Fostering the energy transition in a neighbourhood perspective: towards Positive Energy Districts' application for a university case study

Lorenza Di Pilla*
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: lorenza.dipilla@unipa.it

Maurizio Cellura
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: maurizio.cellura@unipa.it

Domenico Curto
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: domenico.curto@unipa.it

Vincenzo Franzitta
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: vincenzo.franzitta@unipa.it

Francesco Guarino
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: francesco.guarino@unipa.it

Sonia Longo
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: sonia.longo@unipa.it

Domenico Panno
Department of Engineering
University of Palermo, Palermo, Italy
e–mail: domenico.panno@unipa.it

ABSTRACT

The European SET Plan Action 3.2 promotes and supports the planning, the deployment and replication of 100 Positive Energy Neighbourhoods by 2025, in connection with the work carried out by JPI Urban Europe Joint Programming Initiative; notwithstanding, after a careful analysis of Italian current energy policies and economic framework, it seems such an ambitious and virtuous target has not been encompassed yet by policy makers and public official regulations. Consequently, there is an urgent need for defining and adopting an integrated, innovative, incremental, and proper approach, able to experiment and normalise consistent and coherent plans and actions aimed at sustainability.

The aim of the paper is to investigate, in this framework, how an Italian non-residential case-study could reach the target of PED, through a combined energy efficiency and renewable energy systems re-design assessment; its ultimate goal is therefore contributing to fill the already above highlighted gaps, while providing insights for the technical feasibility evaluation of meeting PED targets within an urban, non-residential university district context. This will allow for the identification of a benchmarking for PED performance assessment and potential for PED renovation in the Mediterranean area, also contributing to the overall target of supporting PED definition evaluation and development, as well as fostering PED performance schemes implementation.
This work investigates an Italian university campus located in the city of Palermo (in the south of Italy): its most representative Department Buildings were selected and assessed in a Positive Energy District (PED) perspective; more in detail, the university buildings of interest (hereinafter referred to as “UniPa Campus” buildings) were modelled and simulated in non-steady state conditions in the Energy Plus environment, according to specific boundary conditions, representative energy profiles, typical occupancy rate and overall performances. A calibration procedure was performed to align the energy performances of the modelled district area to the existing neighbourhood selected and then, with reference to the calibrated models, renovation solutions and renewable energy systems were assessed in order to check the feasibility of achieving the level of PED.
The results obtained through this study show that a significant reduction in primary energy demand can be achieved (by implementing a set of effective retrofit measures for opaque and transparent envelopes, lighting systems, electric equipment, and appliances); notwithstanding, the resulting annual energy demand (even though reduced of around 40% for the retrofitted district’s configuration) cannot be entirely covered by rooftop PV panels installation, therefore paving the way toward further solutions (such as implementing larger PV areas, defining more effective actions, and applying additional energy efficient retrofit measures), able to finally meet PED targets.

KEYWORDS

Positive Energy Districts, Neighbourhood, Energy modelling, Energy Plus.

INTRODUCTION

A growing interest on the European Strategic Energy Technology Plan (SET Plan) Action 3.2, through the programme “Positive Energy Districts and Neighbourhoods for Sustainable Urban Development”, triggered and fostered an articulated, international debate on the deployment and replication of 100 Positive Energy Neighbourhoods by 2025; this task, in connection with the work carried out by Urban Europe Joint Programming Initiative (JPI), stimulated a multifaceted discussion, ideas’ exchange and sharing of information among international think tanks, academic researchers, authorities and institutional bodies. Indeed, there is an urgent need for providing a set of tools and guidelines aimed at the planning and deployment of Positive Energy Districts (PEDs) across Europe. This calls for researchers, academics, scientists, and decision-makers, establishing and strengthening a proactive connection to formulate coherent, consistent, and reasonable policy proposals. Starting from the analysis of a particular context of the Mediterranean area and resting on distinctive boundary conditions for a specific non-residential pilot buildings’ complex, the research addresses a tailored definition and analysis of Positive Energy Districts, also adaptable to wider areas.

Definitions.

The PED definition provided by JPI Urban Europe states that PEDs are “[…] energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility, and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability" [1]. Also considering the recently released (on 18/10/2023) Renewable Energy Directive III [2], and according to one of its most important articles (Art. 15a "Mainstreaming renewable energy in buildings"), "[…] Member States shall determine an indicative national share of renewable energy produced on-site or nearby as well as renewable energy taken from the grid in final energy consumption in their building sector in 2030 that is consistent with an indicative target of at least a 49 % share of energy from renewable sources in the building sector in the Union's final energy consumption in buildings in 2030".

It is therefore of crucial importance to redefine and reshape the current national energy policies for pursuing the following PEDs' distinguishing features:

- Energy production function: enabling appointed urban areas to rely on renewable energy only. This represents one of the main contributions towards the achievement of climate neutrality.
- Energy use prioritisation, by striving for energy efficiency: in order to maximise the potentialities of available energy sources. This also passes through existing buildings' thoughtful retrofits and their energy grid's embedding.
- Energy adaptability: by implementing (thanks to a careful context's analysis) reasonable strategies that consider background features and overall boundary conditions (e.g. territory's morphology and topography, population density, type and buildings' purposes, available local renewable energy resources and existing infrastructures).

What observed above, is also in line with one of the most relevant aspects prioritised by the SET-Plan ACTION n°3.2 Implementation Plan [3]. Among the most relevant key-actions to be implemented for boosting "Europe to become a global role model in integrated, innovative solutions for the planning, deployment, and replication of Positive Energy Districts", it points out the importance of:

- Embedding PEDs in "an urban and regional energy system, preferably driven by renewable energy, in order to provide [...] flexibility of supply".
- Promoting high levels of energy efficiency, with the goal of keeping "[...]annual local energy consumption lower than the amount of locally produced renewable energy".
- Properly dealing with the existing regional energy system, in order to foster the "[…] use of renewable energy by offering optimised flexibility and […] district-level self-consumption of electricity and thermal energy".
- Emphasising the distinctive PEDs' aim of joining "[…] built environment, sustainable production and consumption, and mobility to reduce energy use and greenhouse gas emissions and to create added value and incentives for the consumer […]".
- Optimising the use of innovative and/or traditional materials, "[…] local RES and other low carbon energy sources, local storage, smart energy grids […], cutting edge energy management […] and ICT".

According to a literature review focused on the current pathway towards Positive Energy Districts implementation, some of the most relevant key challenges and aspects that influence (hindering and/or delaying) their effective deployment, can be summarised as follows [3, 4, 5, 6]:

- Regulatory framework, certification, and standardisation system [3, 4].
- New energy markets and sustainable business and funding models [3].

- Societal innovation, social entrepreneurship, and citizen sensibilization/participation, as well as capacity-building, education, and training [3].
- Definition and tailoring of harmonised *criteria* and key performance indicators able to clearly define the "concept of an energy positive neighbourhood and the metrics and tools to measure the energy positivity level of an area" [5].
- Development of innovative and integrated technologies ("in many cases, the amount of renewable or sustainable energy needed for the district could possibly be produced in a cheaper and more efficient way outside the district or the city, but such a setup would at least partly go against the PED ambition" [6]).
- Replication, upscaling, and mainstreaming, also thanks to public sector innovation, and procurement [3].
- Economic feasibility and cost efficiency (also considering that energy retrofitting of existing buildings remains costly and characterised by long payback periods) [6].

Notwithstanding, the increasing and outspreading interest on PEDs, and on how to reach such targets can be related to the scale level they are characterised by. It transcends the individual dwelling context, also involving wider possibilities of innovative and advanced technologies' integration, as well as the engagement of a multifaceted audience of potential subjects (ranging from economic investors, societal and institutional bodies, public institutions, private citizens...) [6, 7]. Also the Members of the European Parliament, with the recently approved (on 12th March 2024) "Green Homes Directive" (Energy Performance of Building Directive) [8] further confirmed the urgent need for a paradigm shift to a more conscious and responsible approach to existing and new buildings. Even though it still needs to be formally endorsed by the Council of European Ministers (for being officially turned in law), it undoubtedly addresses and guides European Members in their path for reaching a climate neutrality by 2050, for which PEDs represent a key-factor. By setting new emission-reduction targets for residential and non-residential buildings (also including publicly owned buildings), it actively contributes to the progressive greenhouse gas emissions' curtailment, and to the whole EU building sector energy consumption reduction. Moreover, being PEDs one of the most effective ways to involve such a new building paradigm within an advanced and interconnected energy network (thermal and electrical), they certainly promote - also thanks to the support of innovative IT infrastructures - a proactive shift from a "single dwelling" energy approach to a more inclusive and interactive strategy.

Nevertheless, PEDs are not an entirely new concept and can be considered as an evolution of the concept of Net Zero Energy Districts (NZEDs), as well as of Positive Energy Blocks (PEBs) can be seen as a wider and advanced concept of Nearly Zero Energy Buildings (NZEBs) [8-10]. Since 2017, with the launch of the Positive Energy Districts and Neighbourhoods for Sustainable Urban Development programme [11] (within the larger JPI Urban Europe Initiative [1]), the topic of "Policies and models for the energy transition: from barriers to breakthroughs" has been extensively studied [9].

Applications.

While PEBs request "at least three connected neighbouring buildings producing on a yearly basis more primary energy than what they use" [12], the achievement of 100 Positive Energy Neighbourhoods by 2025 settled by European (EU) Member States, involves the more articulated concept of "[…] energy efficient districts that have net zero carbon dioxide emissions and work towards an annual local surplus production of renewable energy. Such districts help raise the quality of life in European cities, while reaching the COP 21 targets and making Europe a global role model. An open innovation framework with cities, industry, investors, research institutes and citizens' organisations all working together will help develop

PEDs and the necessary R&I Activities. The approach integrates the technological, spatial, regulatory, financial, legal, environmental, social, and economic perspectives" [1].
It is therefore evident that the emergence of a transition process from individual PEBs to interconnected positive energy blocks can trigger innovative actions for sustainable urban development; also the Joint Programme on Smart Cities of the European Energy Research Alliance (EERA JPSC) [13] is lined up to these goals and interesting case studies, and such new approaches to "Zero energy beyond single buildings" were discussed by Mavrigiannaki *et al.* [14], Zhang *et al* [4], within the "Creating Opportunities and Occasions to Promote a European Results-based Action for Training and Education" (COOPERATE) Project [15].

Gaps and Challenges

The following statement can be quoted for appraising the important paradigm shifts introduced: PEB/PED can be defined as "several buildings (new, retrofitted or a combination of both) that actively manage their energy consumption and the energy flow between them and the wider energy system. Positive Energy Blocks/Districts have an annual positive energy balance. They make optimal use of elements such as advanced materials (e.g., bio-based materials), local RES, local storage, smart energy grids, demand-response, cutting edge energy management (electricity, heating, and cooling), user interaction/involvement and ICT. Positive Energy Blocks/Districts are designed to be an integral part of the district/city energy system and have a positive impact on it (also from the circular economy point of view).
Their design is intrinsically scalable, and they are well embedded in the spatial, economic, technical, environmental, and social context of the project site." [16].
In addition, a consistent literature review on how the wide, complex and multifaceted sustainability field has dealt in Europe with Positive Energy Districts implementation [17, 18], highlighted further important aspects and displayed even more food for thought [19], but also challenges and critical points. The most peculiar elements and features that differentiate "Autonomous-PED", "Dynamic-PED", "Virtual-PED" and "Candidate-PED" were described [20, 21], and the operating scheme of the first three of them were clarified and illustrated [22].

Notwithstanding, most of the case-studies displayed and analysed considered suburban-residential areas, characterised by detached houses, low-rise dwellings, and residential neighbourhoods with limited building density areas (see the Table belonging to the Annex section, that reports a detailed insight into the main outcomes of several EU PED projects). Consequently, significant, and tricky challenges emerge when dealing with PEDs implementation, in particular for mixed use neighbourhoods, high rise building districts, and energy intensive constructions; moreover, as highlighted by Vandevyvere *et al.* [6], the task of reaching a PED target in contexts such as urban district renovation projects - with a high building density or dealing with several heritage and historical dwellings - represents a further difficulty. For the above-mentioned cases, it can be also hard to deal with restrictive boundary conditions (e.g. onsite renewable energy generation, regulatory limits, historical ties, reliable energy audits…), and to define a proper and integrated approach, suitable to wider, more articulated and varied contexts.

Aim and Objective of the Study.

The aim of the paper is to investigate, in this framework, how an Italian non-residential case-study could reach the target of PED, through a combined energy efficiency and renewable energy systems re-design assessment; its ultimate goal is therefore contributing to fill the already above highlighted gaps, while providing insights for the technical feasibility evaluation of meeting PED targets within an urban, non-residential university district context. This will allow for the identification of a benchmarking for PED performance assessment and potential for PED renovation in the Mediterranean area, also contributing to the overall target of supporting PED definition evaluation and development, as well as fostering PED performance schemes implementation

METHODS

The adopted methodology includes the following steps:

- The university buildings of interest (for this specific study the ones belonging to the Engineering Department, hereinafter respectively referred to as "Building 6", "Building 7", "Building 8" and "Building 9" presented in the Figures 1 and 2 were modelled and simulated in non-steady state conditions in Energy Plus environment.
- Parallelly, electricity energy consumption and heating gas needs (monthly data from 2017 to 2023), as well as electric load curves and energy loads (hourly data from 2019 to 2023) were collected, mapped, and analysed.
- Buildings' opaque and transparent envelope details, buildings' occupancy rate, lighting and electric equipment devices were then implemented in the models.
- The above task has been further adjusted and fine-tuned according to boundary condition settings, representative energy profiles, typical occupancy rate, internal loads and overall performance definition and customization.
- A calibration procedure was therefore carried out, in order to align energy performances of the modelled buildings to the existing case study.
- Then, with reference to the calibrated models, different renovation solutions and renewable energy systems were assessed.
- This in order to evaluate the technical feasibility of a positive energy balance achievement for the specific application context, with the final goal of meeting targeted PED requirements.

Figure 1:
A view of the Palermo "UniPa Campus" with the two modelled buildings pin-pointed

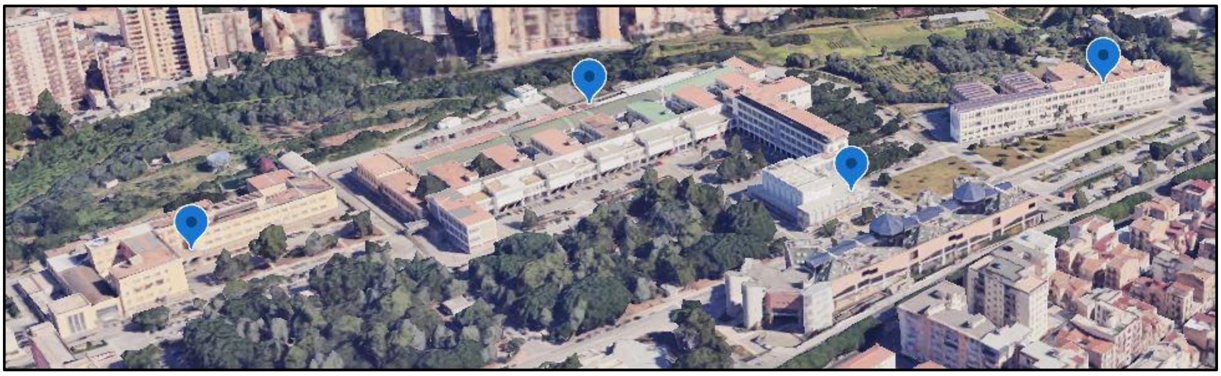


Figure 2:
An aerial view of the Palermo "UniPa Campus" with the two modelled buildings pinpointed

According to all the available information, by implementing the most relevant data and common details for them (also taking as a reference similar dwelling for construction period, occupancy rate and distinctive features), the energy models carried out were performed, finalised and assessed according to the key-steps described by the flow-chart summarized in Figure 3.

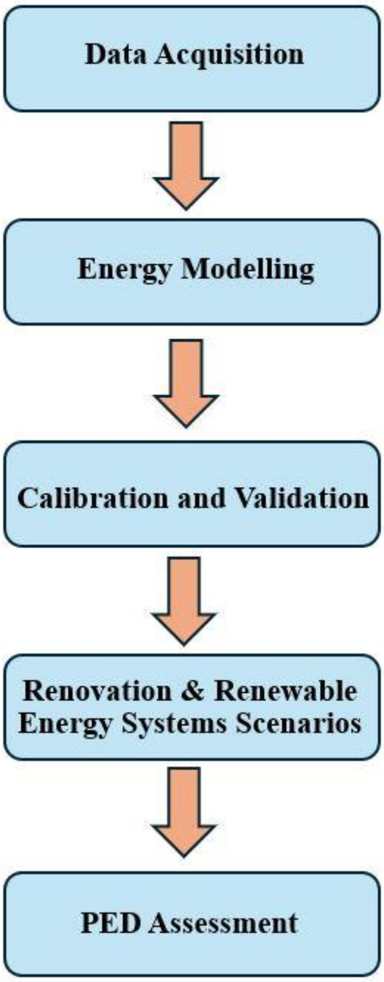


Figure 3: Methodology applied, and key-steps implemented in the research

Moreover, the Table 1 reports the main energy models assumptions concerning the thermal and physical properties of the buildings carried out.

Table 1: Energy Models main settings and key-parameters

BUILDING'S OPAQUE ENVELOPE		**TOTAL THICKNESS**	**ESTIMATED U-VALUE**
Exterior walls (from outside/exterior layer, up to inside/interior layer)	Tuff Stone (high density and porosity local stone, with a decent level of thermal and acoustic performances)	0.36 m	1.4 W/m^2K
	Exterior cement plastering		
	Internally plastered and finished by a cladding paint		
Ground Floors (from outside/exterior layer, up to inside/interior layer)	Top-finishing flooring in grit tiles	0.27 m	2.4 W/m^2K
	Cement screed		
	Stones/rock pebbles		
Interior Floors	Concrete and masonry slabs, plastered and with a top-finished flooring in grit tiles	0.34 m	2.1 W/m^2K
Interior Ceilings	Concrete and masonry slabs, plastered and finished by a cladding paint	0.34 m	2.1 W/m^2K
Flat Roof and Exterior top-level characteristics	Concrete and masonry slabs, plastered and finished by a tiled floor	0.36 m	2.0 W/m^2K
BUILDING'S TRANSPARENT ENVELOPE (GLAZING AND FRAMING FEATURES)		**LAYERS STRUCTURE**	
Exterior Windows	Glazing: double pane, clear glass, air-filled. Frame and dividers: aluminium frame without thermal break	0.012 m (per layer) with 0.010 m of air gap	
THERMAL ZONES DEFINITION, FEATURES, AND USER'S PROFILE (with respective OCCUPANCY RATE, ENERGY LOADS, INTERNAL GAINS and ACTIVITY LEVELS estimated, settled and adjusted accordingly to People behaviours, Electric Equipment, Lighting and other Appliances user rates)		Approx. 100 Thermal Zones (distinguished and classified in Offices, Laboratories, Classrooms, Restrooms, Stairs and Elevators, Unconditioned Spaces and Other Zones)	

For the sake of example, the Figures 4 and 5 provide some views of the buildings analysed and modelled (respectively Building 6 and Building 9).

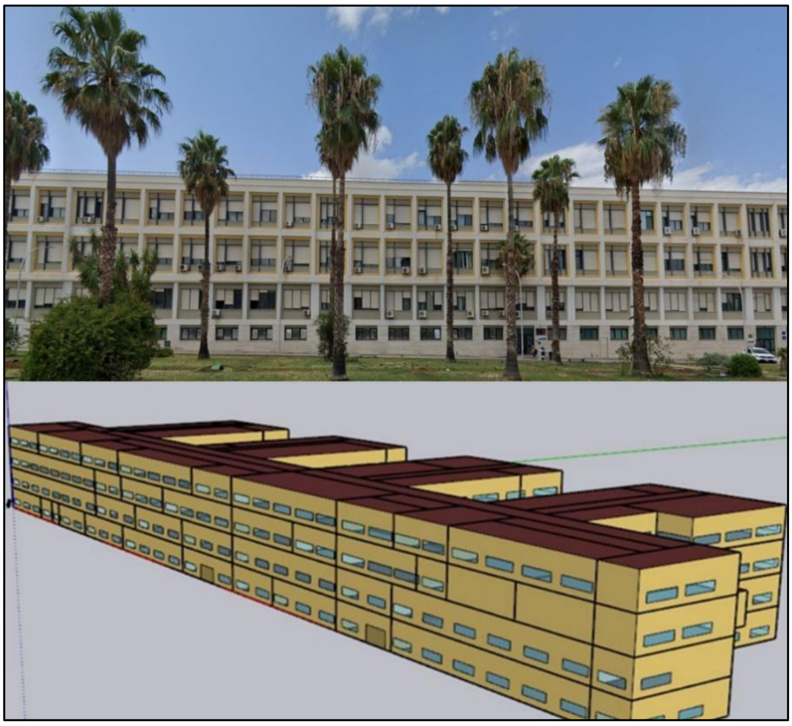


Figure 4: Building 6 picture and, below, a view of the energy model created with SketchUp 3D Modelling Software (integrated by the Euclid-NREL Energy Plus Plugin)

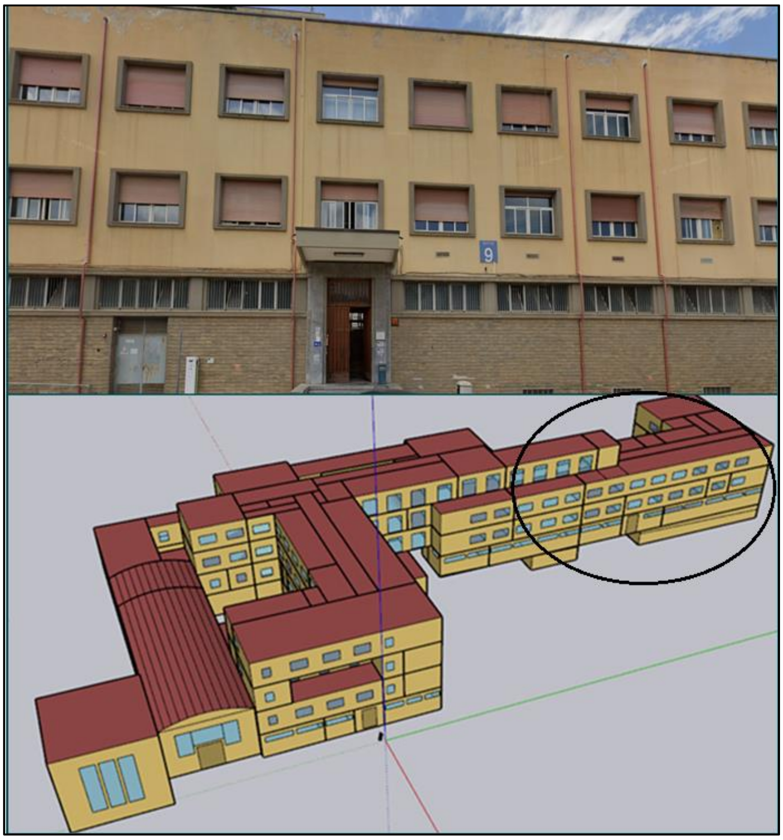


Figure 5: Building 9 picture and, below, a view of the energy model created with SketchUp 3D Modelling Software (integrated by the Euclid-NREL Energy Plus Plugin)

In order to fine-tune and calibrate such models, a careful data collecting campaign has been performed, and all the available information gathered were organised and analysed in dedicated spreadsheets and summary tables. A historical consumption trend (based on the energy billing and/or on heat cost allocator readings of final users) has been inferred through the analysis of a timeframe ranging from year 2017 up to year 2022. While for Building 6 (equipped with an autonomous electrical heating/cooling system with independent split and fan coils units) only the electricity bills were considered, for the Buildings 7, 8 and 9 (provided with a central heating system powered by a thermal gas station) the assessment included heating gas bills. Furthermore, during the cooling period, all these last building are also equipped with electrical independent split units, used as cooling systems. Through an incremental tailoring and calibrating process, gradually adjusted and progressively refined, the energy models were assessed (in terms of schedules, features, user profiles), and validated for a typical year-long operation run-period.

By finalising all the above steps, necessary to configure the effective state-of-the art, and useful to define all the possible retrofit solutions for the case studies, the researched passed to the definition of suitable energy retrofit solutions (opaque and transparent building envelopes, lighting and electric equipment's replacement with more efficient ones, renewable energy systems implementation), and multiple scenarios were modelled and assessed. Table 2 includes the main scenarios implemented in the renovation studies for all the four buildings analysed.

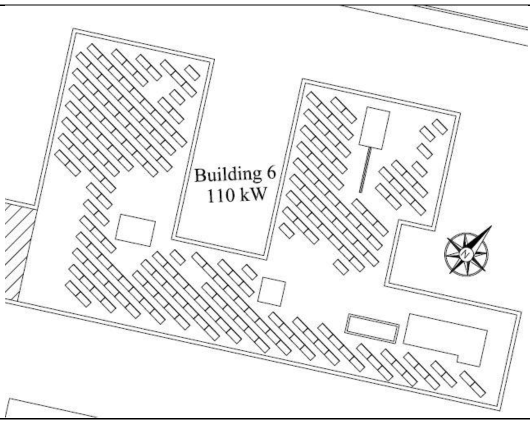
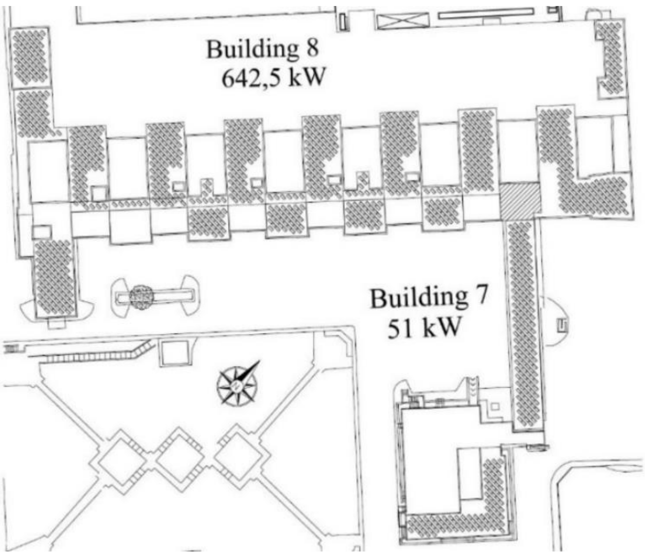
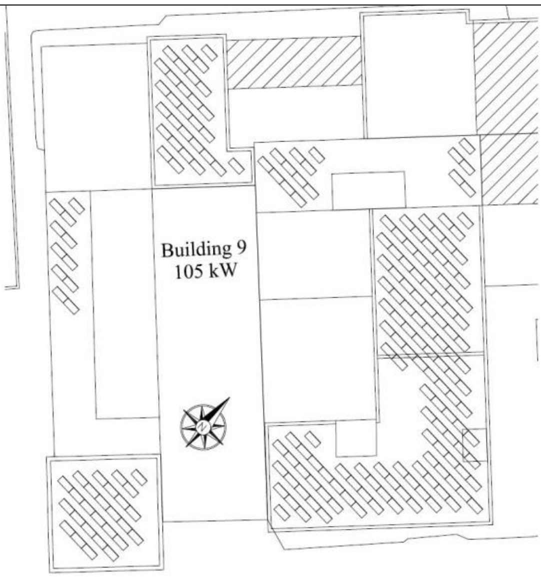
Table 2: Energy Retrofit solutions: main settings and key-parameters

BUILDING'S OPAQUE ENVELOPE RETROFIT SOLUTIONS (by adopting natural-based insulating materials)		**TOTAL THICKNESS**	**ESTIMATED U-VALUE**
ROCKWOOL INSULATION	Defining and adopting a suitable layered anchoring package and supporting retrofit sub-structure	**1)** 0.060 m	0.42 W/m^{2}K (ext.walls) 0.47 W/m^{2}K (roof)
		2) 0.100 m	0.29 W/m^{2}K (ext.walls) 0.31 W/m^{2}K (roof)
		3) 0.140 m	0.22 W/m^{2}K (ext.walls) 0.23 W/m^{2}K (roof)
		4) 0.180 m	0.18 W/m^{2}K (ext.walls) 0.18 W/m^{2}K (roof)
CORK INSULATION	Defining and adopting a suitable layered anchoring package and supporting retrofit sub-structure	**5)** 0.065 m	0.42 W/m^{2}K (ext.walls) 0.47 W/m^{2}K (roof)
		6) 0.110 m	0.29 W/m^{2}K (ext.walls) 0.30 W/m^{2}K (roof)
		7) 0.151 m	0.22 W/m^{2}K (ext.walls) 0.23 W/m^{2}K (roof)
		8) 0.195 m	0.18 W/m^{2}K (ext.walls) 0.18 W/m^{2}K (roof)
PERLITE INSULATION	Defining and adopting a suitable layered anchoring package and supporting retrofit sub-structure	**9)** 0.087 m	0.42 W/m^{2}K (ext.walls) 0.47 W/m^{2}K (roof)
		10) 0.145 m	0.28 W/m^{2}K (ext.walls) 0.31 W/m^{2}K (roof)
		11) 0.200 m	0.22 W/m^{2}K (ext.walls) 0.23 W/m^{2}K (roof)
CELLULAR FIBERS INSULATION	Defining and adopting a suitable layered anchoring package and supporting retrofit sub-structure	**12)** 0.062 m	0.42 W/m^{2}K (ext.walls) 0.46 W/m^{2}K (roof)
		13) 0.100 m	0.29 W/m^{2}K (ext.walls) 0.31 W/m^{2}K (roof)
		14) 0.144 m	0.22 W/m^{2}K (ext.walls) 0.23 W/m^{2}K (roof)
		15) 0.184 m	0.22 W/m^{2}K (ext.walls) 0.18 W/m^{2}K (roof)
BUILDING'S TRANSPARENT ENVELOPE (GLAZING AND FRAMING FEATURES)		**RETROFIT SOLUTION**	
Exterior Windows		**16) Glazing**: double pane, low-e selective glass, air-filled: 0.03 m (per layer) with 0.012 m of air gap. Frame and dividers: thermal break aluminium frame	
Lighting		**17) Existing lights'** replacement with LED, high efficiency lighting systems	
Electric equipment and devices		**18) Existing equipment and devices'** replacement with high efficiency ones (in particular, *Class 9* computers and computer peripheral devices)	

As a further solution for completing the retrofit actions to be considered in the scenario analysis, a photovoltaic system's implementation has also been integrated for all the buildings of interest. According to the assessment of their energy generation potential (carried out through on-site surveys, climatic data, and available buildings' roofing surface, as well as through PV-systems simulation), the estimation following reported can be formulated.

Table 3 provides a view of the layout for PV-systems roofing surfaces' integration, as well as details about PV power potential, with an estimation of yearly energy production.
In addition, it must be highlighted that, for Buildings 7, 8 and 9, the analysed retrofit actions also considered the possible replacement of the existing central thermal gas heating systems with air-to-water heat pumps.

Table 3:
PV rooftop panels installations' potential energy production for all the assessed buildings

<table>
<tr><th colspan="3">PV PANELS INSTALLATION TENTATIVE LAYOUT</th></tr>
<tr><td rowspan="2">BUILDING 6</td><td rowspan="2">
</td><td>Installed PV power (Bld.6)
110 kW_p</td></tr>
<tr><td>Yearly PV Energy Production (Bld.6)
164,40 MWh</td></tr>
<tr><td rowspan="4">BUILDING 7
and
BUILDING 8</td><td rowspan="4">
</td><td>Installed PV power (Bld.7)
51 kW_p</td></tr>
<tr><td>Yearly PV Energy Production (Bld.7)
76,22 MWh</td></tr>
<tr><td>Installed PV power (Bld.8)
642,50 kW_p</td></tr>
<tr><td>Yearly PV Energy Production (Bld.8)
960,25 MWh</td></tr>
<tr><td rowspan="2">BUILDING 9</td><td rowspan="2">
</td><td>Installed PV power (Bld.9)
105 kW_p</td></tr>
<tr><td>Yearly PV Energy Production (Bld.9)
156,93 MWh</td></tr>
</table>

.

RESULTS

BUILDING MODELS' ASSESSMENT AND PRE-RETROFIT CONFIGURATIONS

The energy models' verification for both the buildings analysed was performed through a validation of the respective annual primary energy need: while for building 6 the average deviation between energy model's yearly energy demand and total building's energy bills accounted for 8.6 %, the building 9 assessment reported a value around 6%. By way of example, the below image (Fig. 6) reports the overall building 6 model's assessment.

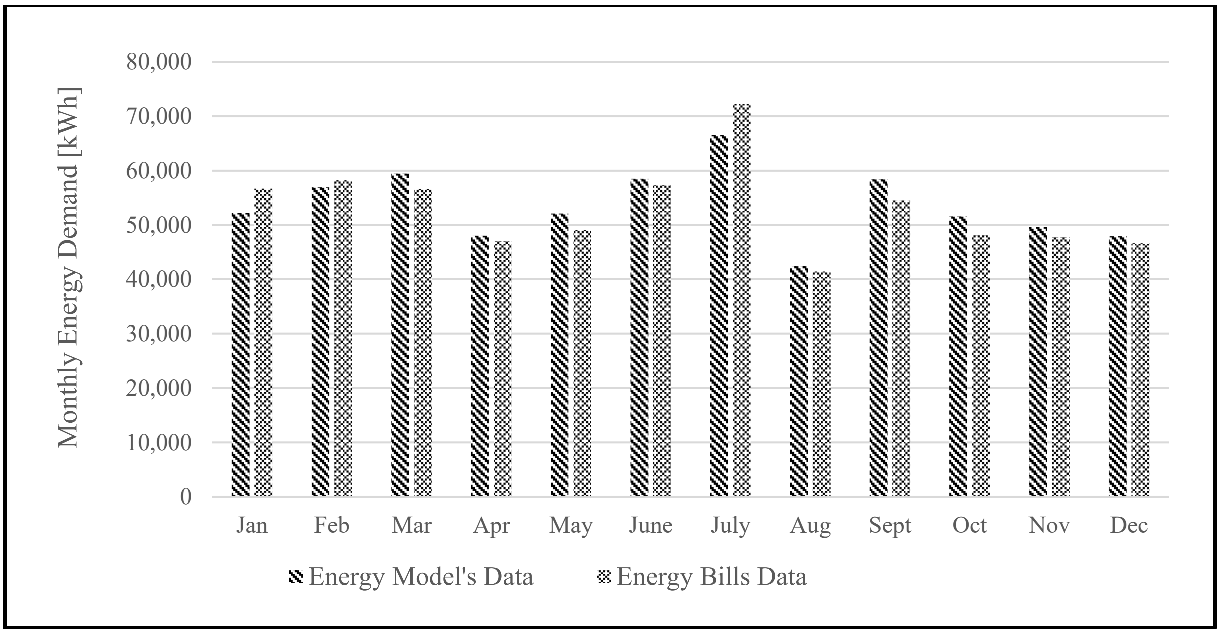


Figure 6: Building 6 - Energy Model Validation

BUILDINGS RETROFIT SOLUTIONS

Selection of the most effective retrofit configuration and comparison between pre-retrofit and post-retrofit annual energy demand.

According to the results achieved by comparing all the assessed retrofit solutions, configurations and possible combinations (in terms of external insulation material and thickness, lighting and electric equipment and appliances replacement), the most effective one (for both the energy models performed) resulted in the application of an external insulation package of rockwool (0.18 m of thickness), combined with the replacement of the existing windows (as displayed in Table 2) and more efficient lights (a LED lighting system), electric equipment and devices. The following Fig.7 summarises, by way of example, the results achievable by applying such solutions to the building 6.

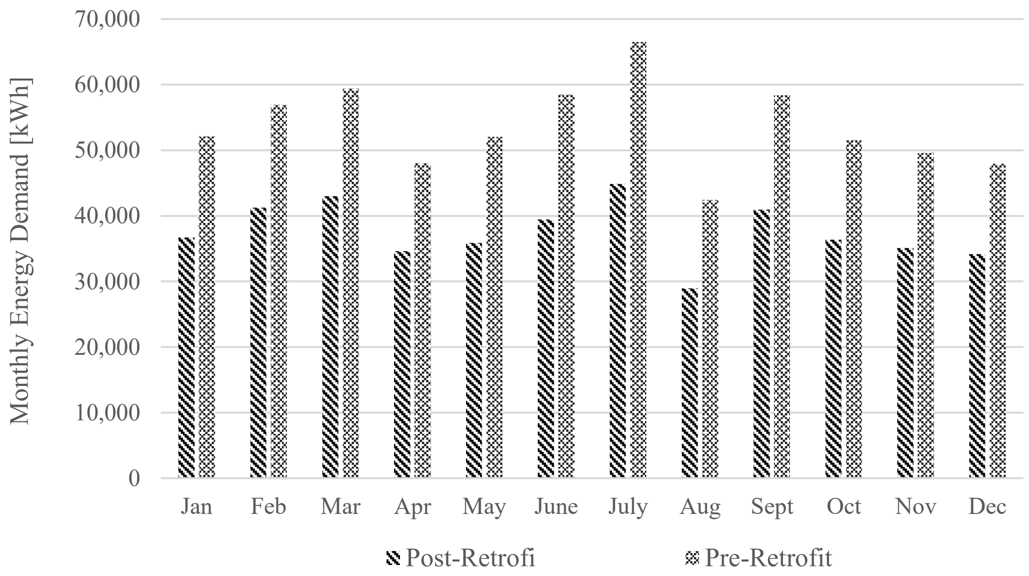


Figure 7: Building 6 - Pre-retrofit *versus* Post-retrofit comparison
by considering the most effective retrofit configuration

Such outcomes show that Positive Energy Districts primary energy balances, computed according to the summary table of below (and without considering neither transport and mobility factors, nor embodied energy and respective impact on energy/carbon balances) are not met with rooftop PV installations when retrofitting an existing district's selected area.

Table 4 and Table 5 include the outcomes of the study, with a focus on the possibility of achieving an actual positive energy balance within the geographical boundaries of the district.

It is worth to highlight that the total generation is equal to around 80% of the consumption of the overall district. Instantaneous auto-consumption of on-site generated energy ranges from 21% to 47 % among the four buildings investigated, with a total value of 37%.
By implementing the concept of PED and allowing peer to peer exchanges, it could be possible to increase the overall quota of auto-consumption by roughly 21% of the overall amount (from 630 MWh to 761 MWh), therefore significantly reducing the import from the grid (by around 12.6%, hence more than 100 MWh per year).

Table 4: Evaluation of the achievable results in a PED perspective

<table>
<tr><th colspan="3">PED YES OR PED NOT? DISTRICT’S LEVEL RESULTS</th></tr>
<tr><td rowspan="4">BLDG.6
+
BLDG. 7
+
BLDG. 8
+
BLDG. 9</td><td>ENTIRE DISTRICT
YEARLY ENERGY DEMAND</td><td rowspan="2">Building 6 Annual Energy Demand
(retrofitted configuration)
361,962 MWh
Building 7 Annual Energy Demand
(retrofitted configuration)
328,566 MWh
Building 8 Annual Energy Demand
(retrofitted configuration)
665,095 MWh
Building 9 Annual Energy Demand
(retrofitted configuration)
319,340 MWh</td></tr>
<tr><td>1674,96 MWh</td></tr>
<tr><td>PV PANELS’
YEARLY ENERGY PRODUCTION</td><td rowspan="2">Building 6 Annual Energy Generation
(according to the PV panels tentative configuration)
164,40 MWh
Building 7 Annual Energy Generation
(according to the PV panels tentative configuration)
76,22 MWh
Building 8 Annual Energy Generation
(according to the PV panels tentative configuration)
960,25 MWh
Building 9 Annual Energy Generation
(according to the PV panels tentative configuration)
156,93 MWh</td></tr>
<tr><td>1357,80 MWh</td></tr>
</table>

Table 5: Overall District assessment

	BLDG. 6	BLDG. 7	BLDG 8	BLDG 9	ALL BUILDINGS	DISTRICT LEVEL	DISTRICT VARIATION
ENERGY CONSUMPTION [MWh]	**361,96**	**328,57**	**665,10**	**319,34**	**1674,96**	**1674,96**	**0%**
ENERGY GENERATION [MWh]	**164,40**	**76.22**	**960,25**	**156,93**	**1357,80**	**1357,80**	**0 %**
IMPORTED ENERGY [MWh]	**228,41**	**257,48**	**349,50**	**209,93**	**1045,32**	**913,89**	**-12,57%**
EXPORTED ENERGY [MWh]	**30,85**	**5,13**	**644,65**	**47,52**	**728,15**	**596,73**	**-18.05%**
AUTO-CONSUMPTION [MWh]	**133,55**	**71,09**	**315,60**	**109,41**	**629,65**	**761,07**	**+20.87%**

CONCLUSIONS

The paper has investigated the potential for renovating an existing typical university district in southern Italy, towards potentially meeting a Positive Energy target within a one-year timespan. The results obtained through this study show that a significant reduction in energy demand can be achieved (by implementing a set of effective retrofit measures for opaque and transparent envelopes, lighting systems, electric equipment, and appliances).

Notwithstanding, the resulting yearly primary energy demand (even though reduced of around 40% for the retrofitted district's configuration) cannot be entirely covered by rooftop PV panels installation, therefore paving the way toward further solutions (such as implementing larger PV areas, defining more effective actions, and applying additional energy efficient retrofit measures), able to finally meet PED targets. Through a complete electrification of the district, large applications of energy efficient solutions and a wide deployment of renewable energy systems, the generation is able to cover up to around 80% of the overall energy consumption of the district.

In this perspective, it is worth mentioning that this is a result that can be extended to large areas of the built environment in the Mediterranean area for similar buildings, thus not meeting the strict mathematical PED clause as defined. Moreover, it is important to highlight that the definition of PED needs also to be expanded from a mere mathematical computation, and properly formulated by adapting and calibrating its peculiar features and distinguishing characteristics according to different boundary conditions, urban restrictions, and specific area requirements. Having high buildings performances and pushing decarbonization is actually the core aim of the PED concept: thus, having higher flexibility in its definition could be beneficial for PEDs diffusion.

As future work's tasks, the analysis will be progressively fine-tuned and gradually extended to broader contexts, up to wider application scales: this process can be actually useful to define and assess a customised concept of PEDs for selected pilot areas in the city of Palermo, also helping to formulate fruitful guidelines that can be applied to similar contexts within Mediterranean area. Sustainability analyses will also be integrated in order to consider the other aspects mentioned in the PED definition.

ACKNOWLEDGMENTS

"This work has received funding from the European Union-NextGenerationEU through the Italian Ministry of University and Research under PNRR - M4C2-I1.3 Project PE_00000018 - HEAL ITALIA – CUP: B73C22001260006. The views and opinions expressed are those of the authors only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them."

https://www.unipa.it/

https://grins.it/

The research is also partially developed within the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Annex 83 "Positive Energy Districts" work program.

The paper should be cited as:

Cellura, M., Franzitta, V., Longo, S., Panno, D., Guarino, F., Di Pilla, L., Curto, D.

Fostering the ecological transition in a neighbourhood perspective: towards Positive Energy Districts' application for a university case study, Proceedings of the 19th Conference on Sustainable Development of Energy, Water, and Environment Systems, SDEWES2024.0703, 1-22.

REFERENCES

1. JPI Urban Europe / SET Plan Action 3.2 (2020). *White Paper on PED Reference Framework for Positive Energy Districts and Neighbourhoods.* Available online: https://jpi-urbaneurope.eu/ped/ [Accessed: 7-March-2024].
   Also downloadable at: https://jpi-urbaneurope.eu/wp-content/uploads/2020/04/White-Paper-PED-Framework-Definition-2020323-final.pdf [Accessed: 7-March-2024]
2. *Renewable Energy Directive III of 18 October 2023*, amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023L2413&qid=1699364355105 [Accessed: 7-March-2024].
3. *SET-Plan ACTION n°3.2 Implementation Plan*. Available and downloadable online at: https://jpi-urbaneurope.eu/wp-content/uploads/2021/10/setplan_smartcities_implementationplan-2.pdf [Accessed: 10-March-2024].
4. Zhang, X., Penaka, S.R., Giriraj, S., Sánchez, M.N., Civiero, P., Vandevyvere, H. Characterizing Positive Energy District (PED) through a Preliminary Review of 60 Existing Projects in Europe. *Buildings,* 11, 318, 2021 https://doi.org/10.3390/buildings11080318
5. Ala-Juusela, M., Crosbie, T., Hukkalaine, M. Defining and operationalising the concept of an energy positive neighbourhood, *Energy Conversion and Management* 125, pp.133–140, 2016 https://doi.org/10.1016/j.enconman.2016.05.052
6. Vandevyvere, H., Ahlers, A. The Sense and Non-Sense of PEDs - Feeding Back Practical Experiences of Positive Energy District Demonstrators into the European PED Framework Definition Development Process, *Energies*, 15, 4491, 2022 https://doi.org/10.3390/en15124491
7. PED-EU-NET | Cost Action CA19126—Positive Energy Districts European Network. Available online: https://pedeu.net/ [Accessed: 14-March-2024].
8. Green houses directive adoption ("Energy Performance of Building Directive"). Available online: https://www.europarl.europa.eu/news/en/press-room/20240308IPR19003/energy-efficiency-of-buildings-meps-adopt-plans-to-decarbonise-the-sector#:~:text=For%20residential%20buildings%2C%20member%20states,20%20to%2022%25%20by%202035 [Accessed: 14-March-2024].
9. Magrini, A., Lentini, G., Cuman, S., Bodrato, B, Marenco, M. From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example, *Developments in the Built Environment*, 3, 100019, 2020 https://doi.org/10.1016/j.dibe.2020.100019
10. Positive Energy Block (PEB) definition provided by the +CityxChange (Positive City ExChange) a smart city project funded by the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 824260.Web page title: https://cityxchange.eu/knowledge-base/positive-energy-block-peb [Accessed: 12-April-2024]
11. Positive Energy Districts Programme and Neighbourhoods definition and description: https://jpi-

urbaneurope.eu/ped/#:~:text=Contributing%20to%20the%20ambitious%20targets,Positive%20Energy%20Neighbourhoods%20by%202025 [Accessed: 14-March-2024]
12. EIP SCC, Sustainable Districts and Built Environment: Positive Energy Blocks, Infosheet. Available online at: https://smart-cities-marketplace.ec.europa.eu/sites/default/files/PostiveEB.pdf [Accessed: 14-March-2024].
13. EERA Joint Programme Smart Cities. Available online at: https://www.eera-sc.eu [Accessed: 15-March-2024].
14. Mavrigiannaki, A., Gobakis, K., Kolokotsa, D., Kalaitzakis, K., Pisello, A.L., Piselli, C., Laskari, M., Saliari, M., Assimakopoulos, M., Pignatta, G., Synnefa, A., Santamouris, M. Zero energy concept at neighbourhood level: A case study analysis, *Solar Energy Advances,* 1, 100002, 2021. https://doi.org/10.1016/j.seja.2021.100002
15. European Commission, 2013. COOPERATE project, control, and optimisation for energy positive neighbourhoods. ref. Pesch D, Ellis K, Kouramas K, Assef J. Deliverable D1.1 of the COOPERATE project: report on requirements and use cases specification. https://cordis.europa.eu/project/id/600063/factsheet [Accessed: 15-March-2024], and http://www.ectp.org/fileadmin/user_upload/documents/E2B/COOPERaTE/COOPERATE_D11.pdf [Accessed: 15-March-2024].
16. Alpagut, B., Gabaldòn, A. Guidelines for Positive Energy District Design - How to Transform a district into a PED. *MAKING-CITY H2020 - Programme under grant agreement n°824418 -* Annex *I*. Accessible and downloadable at: https://makingcity.eu [Accessed: 16-March-2024].
17. Marotta, I., Guarino, F. Longo, S. Cellura, M., Environmental sustainability approaches and Positive Energy Districts: a literature review. Sustainability 2021, 13, 13063. https://doi.org/10.3390/su132313063 [Accessed: 12-April-2024]
18. Europe towards Positive energy Districts; a compilation of projects towards sustainable urbanization and the energy transition. Booklet collected and edited by the PED Programme Management of JPI Urban Europe. Status: February 2020. Accessible and downloadable at https://jpi-urbaneurope.eu (PED-Booklet-Update-Feb-2020_2.pdf) [Accessed: 16-March-2024].
19. Turci, G., Alpagut, B., Civiero P., Kuzmic, M., Pagliula, S., Massa, G., Albert-Seifried, V., Seco, O., Soutullo, S. A Comprehensive PED-Database for Mapping and Comparing Positive Energy Districts Experiences at European Level, *Sustainability* 2022, 14, 427. https://doi.org/10.3390/su14010427
20. Leone, F., Reda, F. Hasan, A.; Rehman, H.u. Nigrelli, F.C., Nocera, F., Costanzo, V. Lessons Learned from Positive Energy District (PED) Projects: Cataloguing and Analysing Technology Solutions in Different Geographical Areas in Europe. *Energies* 2023, 16, 356. https://doi.org/10.3390/en16010356
21. Lindholm, O.; Rehman H.u., Reda, F. Positioning Positive Energy Districts in European Cities. *Buildings* 2021, 11, 19. https://doi.org/10.3390/buildings11010019
22. Bossi, S. Gollner, C., Theierling, S., Towards 100 Positive Energy Districts in Europe: Preliminary Data Analysis of 61 European Cases. Energies 2020, 13, 6083; https://doi.org/10.3390/en13226083
23. Shnapp, S., Paci, D. and Bertoldi, P., Enabling Positive Energy Districts across Europe: energy efficiency couples renewable energy, EUR 30280 EN, Publications Office of the European

Union, Luxembourg, 2020, ISBN 978-92-76-21043-6. Available at https://publications.jrc.ec.europa.eu/repository/handle/JRC121405 [Accessed: 12-April-2024
24. Baer, D.; Loewen, B.; Cheng, C.; Thomsen, J.; Wyckmans, A.; Temeljotov-Salaj, A.; Ahlers, D. Approaches to Social Innovation in Positive Energy Districts (PEDs)—A Comparison of Norwegian Projects. Sustainability 2021, 13, 7362. https://doi.org/10.3390/su13137362
25. The Research Centre on Zero Emission Neighbourhoods in Smart Cities (ZEN Centre) (https://fmezen.no)[Accessed: 11-April-2024].
26. +CityxChange Project's description. Available at: https://cityxchange.eu) [Accessed: 11-April-2024].
27. How to PED, The +CityxChange Cookbook: Experiences and guidelines on Positive Energy Districts. Editors: Dirk Ahlers (NTNU), Kelly Riedesel (NTNU), Taliah Dommerholt.

Available at https://smart-cities-marketplace.ec.europa.eu/news-and-events/news/2024/how-ped-cityxchange-cookbook-experiences-and-guidelines-positive-energy
And downloadable from https://cityxchange.eu/knowledge-base/how-to-ped-cookbook/
[Accessed: 11-April-2024]

28. MAtchUP EU-funded Smart City project: introduction to the Project. Available at: https://www.matchup-project.eu/ [Accessed: 14 -April-2024].
29. The Synikia Project (Sustainable Plus Energy Neighbourhoods): description and features. Available at https://www.synikia.eu/ [Accessed: 15-April-2024].
30. The SPARCS Project description (Sustainable Energy Positive and zero cARbon CommunitieS Available at: https://www.sparcs.info [Accessed: 15-April-2024].
31. Description of the ATELIER Project (EU-funded Smart City *project* aiming to create and replicate Positive Energy Districts). Available at: https://smartcity-atelier.eu/ [Accessed: 15-April-2024].
32. Details and features of the SMART BEEjs Project (Smart Value Generation by Building Efficiency & Energy Justice). Available at: https://www.eurac.edu/it/institutes-centers/istituto-per-le-energie-rinnovabili/projects/smart-beejs [Accessed: 15-April-2024].

Annex: Table representing some of the most representative pilot projects aimed at reaching PED targets

PROJECT NAME	PROJECT REF.LINK	COUNTRIES	PILOT PROJECT	REFERENCE	GOALS	TIME SPAN	REF.
ZEN	The Research Centre on Zero Emission Neighbourhoods in Smart Cities" https://fmezen.no/	NORWAY	Oslo, Bergen, Trondheim *et al.*	Renewable Energy Directive (18/10/2023) European SET Plan Action-PEDs for Sustainable Urban Development	PEB (Positive Energy Blocks)	2017-2024	[23-25]
+CITY xCHANGE	+CityxChange Consortium-Positive City ExChange *https://cityxchange.eu*	NORWAY, IRELAND (Lighthouse Cities) ROMANIA, SPAIN *et al.* (Followers)	Lighthouse Cities (Trondheim, Limerick) Alba Iulia, Sestao *et al.*	Horizon 2020 research and innovation program Grant Agr. N. 824260	PEB leading to PED & Positive Energy Cities	2020-2025	[26-28]
+SYN.IKIA	"Sustainable Plus Energy Neighbourhoods" *https://www.synikia.eu/*	COUNTRIES + 4 DEMO Neighbourhoods (SPAIN, AUSTRIA...)	S.Coloma Gramenet (Med. Climate) Salzburg (Continental) Loopkantstraat (Marine) Verksbyen (Subarctic)	Horizon 2020 research and innovation program Grant Agr. N.. 869918	Sustainable Plus Energy buildings, neighborhoods, and cities	2020-2024	[25, 29]
SPARCS	**S**ust. energy **P**ositive and zero c**AR**bon **C**ommunitie**S** *https://www.sparcs.info*	6 COUNTRIES (FINLAND, GERMANY, GREECE *et al.*)	2 Lighthouse Cities (Espoo, Leipzig) 5 Fellow Cities	Horizon 2020 research and innovation program Grant Agr. N. 864242	Sustainable energy Positive & zero carbon Communities	2019-2024	[30]
ATELIER	AmsTErdam, BiLbao, cItizen drivEn smaRt cities *https://smartcity-atelier.eu*	7 COUNTRIES (SPAIN, PORTUGAL, DENMARK *et al.*)	2 Lighthouse Cities (Amsterdam, Bilbao) + 6 Fellow Cities	Horizon 2020 research and innovation program Grant Agr. N. 864374	PEDs + smart urban solutions	2020-2024	[31]
Smart-BEEjS	Smart Value Generation by Building Efficiency & Energy Justice *https://www.eurac.edu/it/institutes-centers/istituto-per-le-energie-rinnovabili/projects/smart-beejs /*	8 COUNTRIES (PORTUGAL, ITALY *et al.*)	Innovative Training Network, International researchers	Horizon2020 -| MARIE SKŁODOWSKA-CURIE ACTIONS	Local Fight Against Global Climate Change	2022-2023	[32]
MAKING CITY	*https://makingcity.eu*	8 COUNTRIES	2 Lighthouse Cities+6 Follower Cities	Horizon 2020 Grant Agr. N. 824418	Define & apply PED strategies	2018 - 2024	[16]