

Positive Energy District (PED) Selected Projects Assessment, Study towards the Development of Further PEDs

Sofia RUEDA CASTELLANOS^{1*}, Xabat OREGI²

¹*Faculty of Engineering, University of Mons, 9 Rue de Houdain 7000, Mons, Belgium*

¹*University of the Basque Country UPV/EHU, Plaza Ingeniero Torres Quevedo 1-1 48013 Bilbao, Spain*

¹*Department of Mechanical Engineering, Heriot-Watt University, UK EH14 4AS, Edinburgh, Scotland*

²*CAVIAR Research Group, Department of Architecture, University of the Basque Country UPV/EHU, Plaza Oñati, 2, 20018, San Sebastián, Spain*

Abstract – Positive Energy District (PED) is a relatively new concept from which many projects are planned, however, only a few cases are currently close to be materialized, therefore, in this study the PED projects in operation and in implementation process in existing districts are gathered in order to serve as a base for future PEDs. In this sense, certain points of each selected project are highlighted due to their relevance within the project development and their replicability potential. Furthermore, intending to learn from the experience of the assessed case-studies, this paper aims to understand the current situation regarding PED implementation to simplify the development of further PEDs.

Keywords – Energy performance of buildings; Positive Energy District (PED); PED solutions; Smart Cities; Positive Energy Block (PEB); urban energy transition

1. INTRODUCTION

Jointly with the population growth in cities, environmental and energy challenges are increasing. From this perspective, the necessity for a significant decrease in greenhouse gas emissions, the increment of the share for renewable energy and the improvement in energy efficiency are targeted through energy and climate goals. In this sense, European Union (EU) member states have set an energy saving target of 30 % to be reached by 2030 in addition to the commitment to decrease the greenhouse gas (GHG) emissions by 80–95 % by 2050 [1]. Furthermore, the European Directive EPBD (Energy performance of buildings directive) requires all new buildings from 2021 to be nearly zero-energy buildings (NZEB) [2]. Moreover, at the city scale, for example, Limerick, Ireland aims to become by 2050 a Positive Energy City [3] and Turku, Finland aims to be carbon neutral by 2029 and climate positive from then onwards [4].

Furthermore, in order to tackle issues in cities, initiatives are available at different scales, buildings, city-blocks, neighborhoods and districts [5]. The approach of this paper is at the district scale. Despite the fact that buildings account for nearly 40 % of final energy

*Corresponding author.
E-mail address: sofirc7@hotmail.com

consumption [6], in districts, buildings should not be seen as individual systems, to focus on the district level means to gather entities (citizens, buildings, mobility, electricity grid, infrastructure, etc.). In this paper the Positive Energy District (PED) will be addressed.

A PED consists of 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. PEDs have an annual positive energy balance [7] which means that it is an area where energy production is higher than energy consumption. In addition to buildings, other urban infrastructure are included, such as waste and water management, parks, open spaces and public lighting, as well as transport [8]. Fig. 1 illustrates the PED definition in an attempt to ensure its comprehension.

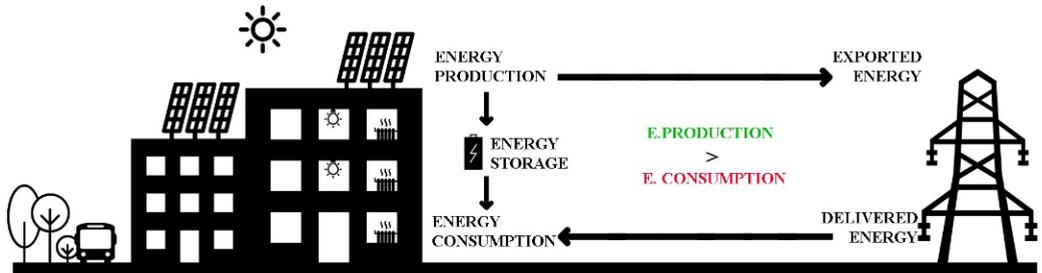


Fig. 1. Graphical explanation of a PED.

Furthermore, a PED includes aspects such as the management of local Renewable Energy Sources (RES) which are the main energy generation source of PEDs. Another important point is that when a district produces more energy than it consumes the surplus energy can be either stored locally or exported, in case of export a connection to the power grid in order to sell energy if there is a surplus or, to buy energy when their own is not enough is needed [8]. Moreover, energy generation techniques, increased deployment of smart e-mobility, building retrofiting, smart energy grids, ICT (Information and Communications Technology), and energy efficiency are also comprehended in the PED.

PED is a concept that, at the present moment, in existing neighborhoods, is only theoretical, since none of the PED projects have been completely implemented nor an operational annual energy balance has been reached.

Currently, there are two programs that target PED: The Program on PEDs and Neighborhoods (PED Program) coordinated by JPI (Joint Programming Initiative) Urban Europe in association with SET (Strategic Energy Technology) Plan Action 3.2 on Smart Cities [7] with the purpose to support the planning, deployment and replication of 100 PEDs by 2025 [10] and 'Horizon 2020' EU Research and Innovation program followed by 'Horizon Europe' (2021–2027) [6], [11].

Regarding the research on the PED concept, an important quantity of studies have been carried out in recent papers [6]–[13]. Conversely, in practice, many PED projects are in planning stage in places such as Pietralata PED in Rome, Italy [12]. Moreover, there are 21 PED projects [13] that are currently being implemented such as ATELIER in Amsterdam and Bilbao [12].

This paper will be focused on assessing only the PED projects that meet two challenges. The first one is to be implemented in a preexisting neighborhood and the second one is to have started the project within 2018 or before and estimate to end it by 2024 or before. From

this perspective, the selected projects are the first PED projects running, thus possibly the most developed PEDs. In this framework, it is possible to learn from their experiences, and therefore serve as a base for future PEDs.

This study is organized as follows. An introduction including the PED concept in the present section, followed by Section 2, where the methodology for analyzing the case-studies is defined. Section 3 identifies the PED projects to be examined; which are: *COOPERaTE*; *+CityxChange* (Positive City ExChange) and *Making City*. Section 4 integrates and compares the PED projects of the last section. And the final section (Section 5) synthesizes the findings in the PED projects assessed that could be profited to develop future PEDs.

2. METHODOLOGY AND ANALYSIS FRAMEWORK PED

With the objective of analyzing the case-studies and making a PED comparison, the following parameters are considered: project area, land use, tools for energy evaluation, Key Performance Indicators (KPI) and energy data. Furthermore, solutions for the implementation of a PED are also assessed; for this, three areas are analyzed: 1) improvement in energy efficiency of buildings, e.g., the enhanced building envelope, 2) RES (Renewable Energy Sources) to be implemented in the district, and 3) energy storage technologies.

3. PED PROJECTS ANALYSED

In the following sections, the selected PED projects listed in Table 1 will be described and assessed as a means to be taken as good practices towards the development of futures PEDs. Moreover, this paper only presents projects in existing neighborhoods and only the first projects running, due to the information availability and the progress achieved within time.

TABLE 1. PED PROJECTS IN IMPLEMENTATION PHASE OR OPERATING IN EUROPE [12]–[14]

Phase	Project name	District	City, Country
In operation 2012–2015	<i>COOPERaTE</i>	CIT Bishopstown campus	Cork, Ireland
		The Bouygues Challenger campus	Guyancourt, France
In implementation process 2018–2023	<i>+CityxChange</i> (Positive City ExChange)	Georgian district	Limerick, Ireland
		Sluppen-Tempe, Brattøra, Gløshaugen	Trondheim, Norway
	<i>Making-City</i>	Groningen North and South districts	Groningen, Netherlands
		Kaukovaio	Oulu, Finland

3.1. CIT Bishopstown campus, Cork, Ireland

The CIT (Cork Institute of Technology) Campus Bishopstown is a neighborhood where three main buildings can be found: NIMBUS, Leisure world (Sports center), and Parchment square (Student accommodation). The input, implemented services and main output of the case-study are shown in Table 2 with the purpose to have an overview of the project.

For CIT Bishopstown demonstration site there were some constraints that did not make possible to consider a full year reporting period. Nevertheless a 1-week (13th to 17th February 2015) reporting period that corresponds to high heating demand was assessed. In addition, a 1-week period during summer and an intermediate week were also considered.

TABLE 2. INPUT, IMPLEMENTED SERVICES AND OUTPUT IN BISHOPSTOWN [14], [15]

Input	Implemented services	Output
– Weather forecasts	– An optimization engine capable of exchanging information that considers energy profiles for working and nonworking days	– A comparison between a baseline and a reported period regarding energy of the neighborhood
– Energy price forecasts	– load forecasts and a method of including Parchment Square in demand response.	– Real-time visualization of the consumption and local production
– Energy Contracts	– Real-Time Actuation of Optimized Set-Points (Supervisory Control Service)	– Hourly energy demand forecast in day ahead mode (kWh)
– Real-time neighborhood monitoring of consumption, storage and local generation	– Decision Support Service	– Yearly energy grid demand forecast (MWh)
– 12-month historical data of the neighborhood/buildings (setpoints, time of operation, temperatures, energy consumption etc.) (anonymized data)	– Analysis Service for Building Upgrade	– Hourly power generation forecast in day ahead mode (kW)
– Thermal and electrical load forecasts	– Optimization of Power Purchases Versus On-Site Generation: This process makes possible to make the right decision between importing power from the grid and using the local generation.	– Optimal schedule for electrical and heating system
– NICORE, Intel system and the NIM to determine day-ahead forecasts for the electrical and thermal consumption		– Optimal set-points for local generation system and storage components
		– Energy cost savings (% , €)

Regarding the individual building features in CIT Bishopstown, in Nimbus building the CHP (Combined Heat and Power) set-points were optimized based upon the electrical and thermal consumption from the previous day's forecast [14]. Similarly, in the Leisure world building (Sports center) the heating load was a constant base load due to the presence of a swimming pool; for this reason the CHP could operate widely. On the other hand, Parchment square (the Student accommodation building) implemented an energy optimization algorithm that allows the battery to be charged when the grid tariff is low and discharged when the tariff is high [14]. The information on the buildings was gathered to obtain the total values for the whole district.

Finally, the points to be checked for future PEDs after CIT Bishopstown campus, Cork, Ireland case-study experience are addressed in the next paragraphs.

It has been found that the optimization system service was the fundamental energy service to reduce costs. Whereby optimization of power purchases from the grid versus on-site generation allows the battery to be charged when the grid tariff is low and discharged when the tariff is high. In short, the optimization system service strategy proved to be able to bring up to 11 % of economic savings, therefore, it could be useful for further saving strategies in PED developments.

Moreover, in future PEDs a point to be checked is the possibility to sell energy to the grid or not, this was one of the main barriers for CIT Bishopstown goals since the energy injected into the grid was not currently rewarded.

Furthermore, it has been found that the possibility to perform yearly analysis and measurements must also be assessed. From this perspective, in Cork demo site, there were some limitations regarding information access, therefore it was not possible to perform a yearly analysis when for PEDs an annual balance is required. As a replacement, the measurements took place during one week of summer and one week of winter.

The last point to take into account while looking at this case study as a good practice for developing PEDs is the fact that CIT Bishopstown district, had as main goal to achieve energy cost savings. Therefore, the decrease in energy consumption and the increase of local renewable energy generation were neglected in relation to the relevance of the main economic goal.

3.2. Challenger campus, Guyancourt, France

A similar approach to the previous case-study, is addressed in the present section since both cases were part of COOPERaTE project. The Challenger campus case-study has features that Cork did not have such as a cooling system intervention (that had as a result a 70 % decrease in the consumption), battery storage management and PV (Photovoltaic) panels [14], [15].

In this sense, it was possible to sell energy to the grid when the PV production exceeded consumptions. On the other hand, the possibility to reach 15 % energy cost savings on the energy bill was found.

Moreover, some of the KPI used were Total energy consumption (GWh/y), Local energy generation (GWh/y), Energy savings (%), CO₂ emission reduction (kgCO₂, %), Energy and cost of energy sold to grid (MWh) and Energy cost savings (%). Whereby 4 % energy saving was obtained, in contrast to the Bishopstown campus case-study where no energy saving was achieved [14], [15]. On the other hand, the district inhabitants are able to follow in real time the consumption of the site and the nature of energy flows, meaning that they can know if the energy is coming from the solar panels, the grid or the batteries through a mobile application.

Finally, the observed aspects for future PEDs after the present case-study experience are summarized in this paragraph. Challenger campus, Guyancourt, France highlight is located in the demand-response service integrated the energy market with the aim to generate possibilities according to the energy prices, consumption, generation and storage.

Similarly, there was the possibility to sell energy to the grid to obtain economic benefits. Moreover, profitable tools for further PED projects could be the integration of different ICT platforms as well as the KPIs and the possibility to assess them in an annual period. In addition, the user awareness system that allows the inhabitants to know the source of energy supply through their smartphones is also spotlighted in an effort to stimulate the participation of the inhabitants in the energy system implemented.

3.3. Georgian district, Limerick, Ireland

Within the frame of Horizon 2020, +CityxChange project selected Limerick as one of two cities to go from 3 Positive Energy Blocks (PEB) 2024 to PEDs by 2030. In Limerick, Georgian Innovation District a 3D model was built from a footprint file provided by the city to complete the preexisting information from Open Street Maps, together with other sources. Afterwards 3 blocks were selected to target energy positiveness. As a next step, one block was selected to firstly become energy positive whereby 5 buildings were selected to be prosumers [21] due to their high energy efficiency and inhabitants and owners willing to participate in the project, these buildings are gathered in Fig. 2.

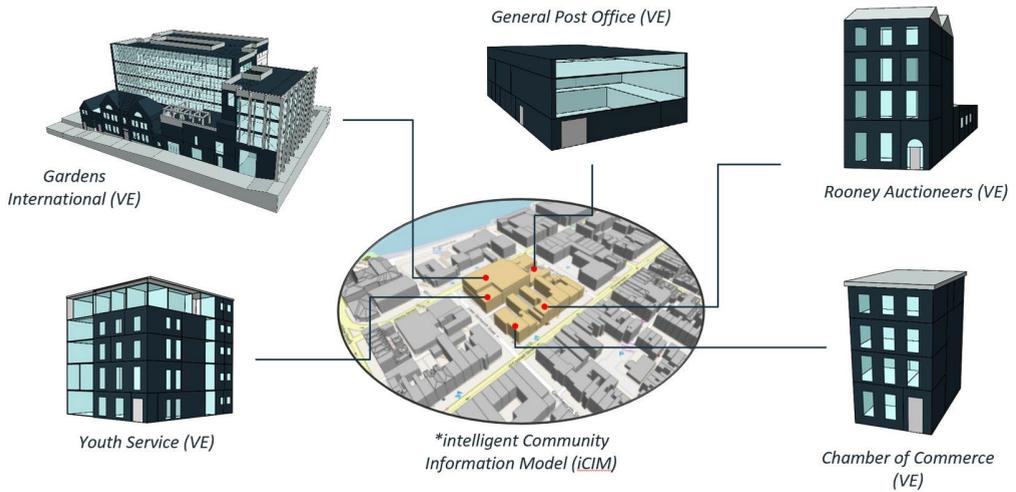


Fig. 2. First city block selected to become energy positive in Georgian district, Limerick [16].

Within the Digital Twin 5 steps to simulate the achievement of the PED were followed:

1. *3D Model*. The first step is the creation of a Digital Twin of each building, where data from the buildings such as the energy bills was used. In addition, the software allowed to fill the missing data with a Machine Learning regression algorithm to be able to obtain the annual energy consumption in kWh/m²/year.
2. *Improve operational efficiency of the building*. Within the 3D model, simple operational energy efficiency measures were identified. The measures could be implemented at little or no cost for instance heating controls, individual room thermostats and reduction of the DHW (Domestic Hot Water) supply temperature. If the Gardens International building LEED (Leadership in Energy and Environmental Design) is not taken into account, energy saving of 13 % over baseline across the other four buildings combined is possible to be obtained [16].
3. *Shallow retrofit measures*. Building airtightness, upgrades to LED (light-emitting diodes) lighting systems and dimming controls and boiler upgrades. Together the operational improvements and these measures have as a result a savings of up to 31 % excluding the LEED building.
4. *Deep renovation measures*. Insulation, window retrofit and change of the gas boiler to an air to water heat pump. When added in conjunction with 3 first stages, the savings are estimated to 64 % without including the LEED building.
5. *Local Renewable Energy Generation*. PV panels on two thirds of the roof surface which covered 14 % of the remaining energy demand of the block were simulated within the Digital Twin. All of these measures together were estimated to reduce the total electricity demand for the block from 1.79 GWh/y to 0.6 GWh/y, which is a reduction of 66.5 %. Moreover a tidal turbine in the nearby river aims to produce 1.0 GWh/y, enabling the block to produce 0.4 GWh/y in total and therefore become a Positive Energy Block (PEB) [16].

On the other hand, some of the assessed KPIs are: RES share, Increase of total RES, RES storage Increase in energy storage (MWh), RES efficiency (kWh sqm y), RES integration (GWh electric / thermal energy of new RES integration), RES flexibility Peak load reduction

(%), Greenhouse gas emissions (Tonnes CO₂eq y), Optimized self-consumption (District level production/total energy consumption), Reduction in energy grid investment compared to planned investments, Increased uptake of EVs (Electric Vehicles) (%), Decrease in payback period and Annual return of investment [3].

The remarkable points of Georgian district, Limerick, Ireland regarding the profitability to achieve PEDs in further projects are the 5 staged achievable percentages of energy saving. Whereby diverse measures were applied in to be able to obtain approximately 65 % of energy savings. Moreover, the idea to add up a tidal turbine that in this case would enable the positiveness of the district [3].

3.4. Sluppen-Tempe, Brattøra, Gløshaugen , Trondheim, Norway

Trondheim was chosen to be one of the leading cities for +CityxChange project together with the last case-study in Limerick. The project is divided in 3 demonstration areas:

Sluppen-Tempe is an area composed of offices, public buildings and dwellings, in addition, a new school, a health and welfare center and dwellings are planned to be built. On the other hand, Brattøra area is integrated by the city's harbour, the office building 'Powerhouse', which is a Positive Energy Building with BREEAM (Building Research Establishment Environmental Assessment Method) with outstanding certification, the Business College of Trondheim BI, hotels, museums, convention center and sports facilities. All of them connected by an energy management system based solely on electricity. In addition, apartment buildings and the Trondheim Station Centre are planned to be built. The third demonstration area is Campus NTNU (Norwegian University of Science and Technology) Gløshaugen which is composed by seven buildings whereby schools, office buildings and the new Valgrinda ZEB Flexible Lab are integrated. NTNU is also in the process of building a new city campus. A remarkable point is that Gløshaugen has its own concession area for both district heating and electricity and has its own Microgrid [17]. Finally, the Interconnection of the 3 PEBs in the above-mentioned demonstration areas is planned to arrive to a PED as well as the case-study in Limerick.

3.5. Groningen North and Groningen South districts, Groningen, Netherlands

Two districts aim to be transformed into PEDs, Groningen North and Groningen South Districts. Both are integrated by residential and public buildings, high-rises, industrial and tertiary buildings specifically the Energy Academy Europe Building, Nijestee Highrise 1 and 2, 3 Terraced houses, Mediacentrale, Powerhouse and a Sports complex. To implement the PED diverse measures are being applied.

Firstly, building retrofitting. Secondly, RES deployment, such as geothermal energy with heat pumps, a biogas plant in one of the buildings and a large surface of PV panels and solar thermal energy. The surplus of thermal energy produced aim to be stored and used during energy demand peaks. A remarkable point is the cycling and electric mobility whereby a cycling lane will be turned into a 'SolaRoad' by the integration of solar panels in its surface able to produce around 60 000 kWh yearly [18]. Additionally, Smart charging stations for EVs connection to the grid will be tested and then further scaled.

It is estimated that Groningen North PED will export 70 MWh/y of electricity and will import 5.5 MWh/y of thermal energy (natural gas), for a total balance in primary energy units of 170 MWh/y exported outside the district. On the other hand, Groningen Southeast PED will export 250 MWh/y of thermal energy and will import 80 MWh/y of electricity

for a total balance in primary energy of 97 MWhp/y exported outside the district. Thus, both districts are estimated to have a positive annual energy balance [18].

To summarize, the points to highlight in Groningen, Netherlands PED project are the building retrofitting coupled with diversified RES. Whereby the consideration of the geothermal district heating system together with heat pumps fed as well with PV, solar thermal and biogas is a particularity to spotlight. Additionally, the PV cycling lane is another innovative strategy within the PED project context. Moreover, another important remark is that the PEDs in Groningen estimate the 'positiveness' regarding the energy exported outside the districts.

3.6. *Kaukovainio, Oulu, Finland*

The measures to be applied are to connect the five buildings of the district, four residential and one shopping mall, to the district heating. Moreover, to add a high performant heat pump in the shopping mall whereby the heat sources are exhaust air, excess heat from refrigeration, district heating return water and uncovered solar collectors.

Furthermore, more measures to be applied are to retrofit the residential buildings. From this perspective PV panels have already been installed on the roofs and on exterior walls of an apartment building. Similarly, geothermal energy aims to be used for seasonal storage to support the district heating system and for winter the energy would be stored in thermal energy tanks. Moreover, soil aim to be used as thermal storage where the incoming fresh air is preheated using the soil under the building as thermal storage with the objective of saving energy. Furthermore, tube-type heat exchanger from the wastewater to the incoming cold water as heat recover aim to save heating energy of hot tap water. Additionally, EVs charging stations aim to be implemented. By implementing the measures 50 % reduction in total energy consumption has been estimated by [19].

The annual positive energy balance is planned to be reached due to the surplus on the energy production of high-performance heat pumps. Oulu PED will export 1020 MWhth/y of thermal energy through the district heating and will import 518 Mwhe/y of electricity, for a total balance in primary units (PE) of 80 MWhp/y exported to outside the district, as a leans to have a positive annual energy balance [18]. In short, similarly to Groningen, in Oulu technologies such as district heating, geothermal energy, heat pumps, PV and Evs are being implemented.

The Phases of *Making City* PED projects (Groningen and Oulu) [20].

1. City Needs Diagnosis energy and land use planning. City needs and priorities are analyzed regarding the city level indicators. Moreover, Energy Demand modelling is part of the identification of main needs and priorities.
2. Resource Availability and Identification of PED Concept Boundary. Natural resources to be deployed as RE plus preliminary PED studies.
3. Linking to Solution. The technologies tested in Oulu & Groningen are assessed in this stage.
4. Barriers / Enablers of PED Solutions. Ideas to overcome the barriers are given to build a feedback loop mechanism though dialogue between technical designers, citizens and local authorities.
5. Detailing solutions in Solution Cards. To describe the solution together with the economic aspects and the timing to apply the solution, as well as the expected impacts [20].

4. PED PROJECTS COMPARISON

The information of the projects described in Section 3 is gathered, simplified and compared in the present section. Similarities and discrepancies within the selected PED projects aim to be found through comparative tables. In Table 3 aspects such as the project surface, the land use, the tools to be utilized to evaluate the energy performance and the KPI of the selected projects are compared.

TABLE 3. DATA COMPARISON OF SELECTED PED PROJECTS

City, country	Cork, Ireland	Guyancourt, France	Limerick, Ireland	Trondheim, Norway	Groningen, Netherlands	Oulu, Finland
District	CIT Bishopstown campus	Challenger campus	Georgian district	Sluppen Brattøra	Groningen North and South	Kaukovainio
Project	COOPERaTE		+CityxChange		Making City	
Status	In operation		Implementation process 2018–2023			
Project area	n/a	67 000 m ²	15 000 m ²	n/a	45 000 m ²	40 000 m ²
Land use	University campus Student accommodation Sport center	Offices Parking	Office 68 % Residential 12 % Social housing 10 % Commercial 10 %	Residential 27 % Office 19 % Commercial 5.5 % Shopping 13 % Hotel 7 % Other 28 %	Residential and public buildings, high-rises, industrial and tertiary buildings	Residential: 3 hectares 75 % Other: Commercial 1 hectare 25 %
Tools for energy evaluation	NICORE, Intel system, NIM for day-ahead forecasts in energy consumption Optimization engine [14], [15].	Optimization engine Forecasting tool Demand response Embix module for energy storage [14], [15].	Digital twin by IESVE, Intelligent Community Information Model (iCIM) [16].		n/a	Open source code platforms. Python, machine learning tools, non-Vendor lock approach.
Key Performance Indicators (KPI)	Energy: Total energy consumption (kWh/day) Local energy generation (kWh/day) Max. power demand (kW) Max. power grid power demand (kW) Environment: Energy savings (%), kWh CO ₂ emission reduction (%), kg CO ₂ Share of local and renewable energy generation (%)		RES share increase, RES storage Increase in e. storage (MWh), RES efficiency (kWh/m ² /y)), RES integration (GWh el/th of new RES integration), RES flexibility Peak load reduction(%), Greenhouse gas emissions (Tonnes CO ₂ eq/y), Optimized self-consumption (District level production/total energy consumption), Reduction in energy grid investment compared to planned investments, Increased uptake		Building and energy: Reduction in annual final energy consumption, RE production, Annual CO ₂ emission reduction, Peak load reduction, Balance in PE (Primary Energy) (MWhp/y exported) ICT: Availability of real time data Improved interoperability between systems, # of smart apps developed using open data platforms E-mobility:	

Economics: Energy and cost of energy sold to grid (MWh) Energy cost savings (% , €) [14], [15].	of EVs (%), Decrease in payback period and ROI [3].	# of public EV charging stations, RE use, CO ₂ emission y reduction, kWh recharged in the EV charging stations [19].
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Table 3 shows how the assessed district areas go from 15 000 m² to 67 000 m² surface. The main land uses are university campuses, offices and residential areas. Concerning the tools for energy evaluation, optimization engines, 3D modelling tools and programming platforms are used in the selected PED projects. On the other hand, for the KPIs Energy consumption/ generation, RES deployment, Greenhouse gas emissions, mobility and economic indicators are evaluated within the selected projects.

Conversely, since the central idea of a PED is to have a positive energy balance, Table 4 compares the energy consumption, energy generation and total energy balance in each one of the assessed projects.

TABLE 4. SELECTED PED PROJECTS ENERGY DATA COMPARISON

City, country	Cork, Ireland	Guyancourt, France	Limerick, Ireland	Trondheim , Norway	Netherlands, Groningen	Oulu, Finland
District	CIT Bishopstown campus	Challenger campus	Georgian district	Sluppen Brattora	Groningen North and South	Kaukivainio
Project	COOPERaTE		+CityxChange		Making City	
Energy Consumption (GWh)	5884 kWh/day	11.8 GWh/y	1.79 GWh/y (Block 1) Estimated to be reduced to 0.6 GWh/y	n/a	n/a	n/a
Energy Generation (GWh/y)	0.000927 el 0.001403 th	2.53	1.00	n/a	0.07 electric 0.25 thermal	1.02 th
Total balance consumption/g eneration (GWh/yr)	n/a	n/a	+0.40	n/a	North district +0.17 PE South district +0.097 PE	+0.08 PE
Reference	[14], [15]	[14], [15]	[16]	–	[18]	[18]

Table 4 shows the expected surplus of energy, however, the measurements for Groningen and Oulu was performed in (GWh/y) of primary energy therefore a units assurance would be needed in order to compare. In addition, it is important to remark that the energy balances are only an estimation since the projects are still in implementation process.

In contrast, Table 5 summarizes the measures that aim to be implemented in the assessed PED projects. They are categorized in 3 sections: The technologies that aim to improve the energy efficiency of the buildings, the RESs planned to be deployed and the Energy Storage systems.

From this perspective, regarding the improvement in the energy efficiency of buildings the measure applied in the majority of the PED projects is an enhanced envelope/ insulation followed by real-time measuring of consumption and heating controls reduction of the DHW supply temperature with heat recovery, as shown in Table 5. From this first point, energy management system (Neighborhood / Building) and boiler upgrades were also utilized by half of the projects.

On the other hand, regarding the RESs the technologies most utilized are Heat Pumps and PV. Finally, concerning the Energy storage solutions, EV, V2G (Vehicle to Grid) and V2B (Vehicle to Building) concepts including smart charging stations implementation are the major solution in the projects followed by batteries and thermal storage as shown in Table 5.

TABLE 5. MEASURES TO BE IMPLEMENTED WITHIN THE EVALUATED PED PROJECTS

Implemented measure or technology	CIT Bishopstown campus, Cork, Ireland	Challenger campus, Guyancourt, France	Georgian district, Limerick, Ireland	Sluppen Brattøra Trondheim, Norway	North and South districts, Groningen, Netherlands	Kaukova inio, Oulu, Finland
PED project	<i>COOPERaTE</i>		<i>+CityxChange</i>		<i>Making City</i>	
Improvement in energy efficiency of buildings						
Demand response	x	x				
Energy management system (Neighborhood / Building)		x	x		x	
Heating controls	x		x		x	x
Reduction of the DHW supply temp, heat recovery						
Smart thermostats per room			x		x	
Real-time measuring of consumption	x	x			x	x
Heat distribution between the buildings on site				x		x
Enhanced envelope/ insulation		x	x	x	x	x
Boiler upgrades	x	x	x			
Renewable Energy Sources (RES)						
CHP (Combined Heat and Power)	x					x
Photovoltaic (PV)		x	x	x	x	x
Solar thermal					x	
Heat Pumps (HP)		x	x	x	x	x
Tidal turbine			x			
Waste digestion					x	x
Geothermal					x	x
Waste heat					x	x
District Heating				x	x	x

Energy Storage technologies				
Batteries	x	x		x
Thermal storage Water tank. Phase Change Material (PCM).	x	x		x
Optimization service for storage management	x	x		
EV, V2G, V2B (Electric Vehicle, Vehicle to Grid, Vehicle to Building)			x	x
			x	x

5. CONCLUSIONS

PEDs could be defined as an area that has an annual positive energy balance. Nevertheless, none of the PED projects assessed in this paper produce more energy than the energy they consume since most of them are still in implementation process. Therefore, the first conclusion of this paper is that there are no PEDs materialized in existing neighborhoods at the moment.

Subsequently, in this study, the selected PED projects were analyzed in order to learn from them and use them as a base in future PEDs. From this perspective, the findings of each project are summarized in the following paragraphs.

CIT Bishopstown campus, Cork, Ireland case-study assess each building individually. On the other hand, to implement an optimization system service has proved to have as a result the reduction of energy costs. Diversely, the KPIs to assess the energy, environment and economic performance of the districts chosen by this PED project seem to be profitable for further projects. Moreover, to perform measurements of the indicators in an annual way is important to stick to the PED definition. Similar beneficial points were extracted from the *COOPERaTE* project in Challenger campus, Guyancourt, France.

The remarkable points found in the Georgian district, Limerick, Ireland case-study are the stages (improvement of operational efficiency of the building, shallow retrofit measures and deep renovation measures) whereby approximately 65 % of energy savings could be reached. Additionally, regarding energy generation, a tidal turbine aims to be implemented to reach a positive energy balance, consequently, it would be the main technology to be learned from. Finally, concerning this case-study as a part of *+CityxChange* project the KPI might be convenient to be used as a base in future PED projects.

About Groningen, the Netherlands PED project, the highlights are on the diversified RES that feeds the district heating system. Additionally, the PV cycling lane is an innovative strategy within the PED project context. Moreover, Kaukovainio, Oulu, Finland, as well as Groningen in the Netherlands, estimate the balance in primary energy units exported outside the district.

Section 4 condenses and contrasts the most relevant aspects found within the assessed PEDs for the development of further PED projects. The project surface, the land use, the tools to be utilized to evaluate the energy performance and the KPI of the selected projects are firstly compared. Concerning the tools for energy evaluation; optimization engines, 3D modelling

tools and programming platforms are used in the selected PED projects. On the other hand, for the KPIs evaluated are mainly Energy consumption/ generation, RES deployment, Greenhouse gas emissions, mobility and economic indicators.

Finally, a summary of the measures that aim to be implemented in the assessed PED projects is categorized in 3 sections: The technologies that aim to improve the energy efficiency of the buildings, the RESs planned to be deployed and the Energy Storage systems. Whereby, the measures applied in the majority of the PED projects are an enhanced envelope/ insulation, the implementation of Heat Pumps, PV energy and EV as shown in Table 5. Also, the preexistence of a District Heating system as well as the Smart grids concept where the possibility to sell energy to the grid and bidirectionality are relevant for the future PEDs.

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