of comprehensive classification regarding the effectiveness of measures, as well as limited data on capital and operational expenditure (CAPEX and OPEX). Additionally, mitigation-related data is often fragmented across different climate contexts, making it challenging to obtain a consistent overview. However, some degree of comparability can be derived for similar climates. The assessment of climate adaptation potential is also rarely quantified and lacks a harmonised definition.

In the next phases of the research, the passive and active energy efficiency and climate adaptation measures identified will be integrated into Task 4.2. This task will focus on architectural, urban, building envelope and system-level refurbishment strategies to support PED transitions, aligning with the specific characteristics of the five living labs. A range of selected measures will be simulated to estimate their mitigation and adaptation potential, thereby strengthening and complementing the catalogue information, particularly for measures for which evidence of effectiveness is currently limited.

Finally, the results will be disseminated and valorised within the DUT ecosystem, contributing to knowledge sharing and supporting the broader adoption of PED-related solutions.

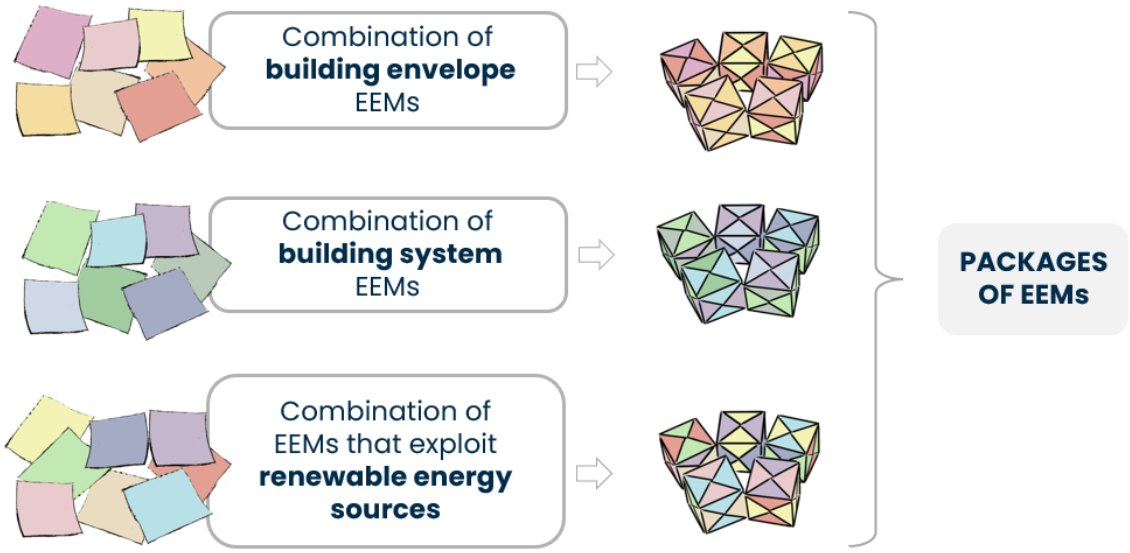

Figure 1 – Energy Efficiency Measures (EEMs) and packages.